GLOBAL ENERGY AND WATER CYCLE EXPERIMENT

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WORLD CLIMATE RESEARCH PROGRAMME (WCRP)

INTERNATIONAL GEWEX PROJECT OFFICE (IGPO)

# MAJOR ACTIVITIES PLAN FOR 1998, 1999 AND OUTLOOK FOR 2000

*for the*

# GEWEX CONTINENTAL-SCALE INTERNATIONAL PROJECT (GCIP)

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**December 1997**

*IGPO Publication Series*

*No. 26*

# MAJOR ACTIVITIES PLAN FOR

# 1998, 1999 AND OUTLOOK

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# GEWEX CONTINENTAL-SCALE

# INTERNATIONAL PROJECT

# (GCIP)

*Compiled by*

John A. Leese

December 1997

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**MAJOR ACTIVITIES PLAN FOR 1998, 1999**

**AND OUTLOOK FOR 2000 FOR THE GEWEX CONTINENTAL-SCALE INTERNATIONAL PROJECT (GCIP)**

# EXECUTIVE SUMMARY

## S1. Background

The World Climate Research Program in its Global Energy and Water Cycle Experiment (GEWEX) has established Continental Scale Experiments to improve scientific understanding and to model on a continental scale the coupling between the atmosphere and the land surface hydrologic processes for climate prediction purposes. The GEWEX Continental-scale International Project (GCIP) was established in the Mississippi River basin in 1992 to take advantage of the extensive meteorological and hydrological networks including the new Doppler radars, wind profilers, and automatic weather stations. GCIP is contributing to the long-term goal of demonstrating skill in predicting changes in water resources on time scales up to seasonal, annual, and interannual as an integral part of the climate prediction system. The overall strategy framework for implementing GCIP is shown in Figure S-1.

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[GCIP_strategy]

**Figure S-1** Strategy Framework for Implementing GCIP.

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The understanding and modeling of a continental scale watershed requires, from the outset, consideration of nonlinear-scale interactions in the aggregation of smaller processes to the larger scale and vice versa. GCIP research involves a systematic multiscale approach to accommodate physical process studies, model development, data assimilation, diagnostics,validation and data acquisition topics. GCIP research activities occur in a phased timetable and emphasize a particular region with special characteristics for a period of about two years. Four Large

Scale Areas (LSAs) have been identified which encompass major river sub-basins of the Mississippi River basin and which, in aggregate, cover most of the GCIP domain, as shown in Figure S-2. The time phasing of activities within each of these areas is also shown in the figure. The GCIP Enhanced Observing Period started on 1 October 1995 and will continue for five years. Although the developmental activities are being initiated in limited regions; a fundamental thrust of the GCIP implementation strategy is that they lead toward an integrated continental-scale capability.

[LSAs]

**Figure S-2** The Mississippi River basin with boundaries defining the Large Scale Areas (LSAs) for GCIP Focused Studies (top). Temporal emphasis for each LSA from 1994 through 2000 (bottom).

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## S2. Coupled Hydrologic/Atmospheric Modeling

**GCIP OBJECTIVE:** *Develop and evaluate coupled hydrologic/atmospheric models at resolutions appropriate to large-scale continental basins.*

Model development in GCIP has two paths as shown in Figure S-1. A key strategy adopted early in GCIP was to fully exploit the high resolution limited area models that were being applied to regional weather prediction through various nesting procedures in the global models. This strategy was implemented as part of the "operational" path to provide the model assimilated and forecast data products for GCIP research as well as serving as a "proof of concept" for components of a coupled hydro-climate model. The "research" path focuses on the longer term activities needed for a coupled hydro-climate model.

**Coupled Modeling Research Objective:** *Identify and understand the coupled processes that influence predictability at temporal time scales ranging from diurnal to seasonal and spatial scales relevant to water resources applications, and to develop a coupled model or models which can be validated (at these scales) using data from the Mississippi River basin.*

### S2.1 Near-Term Priorities for Coupled Modeling Research

In accordance with the overall goals of GCIP, the coupled modeling activities will focus on regional mesoscale modeling activities, to include the imbedding of regional models in global climate models. as an element in developing a capability to produce experimental seasonal-to-interannual climate predictions for the North American continent and evaluate these predictions relative to GCIP data. While recognizing that initially such experimental forecasts are likely only to have limited skill, GCIP will initiate an exploratory investigation of the potential value of such predictions in the context of water resource applications. This initiative will also serve as a mechanism through which to understand and develop the required interface between climate and weather predictions and their hydrological interpretation.

The focus of interest within GCIP in the next two to three years will be on continued development of improved representations of processes in coupled models with an emphasis on:

- development of methods to improve values of parameters in these process representations;
- transition improved process representations and parameters into coupled models, and,
- exploratory runs and evaluation of their descriptive and predictive ability at time scales from diurnal to annual.

### S2.2 Coupled Modeling Research: Long-term Items to be Initiated in the Next Two Years

To achieve the GCIP coupled modeling objective given at the beginning of Section 2, some long term initiatives need to begin in the next two years.These include:

(1) Definition and implementation of a measure of success for hydrologic predictions such as a "hydrologically relevant skill score".

(2) Characterization of hydrological storage in large-scale basins using tracer techniques using hydrograph separation techniques and geologic methods.

(3) Evaluation of relative contributions of land and oceanic influences to precipitation amounts in different seasons and in different regions of the North American continent with initial focus on the Mississippi River basin.

(4) Initiation of a regional ground water element in GCIP, focused on deep aquifer recharge and extraction.

### S2.3 Improvements to Operational Coupled Mesoscale Models

The "operational" path (Figure S-1) provides the model assimilated and forecast output products for GCIP research, especially for energy and water budget studies. The regional mesoscale models also serve to test components of an imbedded regional climate model and can provide output for the evaluation of a coupled hydrologic/atmospheric model during the assimilation and early prediction time periods as a precursor to developing and testing a coupled hydrologic/atmospheric climate model. The output from the Eta, Mesoscale Analysis and Prediction System (MAPS), and Global Environmental Multiscale (GEM) regional mesoscale models is routinely compiled as part of the GCIP data set.

### S2.3.1 Near-Term Priorities for Operational Coupled Mesoscale Models

(1) Use the GCIP special data sets to validate and evaluate the regional model output. Concentrate on validation of surface energy fluxes, surface skin temperature, soil moisture, cloud cover, precipitation, and diurnal planetary boundary layer profiles of temperature and humidity.

(2) Produce plots and graphs of the monthly Mississippi River Basin water budget components from the Eta, MAPS, and GEM model output. Compare with similar but independently computed budget components from observations.

### S2.3.2 Operational Coupled Mesoscale Models: Long-term Items to start in the Next Two Years

(1) Validate and evaluate the 4DDA and forecast runoff of the Eta, MAPS, and GEM models (and later their companion land data assimilation systems), by applying streamflow/river routing algorithms to the gridded runoff archives from these systems.

(2) Investigate and develop algorithms for parameterizing sub-grid scale fractional precipitation distribution for use in the surface infiltration algorithms of coupled mesoscale models. Study the spatial and temporal distribution characteristics of the precipitation fields from the Eta, MAPS, and GEM model assimilation and forecast systems. Also, study the convective stability index products from these three systems.

(3) Investigate and develop strategies for *a priori* continental-scale estimation of key hydrological parameters, such as saturation hydraulic conductivity, soil moisture capacity ("bucket depth"), rooting depth, soil porosity, active soil column depth, and slope.

(4) Imbed coupled mesoscale models into global ocean/atmosphere models and investigate the advantages of imbedding (if any) on the skill and utility of seasonal and annual forecasts.

## S3. Hydrological And Water Resources Modeling

**GCIP Objective**: *Improve the utility of hydrologic predictions for water resources management up to seasonal and interannual time scales.*

In the context of GCIP, one of the eventual aims of the modeling effort is to generate inputs for operational hydrological and water resources management models over a range of time scales up to interannual. The approach will be to link the hydrological and water resources research activities with the coupled modeling and data collection activities to produce more accurate streamflow forecasts, and in turn, to develop methods for utilizing those forecasts in water management decisions. The lead times to be emphasized will be longer than the currently accepted upper limit of weather forecasts (which is currently about one week), up to interannual.The near-term priorities are:

1) To develop procedures to allow GCIP hydrologic models to produce ensemble streamflow forecasts, using ensemble climate forecast model surface fields as forcing values. This will require, in particular, development of schemes to remove bias in both the climate model surface fields, and hydrologic model output; and,

2) to evaluate the worth of climate model ensemble forecasts for operation of one or more water resources systems.

In the longer term (e.g., beyond 2000) it is expected that the research activities will focus on water resources in the western U.S. The hydrologic processes of concern in the West (such as, e.g., snow accumulation and ablation in mountainous regions) are, in some respects, more amenable to improved hydrologic forecasting than are the water resource systems of the Mississippi River basin. Also, linkages between seasonal-to-interannual climate variations and tropical ocean processes (which currently appear to offer the best hope for accurate seasonal to annual forecasts) are generally stronger in the West than in the current GCIP region, so the West arguably offers a better water resources testbed for GCIP models than does its current region. In any event, GCIP will place a higher priority on the development of a demonstration application of seasonal forecast tools in at least one of the major water resources systems.

## S4. Data Assimilation

**GCIP objective**: *Develop and evaluate atmospheric, land, and coupled data assimilation schemes that incorporate both remote and in-situ observations.*

The priority areas for research activities in data assimilation are:

- Assessment of consistency of water and energy budgets via comparative evaluations of data among the three regional mesoscale models (see section S2.3.2 above) and with other data products and observations. This includes soil moisture and temperature observations, cloud and radiation products, and precipitation products. This understanding of consistency and errors in models (and observations) is necessary not only to improve the models themselves, but also to provide necessary information for data assimilation of new GCIP data sets as they become available.

- Development and implementation of assimilation techniques. For the atmospheric models this needs to include the 3-D and 4-D Variational techniques. The emphasis in this development should be on remotely sensed data, cloud and moisture fields, and on attaining consistency with vertical motion fields so that analyzed cloud/moisture features are retained in subsequent model forecasts. For the macroscale land-surface/hydrology models, this should include use of both in situ and remote measurements of soil temperature and moisture, and of snow cover and depth. In order to do this data assimilation work, it will be necessary to have an improved understanding of the error characteristics of both these observations and the models themselves. This improved understanding can come from the assessment efforts advocated in the paragraph above.

- Use surface models from regional models and perhaps from other organizations for the development of land data assimilation systems (LDASs). The LDASs should use observed data sets where possible, e.g., of precipitation and radiation, but also may use combined observation/model techniques to account for inadequacy of observations in certain areas. Again, knowledge of data errors is needed.

An additional future priority is the re-analysis of assimilated data sets using future improvement in data assimilation. A plan for such a regional reanalysis should be started in the immediate future.

## S5. Diagnostic Studies

**GCIP OBJECTIVE:** *Determine and explain the annual, interannual and spatial variability of the water and energy cycles within the Mississippi River basin.*

The ultimate aim of the Diagnostic Studies research is to contribute to further improvements of seasonal to interannual climate predictions in support of water resource management. Diagnostics Studies also provide a basis for evaluation of the atmospheric, land, and coupled model data assimilation schemes as well as the forecasts produced from the prediction models. The near term priority is to describe the water budgets over the Mississippi River Basin and major GCIP-defined sub-basins through the use of observations in conjunction with model analyses. Specific activities over the period covered in this Major Activities Plan include investigation of the full four-dimensional water budgets based on observations and model assimilated data with particular emphasis on the output from the regional scale models producing the output for GCIP. Water budget components will be examined over the Continental Scale Area as well as the Large, Intermediate, and Small Scale Areas identified as focus study areas for GCIP. The effects of spatial and temporal sampling on the evaluation of the water budgets will be examined as well as the multi-year behavior of water balance components including storage.

Energy budgets pose a more complex problem since there are fewer direct measurements of the individual components of the energy budgets available for comparison and evaluation. The analyses are more dependent on model estimates of the energy budget terms in conjunction with observations from GCIP-related projects such at the International Satellite Cloud Climatology Project (ISCCP) and the International Satellite Land-Surface Climatology Project (ISLSCP).

One of the primary goals of Diagnostics Studies is to provide a fuller understanding of long-lasting hydrologic regimes associated with floods and droughts over the Mississippi Basin. Diagnostics Studies aimed at improved understanding of the initiation and maintenance of floods and droughts as well as conditions associated with their demise will be initiated.

## S6. Critical Variables

A number of meteorologicalm hydrological and land surface variables are critical to the success of GCIP and were designated as Research Areas for special emphasis in the early stages of GCIP. The priority research activities for each are summarized in this section.

### S6.1 Precipitation

**Precipitation Objective:** *Achieve a better understanding and estimation of the space-time structure of precipitation over the Mississippi River basin, including improvements in atmospheric model representation of precipitation to support improved coupled modeling*.

#### S6.1.1 Precipitation Research Activities

The near-term priority areas for research in precipitation include:

- Understand the basic physical reasons/processes behind anomalous precipitation at all scales of interest (daily, seasonal, interannual). Of special interest are the large anomalies which cause significant societal impacts. Topics of particular importance include: (a) understanding of land surface influences on precipitation (e.g., orography, soil moisture anomalies, spatial distribution of snow cover etc.), and (b) interaction of dynamics and cloud microphysics.

- Develop innovative approaches and methods for validating rainfall predictions from coupled models at a range of space-time scales, including methods for validating ensemble predictions.. Of special interest are: (a) quantification of how well models capture important physical and statistical features that we have evidence for from observations. This sort of validation can provide guidance for improved cloud process parameterization in coupled modeling; and (b) recognizing the inherent limits of predictability of precipitation.

- Study the sensitivity of predictions to initial and boundary conditions in a nested modeling environment and determine the scales at which it is ``better'' to use a nested approach.

- Improve precipitation measurements with special emphasis on: (a) spatial and temporal distribution of solid precipitation including measurement corrections, (b) improved use of WSR-88D data in precipitation measurement including snowfall water equivalent, and (c) development and testing of methods for combining remote measurements (airborne gamma, satellite and radar) with ground measurements to provide enhanced gridded snow water equivalent fields.

The longer term precipitation research activities which should be initiated in the next two years include:

- Develop active and direct collaboration between the Coupled Modeling and the Precipitation research activities to address precipitation validation issues.

- Initiate research on developing a fully distributed energy balance snow model. Such a model is required to assimilate observed and modelled data sets in order to produce gridded snow water equivalent and snow cover fields. It is also needed to establish initial and boundary conditions for seasonal and interannual hydrologic forecasts.

- Initiate and promote efforts to secure spatial and temporal homogeneity of in-situ precipitation (especially solid precipitation), wind and cloud cover measurements that are used for model validation, data assimilation and/or water and energy budget studies.

**S6.1.2 Precipitation Measurement and Analysis**

GCIP requires the best available precipitation products and recognizes the potential value of the WSR-88D radars in meeting this requirement. It is a **goal** of GCIP to contribute to the development of a derived product which combines WSR-88D, gauge, and satellite estimates of precipitation resulting in a product with a 4-km spatial and hourly temporal resolution. Such a goal is not expected to be achieved for a routine product until much later in the five-year Enhanced Observing Period since it is dependent upon some of the modernization improvements yet to be implemented by the NWS. GCIP has an ongoing effort to provide precipitation data products for GCIP investigators. A precipitation analysis is being produced routinely by the NOAA/NCEP and archived at UCAR. A composite of precipitation observations from all available observing networks is produced and archived as part of the GCIP data set in the *in-situ* data source module.

Associated with the measurement of precipitation caught by the gauge is the question of representative exposure of the gauge and the effect of not having wind shields or the characteristics of different shields on gauge catch, evaporation, etc. The systematic adjustment of gauge errors is a necessary requirement for the development of good-quality precipitation fields. GCIP is also supporting research activities to determine systematic errors in precipitation measurements and to derive adjusted values for in-situ solid precipitation measurements starting in the Upper Mississippi River basin. The results from the snowfall measurement corrections applied to the Upper Mississippi River basin will be used in other regions of the Mississippi River basin to compile corrected snowfall measurements, and thus compile reasonably accurate in-situ precipitation measurements over the full annual hydrologic cycle.

**S6.2 Soil Moisture**

**Soil Moisture Objective:** *Improve understanding and estimation of the space-time structure of soil moisture, the relationship between model estimates of soil moisture and observations of soil moisture, and to produce soil moisture fields for the GCIP area to be used as diagnostic and input data for modeling*.

The near-term priority areas for soil moisture research activities include:

- Develop a daily soil moisture analysis at a scale of about 40 km for four depths for the Arkansas-Red River basin because this is the area where the most *in-situ* measurements are available and the region where current remote sensing can provide the best information because of the relatively dense vegetation cover.

- Develop some initial cold season analysis products for soil moisture and soil temperature fields, including frozen and unfrozen soils.

- Develop an understanding of the relationship between point measurements and areal representations of soil moisture as well as the relationship between surface measurements and the vertical profile of soil moisture.

Long term activities that should be started within the next two or three years include:

- Develop approach and methods to produce a daily soil moisture analysis product for the Mississippi River basin at a scale of 40 km for four depths. Such an assimilated product must be produced from a variety of data sources, including output from hydrologic models driven by measured meteorological data, in situ soil moisture observations, aircraft and satellite remotely sensed data.

- Increase the number of in situ monitoring stations to include additional soil/climate regimes. The North-South transect along 96W longitude represents a good start.

- Develop research plan for using advanced satellite remote sensing capabilities and anticipate the infusion of Advanced Microwave Scanning Radiometer (AMSR) around 1999, and hopefully, L-Band satellite sensor data after the year 2000.

### S6.3 Land Surface Characteristics

**Land Surface Objective:** *Improve the quantitative understanding of the relationships between model parameterizations of land surface processes and land surface characteristics, while also facilitating the development, availability, evaluation, and validation of multiresolution land surface data sets required for land surface process research in GCIP.*

#### S6.3.1 Near-Term Priorities for Land Surface Characteristics

- Facilitate the test and evaluation of newly developed land surface characteristics data sets in GCIP's land-atmosphere coupled modeling research at the large river basin to continental scales.

- Develop multiresolution, aggregated land cover characteristics data sets that are internally consistent and collectively "harmonized" within model spatial domain grid cells. Products will include, at 10 km and 30 km grid cell sizes, the three predominant land cover/land use classes in each grid cell and a climatology of the fractional presence of green vegetation associated with the three predominant land use/land cover classes. The product for the conterminous United States will be based on a five-year climatology, while the prototype global product will be derived from an 18-month time series.

- Conduct land cover characterization research involving multiresolution aggregation, scaling, and validation studies based on 30 m land cover data sets developed from Landsat TM imagery as part of a USGS- and EPA-led activity. Preliminary 30 m land cover data are scheduled for completion in the Eastern U.S. by late 1997 with the completion of the remainder of the conterminous U.S. planned by the end of 1999.

#### S6.3.2 Land Surface Characteristics Long-Term Items to be Started in the Next Two Years

- Conduct GIS-based land surface characterization research studies within the Mississippi River Basin to determine multiresolution interrelationships among land cover, biophysical parameters, soils, and topographic data sets including derived parameter fields. In addition to verification of physically-consistent associations, these studies should also focus on the role of landscape heterogeneity in parameterizing land surface processes.

- Conduct advanced research on satellite data processing and physically-based remote sensing algorithms. Advanced satellite-derived land surface temperature/emissivity algorithms are needed to study land surface fluxes.

- Develop plans to test and evaluate remote sensing data sets that will become available following the launches of the NASA-led Earth Observing System (EOS) AM1 Platform and Landsat 7 during the mid-1998 time-frames. The advanced remote sensing science algorithms under development by the MODIS Land Science Team are of particular relevance to GCIP. In addition, current NASA plans call for near-synchronous orbits of the EOS AM1 and Landsat 7 satellite systems, thereby creating a substantial potential for the complementary operation of coarse-and high-resolution satellite data of interest to some GCIP researchers.

### S6.4 Clouds and Radiation

**Clouds and Radiation Objective:** *Improve the description and understanding of the radiative fluxes that drive land-atmosphere interactions and their parameterization in predictive models, while also facilitating the* *development, availability, evaluation, and validation of multiresolution clouds and radiation data sets required for process studies and coupled modeling research in GCIP.*

As new and improved satellite products for GCIP are developed and brought into production, it is necessary to validate and tune the algorithms to provide the most consistently accurate quantities. This requires operating a parallel system that produces the satellite products off line using the same data and the same algorithms, so that the algorithms can be modified and tuned, and the results compared with ground truth. There are current problems with the retrieval of cloud cover and insolation over a snow covered surface that must be addressed through tuning with a parallel system.

Radiation budget components, cloud amounts and heights, and surface temperatures from the regional scale Numerical Weather Prediction models must be compared with satellite observations of the same quantities. Radiation and cloud output from the Eta model will be collected from selected forecast times and remapped into the resolution and map projection of the GOES satellite products and provided for comparison studies. The degree of agreement, conditions under which the model output and the observations are quite different (season, snow cover, bare soil, etc.), and the degree to which the diurnal cycle in observed variables are replicated by model output are both needing evaluation.

The cloud and radiation components in the Eta and other regional models need improvement and the research to upgrade them needs to be started in the next two years if GCIP is to benefit from the research results. Such topics as the interaction of cloud and radiation fields and surface variability within a grid box, use of better cloud parameterization, and cloud resolving models are all appropriate for research. The specific area of research may be dictated by the results of the comparison of model output with observations.

### S6.5 Streamflow/Runoff

Streamflow data and runoff estimates are required both for the development and for the testing and verification of coupled atmospheric/hydrological models. Streamflow is determined from measurements of stream stage at a stream-gauging station. It is essential that the gauge data used for testing and verification of models be essentially unaffected by upstream regulation or diversion. Runoff is the spatially distributed supply of water to the stream network which cannot be measured directly. Both surface and sub-surface components are part of runoff.

Near-Term Priorities for Streamflow/Runoff:

- Extend the available historical data base for unregulated basins at the intermediate and small scales (10 to 1000 $km^2$) in the Arkansas-Red River basin by updating from 1988 the active streamflow to develop and demonstrate regionalization methods for the estimation of hydrologic model parameters. In addition to allowing the estimation of the land-surface model parameters these data are needed for the development of runoff routing parameters and gridding runoff.
- Develop naturalized streamflow records at key locations in the Arkansas-Red River basin up to the current time to enable the validation of the atmospheric model predictions. Key locations would include the Red River at Shreveport and the Arkansas River at Little Rock, being the largest basins which can be feasibly considered.
- Test a method for estimating gridded runoff data for the Arkansas-Red River basin to enable the direct validation of atmospheric model runoff predictions.

## S7. Data Collection and Management

**GCIP OBJECTIVE**: *Provide access to comprehensive in-situ, remote sensing and model output data sets for use in GCIP research and as a benchmark for future studies.*

As noted in Figure S-2, the GCIP Enhanced Observing Period started on 1 October 1995 and will continue for five years. The data collected during each year will be compiled into a number of standard and custom data sets. The data collection periods for the GCIP standard data sets are shown in Figure S-3. These data sets will be published on CD-ROMs for distribution, especially to international scientists interested in GCIP. Increasingly, the national GCIP investigators are making use of the on-line GCIP data services available through the World Wide Web at the URL address: http://www.ogp.noaa.gov/gcip/

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[datasets]

**Figure S-3** Compiled and Planned Standard Data Sets for GCIP Research.

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### S7.1 Data Sets for Warm Periods

The initial focus of GCIP on the warm season processes in the annual hydrological cycle has produced data sets for three different periods in the LSA-SW(see Figure S-4). The data collected during the Enhanced Seasonal Observing Period in 1996 (ESOP-96) is scheduled to be compiled into a standard data set by December 1997. The types of data which comprise the ESOP-96 are described in the Tactical Data Collection and Management Plan for the 1996 Enhanced Seasonal Observing Period (ESOP-96).

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[LSASW]

**Figure S-4** The LSA-SW Encompasses the Arkansas-Red river basin. GCIP Focus Study Areas in the LSA-SW Include the CART/ARM Site Operated by the Department of Energy and the Little Washita Watershed Operated by the USDA/Agriculture Research Service.

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### S7.2 Data Sets for Cold Periods

The data collection activities for Water Years(WY) 1997 and 1998 include the cold season in the Upper Mississippi River basin identified as the LSA-NC in Figure S-2. The details of the data to be collected during this period are given in the Tactical Data Collection and Management Plan for the 1997 Enhanced Seasonal Observing Period (ESOP-97).

### S7.3 Data Sets for the Annual Hydrologic Cycle

The data collection for the next two years covering the full annual cycle will concentrate on the data needed for energy and water budget studies with some increasing emphasis on coupled modeling validation and evaluation. In this regard a Near Surface Observation (NESOB) Data set for at least one 12-month period beginning 1 April 1997 is being compiled. This special dataset is intended to fulfill the data requirements for:

- Land surface process studies
- Validation and verification of land surface processing schemes
- Detailed validation and verification of model output from regional land-atmosphere coupled models.
- Derivation of surface energy and water budgets.

This integrated dataset is being compiled for the LSA-SW which includes the ARM/CART site, the Little Washita Watershed and the Oklahoma Mesonet (if available) in the Arkansas-Red River basin. The vertical dimension includes from 3000m above the surface to 2m below the surface. The preparation of the archive data by the U.S. Geological Survey is done on a Water Year basis. The streamflow data for the Water Year are archived the following April and May. This will necessitate the compilation of the one-year Near Surface Observation Dataset in two parts. The period from 1 April through 30 September 1997 can be completed by June 1998 and the last six months of the one year dataset will be completed by June 1999.

The data sets for the whole of the Mississippi River basin, as shown in Figure S-3, are planned to be compiled beginning in 1999.

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# 1. THE GCIP PROJECT

## 1.1. Background

The Global Energy and Water Cycle Experiment (GEWEX) Continental-scale International Project (GCIP) was established to improve scientific understanding and to model on a continental scale the coupling between the atmosphere and the land surface for climate prediction purposes. Predicting variations in the earth's climate requires improved understanding of interaction between the atmosphere and land surface. Generally, the sensitivity of the earth's climate is determined by the energetic processes of the "fast climate system". The fast climate processes are manifested by clouds, insolation, precipitation, soil characteristics (moisture), vegetation, state of water resources, and the coupling processes between land surface moisture in (1) the partitioning of energy flux between latent and sensible heat, (2) interpreting precipitation variability; and (3) providing knowledge on infiltration and runoff, and its impact on energy and water budgets. The GCIP activities are focused on the Mississippi River basin (see Figure 1-1) to take advantage of the existing meteorological and hydrological networks that are being upgraded with new Doppler radars, wind profilers, and automatic weather stations. The operational or enhanced observing period (EOP) of GCIP began in October 1995 and is planned to continue for five years.

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[LSAs]

**Figure 1-1** The Mississippi River basin, the focus of GCIP activities.

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GCIP became a member of the GEWEX Hydrometeorology Panel (GHP) when it was formed in 1995. The GHP is the principal group within GEWEX for considering scientific issues associated with water cycle processes involved in the coupling of the atmosphere and the land surface, including the distribution of water and potential impacts on water resources. The main task of the GHP is to improve the collective contribution of the GEWEX Continental

Scale Experiments (CSEs) and ensuring their regional results contribute to improvements in global scale prediction models. The CSEs , in addition to GCIP, consist of the Baltic Sea Experiment (BALTEX), the GEWEX Asian Monsoon Experiment (GAME), the Large-scale Biosphere-Atmosphere experiment in Amazonia (LBA), and the Mackenzie River Basin GEWEX Study (MAGS). The premise of the GHP is that the prediction of regional precipitation and runoff anomalies over period of several months is a possibility with improved understanding of water cycle processes. In this regard, the GHP is working toward the following scientific milestones:

- By the year 2000 quantify evaporation, precipitation and other hydrological processes as required to improve prediction of regional precipitation over periods of one to several months.
- By the year 2005 predict changes in water resources and soil moisture on time scales of seasonal to annual as an element of the World Climate Research Program's goals for the climate system.

## 1.2 Scientific Questions and Objectives

The GCIP Science Plan (WMO 1992) poses four principal questions that need to be addressed in order to advance the scientific research community's knowledge of the hydrological and energy cycles involved in the complex interactions between land, atmosphere, and ocean for a major river basin. These are:

- How do water and energy budgets vary in time and space on a continental scale?
- How can surface and groundwater processes at the catchment scale be aggregated interactively with the subgrid scale atmospheric processes in atmospheric models?
- How can the diverse measurements fundamental to the determination of hydrological and energy cycles be best incorporated (retrieved and assimilated) into analyses and coupled hydrologic-atmospheric models in a consistent fashion?
- What are the best approaches for assessing the effects of climate variability and change on water resources?

To address these four principal questions and others detailed in the GCIP Science Plan, the following objectives have been defined:

The long-term objective of GCIP is:

"***To demonstrate skill in predicting changes in water resources on time scales up to seasonal, annual, and interannual as an integral part of the climate prediction system.***"

A rewriting of the GCIP Objectives by the NAS/NRC Gewex Panel in 1996 contributed to more focus of the GCIP research activities and near-term plans (IGPO 1996a):

1) Determine and explain the annual, interannual and spatial variability of the water and energy cycles within the Mississippi River basin.

2) Develop and evaluate coupled hydrologic/atmospheric models at resolutions appropriate to large-scale continental basins.

3) Develop and evaluate atmospheric, land, and coupled data assimilation schemes that incorporate both remote and in-situ observations.

4) Improve the utility of hydrologic predictions for water resources management up to seasonal and interannual time scales.

5) Provide access to comprehensive in-situ, remote sensing and model output data sets for use in GCIP research and as a benchmark for future studies.

## 1.3 Project Implementation

The GCIP Implementation Plan, comprising three volumes, was completed in 1993 and 1994. Volume I of the GCIP Implementation Plan (IGPO 1993) is the overall planning document for the Project. It addresses the organizational framework for GCIP, the observational and database needs, and the upgrades to be made to existing operational analysis and prediction streams that produce routine four-dimensional data assimilation (4DDA) analyses for the GCIP and global domains. Volume II ( IGPO 1994a) examines the elements of a GCIP research program needed to assist the research community in addressing the specific scientific questions in the GCIP Science Plan. The overall plans for data management through the duration of the GCIP Project are described in Volume III of the GCIP Implementation Plan (IGPO 1994b).

GCIP is making use of existing operational and research programs to meet the research objectives. An important example is the U.S. Department of Energy, Atmospheric Radiation Measurement (ARM) Program, whose data from the Clouds and Radiation Testbed (CART) site are being made available to the GCIP effort. Opportunities for cooperation are being exploited with projects being formulated under other streams related to World Climate Research Programme (WCRP), such as the Climate Variations (CLIVAR) and the Global Ocean Atmosphere Land Surface (GOALS) Program. For example, the Pan American Climate Studies (PACS) project is being formed as a U.S. contribution to CLIVAR/GOALS to conduct research on the role of large-scale forcing from the tropics on continental precipitation in the Americas. A more complete description of collaborative research activities is given in Section 8.

### 1.3.1 Research Approach

GCIP research involves a systematic multiscale approach to accommodate physical process studies, model development, data assimilation, diagnostics, and validation topics. Such a multiscale developmental framework for the GCIP effort has three attributes:

(1) Support for a hierarchy of scales for observational work, algorithm and model development, and validation and diagnostic studies leading to a continental-scale capability.

(2) Capacity for sequential expansion to support the evolution of research themes (e.g., initial emphasis on hydrological implications of warm-season convective precipitation, moving next to issues related to midlatitude cold-season hydrology).

(3) Flexibility to develop methods and algorithms that can be applied in data-sparse areas of the globe outside the Mississippi River basin.

The understanding and modeling of a continental scale require, from the outset, consideration of nonlinear-scale interactions in the aggregation of smaller processes to the larger scale and vice versa. Progress in this area requires that methodologies be developed to represent the coupling of processes that are important in one medium (e.g., the atmosphere) to those that are important in another (e.g., the land surface). These techniques must be suitable at the resolution of operational prediction and general circulation models (GCM) (about 10 to 100 km) and hence must be capable of representing in aggregate the effects of high levels of heterogeneity in the underlying ground surface (WMO 1992). Accordingly, the GCIP research approach addresses activities on four scales (IGPO 1994a):

**Continental-scale area (CSA) activities** that span the entire domain of the Mississippi River basin with a scale size of about 3.2 x $10^6$ $km^2$.

**Large-scale area (LSA) activities** that occur in a phased timetable and emphasize a particular region with special characteristics for a period of about two years. Scale size is about $10^5$ to $10^6$ $km^2$. Four LSAs have been identified that in aggregate cover most of the GCIP domain, as shown in Figure 1- 2. The time phasing of activities within each of these areas is also shown in the figure.

**Intermediate-scale area (ISA) activities** that will be phased in with those for the LSAs and will serve as the basis for the regionalization of the parameters and coefficients of land surface hydrological models. Scale size is about $10^3$ to $10^4$ $km^2$.

**Small-scale area (SSA) activities** that typically occur in association with efforts requiring intensive observing periods (IOP) over a concentrated region to study a focused set of issues. Scale size is less than $10^2$ $km^2$.

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[LSAs]

**Figure 1-2** Boundaries for LSAs and temporal emphasis for each LSA from 1994 through 2000.

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The analyses and diagnostic studies conducted on the CSA, LSA, and ISA scales will derive their data primarily from existing sources, with augmentation of some observing systems as required. A major element of the rationale for carrying out the GCIP effort in the Mississippi River basin is the potential for full utilization of a number of observing systems (e.g., wind profiles and Doppler radars) not available to the same extent anywhere else in the world. In a number of LSAs, data from the existing synoptic and climatological networks operated by the National Weather Service can be augmented by data from relatively dense climatological networks established and operated by other Federal agencies and state organizations.

To the extent possible, the SSAs are being collocated with existing research basins, for example, the Little Washita Experimental Watershed in Oklahoma operated by the U.S. Department of Agriculture. The analyses, diagnostic studies, and model development on the SSA scale are being derived from operational data sources (augmented as necessary), existing research instrument complexes, and specially designed field programs of limited duration.

### 1.3.2 Continental Domain Synthesis

A fundamental thrust of the GCIP implementation strategy is that although the developmental activities are being initiated in limited regions, they lead toward an integrated continental-scale capability. Full continental domain studies have been important in GCIP from the beginning of the EOP in 1995. Retrospective analyses and baseline studies of water and energy balance have been the main focus of the research activities. In fact, as the EOP proceeds, the GCIP-derived budgets based on regional mesoscale models are superior in accuracy to budget estimates from other sources. These diagnostic studies will also be valuable for validating hydrological aspects of climate model simulations and understanding planetary-scale influences on North American hydrology.

## 1.4 Accomplishments to Date

The completion of the GCIP Science Plan in early 1992 heralded the beginning of a number of major activities in GCIP that have progressed steadily over the past five years. Some of the key accomplishments during this period are summarized in the remainder of this section within the scientific/technical implementation framework as outlined in the following section.

### 1.4.1 Scientific/Technical Implementation Framework

The two pivotal components of GCIP are (1) the development of a comprehensive observational database for the Mississippi River basin that will be available for GCIP analyses, and (2) the establishment of an evolving program of model development that will permit the observations to be extended spatially within GCIP or applied globally with new observations. A series of planned and *ad hoc* research and technical activities addressing observing systems, algorithm development, quality assurance issues, and water and energy budget studies link these pivotal components, as shown in Figure 1-3 (WMO 1992).

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[LSAs]

**Figure 1-3** Strategy framework for implementing GCIP.

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With the interest in climate as a science over the past decade or so, computer models of the earth/atmosphere system have taken place along two separate paths. Many of the improvements in global models for weather prediction have occurred in, or in close cooperation with, the major operational analysis centers such as the U.S. National Center for Environmental Prediction (NCEP) and the European Centre for Medium Range Weather Forecasts (ECMWF). Developments in global climate models, which have their origins in the global weather models, have generally occurred in the U.S. in large research establishments such as the NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), the NASA Goddard Space Flight Center (GSFC) and the National Center for Atmospheric Research (NCAR). In the early development of strategies for implementing GCIP, it was recognized that it would be necessary to draw on the strengths offered by both of these paths. A further key strategy that was adopted early in GCIP was the need to fully exploit the high resolution, limited area models that were being applied to regional weather prediction tasks through various nesting procedures in the global models.

The GCIP research activities got underway in 1993 with primary support from NOAA. The results of these early research studies in data analysis, model development, diagnostics of model output, and observing system enhancements were published in a special issue of the *Journal of Geophysical Research* Volume 101, Number D3, March 20, 1996.

### 1.4.2 Research Path Achievements

During the past two years the research emphasis has been on warm season processes using data from the Arkansas-Red River basin in the southwestern part of the Mississippi river basin. Cold season processes using data from the

Upper Mississippi River basin are being added. More than 100 papers have already been published in scientific journals. These research activities, although initiated in limited regions, are leading toward an integrated continental-scale capability.

### 1.4.3 Achievements in the Operational Centers

Since the approaches being taken by the principal operational analysis centers (e.g., the U.S. National Centers for Environmental Prediction [NCEP], the Canadian Meteorological Centre [CMC] and the ECMWF) are different, it is important that GCIP researchers have access to data from more than one assimilation scheme. The NCEP Eta Model and the NOAA Forecast Systems Laboratory MAPS Model are both high resolution nested regional models, the ECMWF and NCEP operate global models at coarser resolution while the CMC uses a variable grid approach with the Global Environmental Multiscale (GEM) Model . Further details on the achievements and near-term plans for improvements to the regional models are given in Section 2. The regional model output data are being made available to GCIP researchers with special efforts being made to archive the output from the regional mesoscale at a central location as described in Appendix B.

### 1.4.4 Database Development

The GCIP Science Plan (WMO 1992) recognized that the building of a database for GCIP scientists would be a major undertaking and that the amount and different types of data needed for GCIP studies would require an efficient data collection and management strategy.

The accomplishments to date in database development are in the areas of Pre-EOP data collection, compilation of several initial data sets, and the implementation of a distributed data management and service system.

### 1.4.5 Data Management and Service System

The responsibilities of the GCIP Data Management and Service System (DMSS) are to provide data services to GCIP investigators, adapt to the evolving data requirements, and compile the information on a five-year consolidated data set at the completion of the EOP. Carrying out these responsibilities involves an implementation approach with evolutionary improvements during the different stages of GCIP. The DMSS implementation strategy makes maximum use of existing data centers to minimize the lead time and expense required for development. These existing data centers are made an integral part of the GCIP-DMSS through four data source modules that specialize by data types (i.e., *in situ*, model output, satellite remote sensing, and GCIP special data) The primary responsibilities for the data source modules along with their major functions and activities were described in Volume III of the GCIP Implementation Plan (IGPO 1994b). Further details on data collection and management are given in Section 9.

## 1.5 Role and Structure of GCIP Major Activities Plan

The purpose of the Major Activities Plan is to project a description of GCIP research and associated activities over the next two to three years to preclude the need for frequent revisions to the three volumes of the GCIP Implementation Plan. The initial version of the Major Activities Plan covered the two-year period of 1995 and 1996 with an outlook for 1997 (IGPO 1994c) and was updated in each of the last two years (IGPO 1995; IGPO 1996a).

The description of planned activities is based on what should be done in an orderly progression toward the end objectives of GCIP and with a realistic assumption about the resources that will be available to do it. Adjustments are made the following year, as appropriate, to rationalize the plans with the actual resources. The adjustments are used as a starting point for projections in the following year's update.

This update of the Major Activities Plan covers the water years of 1998, 1999 and outlook for 2000. It was shown in Figure 1-2 that during this period there will be an emphasis on the four LSAs for two or more years. . Since activities are planned for each of the four LSAs, this will spread out the descriptions pertaining to specific objectives. Activities focused on the four science objectives are described in Sections 2 to 5. A number of variables were deemed critical to the success of GCIP and were designated as Principal Research Areas for GCIP. These include precipitation, soil moisture, land surface characteristics, and, clouds and radiation. The research activities for each of these critical variables are described in section 6. A summary of the research activities planned for each of the four LSAs and the CSA is given in section 7. The increasing importance of the collaborative research activities is described in section 8. The activities related to the data management objective are described in Sections 9 and 10 of this Plan.

## 1.6 GCIP after the Year 2000

The implementation planning for GCIP extends through the year 2000, as noted in Figure 1-2. A major phase of GCIP is the five-year Enhanced Observing Period that started on 1 October 1995 and is scheduled to be completed on 30 September 2000. This initiative is providing a comprehensive observational and model output database needed for GCIP research and as a benchmark for future studies.

GCIP has made tremendous strides in several of its science objectives during the past five years while others, such as the water resources objective, have not yet started. In addition a number of areas have evolved or started since the Implementation Plan was written in 1993 and 1994. Among those which could most affect GCIP plans after the year 2000 are:

1) GCIP and the Pan American Climate Studies(PACS) projects recently developed a prospectus as an initial step toward an integrated study of warm season predictability of precipitation and temperature over North America. It is predicated on the hypothesis that there is a deterministic element in the year-to-year variability of summertime precipitation and temperature over North America. The GCIP/PACS studies will address three major objectives:

> i. Describe, explain and model the North American summer climate regime and its associated hydrologic cycle in the context of the evolving land surface-atmosphere-ocean annual cycle.
>
> ii. Describe, explain and model North American warm season precipitation and temperature variability with emphasis on seasonal and interannual time scales.
>
> iii. Describe, explain and model the spatial variability of summertime precipitation over North America on mesoscale to continental scale.

2) The CLIVAR Implementation Plan identifies GEWEX as the primary source of analyses and modeling of land surface processes as a contribution to global climate modeling. It is clear that the five Continental Scale Experiments (BALTEX, GAME, GCIP, LBA and MAGS), as part of the Gewex Hydrometeorology Panel, will need to play a strong role in this GEWEX contribution to CLIVAR. GCIP needs to develop its strategy for contributing to the overall program for the GEWEX Hydrometeorological Panel. In addition to the GEWEX contribution to CLIVAR, the Gewex Hydrometeorology Panel has set its own strategic objective:

***By the year 2005 predict changes in water resources and soil moisture on time scales of seasonal to annual as an element of the World Climate Research Program's goals for the climate system.***

3) The results of the research during the past five years, especially the successes with the mesoscale NWP models show that GCIP can now increase the time scale for predictions and should focus on developing an initial version of a coupled hydrologic/atmospheric climate model. Also, GCIP needs to increase the priority of its efforts in water resources applications to provide a contribution to the strategic objective for the GEWEX Hydrometeorology Panel.

It can be seen from the brief summary given above that the environment for GCIP research has changed significantly over the past five years since the GCIP Implementation Plan was written. Some changes were foreseen while others were not and the Preface to Volume I (IGPO 1993) states -- " These volumes of the implementation plan will evolve during the course of the project and each will be updated as required". It is apparent that some form of updating should be done to accommodate the knowledge gained during the past five years. It is considered that GCIP could benefit most from the updating of Volume II - RESEARCH- portion of the GCIP Implementation Plan. A proposal for a post-2000 implementation strategy as a first step in this process is given in Appendix A. It is also intended to provide a framework for updating the GCIP Major Activities Plan for the period 1998, 1999 and Outlook for 2000.

# 2. COUPLED MODEL DEVELOPMENT AND EVALUATION

In the context of the GCIP, a coupled atmospheric-hydrologic model is defined to be a model or combination of models which simultaneously represents both atmospheric and hydrological processes, which can operate in predictive mode without the need to specify variables or exchanges at the interface between the two model components, and which can benefit from the assimilation of data to specify that interface. This context provides the framework for the **GCIP Objective:** *Develop and evaluate coupled hydrologic/atmospheric models at resolutions appropriate to large scale continental basins*.

## 2.1 General Approach

The implementation of model development in GCIP has followed two paths as described in the GCIP Implementation Plan (IGPO 1993) and was shown in Figure 1-3. On the "research" path are the longer term modeling and analysis activities needed to achieve the GCIP coupled modeling **Research Goal -** *To identify and understand the coupled processes that influence predictability at temporal time scales ranging from diurnal to seasonal and spatial scales relevant to water resource applications , and to develop a coupled model which can be validated (at these scales ) using data for the Mississippi River basin*.

Research is focusing on determining , understanding and modeling those processes which are demonstrably important in coupling atmospheric and hydrological systems, rather than those processes which are separately important within these two systems. A GCIP Coupled Modeling Workshop (IGPO 1996b) resulted in a number of recommendations which are incorporated in this and other sections of the Major Activities Plan for 1998, 1999 and Outlook for 2000.

An "operational" path was started in 1993 during the GCIP Buildup Phase to develop and implement the improvements needed in the operational analysis and prediction schemes to produce the model assimilated and forecast output products for GCIP research, especially for energy and water budget studies. The regional mesoscale models also serve to test components of a regional climate model and can provide output for the evaluation of a coupled hydrologic/atmospheric model during the assimilation and early prediction time periods as a precursor to developing and testing a coupled hydrologic/atmospheric climate model. The output from three different regional mesoscale models is routinely compiled as part of the GCIP data set as described in Section 2.4 and Appendix B of this plan.

## 2.2 Coupled Modeling Research

The GCIP coupled modeling research is predicated on the hypothesis that the creation of regional-scale coupled models which simultaneously represent both relevant atmospheric and the land-surface processes, and the validation of these models against observations from GCIP, will improve our ability to:

(a) predict variations in weather and climate at time scales up to interannual; and

(b) interpret predictions of weather and climate in terms of water resources at all time scales.

In accordance with this hypothesis, GCIP is focusing on those research activities which create, calibrate, and apply coupled models of the atmospheric and hydrologic systems with priority given to research to improve climate prediction and to improve hydrological interpretation of meteorological predictions at the above time scales. The GCIP coupled modeling research is focusing on three program elements that address the three scientific questions and priority needs given in Table 2-1. These issues and planned research activities are described further in the following paragraphs.

| **Table 2-1: Scientific Agenda for the GCIP Coupled Modeling Research** |
|---|
| **1. "*To what extent is meteorological prediction at daily to seasonal time scales sensitive to hydrologic-*** |

***atmospheric coupling processes?" - the priority research issues to be addressed by GCIP are:***

- The Evidence for, and the Mechanisms Involved in, Seasonal Predictability
- The Relative Importance of Hydrologic-Atmospheric Coupling over an annual cycle
- The Need to Represent Diurnal Variations in Surface Energy Fluxes

**2. "*To what extent can meteorological predictions be given hydrological interpretation?*" - the priority needs in GCIP are for:**

- Evaluation of Seasonal-to-Interannual Predictions
- Definition of the Predictive Products Required by Hydrologists

**3. "*How can models of relevant hydrologic-atmospheric coupling processes be improved to enhance meteorological and hydrological prediction?*"- the priority needs for GCIP are:**

***For Precipitation Processes***

- Improved Parameterization of Convective Precipitation in Atmospheric Models
- Statistical Analyses of Subgrid Scale Precipitation
- Research into Cold Season Precipitation Issues
- Improved Understanding of Topographic Influences on Precipitation

***For Soil Moisture Processes***

- Improved and Extended Soil Moisture Measurement
- Coupled Modeling of the Effect of Soil Moisture Heterogeneity on the Atmosphere
- Improved Parameterization of Hydrologic Submodels

***For Snowcover and Other Cold Season Processes***

- Snow Cover
- Subgrid Interactions
- Hydrologic Interactions

***For Biospheric Processes***

- Vegetation Influences on Hydrologic Cycle

**4. "*To what extent is model parameter estimation for the hydrologic part of coupled models basin dependent?* - the priority needs for GCIP are:**

- Evaluate the Transferability of Existing Parameter Estimation Techniques
- Improved and Extended Parameter Estimation Techniques

### 2.2.1 Atmospheric/Hydrologic Coupling Sensitivity

Progress in the representation of land-atmosphere interactions over the last two decades has been sufficient to motivate several operational modeling centers (for example, the National Center for Environmental Prediction, the European Centre for Medium Range Forecasting, and the Japanese Meteorological Center) to implement and benefit from modern-era, multi-layer soil-vegetation- atmosphere transfer schemes. Planetary, continental, and regional atmospheric circulation patterns in such assimilation systems are constrained near truth by the assimilation of atmospheric observations. Nonetheless, the implementation of improved representation of hydrologic-atmospheric interactions has undoubtedly improved the quality of the precipitation and low-level temperature analysis products provided by data assimilation systems.

#### 2.2.1.1 Evidence of and Mechanisms for Seasonal Predictability

GCIP provides an excellent rationale and data source for investigating the hypothesis, in the context of North America, that (globally determined) soil moisture anomalies at the beginning of the warm season influence the regional precipitation in the subsequent months. Atmospheric general circulation model runs with improved representation of interactive moist processes along with diagnostic studies are needed to test this hypothesis and determine the conditions and limitations of its applicability. These would involve comprehensive analyses to explore the lagged correlation, both locally and perhaps downwind, between all the relevant data (on rainfall, evaporation, temperature, clouds, radiation, vegetative state, etc.) now available within GCIP. In addition, it is now time to undertake experimental, free running seasonal to interannual simulations with coupled models of the land-atmosphere-ocean system to give global and regional forecasts. Realistically, early expectations of the skill of such forecasts should be limited to capturing modest indications of regional-scale monthly or seasonal anomalies of precipitation and temperature.

#### 2.2.1.2 Coupling importance in the annual cycle

The strength and influence of the hydrologic-atmospheric coupling varies between cool and warm seasons, which leads to seasonal differences in the importance of land-atmosphere coupling relative to other regional-scale and global-scale influences. An explicit understanding of the seasonal variation of relative coupling strength is necessary to define the relative prediction. Land-atmosphere coupling processes which are important in seasons when local controls are more important likely need more precise representation than those which are important in seasons when global-scale influences dominate.

The required studies will involve a combination of measurement and modeling activities. Observations would likely include atmospheric profiles of moisture, temperature, and wind during both warm and cool seasons and during the transition from cold to warm season, together with simultaneous measurements of the surface fluxes of water and energy. Modeling studies could include sensitivity studies using validated coupled models applied in different seasons and at different spatial scales.

#### 2.2.1.3 Significance of diurnal variations in surface energy fluxes

Based on the results from a coupled land-atmosphere model, Koster and Suarez (1995) suggested that large scale circulation is affected by short-term variability in the surface energy balance. Hence a land surface scheme that realistically reproduces the mean diurnal cycle of the surface energy balance may nonetheless be inadequate for coupled modeling purposes. The scheme might also need to reproduce the short-term variations in the balance of energy.

The extent to which short-term variations in surface energy balance require representation in predictive models when applied at seasonal-to-interannual time scales merits more detailed investigation. Modeling experiments are required to explore this limit on the complexity of the representation of hydrologic-atmospheric processes.

### 2.2.2 Hydrological interpretation of meteorological predictions

The nature of the meteorological predictions calculated by global-scale models of the ocean-atmosphere-land system is likely to be profoundly different from actual meteorological observations in terms of their spatial and temporal precision and accuracy, even when those predictions have been down-scaled through mesoscale, regional models. Existing hydrological models are designed to work from observations, and their form and function reflect the nature of these observations. Research is required to determine what type of hydrological prediction is possible from seasonal-to-interannual meteorological predictions and at what spatial and temporal scales hydrological interpretation can have worthwhile credibility and utility. Handling uncertainty in meteorological predictions is not a resolved issue in hydrological models, even for short-term forecasts, and reservoir management practice will always need to be incorporated into the hydrological interpretation for North American water resource issues.

There is opportunity to improve communication between atmospheric scientists and hydrologists on this issue, because neither of these two groups have hitherto had opportunity to fully appreciate the relevant capabilities of the other. Hydrologists do not yet appreciate what the nature and form of seasonal-to-interannual meteorological predictions might be, and there is some lack of clarity on this issue. Equally, meteorologists do not yet have an appreciation of what type of seasonal-to-interannual prediction might have practical value to hydrologists. At this time, therefore, the need is to provide better definition of these issues in order to establish a means of interaction between the two communities.

#### 2.2.2.1 Evaluation of seasonal-to-interannual predictions

As noted above, not only is GCIP in a strong position to foster experimental seasonal-to-interannual forecasts focused on the North American continent, it is also uniquely able to provide effective validation of such forecasts by virtue of the existing and new data that are being collected for the U.S. in general, and for the Mississippi River basin in particular. However, some redefinition of GCIP data products will be required. Specifically, once the form, nature, and spatial and temporal scale of seasonal-to-interannual prediction products are defined, it will be necessary to synthesize equivalent observational products from GCIP's precipitation and temperature measuring networks. Future westerly extension of the GCIP study area also seems essential if there is to be a better match between areas in the U.S., where seasonal-to-interannual prediction is most feasible, and areas in which data collection within GCIP has priority. Arguably, the single-most challenging technical problem will be providing a credible regional measurement of cold-season precipitation for the purposes of comparison with seasonal-to-interannual predictions.

#### 2.2.2.2 Definition of the predictive products required by hydrologists

Resource managers within the hydrological community might be able to make use of a range of predicted outputs from coupled land-atmosphere-ocean models, but hitherto they have tended to rely on traditional meteorological and hydrological measurements applied to conventional hydrological models for streamflow predictions. Although hydrologists have a good capability for using statistical forecast information, so far the coupled modeling community has not given priority to providing this type of information. However, research into the possible hydrological interpretation of these predictions cannot begin until the nature and form of such predictions are better defined.

There is a need to develop better understanding of the requirements of the hydrological community so that any predictive meteorological products provided at the seasonal-to-interannual time scale can be tailored more precisely and the opportunities for timely application of GCIP research within hydrology thus enhanced.

### 2.2.3 Improved coupling processes - issues and actions

Accepting the hypothesis that better representation of processes in coupled atmospheric-hydrologic models will yield improved meteorological prediction at all time scales, research is required to determine, understand, and model such coupling processes. The focus of research into several coupling processes might evolve in response to better specification. However, initially, research will address improved representation of precipitation, soil moisture and biospheric processes.

#### 2.2.3.1 Precipitation processes

Clouds and their associated precipitation are important in the global water and energy cycle and their accurate representation in atmospheric models is crucial. However, incorporating moisture processes is difficult because cloud and precipitation physics is poorly understood, and because the horizontal resolution of large-scale models is much larger than the scales at which clouds are formed --hence cloud-precipitation processes are subgrid-scale mechanisms which must be parameterized.

**(1) Improved parameterization of convective precipitation in atmospheric models**

Focused smaller-scale modeling studies are needed to investigate how to improve the parameterization of convective precipitation within regional-scale atmospheric models. To have credibility, such studies require experimental validation. Such experiments would involve simultaneous measurements in the atmosphere and at the surface, and would need to be framed in a proper regional context by specification of the atmospheric flow fields through the study area. GCIP has already begun planning the provision of some of the required observations, in the form of a Near-Surface Observation Data Set described in Section 10. GCIP is also fostering opportunities to validate regional models of precipitation within the Mississippi River basin through collaboration with other observational programs such as ARM, the US Weather Research Program, and the GEWEX Cloud System Study as described in Section 8.

**(2) Statistical analyses of sub-grid scale precipitation**

Studies are needed to characterize the true variability of precipitation in space and time and its relation with the state of the overlying atmosphere. Understanding the relationship between actual continental precipitation and that predicted by atmospheric models is a very high priority for GCIP. Such studies are especially important at hourly to daily time scales and at spatial scales up to the area covered by a few grid intervals in mesoscale and large-scale atmospheric models.

The accuracy with which precipitation can be measured (by gauges, radar, or both) is likely to be an issue in such studies. Recognizing this last point, the LSA-SW would be the appropriate initial focus for such studies since the stage 3, gauge-calibrated radar precipitation products provided by the Arkansas-Red Basin River Forecast Center (ABRFC) now have established value for comparison against modeled estimates using the Eta, MAPS and RFE regional NWP models.

**(3) Research into cold season precipitation issues**

Snow is an important component of precipitation, particularly so in the northern and western regions of the U.S., where it provides an important component of the available surface-water resource. Many of the basic atmospheric parameterization issues are similar for warm and cold season precipitation, though parameter values are likely to change between seasons. However, there are additional important research issues related to quantifying cold season precipitation and its partition into runoff or soil moisture which must be addressed. Such questions will be priority issues in the scientific agenda for GCIP studies in the LSA-NC.

The central question is how to develop precipitation volumes that give an accurate measure of the temporal and spatial distribution of snowfall. Associated with this question is the need to determine how representative are rain gauge measurements of snowfall and how to combine surface observations of snow depth and with remote-sensing estimates from aircraft and satellites. These questions of snowfall measurements are discussed further in Section 6.1.

**(4) Improved understanding of topographic influences on precipitation**

Water is a critical resource in the western U.S. It occurs mainly through the winter season and to a great extent depends on the total water vapor flux across the mountains and, hence, on large-scale circulation in the atmosphere in winter. However, it is strongly influenced by orography, and GCIP has the potential to make an important contribution to the improved seasonal-to-interannual prediction of water resources in the western U.S. by improving the predictability of orographic precipitation. Accurate forecasting of water resources requires better definition of the location of precipitation than is possible with current weather forecast models. The optimal spatial scale for these forecasts is around 2-3 km, but to achieve this would require a nested modeling approach as an extension of presently available systems. Exploratory research is required to evaluate the value of successively nested forecast models as a possible mechanism for applying seasonal-to-interannual forecasts to water resource issues.

**2.2.3.2 Soil Moisture Processes**

Soil moisture possesses a memory during its seasonal evolution, and is determined as the residual between precipitation on the one hand and evaporation and surface and subsurface runoff on the other. Many of the modeling studies which have provided evidence that seasonal predictions show sensitivity to hydrologic-atmospheric coupling have in fact been framed in terms of sensitivity to modeled or prescribed soil moisture. There is, therefore, a clear understanding of the importance of soil moisture for climate prediction at the seasonal time scale.

Heterogeneity in the spatial distribution of soil moisture is an inevitable consequence of uneven precipitation, and this can be exacerbated by the subsequent flow of surface and subsurface water across uneven topography. Modeling investigations (e.g. Avissar and Liu 1996) indicate that naturally occurring soil moisture heterogeneity (acting through land-atmosphere coupling process) significantly influences the behavior of the overlying atmosphere. Progress in understanding the effect of area-average soil moisture, heterogeneity in soil moisture fields, and in validating models which describe the seasonal evolution of soil moisture in space and time have all been curtailed by the historic (and still current) lack of soil moisture measurements.

**(1) Improved and extended soil moisture measurements**

The growing deployment within GCIP of arrays of field systems capable of routine measurement of soil moisture and the prospect of future deployment of aircraft- and space-borne sensors capable of providing indirect measurements of near-surface soil wetness promise relief from observational limits on understanding for soil moisture processes in coupled models.

Installation of automated soil moisture sensors within the ARM-CART, Little Washita Watershed and the Oklahoma Mesonet are in place or underway, and plans are being made to extend deployment in the Oklahoma Mesonet to include all 114 sites and further extensions to similar distributed data collection networks elsewhere in the Mississippi River basin. GCIP is coordinating the collection of a set of soil moisture (and temperature) profile measurements along a north-south transect to make observations over the annual cycle, but with emphasis on documenting freezing and thawing episodes during the cold season. This transect from Plainview, TX (about 30N) to Bemidji, MN (about 47N) in the vicinity of the 96W longitude. In addition to these new data sources, the Illinois state water survey soil moisture data (Hollinger and Icard 1994) remain a valuable data resource for GCIP. The distribution of soil moisture data from these new arrays of soil moisture sensors to the GCIP coupled modeling community is a high priority, as is their synthesis into regional products for model initiation and calibration purposes. A more detailed description of the soil moisture measurement and analysis is given in Section 6.2.

The GCIP community strongly supports the proposal to provide routine remotely sensed measurements of soil moisture using a satellite L-band microwave radiometer. The community understands that such observations can only provide indirect estimates of near-surface soil wetness for certain vegetation covers, but also recognizes that these data are most reliable for short-rooted and sparse vegetation where soil moisture control is most important. Routinely provided soil wetness estimates from satellites could be exploited for coupled model initiation and validation using four-dimensional data assimilation techniques to improve the prospect of better seasonal climate predictions for North America. Moreover, GCIP provides a unique opportunity to validate and calibrate remote-sensing soil moisture data because of the richness of other data fields, such as WSR-88D and gauged rainfall, runoff, and modeled evaporation, from which alternative area-average soil wetness estimates can be made. Calibration of remotely sensed soil wetness data within the GCIP region could thus be the basis for their application elsewhere in the world.

The potential availability of new sources of soil moisture data gives rise to the need to determine how these data can best be used to initiate and validate coupled models. Research is required to investigate how to use sample data from arrays of surface measurements and exploratory remote-sensing data from airborne radiometers. Some modeling studies have been done, but with very limited field validation. Properly conceived combined field and modeling studies such as the recent CASES-97 should greatly illuminate this issue. The coupled modeling community is aware of and applauds the GCIP efforts during the last four years and the DOE, NSF, and NOAA sponsored CASES-97 and the NASA sponsored SGP97 field studies within the ARM-CART study area in the

Mississippi River basin that fulfill some of these observational needs, and look forward to working with the data that will result .

**(2) Coupled modeling of the effect of soil moisture on the atmosphere.**

Investigations on the effect of soil moisture and its heterogeneity in a fully coupled 3-D, atmospheric-hydrological system are required. The opportunity exists to run fine-scale, nested grid microscale (large-eddy simulation) models that can resolve clouds and the resulting precipitation fields in the context of the upcoming observational studies just described. These model results (considered in a statistical sense) can be compared with the airborne sensor and ground soil moisture observations and with radar and gauged rainfall measurements to determine the quality of the model simulation.

An alternative approach to coupled modeling is to assume that precipitation and other atmosphere processes cannot be predicted deterministically and to conceive models that provide statistical representation of these processes. The challenge is then to develop complementary hydrological models that can be forced with statistical distributions of meteorological variables such as precipitation, solar radiation, etc., and to use these to calculate statistical estimates of the feedback to the atmosphere in the form of sensible-heat fluxes, etc. Statistical models of this type would also benefit from validation against the statistical distributions of precipitation and soil moisture observed in the upcoming observational studies discussed above.

A much greater understanding is needed on how coupled models represent and would utilize the soil moisture observations for testing and validation, both in a spatial and temporal context. Efforts are needed to bridge the gap between the disparate scales of the point measurement with the simulation model grid box. Further, basic research is needed to determine to what extent downscaling of remotely sensed soil moisture is required in order to be used in coupled models.

An important aspect of coupled modeling research concerns the possible importance of soil moisture on the formation and evolution of mesoscale convective complexes (MCCs) and mesoscale convective systems (MCSs). Such large mesoscale systems are often initiated over mountainous terrain and move eastward, and they produce a significant portion of warm season precipitation in the Mississippi River basin. Current studies in the western Mississippi River basin need to take account of these mesoscale systems because they play a major role in the warm season hydrological cycle in the southeastern Mississippi River basin. Fine-scale modeling studies are required to ensure adequate simulation of MCCs and to investigate their relation to the underlying soil moisture fields in the regional NWP models. Again these studies would be best linked to upcoming observational initiatives. After accurate trial simulation of MCCs is accomplished in these particular situations model tests of the effect of MCCs on the regional hydrology can be made under varying soil moisture conditions. A further description of this topic in connection with research relative to the GEWEX Cloud Systems Study is given in Section 8.

**2.2.3.3 Snowcover and Other Cold-Season Processes**

**(1) Snow cover**

With its high albedo, low thermal conductivity, and considerable spatial and temporal variability, the seasonal snow cover overlying land plays a key role in governing the Earth's global radiation balance; this balance is the primary driver of the Earth's atmospheric circulation system and associated climate. Of the various surface radiation balance components, the location and duration of snow cover comprises one of the most important seasonal variables. In the northern hemisphere, the mean monthly land area covered by snow ranges from 7% to 40% during the annual cycle, making snow cover the most rapidly-varying surface-feature on Earth. In light of the role that snow plays in determining weather and climate, it is essential that regional and global models used to simulate weather and climate be capable of accurately describing the evolution of seasonal snow covers. In past years, significant strides have been made to better represent snow cover in climate models, but there are still indications that current representations of seasonal snow in these models are plagued by significant deviations from observed snow-related fields.

The timing of snow deposition and melt is one of the most important climatic and hydrologic influences affecting agriculture and water resources. A detailed understanding of snow pack processes, including thermal properties, meltwater percolation, density and albedo evolution (especially during the melt season) is necessary to understand the relationships between snow cover, atmospheric processes, and surface hydrology during 'normal' and 'anomalous' snow cover regimes. Lagged relationships between snow cover and other parameters are also expected to be important. A main goal of GCIP should be to improve our understanding of these processes, and to build better representations of snow cover in the global and regional climate models that are used for GCIP diagnostic and prediction studies. Accomplishing this will require studies which 1) evaluate sub-models using GCIP snow and meteorological field data; 2) develop parameterizations of snow-cover extent for atmospheric models; 3) evaluate coupled simulations using satellite data and other gridded data sets; and 4) identify snow-atmosphere feedback-processes operating within the GCIP regions.

**(2) Subgrid Interactions**

The interactions between wind, topography, vegetation, and snowfall produce snow covers of non-uniform snow-water-equivalent. During these blowing and drifting snow events, a largely unknown amount of moisture is returned to the atmosphere as the snow grains sublimate during transport. When the snow melts, the variable snow depth leads to a patchy mosaic of vegetation and snow that evolves as the snowmelt progresses. From the perspective of a surface energy balance, the interactions between land and atmosphere are particularly complex during this period. Subgrid-scale heterogeneity in land surface use/cover is likely to be an important factor in determining the time dependence of snow cover fraction and albedo during melt episodes. Field experiments need to be conducted to determine the magnitude and principal sources of subgrid-scale heterogeneity in albedo and snow cover for agricultural and mountainous landscapes typical of the Mississippi River Basin. This should be done using both ground-based and airborne measurements. These analyses should also focus on developing methods to incorporate heterogeneity effects into land-surface models using land-cover data. The estimation of snow-cover extent and winter surface albedo also needs to be addressed from the perspective of knowing the fractional snow-covered area within the model domain.

Because of importance of snow in simulating weather and climate, the level of snow-model complexity for use in these models needs to be addressed. Several features of process-level snowmelt models might be used to help capture subgrid-scale variability and improve snowmelt simulations. In particular, important tasks relevant to cold-season processes include: quantifying the feedbacks between exposed vegetation and the melt of adjacent snow covers, demonstrating the importance of fractional snow-covered area in surface-energy partitioning during snowmelt, and identifying significant interrelationships between non-uniform snow distributions, melt rates, and exposure of vegetation.

**(3) Hydrologic interactions**

Important cold-season hydrologic processes include frozen soil, the infiltration of frozen soil, frozen lakes, and relationships between snowmelt and stream discharge. Frozen soils have, until recently, been ignored by most land-surface macroscale models, but they can play an important role in increasing runoff during snowmelt events. In particular, the interactions between snowmelt, frozen soil, ponding, and infiltration need to be addressed. As part of studies focusing on the amount and timing of water resources and the soil moisture available for subsequent evaporation, it is also necessary to document, understand, and model how the water is partitioned into runoff and infiltration when snow and ice melts. Land-surface hydrology models developed for GCIP must include these cold-season-related interactions.

**2.2.3.4 Biospheric processes**

Vegetation type and amount influence various aspects of the hydrologic cycle, from interception of rainfall to active control on the transpiration process through stomatal regulation. This has direct impact on the partitioning of available energy (net radiation) into sensible, latent, and ground heat fluxes. Development of a vegetated canopy also affects the absorption of momentum from the local wind and is manifested in the local friction velocity and corresponding surface roughness. Although the absorption of momentum by the canopy is determined in part by the total amount of leaf biomass, the energy partitioning is closely coupled to the amount of active or green leaf biomass. Land-surface models must be able to account for this difference not only during periods of drought or water stress, but also during the later stages of the yearly growth cycle when many plant species begin senescence. These various stages of the growth cycle are likely to contain a spectral signature that may be used not only to assess the total biomass and percent green leaf area for model evaluation but for future applications in near real-time model data assimilation mode for both short and long range forecasts. Much of this research will be addressed through the International Satellite Land Surface Climatology Project (ISLSCP) from joint NOAA/NASA sponsored observations and modelling studies. In addition to the NOAA sponsored long-term flux measurements, additional sites within the GCIP domain where observations of mass and energy fluxes and information on the planetary boundary layer are proposed. These measurements will be used to not only document the energy balance over the annual cycle, but to test many of the land-surface parameterizations currently used in the short, medium and long range forecasts. It is also anticipated that short-term field campaigns will be conducted in order to evaluate how the energy fluxes and forcing variables vary spatially. This will be accomplished with instrumented aircraft capable of similar energy flux and radiative measurements found on the surface flux systems.

Measurements of soil moisture will play an important role in assessing the role of water stress of plant response and biological processes and the resulting impacts on the surface energy balance. Water stress can play an important role in regulating the surface energy balance. Although an ample amount of precipitation can replenish the available soil water for plant processes, plant recovery is not immediate and may not always be entirely reversible. This "timescale" of recovery can be different depending on the plant species considered. Attempts will be made to evaluate these water related impacts and its impact on the local surface energy balance.

### 2.2.4 Model Parameter Estimation

A key step in applying land surface parameterization schemes is to estimate model parameters that vary spatially and are unique to each grid point. Local model parameters are estimated on the basis of information about vegetation, soils and geology, so gridded fields of these characteristics are needed at various scales to provide such estimates. It has been shown (e.g. In PILPS2c) that existing a priori parameter estimation techniques may produce large errors and biases in the water balance, especially in mean annual runoff. Improved methods for parameter estimation are needed.

#### 2.2.4.1 Parameter Estimation Techniques

Existing parameter estimation techniques generally assume that land surface model parameters are related to various land surface characteristics according to simple a priori relationships. These relationships are assumed to apply universally without regional or climatic variation. For example, the rooting depth of a given type of vegetation is assumed to be the same regardless of the climate where the vegetation is located. Existing parameter estimation schemes are largely untested. It remains to be seen if improved universal parameter estimation techniques can be found for at least some models or if regional relationships may be required.

There already is a wide range of models available. The Project for Intercomparison of Land surface Parameterization Schemes (PILPS) has shown that the available schemes can indeed produce a wide range of results given the same hydrometeorological forcing, land surface characteristics and common rules for parameter estimation. No doubt part of this is due to model structure differences, but much is due to the way model parameters are estimated One approach to developing improved parameter estimation techniques would be to use historical observations of runoff response to observed hydrometeorological forcing of many watersheds over a wide range of climatic and land surface conditions. The steps, which are illustrated in Figure 2-1 are:

1. Develop historical hydrometeorological data sets (model forcing and output) and basin characteristics data (soils, vegetation, topography and climate).

2. Calibrate model parameters for a large number of basins (for a given model).

3. Relate calibrated model parameters to basin characteristics to develop regionalized *a priori* parameter estimation techniques for selected parameters (for a given model)

4. Use the regionalized parameter estimates for a large number of basins. Evaluate the results in terms of model performance when parameters are estimated by:

A. Initial *a priori* parameter estimation techniques

B. Model calibration

C. Regionalized a priori techniques derived using calibrated parameters

5. Test the transferability of the results to other basins not used in the above analysis. These basins may be in the same region or in other continents.

6. Expand the available data sets to include representation from all climate regimes of the earth and to achieve the best possible global coverage.

7. Assess whether parameters for some models are easier to estimate than parameters of others and modify models to have more "observable" parameters.

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[LSAs]

**Figure 2-1** Steps in Parameter Estimation for the Model Parameter Estimation Experiment (MOPEX).

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An important step in achieving this goal is to assemble historical hydrometeorological data and river basin characteristics for about 200 intermediate scale river basins (500 - 10,000 $km^2$) from a range of climates throughout the world. The data sets to be developed would not be model specific and would be appropriate for developing parameter estimation schemes for most, if not all, land surface parameterization schemes. A Model Parameter estimation EXperiment task (MOPEX) has been initiated by GCIP to begin to assemble the required data sets and to organize parameter estimation experiments among model developers and users.

**2.2.4.2 Potential Improvements for Model Parameterization**

Some factors which need to be considered with regard to critical variables in land surface modeling are summarized below:

**1) Soil evaporation.** In many cases, the soil evaporation efficiency parameter (i.e. the so-called beta function) is determined empirically as a function of top-layer soil moisture. It should be thermodynamically based. Most models use very thick layers; this should be adequately thin to represent the diurnal variation of soil evaporation. Therefore, more layers may be needed to overcome the numeric problem. Most models neglect the flux of water vapor in the soil, which may limit their performance over semi-arid land surfaces.

**2) Canopy transpiration.** Most models use the Penman-Monteith approach, and parameterize the stomatal resistance as a function of environmental conditions. The same equations are assumed to apply for different types of vegetation, while the only difference is to adjust values for some parameters. More work is needed to test the universality of these equations.

**3) Canopy evaporation.** In most models, the evaporation from the intercepted water on canopy surface are essentially a "bucket-type" model, in which a constant interception capacity is assumed, and it yields the canopy interception capacity by multiplying a leaf-area index (LAI). The canopy drip would occur only when the canopy interception capacity is reached.

**4) Runoff.** The land-surface models used in atmospheric models have not explicitly considered the effects of the subgrid features of topography on runoff generation on scales from 10km x 10km to 300km x 300km, typical resolutions of weather forecasting and climate prediction models.

**5) Routing.** The horizontal water transport from neighboring grid-boxes are generally neglected in the land-surface models.

**6) Snow and Ice.** Variations of snow- and ice-related features within the GCIP domain frequently occur at subgrid-scales to the regional and global weather and climate models being applied to the area. As a result, these features, which include snow-water-equivalent distributions, snow thermal properties, frozen lakes and soils, and patchy configurations of snow and vegetation during melt, and their associated influence on subgid-scale energy and moisture fluxes, must be accounted for (or parameterized) within these models.

## 2.3 Improvements to regional mesoscale models

For the past four years there has been an extensive effort to acquire the model output from several operational/experimental centers from a range of operational models of varying resolution, physics and data assimilation systems. GCIP is concentrating on three regional mesoscale models (IGPO 1995):

- Eta model operated by NOAA/NCEP
- MAPS model operated by NOAA/FSL
- RFE model operated by AES/CMC (replaced by the Global Environmental Multiscale (GEM) model in February 1997

The participation by the operational centers in providing regional model output for GCIP leads to a mutually beneficial relationship. The principal benefit to GCIP is to provide a measure of the inter-model variability of the outputs from the different regional models which can also be related to the global model output from the operational centers. GCIP can provide benefit to the operational centers by enabling them to make use of the enhanced data sets to calibrate and validate the model data assimilation and forecast systems.

The regional mesoscale models are supporting GCIP research in the following manner:

- Provide model assimilated and forecast data products for GCIP diagnostic studies including energy and water budget studies.

- Test and validate components needed to develop a coupled hydrologic-atmospheric climate model. For example, the regional mesoscale models can be used to address the scientific question - To what extent is meteorological prediction at daily time scales sensitive to hydrologic-atmospheric coupling processes?
- Demonstrate the validity and performance characteristics of a coupled hydrologic - atmospheric model during the assimilation and early prediction time periods as a precursor to developing and testing a coupled hydrologic-atmospheric climate model.

The regional models now running operationally (NCEP/Eta and CMC/GEM) will be upgraded with numerous improvements during the next several years. The GCIP investigators need to be aware of these plans for improvements and the schedule being followed to incorporate these improvements into the operational models. The experimental MAPS model will also be upgraded during the next several years. Projected improvements to each of the regional models is described in the remainder of this section.

### 2.3.1 The NCEP Mesoscale Eta Model and Eta Data Assimilation System (EDAS)

Since April 1, 1995, output from the NCEP Eta model (Black 1994) and its associated Eta-based 4-D Data Assimilation System known as EDAS (Rogers 1995) have been routinely archived for GCIP. In conjunction with this milestone, NCEP implemented for GCIP an extensive expansion of the routine ETA/EDAS output products, including a vast suite of surface and near-surface products that encompass all the surface energy and water fluxes, soil moisture and temperature, snowpack and snowmelt, and surface and subsurface runoff. These output products include a) 3-hourly analysis and 6-hourly forecast horizontal gridded fields (known in GCIP as MORDS) and b) hourly station time series output (known is GCIP as MOLTS) at nearly 300 sites. A number of GCIP investigators have completed and published assessments of the coupled ETA/EDAS land-surface and/or water budget performance, including Berbery et al. 1996; Yarosh et al. 1996; Betts et al. 1997; and Yucel et al. 1997. The assessment being done by Curtis Marshall at the University of Oklahoma is making use of the Oklahoma Mesonet, including the newly installed soil moisture profile sensors.

With GCIP support, and in collaboration with GCIP investigators including the NWS Office of Hydrology (OH), NCEP over the last four years has accelerated ETA/EDAS development and improvement in the following three key areas:

**1) Coupled land-surface/hydrology model**

- physics and parameters
- land-surface characteristics
- initialization of soil water, temperature, snow
- coupled and uncoupled validation (PILPS, ISLSCP/FIFE/GSWP)

**2) 4DDA assimilation techniques and data sources**

- variational assimilation methods (3-D and 4-D)
- assimilation of hourly gage and radar precipitation
- assimilation of satellite-derived water vapor
- continuously-cycled regional assimilation

**3) Precipitation, cloud, and radiation physics**

- adding explicit cloud microphysics
- improving solar insolation physics
- improving cloud and radiation interactions
- testing alternative convective parameterization schemes

These three GCIP-supported NCEP development areas have resulted in the following GCIP-related improvements being implemented operationally into the ETA/EDAS system (including the GCIP model output data sets):

- **October 1995:** Explicit microphysics for cloud water and ice was added, with attendant improvements in the accuracy of precipitation and radiation.

- **October 1995**: Realtime, routine assimilation of SSM/I total column water vapor over oceans including the Gulf of Mexico.

- **January 1996:** The new NCEP/OH/OSU land-surface/hydrology package, with two soil layers, time-dependent soil moisture and soil temperature, seasonally varying green vegetation, and snowpack.

- **July 1996:** Revised adjustment of moist bias in initial soil moisture obtained from Global Data Assimilation System (GDAS), and upward adjustment of low bias in ISLSCP-FPAR values.

- **February 1997:** Significant upgrades to the physics, parameters, surface characteristics, and initialization of the land-surface package:

  - New NESDIS green vegetation fraction replaces ISLSCP;

  - New bare soil evaporation function, improved snowmelt physics;

  - Improved snow albedo, improved solar insolation via improved cloud and ozone effects;

  - Improved numerical advection scheme for water vapor and cloud water.

- **January 1998:** The following Eta model improvements are scheduled to become operational:

  - Computational spatial resolution improved from 48-km to 32-km horizontally and from 38-layers to 45-layers vertically: Output grid for GCIP remains the same at 40-km;

  - Number of soil layers increased from 2 to 4 (total soil depth remains 2 meters);

  - Soil moisture and temperature is continuously cycled day-after-day in the regional Eta assimilation/EDAS replacing the soil initialization from the Global Data Assimilation System;

  - Longstanding optimal interpolation technique is replaced with 3-D variational assimilation;

  - Assimilation of hourly GOES-derived water vapor data.

The steady march of major land-surface implementations in January 1996, February 1997, and January 1998 represent major GCIP coupled model milestones, resulting from the focused and concerted GCIP-funded efforts of both the GCIP Core Project (NCEP, OH, NESDIS) and external GCIP researchers. These operational milestones represent noteable success in the model development strategy laid out in Figure 1-3 of Section 1.4.1, which called for a clearly identifiable operational path to serve as a demonstration and implementation environment and for the research advancements in the research path.

In addition to the above ETA/EDAS model/assimilation changes, production of the following realtime products were initiated for GCIP:

- **July 1996:** In a joint venture with OH, realtime generation and archive of the National Stage IV hourly, 4-km, gage and radar precipitation analysis (an important prerequisite for precipitation assimilation in the EDAS).

- **November 1997:** In a joint venture with NESDIS, realtime generation of a new daily, 23-km, interactive, multi-sensor, Northern Hemisphere snowcover analysis.

The following is a list of ongoing GCIP-focused ETA/EDAS developments now underway with a projected implementation within the next 18 months:

- addition of frozen soil and patchy snowcover physics;
- snowcover initialization via the new NESDIS snowcover cited above;
- surface slope effects on runoff;
- refine soil characteristics and key hydraulic and runoff parameters;
- alternative parameterizations of deep convection;
- assimilation of hourly gage and radar Stage IV precipitation;

The 3-D variational assimilation technique (3-D VAR) implemented in January 1997 represents a major data assimilation milestone. This advanced data assimilation technique allows easier incorporation of non-traditional data sources, such as direct use of satellite radiances, cloud cover, precipitation, radar radial winds, radar reflectivities, wind profilers, WVSS, ACARS, and ASOS.

The follow-on to 3-D VAR, namely 4-D variational assimilation (4-D VAR), employing the linear adjoint of the Eta model, is well advanced at NCEP/EMC and undergoing routine testing. The linear adjoint has been extended to include the new land-surface/hydrology physics, which provides an opportunity for the assimilation of land-surface related information such as streamflow and satellite-derived surface skin temperature. 4-D VAR is computationally expensive and its operational implementation awaits the next generation computer upgrade at NCEP.

### 2.3.2 Regional Model Upgrade at CMC

It is expected that the quality of the regional model outputs at CMC will improve significantly during the coming two or three years, especially in terms of the variables that are important for the water and energy budgets which are of prime interest to GCIP.

The developments during this period will stem from a major change that was made in February 1997 when the Regional Finite Element (RFE) was replaced by the Global Environmental Multiscale (GEM) model. This is the result of a major project which has been in progress at Recherche en prevision numerique (RPN) with the goal of developing a non-hydrostatic variable-resolution global model of the atmosphere. This model uses a finite-element based spatial discretization and has been designed for efficiency and flexibility to satisfy the requirements of operational weather forecasting on a wide range of time and space scales (see the description published earlier in the GCIP Major Activities Plan for 1995, 1996 and Outlook for 1997; IGPO 1994c). This model uses a global variable-resolution strategy, permitting the focusing of an arbitrarily-rotated high resolution latitude- longitude mesh on any geographical area of interest, be it tropical or extra-tropical, making it a more flexible strategy than the former operational RFE model which is limited to extra-tropical applications. The overhead associated with using a model of global extent for short-range forecasting, even at the meso-gamma scale, is relatively small: more than half of the total number of meshpoints are on the uniform-resolution area of interest, and the overhead of using variable resolution outside this area is consequently comparable to that of the sponge regions of one-way interacting models. To maintain the validity of the model at the mesoscale, the formulation uses the non-hydrostatic Euler equations, with a switch to revert to the hydrostatic primitive equations for larger scale applications where the hydrostatic assumption is valid. To this end a pressure-type hybrid vertical coordinate is adopted. Prototype tangent linear and adjoint versions have also been developed in preparation for a 4-dimensional variational (4DVAR) analysis system.

The first implementation of GEM was made with a configuration giving a uniform fine mesh grid over North America and the adjacent ocean areas at a resolution equivalent to the former 35 km RFE one. However, testing of an experimental version with a 15 km resolution over more limited regions of North America is already in progress. This experimental version uses the Fritsch-Chappell meso-scale convective parameterization as opposed to a Kuo-based scheme in the currently operational version. The recent installation of a 32 processor NEC SX-4 supercomputer, with other upgrades to come during the three-year period, should permit a continuing gradual increase in the horizontal resolution, with corresponding increases in the number of vertical levels. Progress with the 4DVAR analysis scheme should also lead to better assimilation of meso-scale data, especially related to moisture which is crucially important for GEWEX. Energy budget calculations are also expected to benefit from more sophisticated solar and radiation parameterizations.

A new concentrated activity on model coupling has been initiated at RPN, to do research and development on the coupling of atmospheric, land surface, hydrology, ocean, ice and wave models in order to construct a more comprehensive environmental prediction system. The construction of the baseline system is expected to take about a year and a half, but it is likely that a more interactive coupled data assimilation and prediction system will become available to CMC during the year 2000, with significant impact on the water and energy components in the analyses and forecasts.

### 2.3.3 Improvements to MAPS

The gridded output from the Mesoscale Analysis and Prediction System (MAPS) will improve over the next several years of the GCIP EOP in different areas including model physics, data assimilation, and spatial resolution.

Some improvements related to GCIP have already been implemented, including access to daily lake-surface temperatures (from NOAA's Great Lakes Environmental Research Laboratory), snow and ice cover (from NCEP and the US Air Force). MAPS is currently using monthly climatological sea-surface temperature, to be replaced by daily information from NCEP in the near future.

The most important of the GCIP-related changes has been the implementation of a multi-level soil/vegetation model. This model, currently running with 5 soil levels, is described by Smirnova et al. (1997). High-resolution data sets for fixed or seasonally varying surface characteristics (soil type, vegetation indices, albedo) made available by NCEP are being used now in MAPS.

Full atmospheric radiation has also been added to the MAPS experimental 40-km model, substantially improving lower troposphere temperature forecasts.

A number of changes implemented during WY'97 in the experimental 40-km MAPS, include:

- 3-d variational analysis in the MAPS isentropic-sigma coordinate, to replace the current optimal interpolation scheme.

- explicit cloud microphysics in the MAPS model, with forecasts for cloud water, rain water, snow, ice, graupel, and the number concentration or ice particles. This is the revised microphysics from the NCAR/Penn State MM5 model.

- an improved forward/backward digital filter initialization.

- an improved turbulence parameterization (Burk-Thompson level-3.0) with explicit forecast of turbulent kinetic energy

- Addition of snow, frozen soil physics to soil/vegetation package, including 1-d tests with PILPS 2-d data sets.

- Initial cloud/moisture analysis.

- Assimilation of precipitation data.

- Assimilation of water vapor data from the ACARS WVSS and GPS data

- Assimilation of GOES, SSM/I precipitable water and wind products.

- Use of improved covariances in 3-d variational analysis allowing better representation of divergent wind component.

Plans for WY98 -

- Incorporation of GOES radiance/imager data in cloud/moisture/temperature analysis.

- Assimilation of WSR-88D radar radial winds.

- Possible specification of soil moisture from an off-line data assimilation system.

Plans for WY99.

- Resolution at 15-20km range.

- Possible incorporation of a non-hydrostatic hybrid isentropic-sigma model.

- Experiments with simplified Kalman filter or 4-d variational techniques.

## 2.4 Model Assimilated And Forecast Data Sets

One of the principal functions of the regional mesoscale models, as was noted in Section 2.3 is to produce the model assimilated and forecast output products for GCIP research, especially for energy and water budget studies. The production of such data sets is designed to achieve the following objectives:

(*i)* To produce model assimilated and forecast data products for GCIP investigators with an emphasis on those variables needed to produce energy and water budgets over a continental scale with detailed emphasis in 1997 on the LSA-SW and the LSA-NC and beginning the application of such detailed emphasis capability to the LSA-E during 1998, and to the LSA-NW during 1999.

(*ii)* To produce a quantitative assessment of the accuracy and reliability of the model assimilated and forecast data products for applications to energy and water budgets.

(*iii)* To conduct the research needed to improve the time and space distribution along with the accuracy and reliability of the model assimilated and forecast data products.

The activities relevant to the third objective above were described in the previous section. The activities relative to the first two objectives are summarized in the remainder of this section.

### 2.4.1 Regional Mesoscale Model Output

The list of model output fields needed by GCIP researchers was given in Table 3, Volume I of the *GCIP Implementation Plan* (IGPO 1993). From the beginning of GCIP, it has been the intent to acquire model output from several different models of varying resolution, physics and data assimilation systems. The large volume of data produced by the current generation of atmospheric models has forced a number of compromises in order to achieve a tractable data handling solution for model output data. The data volume is further enlarged by the GCIP need to enhance the traditional model output to include additional fields needed by researchers to perform meaningful studies of the water and energy cycles. The near-term GCIP needs for model output data will be met by concentrating on three regional mesoscale models:

- Eta model operated by NOAA/NCEP
- MAPS model operated by NOAA/FSL
- RFE (now GEM) model operated by AES/CMC

The model output is divided into three types:

(1) One-dimensional vertical profile and surface time series at selected locations referred to as Model Location Time Series (MOLTS)

(2) Gridded two-dimensional fields, especially ground surface state fields, ground surface flux fields, top-of-the-atmosphere (TOA) flux fields, and atmospheric fields referred to as Model Output Reduced Data Sets (MORDS)

(3) Gridded three-dimensional atmospheric fields containing all of the atmospheric variables produced by the models.

Each model output type is described in more detail in Appendix B.

### 2.4.2 Evaluation of Model Output

**Objective:** *To produce a quantitative assessment of the accuracy and reliability of the model assimilated and forecast data products for applications to energy and water budgets*.

All of the evaluations require a lengthy series of observed data for the variables considered critical to achieve the objective stated above. As a start on this evaluation effort , GCIP is compiling a composite data set for as many of the variables as reasonably available. In order to maximize the number of observed variables this composite is focused on the LSA-SW with the initial emphasis on the ARM/CART site as described in Section 10. Evaluations of the regional model output is also part of the budget studies described in Section 5.

# 3. HYDROLOGICAL MODELING AND WATER RESOURCES

In the context of GCIP one of the eventual aims of the modeling effort is to generate inputs for operational hydrological and water resources management models over a range of time scales up to interannual. The specific GCIP objective for this area is to:

***Improve the utility of hydrologic predictions for water resources management up to seasonal and interannual time scales.***

The area of water resource applications is one of growing importance for GCIP because of both strong interest within NOAA and the priorities of the GEWEX Hydrometeorology Panel (GHP). GCIP is already carrying out research related to this topic. The University of Arizona has prepared summaries of relationships between GCIP and the water resources sector. Relevant studies have been carried out to determine the effects of the spatial scale of precipitation inputs to hydrologic models for streamflow forecasts. Studies have also been done to characterize the scaling properties of precipitation in order to develop a wavelet scheme for downscaling precipitation for input into hydrological models. Work on distributed hydrologic models will facilitate the coupling of hydrologic and atmospheric models for further studies involving the prediction of water budget components. The results of some of this research have already been applied in a water resource assessment project being carried out in the Columbia River Basin.

The **goal** of the GCIP Hydrologic and Water Resources Modeling (HWRM) research activities is to provide the physical understanding, and modeling expertise, to allow the GCIP's objective with respect to water resources stated above to be met. The geographic focus of the HWRM research activities will be within the GCIP region (the Mississippi River basin) and within the GCIP project period. With respect to the latter, the current implementation plan for GCIP extends through 2000, but follow-on work (possibly collaboratively with the Pan American Climate Study, PACS, and possibly beyond the current GCIP study area) would continue through at least 2005.

## 3.1 Approach

The approach will be to link with GCIP coupled modeling and data collection activities, to produce more accurate streamflow forecasts, and in turn, to develop methods of utilizing those forecasts for water management purposes. The lead times to be emphasized in GCIP HWRM activities will be longer than the currently accepted upper limit of weather forecasts, which is currently about one week, and up to interannual.

### 3.1.1 Hydrological Modeling

Present operational hydrologic forecast models in use by opearational agencies, such as the National Weather Service, and water management agencies in the GCIP region do not incorporate explicit representations of the effects of vegetation on surface hydrology that have been developed by the land surface community, nor do they model the surface energy budget. Further, operational forecast models generally make limited use of available soils, land use and remote sensing information of the kind that have been assembled by GCIP and NASA's Mission to Planet Earth. In the past, the land surface models utilized, for instance, in numerical weather prediction and climate models have had much more sophisticated representations of the surface energy balance than of runoff production. However, this situation is changing, and many land surface schemes now include hydrologic components that account for infiltration, surface runoff, and subsurface runoff and water storage. As GCIP progresses, subsurface storage, and other hydrologic processes such as snow accumulation and ablation, and soil freeze-thaw characteristics, will need to be represented better.

Nonetheless, macroscale hydrologic models appear to have potential for improving hydrologic prediction for several reasons. First, they can easily be made consistent with the spatial scale of numerical weather prediction and climate models, insofar as they are, for the most part, grid-based. Second, the more physically based representations offer the potential for greatly reducing the necessity of site-specific calibration both, because of their use of directly observed vegetation, and climate, data, and, because the large scale implementations are amenable to parameter regionalization methods. Finally, the models are consistent with evolving methods for initializing hydrologic variables (such as soil moisture and snow cover) needed by weather prediction and climate forecast models, hence the possibility exists for eventual integration of climate and long-range hydrologic forecasts. The latter is particularly important as ensemble precipitation forecast methods evolve. For instance, NOAA's Climate Prediction Center is moving to a system that will use ensemble forecasts from global and regional numerical prediction models to simulate possible future precipitation outcomes over periods up to several months. The methods to be used will include a range of statistical approaches to post-process model output information, for simulating fine scale space-time characteristics of precipitation not represented in model output, and to accounting for short-term forecast uncertainty that may not be included in NWP ensemble products.

**Related Science Issues:** Can physically based macroscale hydrologic models be used to produce streamflow forecasts that are more accurate, and/or require less initial and ongoing logistical support, than traditional hydrologic forecasting methods? What is the role of calibration in the implementation of physically based hydrologic models?

### 3.1.2 Water Resources Modeling

Previous GCIP Investigators and LSA planning meetings (such as the LSA-E meeting held in Huntsville in November, 1996) have concluded that improvements in short and long-range weather forecasting represent the strongest potential tie between the GCIP and water resources applications communities. Therefore, the current concept is that GCIP will play a central role in developing an experimental water resources forecast capability, as follows:

1) An experimental streamflow forecast capability will be developed for selected locations within the four LSAs. Initial target areas include the two major river systems within LSA-E: The Tennessee-Cumberland, and the Ohio River systems, and perhaps part of the Missouri River system. It is important that this activity be implemented with parallel research and operational pathways, the latter of which would incorporate the involvement of the RFCs that operate within the study regions.

2) For several reasons, a central feature of the experimental forecasts will be an ensemble approach. First, modern water resources systems models are designed to process ensembles of events to evaluate the implications of alternative operating decisions when the future reservoir inflows are not known exactly, hence they need ensemble forecasts of reservoir inflows. In addition, ensemble prediction methods allow uncertainty in future precipitation patterns throughout a river basin to be analyzed in a way that is statistically consistent for all forecast points in the basin. In this context, analysis of precipitation climatologies should be undertaken to support verification and testing of precipitation forecasts, including ensemble precipitation forecasts. In addition, hydrologically relevant verification methods are needed to assess precipitation forecasts. This includes techniques to assure that the climatology of precipitation forecasts (including ensemble forecasts) matches climatology (i.e. the forecasts are statistically unbiased). Also, hydrologically relevant approaches are needed to measure the skill in these forecasts over a range of space and time scales.

**Science Questions:** How can uncertain information from seasonal-to-interannual climate forecasts be used to improve water resources management?

### 3.1.3 Linkages to Coupled Modeling

There are important linkages between the HWRM and Coupled Modeling research activities. For instance, the stated function of the Coupled Modeling Research is to foster development and application of coupled models within GCIP to improve weather and climate prediction up to S/I time scales, and to improve the hydrological interpretation of meteorological predictions. The Coupled Modeling activities have identified three key science questions, the second of which (To what extent can meteorological predictions be given hydrological interpretation?) is central to the objectives of the Water Resources Activities. The hydrological modeling activities of the HWRM therefore, form the bridge between coupled modeling products, and GCIP is water resources objectives.

**Science Questions:** What is the predictability of surface hydrologic variables using global model ensemble forecasts? How can global model ensemble forecasts be downscaled to hydrologically relevant space-time scales in a computationally efficient manner?

## 3.2 Needs from other GCIP Research Areas:

The needs of the HWRM PRA from other PRAs are:

From DACOM: Access to ensemble climate forecasts of surface variables (downward solar and longwave radiation, precipitation, temperature, humidity, pressure, wind), downscaled to the regional level (nominally about 50 km resolution) over part or all of the GCIP region, for forecast lead times of 1-6 months. Initially, the HWRM research questions can be addressed using retrospective forecasts (real time is not necessary). Access to the desired forecast products will require protocols with the major modeling centers, e.g., the Climate Prediction Center of NCEP, ECMWF, and the International Research Institute.

From the Coupled Modeling: Downscaling techniques to produce surface fields of ensemble forecasts at regional scales (roughly 50 km, see above). Consideration should be given to computationally efficient methods that might produce downscaled fields with statistical characteristics similar to those that would be achieved via nested model applications, such as statistical disaggregation methods or resampling from archived nested model simulations.

From the Diagnostic Studies: Evaluation of ensemble forecast surface fields to offer insight into model strengths and weaknesses at climate forecast time scales.

## 3.3 Near-Term Priorities:

The near-term priorities of the HWRM research activities are:

> 1) To develop procedures to allow GCIP hydrologic models to produce ensemble streamflow forecasts, using ensemble climate forecast model surface fields as forcings. This will require, in particular, development of schemes to remove bias in both the climate model surface fields, and hydrologic model output;
>
> 2) to evaluate the worth of climate model ensemble forecasts for operation of one or more water resources systems within the GCIP study area.

Both of these priorities will require a shift in emphasis of GCIP to include a stronger focus on climate, as opposed to weather forecasts (e.g., forecast lead times of one to six months, and eventually longer, rather than hours to days). Although weather forecast model products, e.g., analysis fields, can be used for some aspects of testing of hydrologic and water resources models, stronger interactions with the climate forecast community will be essential for the HWRM research activities to achieve the research goal and GCIP objective.

## 3.4 Long-term Priorities

In the longer term (e.g., beyond 2000) it is expected that the HWRM research activities will focus on water resources in the western U.S., which are currently outside GCIP's geographic area. The hydrologic processes of concern in the West (such as, e.g., snow accumulation and ablation in mountainous regions) are, in some respects, more amenable to improved hydrologic forecasting than are the water resource systems of the Mississippi River basin. Also, linkages between seasonal-to-interannual climate variations and tropical ocean processes (which currently appear to offer the best hope for accurate seasonal-to-interannual climate forecasts) are generally stronger in the West than in the current GCIP region, so the West arguably offers a better water resources testbed for GCIP models than does its current region. In any event, a high priority for GCIP in this time frame is development of a demonstration application of seasonal forecast tools in at least one of the major water resource systems of the West.

# 4. DATA ASSIMILATION

The NAS/NRC GEWEX Panel in its review of the GCIP Objectives recommended that more emphasis should be placed on data assimilation and should be included as one of the GCIP objectives:

***Develop and evaluate atmospheric, land, and coupled data assimilation schemes that incorporate both remote and in-situ observations.***

## 4.1 Background

Improved understanding of the hydrological cycle depends critically on atmospheric and surface fields which synthesize various observations in a manner consistent with constraints inherent in the physical laws governing evolution of these fields. Typically, these constraints are applied through the equations solved in a state-of-the-art forecast model. This process of data synthesis is known as data assimilation.

In operational numerical weather prediction (NWP), data assimilation has become recognized, over the last 10 years, as nearly equivalent in importance to model development for improvement of model forecasts of all time durations, from a few hours to many days or weeks. Forecast error is understood now to be as often a function of inadequate initial conditions as from model deficiencies.

The data assimilation challenges facing GCIP are essentially those facing mesoscale meteorology, but are further complicated by the need to account for land surface and hydrological processes. Atmospheric data assimilation techniques are designed to minimize analysis error in an undetermined problem; that is, conditions must be estimated at many grid points where no data exist. Furthermore, account must be made for varying data error characteristics and irregular spatial and temporal sampling in those observations. This problem of underdeterminacy is particularly serious regarding surface fields, where observations are sparse and often representative only of very local regions.

The basic shortcoming in the current observational database is a lack of coincident data in time and space for estimating energy and water budget components. Limitations arising from the diverse nature of observational platforms and their associated algorithms are well known. Some variables, such as precipitation, soil moisture, and runoff, can be observed adequately at point locations but only with greater uncertainty at large spatial scales. Some variables integrate in nature over time and space, e.g., streamflow, aerological determination of evaporation, and precipitation difference, but are poorly related to instantaneous point processes. Some variables, particularly the surface latent and sensible heat fluxes and soil moisture , are not directly observable over large regions. In this case 4DDA methods become an essential strategic methodology for incorporating various data into models that will be validated with GCIP data sets. On the other hand, many characteristics of the surface do not change in time and data sets of these variables are being gathered with increasing precision and spatial coverage.

Data assimilation is also important for GCIP to provide improved analyses of moisture fields in the atmosphere. These moisture fields are a product of the full dynamic/physical processes in the atmosphere and surface, so ultimately, GCIP must be concerned with the full data assimilation process. Currently, research in data assimilation is related to forward static techniques which use a forecast model only in a forward sense, and to more fully 4-dimensional techniques which fit observations to a model state integrated over some time period. In the forward techniques, model forecasts are corrected at different points in time based on current observations. These techniques include the commonly used optimal interpolation statistical technique and 3-D variational techniques. The frequency with which observations are incorporated can vary to as often as every model time step, in which case the assimilation is sometimes called nudging. The 4-dimensional variational techniques may have greater potential for improvement of initial conditions, but are much more computationally expensive.

Another recent impetus to data assimilation research has been the availability of new data sources, including wind profilers, commercial aircraft, Doppler radars (reflectivity and radial winds), and improved satellite sensors.

The variational technique provides an improved framework for assimilation of these observations, many of which are not explicitly forecast by the forecast model (e.g., satellite-observed radiances). The use of raw observations rather than processed retrievals (e.g., temperature and moisture soundings derived from satellite radiances) has been recognized as providing improved information from these sources.

Based on these considerations, the principal areas in data assimilation for GCIP are summarized as follows:

- application of improved data assimilation techniques (e.g., 3-D variational and 4-D variational) to coupled atmospheric/hydrologic models;

- improved algorithms that translate from observation variables to model variables and vice versa (e.g., radiative transfer models, hydrological models);

- incorporation of new data sources (which must pass the test of providing additional information over that already known from other sources and the model forecast), and also process rates such as rainfall rate, streamflow, and TOA radiative fluxes, and various soil-moisture measurements; and

- understanding of uncertainty in GCIP analyzed data sets.

## 4.2 GCIP Needs For Model Assimilated Data Sets

The major components of the hydrological cycle are soil moisture, surface evaporation, water vapor, clouds, rainfall, and runoff. The first two components are not observed routinely over continental areas such as the GCIP domain. The GCIP analyses of soil moisture and surface evaporation must therefore be products of a 4DDA system. For the long GCIP time period, such assimilations can be provided conveniently only by on-line operational centers.

Modern 4-D data assimilation systems use objective analysis techniques combined with advanced atmospheric forecast models to blend observations of varying types, timeliness, accuracy, and spatial coverage into self-consistent uniformly gridded fields of atmospheric and surface fields. For fields that are not observed (or very sparsely observed), 4DDA systems rely on the atmospheric model to generate realistic analyses based on the internal physical and dynamic coupling within the model to those fields that are observed.

The moisture cycle in models is largely determined by subgrid scale parameterizations, which typically drive atmospheric models rather quickly to an equilibrium between evaporation and precipitation, both of which are crucial to the terrestrial water cycle. The model's moisture equilibrium may be realistic but upset in assimilation by incorrect data; on the other hand, good data may be subverted in the assimilation by systematic deficiencies and biases in the model.

In this context, Lorenc (1992) emphasized that the vast detailed information generated when fitting the model to data in the assimilation process provides unique tools to diagnose the model or data weaknesses. The extensive long-term GCIP database will provide substantially enhanced opportunities to do just that for components of the water and energy cycles not routinely observed, leading to assimilation improvements, which, in turn, over the GCIP period will lead to more realistic representations of these cycles. Hence, together, the special GCIP observations and operational 4DDA systems (including their periodic upgrades growing out of GCIP research) represent a synergistic opportunity to improve both specification and simulation of the global energy and water cycles. To take advantage of this opportunity, operational assimilation products will require extensive diagnosis and validation by GCIP researchers.

For operational NWP and 4DDA systems, then, this operational plan, coupled with the companion research plan in Volume II (IGPO 1994a), must achieve the following tasks:

(1) Detailed studies of the water and energy cycles in current operational models and assimilation systems.

(2) Identification of shortcomings by comparison with observations (especially exploiting the long-term character of the GCIP observation enhancements).

(3) Implementation of improvements, especially assimilation improvements and physical parameterization improvements, stemming from concurrent GCIP modeling research.

With today's advancements in computer power, it is widely accepted that the separation between climate models and NWP models is becoming less pronounced. Taking advantage of the long time scales and breadth of observations and model output of GCIP, researchers can quantify the behavior of a range of operational NWP systems over a range of spatial resolutions, physical complexity, and data assimilation approaches to help identify those key water and energy cycle components and scales that climate models must ultimately include to achieve a new level of reliability.

## 4.3 Observational Data For GCIP Data Assimilation

An inventory of possible data for assimilation includes the following:

**a. Surface-related data**

in situ soil moisture and soil temperature profiles
satellite-sensed skin temperature
GOES surface radiative fluxes
snow depth
snow water equivalent
streamflow
vegetation - NDVI, leaf-area index (LAI), rooting depth
land surface characteristics
albedo
surface fluxes (e.g., SURFRAD)
aircraft microwave measurements of temperature and moisture

**b. Atmospheric data**

satellite-based

- precipitable water (SSM/I, GOES)
- direct radiances
- imagery
- cloud liquid water (SSM/I multi-spectral)
- cloud and water vapor track wind estimates
- GPS integrated precipitable water (combined satellite and surface GPS site - near future)

radar-based

- reflectivity
- precipitation rate product (WSR-88D)
- radial winds
- velocity azimuth display (VAD) horizontal winds
- vertical velocity
- vertically integrated liquid (VIL)

profiler-based

- NOAA network
- boundary-layer profilers
- radio acoustic sounding system (RASS)
- water vapor profiles

*in situ*

surface
rawinsonde
aircraft
SURFRAD

## 4.4 Data Assimilation Techniques Relevant To GCIP

**a. Surface-related**

- uncoupled, after the fact (off-line) assimilation based on precipitation analyses (e.g., NCEP's proposed Land Data Assimilation System)
- uncoupled real-time assimilation based on predicted precipitation (e.g., FSL's ongoing MAPS cycle with evolving soil moisture and temperature)
- infer soil moisture from rate of change in skin temperature (inversion of soil/vegetation model)
- adjoint of soil/vegetation model within uncoupled or coupled model
- use of hydrological model and its adjoint to assimilate streamflow observations
- direct use of satellite-sensed skin temperature (e.g., via NASA's incremental update)
- assimilation of surface radiative fluxes

**b. Atmosphere related**

- 3-dimensional variational methods
- 4-dimensional variational methods
- cloud/moisture analysis
- initialization for stratiform and convective precipitating systems, consistent with model parameterizations of those systems

- specification of latent heating within model integration

- application of different coordinate systems (e.g., quasi-horizontal versus isentropic)

**c. Assessment of model and observational errors**

While some investigation of single-sensor data and processing may be appropriate in some circumstances, the emphasis for GCIP should be on assimilation of different types of data together and doing so in the context of coupled models.

The success of various diagnostic budget studies of the hydrological cycle is critically dependent on the quality of these analyses.

## 4.5 Data Assimilation Research Priorities

Assessment of consistency of water/energy budgets via intercomparison of MORDS/MOLTS data among GCIP models and with other GCIP products and observations. This includes soil moisture/temperature observations, cloud/radiation products, and precipitation products. This understanding of consistency and errors in models (and observations) is necessary not only to improve the models themselves, but also to provide necessary information for data assimilation of the new GCIP data sets (see below).

Development and implementation of assimilation techniques. For the atmospheric models this needs to include the 3-D and 4-D Variational Techniques. The emphasis in this development should be on remotely densed data, cloud and moisture fields, and on attaining consistency with vertical motion fields so that analyzed cloud/moisture features are retained in subsequent model forecasts. For the macroscale land-surface/hydrology models, this should include use of both in situ and remote measurements of soil temperature and moisture, and of snow cover and depth. The emphasis should be on combined use of observations and coupled models. In order to do this data assimilation work, it will be necessary to have improved understanding of the error characteristics of both these observations and the models themselves. This improved understanding can come from the assessment efforts advocated in the paragraph above.

Use surface models from regional models and perhaps from other organizations for the development of land data assimilation systems (LDASs). The LDASs should use observed data sets where possible, e.g., of precipitation and radiation, but also may use combined observation/model techniques to account for inadequacy of observations in certain areas. Again, knowledge of data errors is needed.

An additional future priority is the re-analysis of assimilated data sets using future improvement in data assimilation. A plan for such a reanalysis should be started in the immediate future.

# 5. DIAGNOSTICS STUDIES

The Diagnostics Studies Principal Research Area (PRA) is directed towards improved quantitative descriptions of all aspects of the water and energy cycles and their spatial and temporal variability over the Mississippi River Basin.

**OBJECTIVE:** *Provide a better description and understanding of the factors which control the mean annual cycle and seasonal to interannual variability of hydrological processes over the Mississippi River Basin.*

The core diagnostics activities consist of three interrelated program elements:

- Energy and Water Budget Diagnostics
- Land Surface Boundary Layer Coupling
- Diagnostic Studies of Long-lasting Hydrological Regimes

## 5.1 Energy And Water Budgets

**OBJECTIVE:** *Determine the time-space variability of the hydrological and energy budgets over the Mississippi Basin.*

There are four near-term objectives for the period covered by this major activities plan:

1. Sustain and enhance the program for the routine production of monthly-averaged energy and water budgets for the Continental-Scale Area (CSA) and four large-scale (LSA) sub-basins of the Mississippi River Basin.

2. Develop and implement, in support of the studies of cold season hydrological processes a capability to produce multi-scale energy and water budgets over the LSA-NC from basic and derived data sets and variable fields generated by four dimensional data assimilation (4DDA) procedures.

3. Produce and evaluate multi-scale water and energy budgets for the LSA-SW and LSA-NC during the WY 1998 and perform comparisons with WY 1997.

4. Implement the methodology developed for the LSA-SW to the evaluation of multi-scale budgets over the LSA-NC in support of the WY 97 and WY 98 studies of cold season hydrological processes and adapt and develop new methodologies to the study of hydrological processes over complex terrain for the LSA-E in WY 98 and WY 99.

In order to meet these near-term objectives, diagnostic studies will be undertaken which (1) will obtain area-averaged variables from the available data and derived data products; (2) compare budget results obtained from model-generated 4DDA fields and MOLTS with results obtained from different sources of data and analyses in order to evaluate their relative quality and sources of error; and (3) critically compare budget residuals with limited measurements and empirically derived values of evaporation and soil water storage.

The emphasis of these activities is on combined atmospheric land-surface budgets. There will be additional ISA/SSA land-surface budget analyses based on the output of surface hydrological models to atmospheric forcing, e.g. observed precipitation and surface meteorological variables. These studies are discussed in the context of the coupled model research in Section 2 and in terms of model assimilated data and analyses in Appendix B.

The overall activities for budget studies include the following:

1) Water and energy budget studies over the GCIP area will be performed using observational analyses and analyses and forecasts from operational and research analyses/forecast systems.

2) Inter-comparisons will be performed among several regional models including the Eta, MAPS, GEM and NCEP's Regional Spectral Model (RSM).

3) Water and energy budget studies and intercomparisons will be performed of regional models imbedded in NCEP, DAO or ERA Reanalyses and in imbedded in free running GCMs in AMIP mode i.e., with specified large scale ocean boundary conditions.

### 5.1.1 Budget Variables

The basic budget variables to be examined and the potential sources of estimates for these variables are summarized in Tables 5-1 and 5-2 with separate tables for the two different scales. Table 5-1a identifies the Atmospheric Profile variables and the potential data sources for the CSA and LSA scales. Table 5-1b provides the same information for the ARM/CART region.

**Table 5-1a Energy and Water Variables: Atmospheric Profiles CSA & LSA Scales**

| VARIABLE | MEASURED | REMARKS | DERIVED | REMARKS | MODEL OUTPUT | REMARKS |
|---|---|---|---|---|---|---|
| Water Vapor (q) | X | RWS | | | X | App. B |
| Dry Static Energy (CpT+qZ) | | | X | Investigator Derived | X | App. B |
| Wind | X | RWS & Profilers | | | X | App. B |
| Water Vapor Flux | X | Investigator Derived | | | X | App. B |
| Dry Static Energy Flux | X | Investigator Derived | | | X | App. B |
| Vapor Flux Divergence | | | X | Investigator Derived | X | App. B |
| Energy Flux Divergence | | | | Investigator Derived | X | App. B |
| Longwave Flux | | | X | NESDIS | X | App. B |
| Shortwave Flux | | | X | NESDIS | X | App. B |
| TOA Flux | | | X | NESDIS | X | App. B |
| Cloudiness | X | ASOS & GOES | | | X | App. B |
| Net Radiative Heating | | | X | NESDIS | X | App. B |
| Condensation Heating Vertically (Integrated) | | | X | Investigator Derived | X | App. B |

**Table 5-1b Energy and Water Variables: Atmospheric Profiles ARM/CART Region for ESOP-96**

| VARIABLE | MEASURED R.* | MEASURED E.* | REMARKS | DERIVED R.* | DERIVED E.* | REMARKS | MODEL OUTPUT | REMARKS |
|---|---|---|---|---|---|---|---|---|
| Water Vapor (q) | X | X | RWS-NWS, ARM include IOP | | | | X | App. B |
| Dry Static Energy (CpT+qZ) | | | | X | X | Investigator derived | X | App. B |
| Wind | X | X | RWS-NWS, ARM include IOP Profilers, NEXRAD | | | | | App. B |
| Water Vapor Flux | | | | X | X | Investigator derived | X | App. B |
| Dry Static Energy Flux | | | | X | X | Investigator derived | X | App. B |
| Vapor Flux Divergence | | | | X | X | Investigator derived | X | App. B |
| Energy Flux Divergence | | | | X | X | Investigator derived | X | App. B |
| Longwave Flux | | | | X | X | NESDIS; CAGEX ARM database | X | App. B |
| Shortwave Flux | | | | | X | NESDIS; CAGEX ARM database | X | App. B |
| TOA Flux | | | | | X | NESDIS; CAGEX ARM database | X | App. B |
| Cloudiness | X | X | GOES-ASOS; Sfc. Composite ARM database | | | | X | App. B |
| Net Radiative | | | | | X | NESDIS; | X | App. B |

| | | | | | | |
|---|---|---|---|---|---|---|
| Heating | | | | CAGEX ARM database | | |
| Condensation Heating | | | X | Houze (WSR-88D) | | |
| Aerosol Concentration | X | ARM Central Site Database | X | | | |

***R. - Routine**

***E. - Enhanced**

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Table 5-2a identifies the Surface Budget variables and the potential data sources for the CSA and LSA scales. Table 5-2b provides the same information for the ARM/CART region. The data and information required for the evaluation of area- and time-averaged land/atmosphere energy and water balances will be provided by several GCIP Principal Research Areas and the Data Management and Service System (DMSS). The evaluation of the energy balance is particularly dependent on satellite products for estimates of surface variables and atmospheric radiative heating profiles.

**Table 5-2a Energy and Water Budget Variables: Surface CSA & LSA Scales**

| VARIABLE | MEASURED | REMARKS | DERIVED | REMARKS | MODEL OUTPUT | REMARKS |
|---|---|---|---|---|---|---|
| Surface Elevation | X | | | USGS/EDC | | |
| Vegetation (NDVI) | | | X | NESDIS | | |
| Precipitation | X | Ppt. Composite obs. | X | NCEP Mesoscale Analysis | X | Sec. 6.1 |
| Storage Snow Water Equiv. | | | X | NOHRSC | X | Sec. 6.1 |
| Stream Discharge | X | USGS | | | | |
| Resevoir Storage | X | USGS | | | | |
| Water Table (Wells) | X | Not Applicable | | | | |
| Soil Moisture | | Not routinely | X | GCIP/ISLSCP joint project in 1999 | X | App. B |
| Surface Temperature | X | Sfc. Composite | X<br>Clear Sky | NESDIS | X | Sec. 6.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Albedo | | | X | NESDIS | X | [Sec. 6.4] |
| "Surface" Specific Humidity | X | Sfc. Composite | | | X | [App. B] |
| Sensible Heat Flux | | | X | GCIP/ISLSCP joint project in 1999 | X | [App. B] |
| Latent Heat Flux | | | X | GCIP/ISLSCP joint project in 1999 | X | [App. B] |
| Longwave Radiation | | | X | NESDIS | X | [Sec. 6.4] |
| Shortwave Radiation | | | X | NESDIS | | |

**Table 5.2b Energy and Water Budget Variables: Surface ARM/CART Region for ESOP-96**

| VARIABLE | Measured R* | Measured E* | REMARKS | DERIVED R* | DERIVED E* | REMARKS | MODEL OUTPUT | REMARKS |
|---|---|---|---|---|---|---|---|---|
| Surface Elevation | | | | | X | Sec. 6.3 | | |
| Vegetation (NDVI) | | | | X | | Sec. 6.3 | | |
| Precipitation (Liquid) | X | | ESOP-96 Precip. Composite (15 min, hrly, daily) Sec. 5.4 Task 5.4.2 | X | | NCEP Mesoscale Analysis | X | Sec. 6 |
| Stream Discharge | X | | USGS & USACE daily stream flow Sec. 6.5 | | | | | |
| Reservoir Storage | X | | Sec. 6.5 | | | | | |
| Water Table (Wells) | X | | Sec. 6.5 | | | | | |
| Soil Moisture<br><br>Total Column Profile | | X<br><br>X | Section 6.2 Little Washita & ARM/CART data OK Mesonet | | | | X | App. B |
| Surface Temperature | X | | Hrly. Sfc. Composite Sec. 10 | X | | NESDIS & CAGEX | X | Sec. 6.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | (Clear Sky) | | | |
| Albedo | X | ARM/CART Sec. 10 | X | 2-D Grid ARM/CART | X | Sec. 6.4 |
| "Surface" Specific Humidity | X | Hrly Sfc. Composite Sec. 10 | | | X | App. B |
| "Surface" Wind | X | Hrly. Sfc. Composite Sec. 10 | | | X | App. B |
| Sensible Heat Flux | X | LWW & ARM/CART flux sites | | | | |
| Latent Heat Flux | X | LWW & ARM/CART flux sites | X | 2-D Grid ARM/CART | X | App. B |
| Longwave Radiation | X | Sec. 6.4 ARM/CART | X | NESDIS & CAGEX<br><br>2-D Grid ARM/CART | X | App. B |
| Shortwave Radiation | X | Sec. 6.4 ARM/CART | X<br><br>X | NESDIS & CAGEX<br><br>2-D Grid ARM/CART | X | App. B |

*** R - Routine**

*** E - Enhanced**

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### 5.1.2 Basic Strategy

The basic strategy for the energy and water budget analyses involves distinctly different approaches for the LSA budgets and the more diverse ISA/SSA budgets.

#### 5.1.2.1 CSA and LSA Budgets

**OBJECTIVE:** *Develop research quality mean monthly time series of basin-averaged budget variables and use these to develop a better documentation and understanding of the "bulk" water and energy cycles over the CSA and LSA sub-basins of the Mississippi*.

The development of CSA and LSA budget time series is a continuing activity, and will produce a continuous time series of mean monthly budget variables for duration of GCIP. Although the temporal and spatial resolution of these "bulk" budgets is limited, much can be learned about continental hydrological processes by deriving budgets and evaluating model results over areas that are large enough and time periods long enough to allow accurate evaluation of the heat and water balances of the overlying atmosphere. This derived budget data set is therefore a basic requirement for a variety of diagnostic and model evaluation activities that address the major objectives of the GCIP program.

The basic averaging period for the CSA and LSA budgets is monthly. The evaluation of the individual water and energy budget components and contributing variables depends heavily on the availability of operational observations and on operational 4DDA fields. Mesoscale resolution is required to adequately resolve the effects of terrain and to accurately resolve the irregular boundaries of a specific drainage basins for LSA studies. This resolution is provided by the data assimilation systems of regional mesoscale models e.g. NCEP Eta model, the FSL MAPS analyses and the Canadian GEM model. However, to fully understand and interpret all available budget study data and model analyses, it is necessary to utilize the 4DDA capabilities of the model output in conjunction with observational data and make these available to GCIP investigators. This aspect of the Diagnostics Studies PRA requires a program of intercomparison and evaluation studies.

Among the methods available to GCIP investigations for evaluating large-scale atmospheric vapor flux divergence are (1) line integral computations made directly from routine 12-hourly rawinsonde wind, humidity and temperature observations and hourly profiler wind observations, and (2) operational 4DDA products from meso-scale models. Intercomparison of observational data with the 4DDA fields are providing information on the quality of the 4DDA fields and the impact of changes in the model's data assimilation system on the one hand and the impacts on budget estimates of the relatively spare spatial and temporal sampling of the observational array on the other. The GCIP areas available for direct observational and model comparison is limited by the relatively sparse distribution of rawinsonde and profiler stations. However, two areas have been identified for ongoing intercomparison; (1) the continental-scale area (CSA) enclosed by the rawinsonde stations shown on Figure 5-1, and (2) the large-scale profiler array in the central United States, Fig. 5-2. Intercomparisons over the profiler array are limited to winds and velocity divergence fields. Intercomparisons are also being performed between the MOLTS and the radiosondes in the CART/ARM hexagon. These provide an independent comparison to model estimates of mass convergence since the CART/ARM observations were not assimilated by the models.

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[flux]

**Figure 5-1** Continental Scale Area for intercomparison of atmospheric flux-diveregence results.

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[profiler]

**Figure 5-2** Large-scale profiler array in the Central U. S.

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#### 5.1.2.2 ISA/SSA Budgets

**OBJECTIVE:** *Develop energy and water budgets for selected ISA/SSA in support of specific GCIP program elements.*

The Implementation Plan for GCIP, Volume II, Research (IGPO 1994a) outlined a multi-scale research strategy for GCIP which is summarized in Section 1. The ISA/SSA budgets are of a more specialized nature than the routinely computed LSA budgets. They are computed for limited areas and in for limited periods of time. They depend to a much greater degree on data acquired from special observing systems or networks, in some cases during short periods of enhanced observations. Their objectives are more process oriented e.g. land surface processes; development and testing of model subcomponents; more detailed decomposition of atmospheric budget residuals i.e. Q1, Q2, total surface storage where Q1 is the apparent heat source and Q2 is the apparent moisture sink as defined in Appendix B of the GCIP Science Plan (WMO 1992).

During WY 97 and continuing to WY 98 one geographical focus is on the LSA-NC. The phenomenological emphasis is on various aspects of the cold season hydrological cycle. It includes studies on the LSA, ISA and SSA scales. Another geographical focus continues to be the LSA-SW. Many of the ISA activities continue to be focused on the ARM/CART site that occupies almost 20 per cent of the LSA-SW. SSA studies will exploit the well instrumented Little Washita Watershed.

#### 5.1.3 WY 98 Activities:

1) LSA and CSA Energy and Water Budgets

a) Continue routine assembly of area averaged mean monthly LSA and CSA energy and water budget variables as the data become available (one to 7 months after observation time depending on the variable and source of the data) for all sub-basins (Missouri (upper and lower), Red-Arkansas, Ohio, and Upper Mississippi) (Fig. 5-3) as well as for the two intercomparison areas (Fig. 5-1).

[subbasins]

**Figure 5-3** Subbasins of Mississippi River to be used in Computing Energy and Water Budgets.

b) Conduct ongoing intercomparisons of atmospheric budgets obtained directly from observations and those computed from operational analyses.

c) Continue and improve development of methods for using 4DDA operational output, including MOLTS from the ETA, FSL and Canadian GEM mesoscale models, to derive area averaged surface/atmosphere budgets.

d) Develop a description of the WY 98 annual cycle of the land surface and atmosphere hydrological and energy cycles over each LSA and the CSA drainage area and compare to the WY 97 and historical radiosonde-based analyses.

e) Initiate water and energy budget studies for selected flood and drought periods including long-lasting hydrologic regimes that had developed during WY 97.

2) ISA/SSA Energy and Water Budgets.

a) Assemble all available surface/atmosphere budget information acquired over the ARM/CART area and appropriate LSA-NC and LSA-E areas.

b) Analyze area averaged surface/atmosphere energy and water budgets during intensive observation periods for the area enclosed by the four-station ARM/CART rawinsonde array.

c) As the data become available, develop area-averaged estimates ofsoil moisture and surface meteorological parameters for the Little Washita Watershed. Compare these values with output from operational mesoscale models.

d) Analysis of ISA/SSA budget computations over the LSA-NC.

### 5.1.4 WY 99 Activities:

1) LSA and CSA Budgets.

a) Continue the routine evaluation of mean monthly budget time series for all LSAs and the CSA.

b) Develop a description of the WY 99 annual cycle of the land surface and atmosphere hydrological and energy cycles over each LSA and the CSA and compare to the WY 97 and WY 98 analyses.

c) Continue ongoing intercomparisons between atmospheric budgets obtained directly from observations and those computed from operational analyses.

d) Continue investigation of long-lasting hydrologic regimes including those that may have developed in WY 98.

e) Initiate studies with the Pan-American Climate Studies (PACS) Program to investigate the relative roles of land surface boundary, i.e. Local conditions, and large scale boundary conditions, i.e. ocean sea surface temperatures, on the initiation, maintenance and demise of long-lasting hydrologic events.

2) ISA/SSA Budgets.

a) Continue compilation and analysis of area averaged surface and atmosphere energy and water budgets for the area within the LSA-NC ISS/SSA and appropriate data from the ARM/CART rawinsonde array.

b) Continue the routine computation of area-averaged estimates of soil moisture and surface meteorological parameters, including fluxes, over the Little Washita Watershed, and begin similar computations for the ARM/CART array. Compare these values with output from operational mesoscale models.

c) Compare soil moisture estimates from observational and model- derived moisture budgets with instrumental estimates over the ARM/CART array.

d) Continue evaluation of available surface/atmosphere budget information acquired during WY 98 in the ISA/SSA and initiate evaluation of ISA/SSA budget computations over LSA-E.

e) Complete planning and implementation of a program of ISA/SSA budget computations over the LSA-NW during WY 2000.

### 5.1.5 Outlook for WY 2000

1) Continue evaluation of CSA and LSA water and energy budgets. Mean monthly LSA budget time series will be extended into WY 99. The fourth year (WY 2000) annual cycle will be analyzed and compared with the earlier years.

2) Continue studies with the Pan-American Climate Studies (PACS) Program to investigate the relative roles of land surface boundary, i.e. Local conditions, and large scale boundary conditions, i.e. ocean sea surface temperatures, on the initiation, maintenance and demise of long-lasting hydrologic events.

3) ISA/SSA Budgets. Continue evaluation of ISA/LSA budgets within the LSA-SW and LSA-E. Began compilation of data for ISA/SSA budgets for specified areas in the LSA-NW.

## 5.2 Land-Surface Boundary Layer Coupling

**OBJECTIVES:**

1. Develop an improved documentation and understanding of the processes controlling the seasonal cycle of fluxes of water and energy across the land/atmosphere interface and within the planetary boundary layer.

2. Establish relationships between surface conditions and boundary layer processes, particularly as they relate to the partitioning of surface fluxes between latent and sensible heat.

Surface fluxes, including evaporation, are at the end of a long chain of processes and interactions involving cloudiness (which affects surface net radiation), soil water content (which is dependent on rainfall), and vegetative cover. The planetary boundary layer can act as a governor on the transfer process at the surface. In turn, the boundary layer response depends on the partitioning between surface latent and sensible heat fluxes.

The diurnal and annual cycles have a fundamental effect on the coupling of the surface and the Planetary Boundary Layer (PBL). The diurnal cycle itself has a pronounced annual cycle, with maximum amplitude during the warm months, when the land surface and atmosphere are most strongly coupled.

This element of the Diagnostics Studies PRA will progress as a phased study of processes during different seasons over different sub-basins of the Mississippi Basin, with the overall results integrated into a coherent picture of the seasonality of hydrological processes over the basin. The strategy therefore involves a specific LSA and seasonal focus at any particular time, in which is embedded limited time/space ISA/SSA enhanced observational programs during various seasons and throughout the entire year.

### 5.2.1 Warm Season Processes

During WY 97 the focus of GCIP activities will be on warm season processes in the LSA-SW. Within the LSA-SW region there will be concentrated data collection and diagnostic studies over the ARM/CART site and the Little Washita Watershed. The LSA-SW, ARM CART and Little Washita combination of activities will provide a "nested" set of studies on scales ranging from approximately $10^3$ to $10^6$ $km^2$.

The conceptual framework for multi scale diagnostic studies of warm season processes can be summarized as follows.

**LSA-SW Setting**

The variability at a point includes the effect of large-scale and small-scale advection, and the net effect of land surface forcing on scales ranging from local to continental. Process studies over limited time-space domains need to be interpreted in the context of gradients associated with larger scales of continental forcing. GCIP continental-scale data sets and derived data products will be used to describe the general nature of the continental-scale warm season processes as they relate to the LSA-SW, and to the ARM/CART ISA and Little Washita SSA low level northward flowing moisture jet, which exhibits large variability on diurnal, synoptic and interannual time scales, and the pronounced warm season diurnal cycle of hydrologic and circulation features over the LSA-SW, which includes a nocturnal maximum in thunderstorm and precipitation occurrence.

The routine observational system over the LSA-SW will consist of conventional surface and upper air observations (rawinsonde, wind profilers), aircraft observations, and NEXRAD observations of precipitation. These observations will be assimilated by 4DDA methods into regional mesoscale models to provide operational analysis/forecast products on a grid mesh of a few tens of kilometers. The availability of routine three-hourly regional mesoscale model analyses will provide an improved description of many features of this continental scale diurnal mode, and contribute to an improved documentation of its effect on LSA-SW hydrology.

The routine observations from the national networks will be supplemented by regional observational systems within portions of the LSA-SW. Notable among these are the following:

1) The Oklahoma Mesonet

2) Observations from the DOE ARM/CART area (~300 km x 200 km) which includes portions of Oklahoma and southern Kansas. These observations have been focused on atmospheric radiation processes, but will also provide continuous observations of soil moisture profiles at a steadily increasing number of sites and high frequency rawinsonde observations (three-hourly) from five sites during the 3-week ARM-CART Intensive Observational Periods.

3) A relatively dense network of continuous surface meteorological and soil moisture/temperature profile observations over the Little Washita Watershed.

**ARM-CART Setting**

The observations from the ARM/CART array provides data required for process studies and more detailed intercomparisons and validation of both surface and atmospheric model subcomponents. Among the major enhancements to the operational data which are available from the ARM/CART area are the following:

1) Data for the evaluation of the surface radiation balance and surface fluxes. These data are provided from a number of different ARM instrument systems and sites. Emphasis is placed on instrumental calibration to assure that the measurements are consistent, compatible and reliable.

2) Soil moisture measurements. Continuous automated soil moisture measurements in the ARM/CART site were initiated in the spring of 1996 with the installation of instruments at sites. An additional 15 sites are scheduled to be instrumented prior to April, 1997, thus providing a large scale but sparse array of soil moisture monitoring sites over the ARM/CART site beginning in April 1997.

3) Aerosol concentration measurements from the ARM/CART central site. These data will provide important information on the effect of aerosols on the radiation balance.

4) PBL Structure. Detailed monitoring of the PBL structure will take place during the three-week intensive observational periods, when rawinsondes will be launched eight times daily from the ARM/CART central facility and four profiler sites. These data will provide the time/space sampling required to characterize the detailed structure of the PBL, and evaluate the heat and moisture budgets on this spatial scale during different seasons.

There will likely be several intense synoptic or mesoscale events which will pass across the ARM/CART site during the these intensive observing periods. These occurrences will be viewed as "targets of opportunity" and designated for special study.

**Little Washita Watershed Setting**

A relatively dense network of continuous automated soil moisture measurement sites are being established over the Little Washita Watershed. This provides a more dense network of soil moisture profile measurements than are available from the ARM/CART network. The existing meteorological observations over the basin will also be evaluated and upgraded if necessary to provide the data needed to quantify the surface fluxes over the watershed.

**5.2.2 Cold Season Hydrology**

In order to model the annual cycle of surface fluxes, it is crucial that the processes of both warm and cold season hydrology be documented and understood. Therefore, in WY 97 a regional focus shifted to the LSA-NC where the phenomenological focus is on cold season hydrology. Cold season processes of central importance include the following:

1) The effect of snow cover on PBL structure and surface transfer processes;

2) The effect of frozen ground on infiltration and soil moisture loss;

3) The evolution of the soil moisture field during the period between initial freeze-up and to final thaw and snow melt;

4) The processes of snow accumulation, sublimation, ripening and melt, which involves terrain effects, wind redistribution, vegetation (interception) and advection associated with both local patchiness and large-scale circulation.

A prerequisite for the improvement of the modeling of cold season hydrological processes is an improved data base of relevant parameters. A program of ISA/SSA studies aimed at a better documentation and understanding of these processes, comparable to the LSA program for the study of warm season processes, was developed during WY 96 for the LSA-NC. The enhanced winter observing period (ESOP-97) included improved documentation of snow cover, snow water content, vertical variation of snow thermal properties, snow albedo, soil water content and soil temperature over one or more ISA/SSA in the Upper Mississippi Basin. An enhanced observation period is also planned for WY 98 (ESOP-98) which will supplement observations taken during ESOP-97 as well as supplementing routinely available information from in-situ, aircraft and satellite observations in the LSA-NC.

### 5.2.3 Near Term Activities

**WY 98 Activities:**

1) Perform diagnostic analyses of continental-scale features associated with the cold season circulation as they relate to hydrological and land-surface processes over the LSA-NC and the ISA/SSA within this region. Initiate analysis of the data gathered during ESOP-97 for the LSA-NC. Since twice daily rawinsonde observations are not adequate to study the diurnal cycle, the diagnostics and land surface studies will also exploit the three-hourly EDAS analyses and selected forecast products, along with diagnostic studies of extended model simulations.

2) Continue to perform diagnostic analyses of continental-scale features of the warm season circulation as they relate to land surface and other hydrological processes over the LSA-SW and the ISA/SSA within this region.

3) Continue the analysis of the data collected over LSA-SW and the two sub-areas during ESOP-95 and ESOP-96. This includes the characterization of summertime conditions as well as the annual cycle of surface-planetary boundary layer interactions, particularly over the ARM-CART Array. Coordinate these diagnostic studies with ISLSCP-GCIP activities.

4) Implement plans for ESOP-98 land surface diagnostic studies over the LSA-NC region and formulate plans for an ESOP-99 over the LSA-E.

**WY 99 Activities:**

1) Continue diagnostic studies of the data collected over LSA-NC and subareas during ESOP 98.

2) Continue the analysis of the data collected over LSA-SW and the two sub-areas during ESOP 96 and ESOP 97.

3) Begin implementation of plans for land surface and diagnostic studies over the LSA-E in WY 99.

**WY 2000 Outlook:**

Emphasis will be placed on a synthesis of the results from the warm season and cold season analyses and integration of the studies undertaken over complex terrain in the LSA-E. Planning for studies over the LSA-NW will be completed and enhanced observations initiated.

## 5.3 Diagnostic Studies of Long-Lasting Hydrological Regimes

**OBJECTIVE**: *Provide more complete descriptions and understanding than previously available of the initiation, evolution and decay of long lasting (months) continental-scale anomalous hydrologic regimes; particularly, as they relate to budget derived evapotranspiration and surface and subsurface storage.*

The profound societal impacts of anomalous large-scale hydrological regimes is well illustrated by the series of major regional fluctuations which have occurred during the past quarter century. Of particular significance to GCIP are the upper Midwest drought of 1988 and the winter and spring wet spell which culminated in the catastrophic 1993 summer floods in the upper Mississippi River Basin. These two contrasting lengthy, continental-scale anomaly regimes will continue to be a focus of studies during WY 98 and WY 99.

We anticipate that these studies will serve as "benchmark cases" for use in subsequent simulation experiments and continental-scale validation of land- atmosphere hydrological subcomponents. The relevant questions can be addressed most effectively if the diagnostic studies are carried out in tandem with activities of the GEWEX Numerical Experimental Group (GNEG) and the Pan American Climate Studies (PACS) Program.

Because of the global component of these studies, steps are being initiated to carry out these studies as a joint effort between the GCIP and the PACS Program. The effort requires collaboration among the global and regional diagnostics studies communities, global and mesoscale modeling groups as well as scientists involved in land surface parameterization and data assimilation.

The development of large-scale anomaly patterns will be examined in the context of the annual cycle; e.g. the "cold season carry-over" contribution to anomalies during the growing season. Underlying these studies is the important question of the relative roles of regional surface anomalies, remote forcing, and internal dynamics in the perpetuation and intensity of the anomalous regimes. In addition there is the question of the extent to which positive feedback between anomalous land surface conditions and an anomaly-sustaining atmospheric circulation exist during these regimes. Is such feedback a significant factor in the evolution of land surface anomalies, or is it easily overpowered by other influences, e.g. a remote response to large-scale SST anomalies? Are changes in precipitation recycling over the continent an important factor?

**WY 98 Activities:**

GCIP-GNEG-PACS joint planning activities will continue. This will include specifying the required data sets. The feasibility of generatingEDAS reanalysis data sets for the appropriate periods will be examined. Diagnostic studies based on output from the NCEP global reanalysis project will be initiated.

The GCIP-PACS joint study of the North American Monsoon System will be initiated.

**WY 99 Activities:**

Diagnostic studies of the 1988 and 1993 anomaly regimes will extend into WY 99 and new studies of large-scale anomaly regimes which occurred during the 1995 to 1997 WYs will be initiated.

**WY 2000 Outlook:**

Continuation of studies of large-scale anomaly regimes which occurred during 1995-1999 with emphasis on the interactions among the large scale atmospheric circulation features and the ISA/SSA, LSA and CSA hydrology.

# 6. CRITICAL VARIABLES

A number of variables are critical to the success of GCIP and were designated as Principal Research Areas for GCIP. Each of these are described in this section in terms of research activities needed by GCIP and the plans for data products to support GCIP research activities.

## 6.1. Precipitation

**GOAL:** *To achieve better understanding and estimation of the space-time precipitation structure over the Mississippi River Basin including improvements in atmospheric model representation to support improved coupled modeling*.

The accurate prediction of precipitation in atmospheric and coupled models is a key element in reaching GCIP's objectives. How well precipitation can be predicted by a model depends on many factors including model physics, model resolution, scale at which predictions are evaluated, initial and boundary conditions, extent of data assimilation, accurate modeling of land-surface influences, etc. These factors interact with each other in nonlinear ways and improvement in one might not always proportionally counteract deficiencies in another. For example, improving cloud microphysics while neglecting key land-surface influences will not realize proportional overall prediction improvements. Studying and understanding the effects of all these factors on precipitation prediction forms a major focus of the Precipitation research area within GCIP.

Although for climate studies, the scales of prediction are monthly to seasonal, efforts in understanding precipitation processes at very fine scales should be vigorously continued. Precipitation anomalies (which cause the largest societal impacts) are dominated by a few extreme events within which the key physics are extremely intermittent in time and space. This requires study of precipitation on an event-by-event basis and on very fine spatial scales (down to 1 km). Such understanding will also be essential in translating the results of a global or climate model down to hydrologic scales via downscaling or via a nested modeling environment when the high resolution model must conserve the large-scale average and be able to reproduce the space-time dynamics and the location and maximum precipitation within the large-scale model grid cell.

Issues on Precipitation research have been grouped below in the following categories:

(1) Space-time precipitation variability;
(2) Atmospheric precipitation processes;
(3) Orographic precipitation;
(4) Precipitation predictability;
(5) Snow and snow water equivalent;
(6) Data for GCIP precipitation research;
(7) Precipitation measurements and analysis; and,
(8) Snow measurements and analysis.

### 6.1.1. Space-time Structure of Precipitation Fields

**OBJECTIVE:** *Study the statistical structure of precipitation variability at a range of space-time scales and develop precipitation downscaling algorithms and accurate parameterizations of precipitation processes to be used in atmospheric models or coupled atmospheric-hydrologic models*.

Activities to support this objective are:

- A comprehensive study of the space-time rainfall variability over the Mississippi river basin (MRB) as function of storm type and physical parameters of the storm environment. Scale-invariant relationships are especially useful as they provide efficient parameterizations over a large range of space-time scales.

- Development of precipitation downscaling algorithms that can recreate the subgrid scale statistical variability of rainfall given its large scale average and other physical characteristics of the storm environment. The reconstruction of the fraction of area covered by rainfall as a function of scale (grid box) is especially desirable in these downscaling algorithms.

- Characterization of the time evolution of the subgrid scale precipitation variability, e.g., at the build-up, maturity and dissipation stage of a storm system of continuous-time rainfall downscaling and parameterization of precipitation processes. For this task it is particularly useful to connect statistical subgrid scale parameterizations to observables which can be computed from observed meteorological variables or can be predicted by atmospheric models as the storm evolves.

- Determine the accuracy and resolution requirements on spatial precipitation measurements for accurate precipitation and runoff prediction for water resources and societal impact assessment.

### 6.1.2. Atmospheric Precipitation Processes

**OBJECTIVE:** *Understand the physics of precipitating clouds and their relation to the storm environment and the produced precipitation fields.*

Activities to support this objective are:

- Understand the three-dimensional structure of precipitation fields and its variation in time, especially in relation to extreme surface precipitation and flooding and to the interaction of storms with the vertical distribution of water vapor in the large-scale storm environment.

- Understand the physical reasons/processes behind anomalous precipitation at all scales of interest, e.g., daily, seasonal, interannual. Precipitation anomalies are dominated by a few extreme events, and within these events key physics are extremely intermittent in time and space. Thus, to address this problem it is essential to study precipitation on an event-by-event basis and on very fine spatial scales (down to 1 km).

- Understand the impact of relative amounts and patterns of stratiform and convective precipitation on: (a) the mesoscale organization of the weather system producing the precipitation, (b) the nature of precipitation mechanisms producing the precipitation, (c) the water budgets of individual storms, (d) the vertical distribution of heating associated with the precipitation process, and (e) the redistribution of water vapor in the environment by individual storms.

- Develop a radar-based climatology of storms over the Mississippi river basin including algorithms for convective vs. stratiform separation of precipitation from radar echoes and a method for estimating the vertical redistribution of water vapor in the large-scale environment in relation to the observed amounts of convective and stratiform precipitation.

- Develop and test parameterizations of precipitation processes including subgrid-scale convection and cloud microphysics.

- Understand the interaction of space-time precipitation dynamics and cloud microphysics.

### 6.1.3. Orographic Precipitation

**OBJECTIVE:** *Improve the understanding of the precipitation climatology in the Appalachian region of the Mississippi River Basin.*

Activities to support this objective are:

- Understand the effects of orographic influences on the space-time structure of the produced precipitation.

- Understand the effects of orographic precipitation processes on warm season precipitation in the Appalachian region of the Mississippi River basin, with special emphasis on heavy rain events.
- Develop a radar-based climatology of rainfall over the Appalachian region for comparison with climatological information derived from high-elevation rain gauge networks in the region.
- Develop improved algorithms for estimating rainfall in the Appalachian region from WSR-88D observations.
- Validate the performance of orographic precipitation models for the Appalachian region.
- Develop downscaling algorithms of orographic precipitation.

**Note:** A Pilot Project involving studies of Orographic Precipitation in the LSA-NW and specifically the Black Hills region of South Dakota is described briefly in Section 7.4.2.

### 6.1.4. Precipitation Predictability

**OBJECTIVE:***Assess the limits of predictability of atmospheric model precipitation as a function of scale.*

Activities to support this objective are:

- Understand the effects of relative patterns of convective/stratiform rainfall and of subgrid scale spatial rainfall variability on rainfall prediction at the atmospheric model grid scale and temporal scales of hours to days.
- Understand how parameterizations of cloud microphysical processes affect precipitation prediction at the atmospheric model grid scale and temporal scales of hours to days.
- Investigate the accuracy of rainfall predictions at the monthly, seasonal, and interannual scales.
- Understand how the resolution of orography affects precipitation predictions,which affect hydrologic balances and flooding over the Mississippi river basin.
- Develop innovative approaches for validating rainfall predictions from atmospheric and coupled models at a range of space-time scales of special interest and quantify the degree to which models capture important physical and statistical features/signatures that there is evidence for, from observations. This sort of validation can provide guidance for improved cloud process parameterization in coupled modeling.
- Determine the inherent limits of predictability of precipitation, by studying the sensitivity of predictions to initial and boundary conditions, and in particular in a nested modeling environment, and also study the scales at which it is ``better'' to nest.
- Develop methods for validating ensemble predictions.
- Develop methods for integrating information at different scales i.e., point observations versus remote sensing measurements and model outputs which are space-time averages over varying scales.

### 6.1.5 Snow and Snow water Equivalent

**OBJECTIVE:***Develop improved parameterizations of snow processes, develop supporting data sets and produce gridded snow water equivalent for the upper Mississippi River basin by integrating ground-based, airborne, WSR-88D radar and satellite snow data.*

Activities to support this objective are:

- Develop and test method of adjusting ground measurements of solid precipitation since present and historical measurements have been shown to be significantly less than ``actual'' and do not meet the needs of modelers.

- Recognizing that reliable information on solid precipitation is essential for climate model validation purposes, prepare historical files of adjusted daily measurements of solid precipitation.

- Develop and test methods of estimating solid precipitation from the WSR-88D radars.

- Develop and test methods to provide enhanced gridded information on snow water equivalent and snow cover by combining remote measurements (airborne gamma, satellite and radar) with ground measurements and computed values of snow water equivalent from adjusted solid precipitation and other meteorological variables.

- Refine algorithms for cloud detection for GOES data over snow and AVHRR scenes over snow. Incorporate satellite cloud masks developed by the cloud and radiation research of GCIP.

- Develop techniques to automatically assimilate appropriate ground-based, modeled and satellite data sets to generate cloud-free snow cover images.

- Identify suitable Landsat data, contemporaneous with assimilated snow cover images for validation/modification of the prototype snow cover assimilation algorithm.

- Enhance implementation to ingest and process ground-based snow data from River Forecast Centers (RFC) and WSR-88D snow estimates for incorporation with airborne and satellite snow data into the Snow Estimation and Updating System (SEUS) for the Upper Midwest.

- Initiate research on developing a fully distributed energy balance snow model. Such a model required to assimilate observed and modeled data sets in order to produce gridded snow water equivalent and snow cover fields. It is also needed to establish initial and boundary conditions for seasonal and interannual hydrologic forecasts.

### 6.1.6 Precipitation Data for GCIP Research

**OBJECTIVE:** *Improve the availability and quality of data that are needed to support the research activities described above.*

Activities to support this objective are:

- Improve the availability and quality of WSR-88D and concurrent atmospheric observations and develop better algorithms for using these data for atmospheric model verification and analysis of space-time rainfall and snowfall distributions. Other atmospheric observations include GOES satellite data, soundings, runoff, fluxes, as well as more frequent observations of standard surface meteorological variables.

- Evaluate if current gridded precipitation products (e.g., hourly 4x4 km composites) meet the requirements for atmospheric model verification studies and for analysis of space-time precipitation structures.

- Develop methods for better use of WSR-88D scans over complex terrain, especially use of information obtained in higher elevation scans and possibly modifying the scans over complex topography to take advantage of this information. Investigate the feasibility of using the vertical profile of reflectivity to improve the accuracy of WSR-88D estimates of precipitation.

- Initiate and promote efforts to secure spatial and temporal homogeneity of in-situ precipitation (especially solid precipitation), wind and cloud cover measurements that are used for model validation, data assimilation, and/or water and energy studies.

### 6.1.7 Precipitation Measurements and Analysis

It is a **goal** of GCIP to contribute to the development of a derived product which combines WSR-88D, gauge, and satellite estimates of precipitation resulting in a product with a 4-km spatial and hourly temporal resolution. Such a goal is not expected to be achieved for a routine product until much later in the EOP since it is dependent upon some of the modernization improvements yet to be implemented by the NWS.

**OBJECTIVE:** *Produce the best possible estimates of spatial and temporal distribution of precipitation at time increments of one hour to one month and spatial increments of 4 to 50 km.*

GCIP requires the best available precipitation products and recognizes the potential value of the WSR-88D radars in meeting this requirement. Combined radar and gauge-based precipitation fields are expected to provide better estimates of precipitation than estimates based on raingauge values only. However, the limitations of radar estimates need to be evaluated because these are not well enough understood to provide research quality data sets over continental-scale areas.

Associated with the measurement of precipitation caught by the gauge is the question of representative exposure of the gauge and the effect of not having wind shields or the characteristics of different shields on gauge catch, evaporation, etc. The systematic adjustment of gauge errors is a necessary requirement for the development of good-quality precipitation fields. The National Climate Data Center (NCDC) applies basic quality control techniques to the cooperative observer network, but quality control and adjustment for measurement errors of all the operational data that might be used in a national precipitation product are major tasks that could require the development of new techniques.

GCIP has an ongoing effort to provide precipitation data products for GCIP investigators. A precipitation analysis is being produced routinely by the NOAA/NCEP and archived at NCAR. A composite of precipitation observations from all available observing networks is produced by the UCAR/JOSS and archived as part of the GCIP data set in the In-situ data source module.

The current precipitation analysis product consists of a national daily precipitation analysis at a 40 km resolution based on the gauge only measurements collected in near real time at the NCEP. This is an operational product produced by the NCEP beginning in the summer of 1994. Evolutionary changes are being implemented as part of a Stage IV national precipitation composite mosaic at the NCEP. An interim real-time Stage IV national product is being produced hourly since the summer of 1996, using real-time Stage I products and gauge data as well as any Stage III products then available. Improvements in the spatial and temporal resolution are also being made.

The contact person for this archived precipitation analysis data product is Roy Jenne at NCAR (e-mail: Jenne@ucar.edu).

The objective of the precipitation observation composite is to provide a quality controlled composite of all available precipitation gauge observations in a common format. The data product contains precipitation data from all real-time and recording gauges in the geographic domain as both hourly and daily totals. The Composite is produced by the In-Situ Data Source Module using data from up to 14 different observing networks. A precipitation observation composite was produced for each of the GCIP Initial Data Sets. Evolutionary improvements in quality control procedures will be implemented as proven techniques warrant. There are no current plans to correct for measurement errors by the different sensor systems. However, it is expected that any adjustments for measurement errors could be done using this precipitation observation composite data set. The contact person for this archived precipitation observation composite data product is Steve Williams at UCAR/JOSS (e-mail: sfw@ncar.ucar.edu).

### 6.1.8 Snow Measurements and Analysis

Point snow measurement relies primarily on the Natural Resources Conservation Survey SNOpack TELemetry (SNOTEL) network, which is largely to the west of the Mississippi River basin, and a comparatively sparse network of snow depth measurements at NWS synoptic stations. Snow courses are measured by various agencies, but these are limited and are restricted to the higher snowfall areas.

Remote sensing offers a more practical approach to assess snow over large areas. However, the need for new techniques or additional ground truth measurements has to be considered. The program in NESDIS is focused on the development of an interactive system for producing daily, rather than the current weekly, Northern Hemisphere snow maps on Hewlett Packard 755 UNIX-based workstations from a variety of satellite imagery and derived mapped products in one hour or less. Resolution of the final product will be improved from 190 Km to 23 Km. The final product will also provide information on snow depth in addition to snow cover.

GCIP is planning to derive adjusted values for in-situ solid precipitation measurements compiled for ESOP-97 and ESOP-98 based on the results of studies by E. Peck and P. Groisman now underway.

## 6.2 SOIL MOISTURE

**OVERALL OBJECTIVE:** *Improve understanding and estimation of the space-time structure of soil moisture, the relationship between model estimates of soil moisture and observations of soil moisture, and to produce soil moisture fields for the GCIP area to be used as diagnostic and input data for modeling.*

### 6.2.1 In Situ Soil Moisture Measurements

A survey by the Natural Resources Conservation Service at the time GCIP was preparing its implementation Plan in 1992-93 revealed that there were very few soil measurement sites in the Mississippi river basin. A network operated by the Illinois State Water Survey could provide measurements on a weekly schedule during the crop growing season and biweekly during the remainder of the year.

GCIP started an effort in 1994 to enhance the soil moisture measurements both in number of sites and frequency of measurements by providing some support to the ARS experimental site in Little Washita Watershed to analyze a set of automated soil moisture profile measurement systems and to install some test sites in the watershed. This small evaluation task has evolved to a rather extensive network of soil moisture and soil temperature profile measurement sites in the LSA-SW.

Six soil moisture sensing systems were installed in the Little Washita Watershed in the summer of 1995. An additional seven sensor systems were installed in this Watershed during 1996. A total of 22 soil moisture sensing systems were installed within the ARM/CART site. The first seven were installed and operating by the beginning of ESOP-96 in April 1996 and the remaining were installed by April 1997. An example of the relative soil moisture response curves in the ARM/CART site is given in Figure 6-1 which was very dry during the spring and early summer. The Campbell Scientific Heat Dissipation Soil Moisture Sensor (Model 229L) provides data from six different depths as shown in Figure 6-1. The calibration to convert the sensor is not yet completed. Therefore, the relative response in degrees celsius is given in the figure with lower values wetter and higher values drier. The curves from Ashton in May 1996 are typical of the response from many sites this spring and summer. The soil was very dry throughout the profile, and what little rain fell did not infiltrate very deeply into the profile. At Ashton, the rain on May 10th wetted the top two sensors, with only a slight amount of moisture penetrating as far as the 35-cm sensor. The Oklahoma Mesonet installed soil moisture sensing systems at about half of their 109 stations in the state-wide mesonetwork. There are plans to extend the soil moisture measuring systems to all of the 109 sites in the network. The situation in the LSA-SW is such that GCIP can potentially compile in-situ soil moisture measurements on three different scales using automated soil moisture sensing systems

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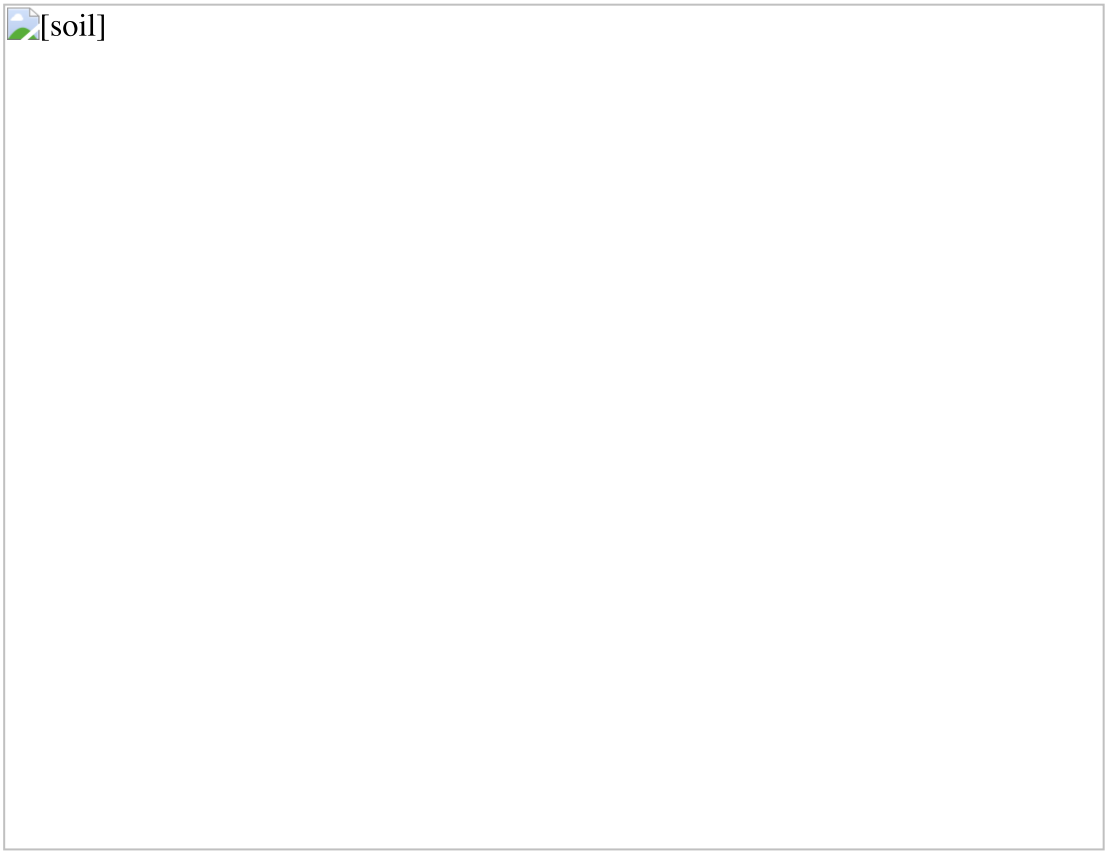


**Figure 6-1** Relative soil moisture response curves for Ashton, OK during May 1996 from the Campbell Scientific Heat Dissipation Soil Moisture Sensor.

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An initial soil moisture data set for the ARM/CART site is being compiled as part of the ESOP-96 data set. In-situ soil moisture measurements on the three different scales noted above are potentially available as a more complete data set during WY97, if the issues of data availability and distribution can be resolved.

GCIP is supporting some additional soil moisture measurements in the LSA-NC. Partial support was provided to the Water Resources Division of the USGS to install soil moisture sensors at the Shingobee River watershed. The surface flux site installed near Bondville, IL includes soil moisture sensors. J. Baker is installing soil moisture sensors at Lamberton and Waseca, MN.

GCIP is also coordinating an activity to establish a North - South Transect of soil moisture and other measurements along or near 96W longitude. The N-S transect starts at Plainview , TX (~30N latitude ) and continue North to Shingobee Watershed (~47N latitude) . Although sparse in the LSA-NC portion, the temporal variability of the soil moisture and soil temperature profiles over the course of an annual cycle should still be informative , especially during the cold period of theESOP-98 from October 1997 to May 1998. Contributions of measurements are being made by the USDA/ARS sites at Little Washita Watershed, National Soil Tilth Laboratory near Ames, IA and the Rosemount plus the two other sites mentioned in the preceding paragraph by J. Baker of the ARS. The NRCS is contributing data from three sites and the ARM/CART site has at least eight measurements sites applicable to the transect. The northern end measurements at Bemiji, MN and Shingobee Watershed are contributed by the Bureau of Reclamation in the Department of Interior.

There are a number of large-scale data sets of gravimetric soil moisture (Global Soil Moisture Data Bank, located at the University of Maryland) being assembled from the former Soviet Union, Asia, and the United States for studying variability and scales of soil moisture variations, for development and validation of land surface models, and for the calibration of satellite microwave indices. The data cover a number of different climate zones and will be used to evaluate interseasonal and interannual trends in soil moisture.

The Southern Great Plains Experiment conducted in June-July 1997 was an intensive observing period focused on measuring and mapping soil moisture. Further details on this experiment are provided in Section 6.2.5

Additional in situ soil moisture measurements throughout the GCIP region should be encouraged, especially in the LSA-E and LSA-NW. The in situ measurements are necessary to document the seasonal and interannual variability in addition to providing index measurement sites for the validation and continued evaluation of model estimates of soil moisture discussed in the following section.

### 6.2.2 Soil Moisture Fields

**OBJECTIVE:** *Produce the best possible estimates of soil moisture at four depths over the entire GCIP study area with the initial emphasis over the LSA-SW.*

Activities that are needed to support this objective are:

- A validated soil moisture product is needed for the Mississippi River Basin at a spatial scale of about 40 km and a daily temporal scale for four depths corresponding to the Eta and MAPS model output. This assimilated product must be produced from a variety of data sources, including output from hydrologic models driven by measured meteorological data, in situ soil moisture observations, the NOAA/NWS gamma flights and satellite remote sensing. The currently available remote sensing data are from the SMMR and SSM/I satellites and, although not ideal for a soil moisture measurement, do have a soil moisture response over much of the GCIP area. The challenge will be to combine the various data forms to produce the "best" possible gridded product and to develop a way to validate the product with in situ data, preferably data not used in the assimilation process.

- Initially, a subset of the soil moisture product should be developed for the LSA-SW because this is the area where the most in situ data are available and the region where current remote sensing can provide the best information because of the relatively less dense vegetation cover.

- A second subset of the soil moisture product needs to be developed for the LSA-NC. Here the Illinois in situ soil moisture data set can be used for validation and/or assimilating the data set. The issue of cold season hydrology and frozen soils needs to be addressed with this data set.The development of methods to combine remotely sensed and in situ soil moisture should be encouraged. Of particular interest are methods that are accurate at the beginning of the cold season, just before the soil freezes and snow cover commences, and just after snow cover has disappeared. An example of this is the combining of aircraft and in-situ measurements made at the beginning of the cold season by the NOAA/NWS - National Operational Hydrology Remote Sensing Center . In addition, passive microwave data should be useful for delineating frozen and non-frozen soils.

### 6.2.3 Model Estimates of Soil Moisture

**OBJECTIVE:** *Assess the role of soil moisture in hydrological models and develop understanding of the relationship between model soil moisture state variables and observation-based values of soil moisture, i.e., is the model-produced value of soil moisture comparable with the in situ measurements?*

Activities that are needed to support this objective are:

- Comparisons of actual model estimates of soil moisture (spatially and temporally) with measured values. The measured values may come from the index stations, existing data collection programs (Little Washita, Illinois State Water Survey, FIFE, etc.), or from airborne remote sensing campaigns. The objective of these comparisons is to evaluate which models may be able to use measured data and what data might be used. A subsidiary task is to modify existing models to use measured data.

- Investigation of the seasonal to interannual variability of soil moisture and the minimum duration of observations needed to experience a wide range of soil moisture anomalies. This investigation will have to be done by modeling with some in situ data used for validation. Using models developed or tested as described in the two above activities, the seasonal to interannual variability of soil moisture can be simulated by using historical weather records that include wet and drought years.

- There is a current study to investigate the long term seasonal-to-interannual variability of land surface processes. This study aims to develop data sets of best possible estimates of continuous long term soil moisture fields, from 1979 to the present, for the Mississippi River basin. A combination of in-situ data, numerical modelling, satellite observations, and data assimilation will be used to create these data. These years are important, because they represent the beginning of a period of intensive global data collection, both on the ground and from space. Soil moisture estimates derived from satellite microwave data will be merged with an assimilated soil moisture data set, to achieve the most reliable and spatially consistent data product possible. This validation data set will permit even greater improvements in microwave inverse modelling technology. Additionally, the spatial and temporal distributions of both satellite-derived soil moisture and the validation data set will be investigated. Analysis of accurate estimates of long term soil moisture may provide an improved understanding of the distribution and evolution of drought phenomena and desertification. The study will also investigate relationships between basin soil wetness conditions and streamflow characteristics during extreme events. Finally, the gridded soil moisture data products from the investigation will serve as an independent source for comparison and validation with other regional and global scale soil wetness products.

- Analysis of selected one-dimensional land-atmospheric models and three-dimensional (3-D) hydrological models to document how they represent and use soil moisture. Comparison with measured surface and profile data such as that from the Little Washita or other well instrumented watersheds.

- Performance of model sensitivity tests.

- Use of selected data sets from field campaigns to compare model derived soil moisture with measured soil moisture using various means and modification of models if necessary.

- Selection of a suitable model or models to force with some long term data sets of precipitation and potential evapotranspiration.

### 6.2.4 Local Variability of Soil Moisture

**OBJECTIVE:** *Use a combination of in situ, remotely sensed measurements, and physically based models to develop procedures for scaling up of soil moisture from point to hillslope to grid cell and to characterize the uncertainties associated with the data at all scales.*

Activities that are needed to support this objective are:

- Improved understanding of soil moisture dynamics using the local measurements of soil moisture and available water and energy forcing from comprehensive field experiments such as FIFE, HAPEX-Sahel, Multi-sensor Aircraft Campaign (MAC)-Hydro 90, Monsoon 90, and Washita. The issues to be addressed here are the control exhibited by soil physical properties, vegetation, and topography on the interstorm changes in surface and profile soil moisture. Although sufficient data may not be available to address these questions, the attempt should be made with the existing data and hillslope models such as Topography-based (TOP) model and with other work done in the partial area runoff field.

- Development of an improved strategy for using local soil moisture observations in GCIP to develop an improved soil moisture sampling plan. The strategy here should be to establish index soil moisture measuring locations that are supported by coexisting hydrologic and atmospheric data collection programs. No attempt will be made to address the horizontal spatial variability with these index stations. Instead, these stations should focus on monitoring the temporal changes with depth. Their locations should be chosen geographically to represent the major soil-vegetation-climate regions within the GCIP region. A major objective of these index stations will be to identify the timing of deep seepage (ground water recharge) in the relatively humid areas and the depth and duration of a zero flux boundary in the more arid regions.

- Development of a procedure for extrapolating or assimilating these point or small area measurements to represent the soil moisture distribution on a basin and a regional basis. This procedure should use static data such as soil properties and topography and atmospheric forcing in the form of WSR-88D radar rainfall products and evaporation estimates from mesoscale atmospheric and hydrological models. Estimates of the accuracy of these procedures should be carried out with short but intense field sampling programs.
- Organization and assembly of data sets with remote sensing data, soil moisture measurements, and concomitant hydrological and flux data, DEMs, soils, land cover maps, etc.
- Inventories to determine which of the Natural Resources Conservation Service soil moisture sampling locations are suitable for GCIP, collection of historic data, and determinations if any USDA Natural Resources Conservation Service stations need upgrading.
- Development of the criteria for establishing the location, number, depths, etc., for establishing *in situ* soil moisture index stations within the GCIP area
- Prioritization of the locations and installation of the instrumentation.
- Examination of the possibility of using SAR data from ERS-2 and RADARSAT to extend the *in situ* data to larger areas.
- Examination of the possibility of using hydrological models forced by measured inputs to extend the point samples of measured soil moisture to larger areas.

### 6.2.5 Remote Sensing of Soil Moisture

**OBJECTIVE:** *Develop improved remote sensing techniques for areal estimation of soil moisture.*

An EOS interdisciplinary science hydrology experiment conducted by NASA and USDA called Southern Great Plains '97 (SGP97), which involved mapping surface soil moisture with an airborne L band microwave radiometer on a daily basis for a month over an 11,000 $km^2$ area at 1 km resolution, took place in June-July, 1997 in Oklahoma. Operated at a scale equivalent to a GCIP ISA, this experiment offers a unique data set for examining the applicability of microwave soil moisture retrieval algorithms at spatial and temporal scales more typical of satellite systems, as well as the value of soil moisture information to regional scale hydrology, weather, and land-atmosphere interactions. The spatial area covered ranged from the Little Washita River watershed in the south to the ARM/CART Central Facility near the Kansas border in the north. Extensive ground measurements of soil moisture were collected at the Little Washita watershed and the Central Facility area as well as USDA's El Reno watershed in conjunction with the aircraft mapping. On four occasions microwave mapping of soil moisture was also extended to the CASES site in Kansas. A total of 18 complete missions and 3 partial missions (truncated due to occurrence of severe weather) were successfully flown with the ESTAR airborne L-band microwave radiometer during the experimental period.

The primary objectives of SGP97 are to:

- Establish that the retrieval algorithms for surface soil moisture developed at higher spatial resolution using truck- and aircraft-based sensors can be extended to the coarser resolutions expected from satellite platforms;
- Verify spatial-temporal estimators of soil moisture and to examine the utility of pedotransfer functions in hydrologic modeling;

- Examine the feasibility of inferring soil moisture and temperature profiles using surface observations in conjunction with in situ measurements; and
- Examine the effect of soil moisture on the evolution of the atmospheric boundary layer and clouds over the Southern Great Plains during the warm season.

Additional activities as part of SGP97 include:

- Development and validation of algorithms to estimate soil moisture from both active and passive microwave sensors. The issues to be addressed are the effects of roughness, vegetation, and topography.
- Studies to understand the relationship between soil moisture in the top ~ 5 to 10 cm and total profile soil water to depths accessible to plants. Modeling approaches need to be pursued that consider the plant species and information about rooting depths and seasonal growth curves. Direct statistical techniques also need to be pursued for the relationship between microwave response and measured soil moisture at certain index measuring stations.
- Studies to investigate whether a relationship exists between direct measurements of the surface (the composite of soil and various vegetation types) with microwave instruments and surface wetness. Direct microwave measurements include the effects of soil moisture as well as the biomass (and other factors such as roughness). These issues are difficult to separate in algorithms without a lot of detail and difficult to measure characteristics of the surface and canopy. The possibility exists that the microwave measurement is "seeing" something that correlates well with what the atmosphere sees. That is, might the microwave measurement provide an empirical measure of some surface wetness function that could be used directly to describe the moisture available to the atmosphere (i.e., a combination of soil moisture and vegetation condition)?
- Tests of various algorithms with existing data sets.
- Evaluation of in situ data from bare and vegetated soils to determine the conditions under which the surface soil moisture is decoupled from the remainder of the soil moisture profile.
- Development of simple statistical models relating soil moisture profile to the surface layer.
- Initiation of studies to compare existing remote sensing data sets with output from mesoscale models.
- Studies to use ERS-2 and RADARSAT data over the SGP97 study area for comparisons of soil moisture or wetness product with Eta and MAPS model output. Approximately 20 RADARSAT scenes were acquired during the experiment.

**Other Participants in SGP97**

Over 30 guest investigators also participated in the experiment to extend the utility of the resulting data set to broader areas of interdisciplinary research in hydrology, meteorology, and associated modeling and scaling issues. Besides the core mapping by the ESTAR airborne radiometer, the experiment included a comprehensive flux measurement component, enhanced ground measurement of soil and vegetation properties, extensive soil moisture sampling through both gravimetric and TDR techniques, and other aircraft remote sensing instruments (SLFMR, TIMS, CASI, LASE, etc.). Temporal analysis of the microwave data will be facilitated by continuous 24-hour observations made by truck and tower based microwave radiometer systems to complement the once-a-day aircraft measurements; these observations cover the microwave spectrum from ESTAR to SSM/I frequencies. Studies of the influence of soil moisture on the local and mesoscale surface energy budget will utilize automated micrometeorological and soil profile measurements from the three research instrument networks in the SGP97 area: the DOE ARM/CART facilities, the Oklahoma Mesonet, and the USDA/ARS Micronet in the Little Washita watershed.

Surface cover in the test area during the experiment time frame from June 18 to July 16, 1997 was predominantly senesced or harvested winter wheat and rangeland pasture. Several significant soil moisture dry downs occurred at different times in different parts of the test area due to thunderstorm activity. Additional information about SGP97 can be found on the World Wide Web at the URL address: http://hydrolab.arsusda.gov/sgp97/

ESTAR brightness temperature maps of the SGP97 area are currently undergoing detailed reprocessing and registration. It is anticipated that soil moisture maps derived from the ESTAR data will made available to the scientific community near the end of 1998.

**Future Satellite Sensors**

Within the near future, there will be several space borne instruments that will contribute to the technology of remote sensing of soil moisture. The japanese are currently building two identical passive microwave instruments, AMSR (Advanced Microwave Scanning Radiometer) that will have a C-band radiometer (6.9 GHz) in addition to other microwave bands that match the SSM/I bands. The first instrument will be launched on the Japanese ADEOS-II (Advanced Earth Observing Satellite-II) in 1999 and the second will be launched on the NASA EOS PM platform in 2000. The C-band instrument will provide useful data for soil moisture at a spatial resolution of about 50km and a three to four day repeat cycle.

The first opportunity for an L-Band instrument may come in the 2002 to 2003 time frame through an ESSP (Earth System Science Pathfinder) program. The challenge for an L-Band instrument is to erect a very large antenna in space in order to achieve useful spatial resolution. Several concepts are being studied and one or more will be proposed in 1998. The ESTAR instrument flown in the SGP-97 is an airborne prototype of a likely space borne instrument and the previous flights with this instrument have provided a large amount of data and experience in imaging processing and algorithm development.

### 6.2.6 Recommended High Priority Activities

The Soil Moisture Research Area has very little ongoing research or activities that can be specifically attributable to GCIP, with a major exception being the support for installation of in situ soil moisture stations. The needs for soil moisture have been expressed by a number of other GCIP Research Areas, e.g. Coupled Modeling Research in Section 2, as well as individual researchers. The following items were identified in the GCIP Soil Moisture meeting (in Boulder in November 1997) as being essential to the successful implementation of the entire GCIP program:

- Variability of soil moisture; understanding the relationship between point measurements and areal representations AND the relationship between surface measurements and the total profile soil moisture.
- The need to develop validated, daily soil moisture fields for the entire GCIP area at a 40 km grid and four depths.
- To develop the cold season products of soil moisture and temperature fields, including frozen and unfrozen soils.

Three specific steps were recommended to accomplish this:

- Coordination among the various funding agency program managers, both in the inclusion of these three specific needs in future research announcements and in the budgeting of sufficient funds to do the job.
- Recognition that we can measure soil moisture with existing satellite borne sensors.
- Use the SGP-97 data sets and activities as the spring board to accomplish these goals.

**Long term** activities that should be started within the next two or three years includes:

- Increase the number of in situ monitoring stations to include additional soil/climate regimes. The North - South transect along 96W longitude represents a good start.

- Start using existing remote sensing capabilities and anticipate the infusion of AMSR and hopefully L-Band data.

- Interact with the coupled modeling community.

## 6.3 Land Surface Characteristics

**OVERALL OBJECTIVE:** *Improve the quantitative understanding of the relationships between model parameterizations of land processes and land surface characteristics; and facilitate the development, test, evaluation, and validation of multiresolution land surface characteristics data and information required by GCIP researchers for developing, parameterizing, initializing, and validating atmospheric and hydrological models.*

### 6.3.1 Land Surface Characteristics Research

The strategy for this land surface characterization research is twofold. In the near term, the primary emphasis is on facilitating the adaptation, tailoring, test and evaluation, and validation of existing land surface characteristics data sets that will meet the immediate requirements of GCIP's Principal Research Areas. The multiresolution land surface data requirements of GCIP researchers will be documented and the GCIP land surface characterization research plan will be updated based on regular feedback from GCIP modelers, as well as research results concerning land process modeling activities of PILPS and ISLSCP. This near-term strategy also includes adapting and testing promising biophysical remote sensing algorithms that are available in the literature, for example published results from ISLSCP's remote sensing science activities involving FIFE, Boreal Ecosystem Atmosphere Study (BOREAS), or the GEWEX/ISLSCP global one-degree latitude-longitude global land data sets published on compact disk, read-only memory (CD-ROM). Many GCIP modelers will conduct land characterization research as an integral part of their efforts to develop land surface process models and parameterizations, therefore, facilitating the cross-disciplinary flow and sharing of land characterization results and information within the GCIP research community is needed. GCIP's longer-term strategy for land surface characterization research will focus on developing and testing enhanced high-resolution land data sets. This includes collecting field data that are necessary to develop, adapt, test, and validate promising remote sensing algorithms for land cover characterization and model parameterizations; conducting advanced remote sensing research, for example, canopy reflectance modeling; and investigating landscape heterogeneity, grid cell aggregation rules, and land data interrelationships as related to land process parameterizations. This longer-term strategy also includes provisions by GCIP to test and evaluate remote sensing data sets that will become potentially available at as yet unknown dates following the planned launches of the NASA-led Earth Observing System (EOS) AM1 Platform and Landsat 7 during the mid-1998 time-frame.

Multiresolution land surface characterization research in the near-term will be directed towards meeting the minimum requirements of GCIP Principal Research Areas for land cover, soils, and topographic data, including associated characteristics and properties of each, at four regional scales. For example, the initial project regions and their associated gridding intervals included the CSA and LSA-SW (30-km grids), ARM/CART as the initial ISA (10-km grid), and Little Washita as the initial SSA (4-km grid). The primary land surface data sets that were available throughout the conterminous United States to meet some of GCIP's early requirements for land data within these four regions included various 1-km and coarser spatial resolution, advanced very-high-resolution radiometer (AVHRR) data products from NOAA's polar-orbiting satellites; the 1:250,000-scale USDA/Natural Resources Conservation Service State Soil Geographic Database (STATSGO); and DEMs of 0.5-km and approximately 100-m grid cell resolutions, respectively, available from the USGS. Land characterization research focused on the adaptation and use of these primary data sets as the basis to develop, test, and evaluate key derivative land surface characteristics data sets for use by GCIP modelers.

As GCIP evolves, land surface characterization research will focus on meeting the changing requirements of coupled modeling in GCIP and the testing of land surface data in newly defined LSAs. For example, land surface parameterization sensitivity studies by PILPS and GCIP investigators have helped to identify critical requirements for detailed soils information and fractional vegetation cover data (percent bare soil .vs. percent vegetation) as key inputs to land surface parameterizations. The GCIP research activities for the LSA-NC began in 1997 with research planning for the LSA-E (1998-1999) in the final stages. The GCIP research planning for the LSA-NW (1999-2000) is scheduled to begin in early 1998. The GCIP research at the CSA and LSA scales will benefit from land cover characteristics data derived from remote sensing algorithms developed as part of ISLSCP Initiatives (No. 1 and No. 2) or, as part of EOS AM1 project activities, when available.

Higher resolution land data sources are need for ISA-scale and small watershed regions in GCIP. Examples of these subregions include the ISA ARM/CART, the Upper Walnut River watershed located within the ARM/CART as part of the Cooperative Atmosphere-Surface Exchange Study (CASES) project, and the SSA Little Washita watershed located just to the south of the ARM/CART. Candidate SSAs within the LSA EAST include the river subbasins within the Tennessee River drainage basin and the Goodwin Creek watershed (part of the Yazoo River basin), a USDA/ARS experimental watershed located in north central Mississippi. Similar ISAs and SSAs for the LSA-NC and the LSA-NW are yet to be determined.

Some of the key secondary land data sources could include various types of 30-m LANDSAT thematic mapper (TM) data products for land cover characterization within the ISA- and SSA-scale regions, selected county-level digital USDA/Natural Resources Conservation Service Soil Survey Geographic Database (SSURGO) (as available), USGS digital 60-m DEMs for the ARM/CART, and USGS 30-m DEMs available in a 7.5-minute quad format for selected locations within the GCIP domain. The land data sets developed for the Upper Mississippi region by the Scientific Assessment and Strategy Team (SAST) concerning flood plain management following the 1993 floods potentially represent a significant contribution to the land surface characterization requirements for the LSA-NC and LSA-NW (see the World Wide Web at the URL address: http://edcwww.cr.usgs.gov/sast-home.html). Detailed analysis of multiresolution satellite data for the ISAs, for example the ARM/CART region, can contribute improved remote sensing algorithms that can be applied within the LSA- and CSA-scale regions.

Additionally, the identification and facilitation of the use of appropriate data analysis tools, such as GISs and digital image processing systems, will be needed to tailor land surface characteristics from primary data sets and to integrate and analyze disparate data sets of interest to land process researchers. Both standard and new image processing techniques will be necessary for analysis of multitemporal land cover characteristics data, frequently available from satellite remote sensing systems with different spatial resolutions. Moreover, the application of appropriate geostatistical techniques, such as measures of dispersion or aggregation of landscape patterns, will be investigated to assist in understanding the spatial linkages extant between land surface characteristics and the hydrometeorological conditions within the GCIP study area.

Land surface characterization research is highly interdisciplinary in scope. Therefore, an equally important high-priority task is to develop Federal agency participation and resource support for cooperative work on the accomplishment of GCIP's land surface characteristics research objectives and activities. Some of the potential Federal agency participants for conducting and supporting this land surface characterization research include NOAA (NWS and NESDIS), the USGS (National Mapping Division and Water Resources Division), NASA [Marshall Space Flight Center (MSFC) and GSFC] and the USDA [ARS, Natural Resources Conservation Service, and National Agricultural Statistics Service (NASS)]. In many cases, the results of this interdisciplinary land surface characterization research will directly benefit agency missions, such as those concerning land data set development, remote sensing science, operational programs involving atmospheric and hydrological modeling, natural resource assessment, and agricultural monitoring and forecasting. Furthermore, activities such as SAST, involving flood disaster management, can contribute to GCIP both in terms of a supplier of land data and as a key user of GCIP atmospheric, hydrologic, and water resource products for policy decision making. The efforts of such Federal agencies would complement contributions made by GCIP's research community including expertise at universities. The coordination of this research with potential contributions by GEWEX/ISLSCP presents an outstanding opportunity, especially for biophysical remote sensing algorithm development, operational data set development, and scaling research.

This land surface characterization research strategy will be accomplished through objectives and associated research activities involving land cover characteristics, soils and geology, and topographic information. The research activities under each objective are listed according to priority for accomplishment.

### 6.3.2 Land Cover Characteristics and Associated Data Products

The biophysical remote sensing and land-atmosphere interactions modeling communities are currently addressing many of the research questions and related data development issues concerning the potential role of land cover characteristics as determinants of land surface processes. This research by atmospheric and hydrological modelers is concerned with understanding and parameterizing the effects of land cover characteristics in their models and parameterizations (i.e., land cover and vegetation type, land use, the physical and biophysical properties of vegetation including the temporal dynamics, and more recently the spatial heterogeneity of the landscape). In many cases, these two communities also share common interests in developing the experimental remote sensing algorithms that are needed to estimate or derive various types of land cover characteristics from satellite data over large areas. Examples range from the use of multitemporal satellite-derived spectral vegetation greenness indexes for land cover classification and estimating leaf area index (LAI) to more advanced canopy reflectance modeling for estimating biophysical parameters and processes. Facilitating the adaptation and use of published research results and biophysical remote sensing algorithms within GCIP is a key requirement.

Some of the sources for land cover characteristics data include the global land data sets for land-atmosphere interactions modeling published on CD-ROM by NASA/GSFC under GEWEX/ISLSCP Initiative No. 1, plus various AVHRR data sets produced by NASA, NOAA/NESDIS, and USGS. For example, NASA's ISLSCP Initiative No. 1 CD-ROM includes monthly one-degree by one-degree latitude-longitude calibrated, continental-scale NDVI data (1987-88); enhanced NDVI fields; Fraction of Absorbed Photosynthetically Active Radiation (FPAR) fields derived from enhanced-NDVI data; LAI and canopy greenness resistance fraction calculated from the derived FPAR fields; surface albedo and roughness length fields derived from land process models; and canopy photosynthesis and canopy conductance fields estimated by inverting the Simple Biosphere Model (SiB2) land surface parameterization (LSP) with FPAR as the key model input. A key step in the biophysical parameter estimation was the development of the "Fourier-adjusted, solar zenith angle-corrected, interpolated and reconstructed" (FASIR) algorithm to derive the enhanced-NDVIs. The CD-ROM also includes a one-degree global land cover data set developed by the University of Maryland. Overall, this ISLSCP CD-ROM contains the first set of global land cover and land cover biophysical parameter data that are derived in an internally consistent fashion.

Although these ISLSCP Initiative No. 1 CD-ROM data are of direct interest to GCM and coarse grid cell resolution mesoscale modeling, the remote sensing algorithms and approaches for processing satellite reflectance data and inverting an LSP to derive the land cover characteristics can guide similar data set development efforts using higher resolution AVHRR and LANDSAT TM data. The FASIR algorithm can be adapted for developing LSA-scale data sets for test and evaluation in GCIP. NASA/GSFC is currently leading the development of new global consistently-derived data sets under the ISLSCP Initiative No. 2 activity which is focusing on enhanced global land cover characteristics data sets at a 1/2-degree latitude-longitude grid for the ten year period, 1986-1995. The ISLSCP No. 2 data are planned for release during the 1998-99 timeframe. One source for this multi-year global analysis is the 8-km AVHRR Global Area Coverage (GAC) Pathfinder data set developed jointly by NASA and NOAA for the period 1982-1995. This global 8-km data set and the ISLSCP Initiative No. 1 global data can be obtained via the NASA/GSFC DAAC WWW site ( http://daac.gsfc.nasa.gov).

The NOAA/NESDIS has developed several AVHRR global vegetation index (GVI) data sets. These data sets include weekly satellite image composites consisting of five AVHRR channels, solar zenith and azimuth angles, and the GVI for 1985 to the present. These data are calibrated for sensor drift and intersensor variability, and are available in a 1/6-degree resolution latitude-longitude global product. NOAA/NESDIS has produced a five-year climatology of average GVI data for the globe. More recently, NOAA/NESDIS has developed a NDVI-scaled "fraction of green vegetation index" ( http://orbit-net.nesdis.noaa.gov:80/ora/lst/gutmanpage.html). This data set is currently undergoing test and evaluation in the NOAA/NCEP Eta model. NOAA/NESDIS has also investigated the use of GVI data in vegetation crop indexes as a tool to detect and monitor large-area meteorological drought. Finally, the NOAA/NESDIS National Geophysical Data Center recently released Disk B of the Global Ecosystems Database that includes the Fedorova et al., World Vegetation Cover and the Bazilevich Global Primary Productivity.

The USGS EROS Data Center (EDC) has developed 1-km AVHRR data sets for the conterminous United States and is now processing global 1-km AVHRR data for land areas. The data sets for the conterminous United States include biweekly AVHRR time-series image composites on CD-ROM (1990-1996) and a prototype land cover characteristics data set for 1990 on CD-ROM. Ongoing USGS activities for the conterminous United States include the development of experimental, temporally smoothed 1-km seasonal NDVI greenness statistics for test and evaluation. These statistics consist of 12 seasonal characteristics that are associated with each 1-km NDVI seasonal profile for each year during the period 1989 to 1993, as well as the five-year means throughout the conterminous United States.

Under the auspices of the International Geosphere-Biosphere Project (IGBP)-led 1-km AVHRR global land cover data set development activity, the USGS is currently processing global, 10-day AVHRR image composites for land areas. Prototype 1-km AVHRR land cover data sets for the North American continent were developed as part of a global land cover mapping effort. These land cover data for North America include individual data sets for the BATS, Sib2, IGBP, and other land cover classification schemes plus associated monthly AVHRR image composites and a 1-km digital elevation model (DEM) for North America. These data sets can be accessed online via the EDC Distributed Active Archive (DAAC) Home page (http://edcwww.cr.usgs.gov/landdaac/). The 1-km AVHRR IGBP global land cover data are currently undergoing validation as part of an independently-led IGBP project activity. Several global climate change research modelers, including some GCIP investigators, are currently testing and evaluating these USGS data sets.

In mid-1998, the Earth Observing System (EOS) AM1 platform is scheduled for launch as part of NASA's Mission to Planet Earth (MTPE). A wide variety of land cover characteristics data are scheduled to be produced from data collected by the MODIS, MISR, ASTER, and CERES sensors on board the AM1 Platform. When ready for test and evaluation at some later date, these new data sets would be an important contribution to GCIP research investigations. For example, enhanced atmospherically-corrected reflectance data and spectral vegetation index data would be potentially available. In addition, current NASA plans also call for the 1998-launch of Landsat 7, which will be in near-synchronous orbit with the AM1 package. Land surface research will benefit from concurrent overlapping Landsat 7 and EOS AM1 products. Further information is available from the NASA Mission to Planet Earth WWW page (http://www.hq.nasa.gov/office/mtpe).

**OBJECTIVE**: *Improve the quantitative understanding of the relationships between land cover characteristics and the land surface parameterizations and land process components of atmospheric and hydrological models, and meet the requirements of the GCIP modeling and research activities for multiresolution land cover characteristics data.*

Activities in support of this objective in order of priority will:

- Define the requirements of GCIP modelers for multiresolution land cover characteristics data, document available data sources, and assess the adequacy of available data for GCIP Principal Research Areas based on interviews with GCIP PIs. Ongoing feedback is needed from GCIP, PILPS, and ISLSCP activities concerning requirements for land cover characteristics data and the results of model sensitivity tests.

- Facilitate the test and evaluation of recently developed land cover characteristics data sets at the continental scale including new USGS 1-km AVHRR land cover and NOAA/NESDIS 1/6-degree latitude-longitude fractional vegetation greenness index data.

- Develop multiresolution, aggregated land cover characteristics data sets that are internally consistent and collectively "harmonized" within model spatial domain grid cells. Products will include, at 10 km and 30 km grid cell sizes, the three predominant land cover/land use classes in each grid cell. Products will also include a climatology of the fractional presence of green vegetation associated with the three predominant land use/land cover classes. Products for the conterminous United States will be based on a five-year climatology, while the prototype global product will be derived from an 18-month time series.

- In addition to data quality and evaluation criteria, this research also requires investigation of various aggregation rules, such as aggregation by predominant land cover class or aggregation that retains the percent composition in each grid cell. For example, the Eta model's land surface parameterization now has a requirement for 10-20 km grid cell aggregations of land cover (dominant and secondary classes), multi-year average NDVI, fractional vegetation greenness index, albedo, and other biophysical parameters that are internally consistent with each other from a land surface process perspective within each Eta model grid cell. Mesoscale atmospheric and macroscale hydrologic basin-scale models require the incorporation of soils properties and topographic features. These types of land surface data sets are needed at multiple resolutions to meet the nested grid requirements in this GCIP coupled modeling approach.

- Deliver enhanced land surface characteristics data sets and place them on-line for easy access. Improved seasonal biophysical parameters at 10-20 km grid cell aggregations are needed by coupled modelers in GCIP. These include improved spectral vegetation indexes, land surface albedo, surface roughness, fractional vegetation coverage (percent vegetation .vs. percent bare ground), LAI, FPAR, and "wet" biomass for passive microwave soil moisture research. Requirements range from basin-scale modeling to GCIP research in the LSAs, especially the LSA-East and LSA-NW. In general, physically-based algorithms are an essential requirement for biophysical parameter estimation at least on monthly time scales. For example, the NASA-led ISLSCP/GEWEX Initiative Number 2 could provide enhanced biophysical land cover land cover parameters at a 0.5 degree grid size based on the FASIR algorithm. Adapting this FASIR algorithm approach for application at a 10-20 km analysis is another option. These GCIP research efforts would be conducted in parallel with and complement the development of land cover characteristics algorithms by NASA-science teams associated the EOS AM1 spacecraft.

- Conduct land cover characterization research with 30 m land cover data sets developed from Landsat TM imagery as part of a USGS- and EPA-led multiresolution land cover characterization activity. Preliminary 30 m land cover data are scheduled for completion in the LSA-East by late 1997 with completion for the remainder of the conterminous United States planned by the end of 1999. These high-resolution land cover data could benefit GCIP LSA-scale research activities involving multiresolution aggregation, scaling, and validation studies. In addition, the DOE ARM program has identified available high-resolution land cover and land use data sets for the ARM/CART, while the USDA/ARS is presently completing a GIS for the Little Washita including recent Landsat TM-derived land cover classifications, historical Landsat MSS products back to 1972, and other land surface characteristics data sets.

- Use GCIP findings to assess the new levels of understanding concerning the role of land surface characteristics in land surface parameterization research.

- Facilitate the use of GCIP model output and data assimilation products by remote sensing data centers to improve remote sensing processing techniques, especially approaches for making atmospheric corrections to satellite reflectance data for atmospheric water vapor content and aerosol concentrations.

- Conduct GIS-based land surface characterization research studies within the Mississippi River Basin to determine multiresolution interrelationships among land cover, biophysical parameter, soils, and topographic data sets including derived parameter fields. In addition to verification of physically, consistent associations, these studies should focus on the role of landscape heterogeneity in parameterizing land surface processes. Several 1-km data sets now available for the conterminous United States establish the foundation for this GIS-based multiresolution analysis. These include USGS 1-km satellite-derived data sets (AVHRR image composites, extensive land cover data, and 5-year average NDVI statistics), a USGS 1-km DEM, and the PSU/ESSC 1-km CONUS-SOILS data set. Other data such as NOAA/NESDIS GVI-based multi-year average NDVI and fractional green vegetation index can be resampled to 1-km (no increased resolution). Ancillary data sets include the GCIP GREDS CD-ROM and the USGS Companion

Data sets for the Conterminous United States on CD-ROM. Several GCIP PI's have expressed interest in a GCIP GIS. These data sets provide an opportunity for climatologists, physical geographers, soil scientists, and others to understand interrelationships in the data.

One prime reason for this research is to ensure that the land surface characteristics data sets on land cover, vegetation attributes, soil properties, and topography are appropriately and consistently tailored within model grid cells or watershed polygons for model applications. In addition to model sensitivity studies concerning accuracy issues for individual data layers, error propagation analysis will also be conducted to assess the net impact of effectively "overlaying" land cover, soil, and topographic data sets in the model, where these data are characterized by differing levels of accuracies, precision, uncertainties, and other data limitations.

- Research is needed to investigate how the spatial heterogeneity of vegetation (i.e., landscape patchiness) affects model parameterization, especially as related to spatial aggregation of data within model grid cells and polygons, or scaling parameterizations. This land surface characterization research emphasizes the spatial component within the landscape, for example, concerning the arrangement, pattern, distribution, and composition of various land cover types within a region that influence or potentially affect land-atmosphere interactions and hydrometeorological relationships.

- Conduct advanced research on satellite data processing and physically-based remote sensing algorithms. For example, atmospherically corrected satellite reflectance data are needed to help overcome the adverse and variable affects of atmospheric water vapor and aerosols on surface reflectance retrievals. Lack of such atmospheric corrections, as well as bidirectional reflectance distribution function (BRDF) corrections, significantly degrade the use of existing satellite reflectance data to calculate vegetation greenness indexes that can be reliably used to study intra-and inter-annual variability of vegetation greenness,i.e., change detection. Advanced land surface temperature/emissivity and biophysical remote sensing algorithms are need to study land surface energy and surface flux conditions.

- Develop plans to test and evaluate remote sensing data sets that will become potentially available at some date following the launches of the NASA-led Earth Observing System (EOS) AM1 Platform and Landsat 7 during the mid-1998 time-frames. The advanced remote sensing science algorithms under development by the MODIS Land Science Team are of particular relevance to GCIP. In addition, current NASA plans call for near-synchronous orbits of the EOS AM1 and Landsat 7 satellite systems, thereby creating a substantial potential for the complementary operation of coarse- and high-resolution satellite data of interest to some GCIP researchers. By testing and evaluation of MODIS land products and by making comparisons to field data, GCIP investigators could make important contributions to the validation of MODIS products.

- Investigate the relationships of landscape thermal infrared conditions, as derived from satellite data (for example, MODIS, ASTER, and Landsat 7 data), with land cover type, biophysical land cover parameters, the land surface energy budget, sensible and latent heat fluxes, and other land surface processes.

- Contribute to the Mississippi River Basin Experiment (MRBEX) in the Year 2000. Early GCIP efforts for MRBEX could potentially begin in Year 1999 in conjunction with the GCIP LSA-NW which will have the theme of "Land Cover Over the Annual Cycle" associated with sparse land cover and snow. The data collection for MRBEX would begin in 1999 with the actual observation period for Year 2000. The GCIP LSA-NW would be used as a means to scale up to the whole Mississippi River Basin in MRBEX. Selected MODIS land surface data products potentially available could make important contributions in the LSA-NW. Use Landsat 7 products in combination with field observations to assist in the validation of existing land cover characteristics data sets and to make recommendations for revisions.

### 6.3.3 Soils, Geology and Associated Data Products

Information on the nature of soils and geology is needed to support the parameterization of land surface processes in atmospheric and hydrological models. Soil is an important coupling mechanism between the land surface and the atmosphere. The pore space between the various constituent elements of the soil (sand-silt-clay particles, rock fragments, plant roots, etc.) forms the"reservoir" of water available for meeting the evaporation and transpiration demands at the landsurface-atmosphere interface, in addition to being the recharge source for ground water. An accurate description of soil and soil-water relationships is a prerequisite for improving the simulation of water movement in the subsurface and, ultimately, the water and energy exchange at the land surface-atmosphere interface. Beneath the soil, the geologic structure and properties control the saturated zone (ground water) component of the hydrological cycle. A complete portrayal of the hydrological cycle requires an understanding of the physical and hydraulic properties of both the soil and geology beneath the land surface.

The land-atmosphere interactions modeling community is interested in the movement of water within the soil, as well as the influence of vegetation in linking soil water with the atmosphere. Modeling approaches are typically based on the Richards equation which describes the flow of water through the soil as a function of soil water content and its vertical gradient. The texture and structure of the soil medium are the primary controls on water movement. These physical properties determine the hydraulic nature (water-holding capacity and conductivity) of the soil. Due to the extremely difficult and tedious nature of the procedures required to measure the water content and hydraulic conductivity of soils, research since the early 1950s has focused on developing empirical relationships between traditionally observed soil physical properties and hydraulic characteristics. This work has been referenced by the land-atmosphere interactions modeling community in an effort to parameterize soil moisture conditions over the typically large domains encountered in mesoscale modeling. Unfortunately, the lack of a soil data set corresponding to these regional scales has confounded efforts to improve this portion of the parameterization dilemma. Clearly, the community of modelers working in this area requires reliable, quantitative information on soil physical properties and, where feasible, direct observations of the hydraulic nature of the soil for use in quantification and validation of the empirical approaches used over large areas to estimate these properties. A range of soil survey products and data sets will be required by GCIP researchers for use in land surface parameterizations.

The USDA-Natural Resources Conservation Service, through the National Cooperative Soil Survey (NCSS), is developing soil geographic data sets at three scales. The familiar county-level soil survey is being converted to a digital data set for use primarily in local-level planning. This data set is SSURGO. At the regional level, the State Soil Geographic Database (STATSGO) has just been developed for river basin, multistate, state, and multicounty resource planning. The compiled soil maps were created with the USGS 1:250,000-scale topographic quadrangles as base maps and comply with national map accuracy guidelines.

The STATSGO data set provides the most useful resource for characterizing the role of soil in mesoscale atmospheric and hydrological models. This data set was developed by generalizing soil-survey maps, including published and unpublished detailed soil surveys, county general soil maps, state general soil maps, state major land resource area maps, and, where no soil survey information was available, LANDSAT imagery. Map-unit composition is determined by transects or sampling areas on the detailed soil surveys that are then used to develop a statistical basis for map-unit characterization. The STATSGO map units developed in this manner are a combination of associated phases of soil series.

GCIP-funded research has resulted in the development of the first 1-km multi-layer soil characteristics data set for the conterminous United States (CONUS-SOIL). This data set is based on the STATSGO data and provides soil physical and hydraulic properties (soil texture, rock fragment class and volume, depth-to-bedrock, bulk density, porosity, sand, silt, and clay fractions, available water capacity, and hydrologic soil group) for the 48 conterminous United States. A key element of the functional design requirements behind CONUS-SOIL was to provide the data in map projections and formats that would permit users to more easily integrate soil information into their particular modeling applications.The complete CONUS-SOIL data set was released in February, 1997 (WWW access: http://www.essc.psu.edu/soil_info/). The response to this data set from the environmental modeling community has been extremely supportive and positive. System logs indicate downloads of various portions of the data set at a rate of about one dozen per week. Other forms of feedback, including requests and comments, indicate a measurable level of success for this approach to delivering soils information.

CONUS-SOIL provides the most useful data set for regional-scale analysis; however, GCIP researchers will still require, on a selective basis, SSURGO data for detailed watershed studies and intense field observation programs. Although this data set will not be complete for the entire United States or even the GCIP study area for many years, selected watersheds within the Mississippi basin should have this, or similar coverage, within the EOP. The SSURGO and S%' *sets are linked through their mutual connection to the NCSS Soil Interpretation Record (Soil-5) and Map Unit Use File (Soil-6).

A geologic map of surficial geology for the upper Mississippi River Basin was developed by Dr. David Soller of the U.S. Geological Survey in Reston, VA.

**OBJECTIVE**: *Develop methods for using soil physical property data for GCIP atmospheric and hydrological modeling*.

Activities in support of this objective in order of priority will:

- Continue to refine the requirements of GCIP modelers and scientific investigators for multiresolution soil physical and derived hydraulic properties data.

- Further research is needed to more fully incorporate the PSU/ESSC 1-km CONUS-SOIL data (available on the WWW site http://www.essc.psu.edu/soil_info/) into the land surface parameterizations of atmospheric and hydrologic models.

- In addition, ongoing feedback is needed from GCIP, PILPS, and ISLSCP activities concerning data requirements for soil properties and the results of model sensitivity analysis to these properties.

- These requirements will need to come from the GCIP modeling community. Conceivably a broad range of models ranging from detailed, distributed parameter, physically based models to lumped parameter and stochastic models will be used in GCIP activities. Each may require a unique level of detail of soils information. The modeling and data set development (soil science) communities must consult on the nature of these needs.

- Continue to refine CONUS-SOIL and extend the data set to a complete North American product by the addition of soils data for Canada and Mexico. Many of the mesoscale models being used in GCIP require land surface characteristics information for model domains which cover a large portion of North America. Recent developments in the Mexican and Canadian soil surveys have now made it possible to begin the task of developing a "CONUS-SOIL-like" product for the full North American continent. In fact, the need for such a data set has been expressed on a number of occasions by GCIP modelers.

- Facilitate development of SSURGO data sets for selected watersheds within the GCIP domain. This information will be vital for support of intense field observations and campaigns during the EOP.

- Test and evaluate the CONUS-SOIL and SSURGO data in GCIP modeling activities.

- Improve quantitative understanding of SOIL data limitations for developing gridded soil physical and hydraulic properties. Specifically, GCIP researchers need quantitative estimates of the uncertainties inherent in the aggregation and disaggregation of soil properties based on sparse soil field measurements and of the limitations of traditional methods for estimating soil hydraulic characteristics (e.g., hydraulic conductivity/matrix potential) from soil physical properties.

- This activity also entails research to determine the acceptable minimum resolution for gridding SSURGO and CONUS-SOIL data according to soil property and location within the GCIP domain. Research is required to investigate various approaches for generating soils information for models. Sensitivity analyses must be conducted.

- Explore need for and availability of geologic data sets on local and regional scales for use in defining the impact of ground water on land surface- atmosphere interactions.

- The impact of ground water on land surface-atmosphere interactions must be further explored. Typically, the upper 2 to 4 m or less of soil profile has been the focus of concern for the parameterizations of these processes. Locally, however, the link to ground water may be significant. GCIP should support further research on this topic by studies of selected data as geologic properties, structure, and knowledge of their relationship to ground water characteristics are known.

**6.3.4 Topographic Information**

Topographic information includes surface elevation data and various derived characteristics such as aspect, slope, stream networks, and drainage basin boundaries. In general, the requirements of atmospheric modelers for topographic data (i.e., spatial and vertical resolution and accuracies) are much less demanding than the requirements for hydrological modeling. For example, available DEMs for the conterminous United States (0.5 km and approximately 100-m resolution) are generally adequate for most atmospheric modeling. A 60-m DEM derived by USGS from 2-arc second elevation contours is available for the entire ARM/CART region and other selected quads. In addition the USGS EROS Data Center has recently completed the development of a global 1-km digital elevation model (DEM), now available on the WWW (http://edcwww.cr.usgs.gov/landdaac/).

The 100-m DEM is generally appropriate for hydrological modeling in large basins (e.g., greater than 1,000 km2 in area). However, topographic data for small basins down to watersheds are needed at two general hydrological scales: hillslope and stream network. The hillslope scale is the scale at which water moves laterally to the stream network. Available USGS 60 m DEMs derived from 2-arc second contour data are generally available for the ARM/CART region.

Hillslope flow distances vary and may be as great as 500 m to 1 km. Definition of hillslope flow paths and the statistics of hillslope characteristics require surface elevation data at about 30 m spatial resolution. Such data have been digitized by the USGS from 1:24,000 scale map sheets for part, but not all of the Mississippi River basin. Also, stream locations (but not drainage boundaries) are available in vector form for these map sheets. Because 30-m resolution data are not available globally nor in some parts of the Mississippi basin, research is needed to see how well hillslope statistics, that are important to some hydrological models, can be estimated from topographic properties of lower resolution terrain data. Research is also needed to determine how important hillslope information is to hydrological response of the land surface. Because 1:24,000 scale maps are not available globally, research is needed on how best to use remote sensing techniques as part of a sampling strategy to develop regionalized hillslope statistics (which may be mapped at an appropriately large scale).

An important application of topographic information is to define the hydrological connectivity of basic hydrological computational elements of a model. These elements may be hydrological subbasins or grid elements. The model domain may be a river basin or a set of atmospheric model grid elements. In any case, a set of methods is needed to merge digital terrain, stream location, and existing basin boundary data to establish additional drainage boundaries relative to key locations in the stream channel network and to establish the hydrological connectivity of model elements. The research need is not so much to develop new methods but rather to organize some of the existing methods into a robust and user-friendly system to satisfy many of the needs for basin boundary locations and for hydrological connectivity. (The USGS/WRD and NOAA/NWS are developing a project to address some of these watershed basin and stream network delineation issues, especially standardization of algorithms and data).

The resolution at which stream network data are needed varies depending on the application. Digital stream locations data are available for the entire United States at several resolutions ranging from 1:250,000 to 1:24,000 scale.

**OBJECTIVE**: *Develop strategies to use available topographic information for model development and model parameter estimation, and investigate approaches suitable to obtain required multiresolution topographic data on a global basis.*

Activities in support of this objective include:

- Define overall GCIP modeler and scientific investigator requirements for multiresolution topographic data including derivative topographic characteristics, documentation of available data sources, and assessment of data adequacy for GCIP Principal Research Areas.

- Organize existing topographic data analysis tools and algorithms into a user-friendly software package that will facilitate the generation of basin boundary locations and hydrological networks from existing topographic data resources, as well as hydrological modeling research.

- Facilitate hydrological modeling research that is focused on determining which topographic properties, including appropriate horizontal and vertical DEM resolution and accuracies, are essential for properly modeling the effects of hillslope processes on the surface water budget and on the timing of hillslope runoff.

- Determine the adequacy of available multiresolution topographic data sets to meet model requirements based on research results in the preceding activity.

- Investigate remote sensing technology as part of a sampling strategy to develop regionalized hillslope statistics that are suitable for global data set development, especially in other GEWEX project areas.

## 6.4 Clouds And Radiation

Clouds and radiation are important for several GCIP studies. Cloud formation, in which water vapor condenses into water or ice phase droplets, is an important part of the hydrological cycle. Furthermore, clouds are the major modulator of the Earth's radiation budget. Radiative fluxes at the surface, in the atmosphere, and at the top of the atmosphere are critical factors in the land-atmosphere energy budget. The solar radiation that reaches the surface drives the diurnal and annual cycles of land-atmosphere interactions. Radiation absorbed in the atmosphere is also important for the diurnal cycle of some cloud systems (e.g., stratocumulus) and is always important for the annual cycle. Radiative forcings due to changes in aerosol and land use (surface albedo) have not been accurately quantified to date by the International Radiation Commission. Satellite data, ground based measurements, and models will be integrated over the ARM/CART site to determine such forcings in GCIP.

**OVERALL OBJECTIVE:** *Improve the description and understanding of the radiative fluxes that drive land-atmosphere interactions and their parameterization in predictive models.*

### 6.4.1 Satellite Product Development

**OBJECTIVE:** *Produce satellite products to define spatial and temporal variability of clouds and radiation over the Mississippi basin.*

Activities to support this objective include:

- Development of high-resolution radiation products for the LSA-SW or ARM/CART area.

  The components of the Earth's radiation budget at the top of the atmosphere--planetary albedo and outgoing longwave radiation (OLR)--are routinely derived by NOAA/NESDIS from the AVHRR on NOAA's polar orbiters and will be part of the derived data products of GCIP. But polar satellite observations provide only two measurements per day for each area: one in the daytime and one at night. Clearly, for land/atmosphere interactions the diurnal variation of radiation is a key factor, and the geostationary satellites can provide such information.

  Algorithms for deriving planetary albedo and insolation from GOES observations of reflected solar radiation have been developed by several investigators (e.g., Pinker and Laszlo 1992). Further research is needed to accurately retrieve the vertical profile of shortwave and longwave radiative fluxes.

GOES longwave products [OLR, downward longwave radiation (DLR), and longwave cooling (LC)] can be derived from GOES sounder data using the techniques developed for the polar-orbiting sounder data [the high-resolution infrared sounder (HIRS)] (Lee and Ellingson 1990; Ellingson et al. 1994a; Ellingson et al. 1994b; Shaffer and Ellingson 1990). Although the satellite platforms are quite different (geostationary vs. polar orbiting) with sharply differing altitudes, the structure of the algorithms will be quite similar. The OLR will be estimated from the sounder channels as the weighted sum of radiance observations in a number of narrow spectral intervals. Regression equations relating DLR and LC to cloud-cleared sounder radiances and effective cloud fraction will be derived. Most of the progress to date in satellite OLR, DLR, and LC have been for cloud-free conditions. The difficulty in making radiation budget estimates under cloudy sky conditions is related to problems in determining accurate cloud base altitude from satellite observations.

The clear sky OLR, DLR, and LC that are obtained from the GOES sounder will be compared with equivalent values derived from the polar sounder for identical targets and for times of observation that are reasonably close.

- Development of high resolution spatial and temporal cloud products for the LSA-SW

  A gridded version of the GOES ASOS cloud cover product will be generated routinely at the NOAA/NESDIS within a few months. This product is derived from the GOES sounder and is produced hourly whenever the sounder data are available. This product is generated without using the visible band of the sounder and is fairly accurate at higher levels in the atmosphere, but it may not do a good job of estimating low level clouds or subpixel cumulus clouds. Both the POES and GOES satellite cloud products will provide cloud information for the GCIP continental-scale area at 0.5° spatial resolution and hourly (GOES) to twice daily (POES) time resolution.

  A significantly more accurate, high resolution satellite cloud product is needed from the GOES (hourly) that would provide cloud information at a resolution of 5 - 10 km. This product would allow validation and improvement in the cloud physics parameterization (and from this, the radiation physics and surface energy fluxes) in climate and NWP models. The imager on the current generation of GOES is a 5 channel instrument with resolution and bands very similar to AVHRR. An automated cloud detection algorithm (CLAVR) has been developed and tested on AVHRR data. This algorithm does a better job of cloud detection than the sounder product described above because CLAVR makes use of the very high contrast between land and clouds in the visible band. To properly meet the GCIP cloud requirements, CLAVR, modified to work with the GOES imager data should be developed and implemented. Such an algorithm applied to GOES imager would be of much use for snow/cloud discrimination applied to snow mapping.

### 6.4.2 Validation of Satellite Algorithms to Retrieve the Surface and Atmospheric Radiation Budget

**OBJECTIVE:** *Assess satellite retrieval algorithms and select a preferred algorithm for retrieving GCIP surface and atmospheric radiation budgets.*

This objective meets one of the central goals of GCIP--namely, the improvement of global systems for the observation of the energy cycle by means of intensive studies in well-instrumented areas. This GCIP activity will:

(1) validate the NOAA operationally-based retrievals of radiation and cloud parameters, especially the new product list from the GOES I spacecraft series (described in the previous section ).

(2) regionally validate the fluxes from the GEWEX global-scale Surface Radiation budget (SRB) Project (Whitlock et al. 1995);

(3) foster the development of Satellite and Atmospheric Radiation Budget (SARB) retrievals in the EOS Clouds and the Earth's Radiant Energy System (CERES) (Wielicki and Barkstrom 1991) and in the French-Russian Scanner for Earth Radiation Budget (ScaRab); then validate CERES and ScaRab retrievals

of the SARB;ScaRab was launched in February 1994, and it functioned until March 5, 1995. A preliminary comparison of ScaRab with the ERBE wide field of view (WFOV) measurements for March 1994 is favorable (T.D. Bess, personal communication, NASA La RC).

(4) expand the use of ARM, SURFRAD, and BSRN surface-based measurements to operational satellite systems and to the MODIS (Moderate Resolution Imaging Spectrometer), MISR, ASTER (Atmosphere Surface Turbulent Exchange Research facility,CERES, and AIRS (Advanced Infrared Studies) sensors on EOS.

Recent advances in fast radiative transfer techniques (i.e. Fu and Liou 1993), in satellite remote sensing, and in the deployment of surface instruments in the GCIP region permit the development of a more accurate and comprehensive description of the radiative fluxes in the atmospheric column. Previous efforts to obtain radiative fluxes by remote sensing have concentrated on the surface (SRB) and the top of the atmosphere (TOA). The full vertical profile of broadband fluxes, as well as the narrowband radiances observed by the satellites, can now readily be computed and compared with measurements at a number of sites. A more internally consistent description of atmospheric radiation is thereby produced. The resulting surface fluxes can be used to validate the operational retrievals described in the previous Section 1. They also serve to test the satellite-based retrievals of clouds, which are used for the calculations. The within-the-atmosphere flux profiles (SARB) can be used to test the fluxes produced by mesoscale and general circulation models. The SARB is the basic driver of the hydrological cycle, the general circulation, and global change.

Version 1 of the CERES/ARM/GEWEX Experiment (CAGEX) contains such a comprehensive radiative description of the atmosphere in the longwave (LW) and shortwave (SW). CAGEX (Charlock and Alberta 1995) Version 1 provides, for 26 days in April 1994, a space-time grid with:

(a) satellite-based cloud properties, aerosol, and atmospheric sounding data that are sufficient for broadband radiative transfer calculations;

(b) vertical profiles of radiative fluxes calculated with that data as input; and

(c) validating measurements for broadband radiative fluxes and cloud properties.

CAGEX is available by anonymous FTP: ( http://www.arm.gov/docs/data/CAGEX.html, with instructions). Version 0 was issued in February 1995 at NASA Langley, where it was used to test the Gupta LW algorithm for the next phase of the GEWEX SRB Project. CAGEX is used to test radiation codes at GKSS (Germany), McGill University (Canada), ECMWF, and other institutions. Version 1 also has SW fluxes and aerosol data. Version 2.0.0 of CAGEX covers the ARM Enhanced Shortwave Experiment (ARESE) from Sept. 25 to Nov. 1, 1995. New features of Version 2.0.0 include (a) multiple sets of sounding data from 3-hourly ARM radiosondes, from instruments like the ground-based AERI (LW spectrometer), the MWR (microwave) and the GPS receiver, and from the NCEP Eta model output, (b) broadband surface radiation measurements from RAMS (Valero et al.) and adjustments to standard observations based on cavity measurements (Michalsky et al.), (c) vertical profiles of aerosol from the MicroPulse Lidar (MPL; Spinhirne and Hlavka), (d) cloud profiling radar data (Clothiaux), (e) cloud LWP from MWR, (f) changes to the Fu-Liou code including the insertion (Kratz and Rose) of the CKD (Clough et al.) LW H2O continuum, (g) calculations with aerosol optical properties for various mineral dust particle sizes (Tegen and Lacis), in addition to the original d'Almeida et al. aerosols, and (h) modifications to the Minnis et al. GOES-8 TOA fluxes and cloud property retrievals.

The clear-sky data in CAGEX Version 2.0.0 has been designed, as per the "Open SW Workshop" at the AMS Ninth Conference on Atmospheric Radiation at Long Beach (Feb. 97), to permit more rigorous testing of SW radiative transfer routines and input data, as well as measured fluxes. Clouds observations in Version 2.0.0 have more redundancy; optical depth from GOES-8 and LWP from surface MWR; height of cloud top from GOES-8 and radar; measurements of the height of cloud base from lidar and radar (and estimates from GOES-8).

In CAGEX Version 1's for April 1994, the computed SW insolation for clear skies generally exceeded the observations; the discrepancy for cloudy skies was similar. By using different aerosol optical properties, some colleagues (Trishchenko, Li, Fu and others) have reduced or eliminated the clear sky discrepancy for April 1994. The clear sky discrepancy for Version 2.0.0 (Fall 1995) appears to be more robust. A large cloudy sky discrepancy for ARESE October 30, 1995 (first reported by Pope and Cess using aircraft data) is quite apparent when comparing computed fluxes with satellite and surface data in Version 2.0.0.

CAGEX Version 2.0.0 has been used to test the vertical profiles of humidity, SW diabatic heating, and LW diabatic cooling in the NCEP Eta model, which activated a prognostic scheme for clouds during fall 1995.

One surprising result in CAGEX is the demonstration of a significant discrepancy between measured and computed SW fluxes at the surface for clear skies; this has been confirmed by various ARM researchers in ARESE. In the NASA EOS, CAGEX serves as a window for community-wide access to preliminary retrievals of fluxes and cloud properties in the CERES program. CAGEX fluxes are determined with the Fu and Liou (1993) delta-4-stream radiative transfer code using the Minnis et al. (1993) cloud retrievals. Experiments with tuned fluxes, in which atmospheric constituents are adjusted to cause computed and observed fluxes to better match, are underway ( Charlock et al. 1994). For limited time periods, within-the-atmosphere fluxes as measured by Unmanned Aerospace Vehicles (UAV) will be inserted in the data stream. Subsequent versions of CAGEX will be used to validate CERES determinations of atmospheric fluxes and similar exercises using ISCCP and ScaRab. Hence CAGEX will continue well after the launch of CERES on TRMM in November, 1997 and EOS-AM (1998). The MODIS and CERES teams in EOS are now drafting plans for a concentrated validation effort over the ARM/CART site in September 1998. "Joint validation planning among the MOPITT, MISR, ASTER, CERES, MODIS, and SAGE III teams were discussed at the Workshop on Atmospheric Validation in EOS-AM1 and SAGE III (WAVES) at Hampton University in October, 1997.

The dense coverage of measurements over the ARM site are presently supplemented with the geographically dispersed SURFRAD described later in this section. When combined with comprehensive satellite-based retrievals and radiative transfer calculations, SURFRAD will provide a rigorous measure of the radiative forcing of climate at selected sites. For example, the present satellite-based record of the interannual variability (IAV) of snow cover lacks an exacting validation in terms of radiative flux; this poses a great uncertainty in monitoring a key climate feedback. There is a corresponding uncertainty in radiative forcing of aerosols; measurements of aerosols and measurements of fluxes have not been matched with calculations to satisfactory accuracy. The SURFRAD monitoring sites at Fort Peck, Montana (high seasonal snow cover and IAV) and Bondville, Illinois (large annual loading of atmospheric sulfur) are well-suited for diagnosing the impacts of snow and aerosols when combined with calculations such as CAGEX (above) or with the NOAA retrievals (Section 6.5.1), which are based on operational satellite data.

The procedures honed in these exercises will be used again with more advanced MODIS, MISR, ASTER, and CERES sensors after the launch of EOS-AM in 1998. In preparation for CERES, helicopter measurements of the SW bidirectional reflectance function (BDRF with about 10 nanometer resolution spanning the shortwave spectrum, the LW window directional radiance, and the broadband SW and LW fluxes (i.e., Purgold et al. 1994) are planned for the ARM/CART site during the spring of 1998. The helicopter measurements are vital for improving the integration of space-based and surface-based data for two reasons. First, they are needed to determine the full angular dependence of surface radiation; a given satellite measurement covers only a single angle. Second, they are needed to determine the spatial distribution of radiation about the surface radiometer; the surface radiometer covers only a tiny area. It is hoped that resources will permit helicopter measurements over some SURFRAD and BSRN sites, too. Another supplement to routine surface measurement is enhancement with a spatial network of instruments. In conjunction with CERES preparations during the fall of 1995, NASA Langley deployed a network of five additional radiometer sites to supplement CAGEX retrievals of surface fluxes in the ARM Enhanced Shortwave Experiment (ARESE). The enhanced spatial network measures fluxes over a large area, as does a satellite pixel, permitting a more realistic validation of the satellite results.

The combination of (1) detailed radiative transfer calculations, (2) satellite-based retrievals, and (3) surface measurements as anticipated in GCIP will permit a significant advance in the description of atmospheric radiation and associated forcings and feedbacks. Supplements to the surface measurements are needed, however; only a single helicopter survey of ARM is definitely planned; deployment of photometers and cloud lidars at more surface sites is uncertain; the determination of aerosol optical properties is a step forward but not the answer; and snow sites especially should have a network of radiometers on towers.

### 6.4.3 Validation and Improvement of Operational GOES Shortwave Radiation Budget Products

The operational production of downwelling and upwelling shortwave (SW) and photosynthetically active radiation (PAR) for GCIP is done using the University of Maryland algorithm (Pinker and Laszlo 1992), as modified for the GOES 8/9 imager. The model also allows estimation of top of the atmosphere shortwave radiative fluxes. The procedure uses clear sky and cloudy top of the atmosphere calibrated radiances in the visible band, the cloud fraction in the target, and information on the state of the atmosphere, as available in real-time from the Eta model, as input to the algorithm. Snow information is also appended, as available fa new routine snow map product at NESDIS. Cloud detection is done with a two threshold method, from visible data only. The new GOES 8/9 procedures, namely, the algorithm, the cloud detection methods, the atmospheric input parameters, and changes in calibration, need to be evaluated. The need for incorporation of seasonal/monthly surface type models in the shortwave algorithm has also to be evaluated.

A process has been established whereby the University of Maryland accesses the GCIP insolation products as generated at NESDIS, as well as the input files used at NESDIS to generate the product. The input files are used to run the model off-line, compare with the product produced at NESDIS, and to test various options in the model configuration. Of particular interest are possibilities to optimize the models operation and/or introduce simplifications. The model output will be validated against ground observations,to include, in the near future, observations from SURFRAD, BSRN and ARM/CART. Ground truth data for PAR are also needed for validation of this component of the SRB. This process is essential for achieving the best possible accuracy from satellite products.

In addition to the NOAA GOES-8/9 and POES operationally based retrievals in GCIP, the NASA CERES is sponsoring a more limited domain program of research retrievals of the SARB (Charlock et al. 1994). Satellite-based cloud retrievals, meteorological data, and radiative transfer calculations will be used to retrieve the SARB over the ARM/CART site in Oklahoma. Computed fluxes and radiances will be compared with ARM-observed surface and unmanned aerospace vehicles (UAV) fluxes, as well as with other satellite data. Tuning algorithms will subsequently adjust atmospheric and surface input parameters, bringing the calculated SARB to closer agreement with observations. Results of the SARB retrievals will be compared with those of other groups and with data. The aim is to develop accurate retrievals of the SARB based on satellite data and to foster the development of such retrievals in the atmospheric sciences community. The first research data set in this CERES/ARM/GEWEX activity covers the April 1994 IOP. In a 3 x 3 matrix with 0.3° increments, daylight cloud retrievals every 30 minutes are provided from GOES-7 with the Minnis et al. (1993) cloud retrievals for cloud albedo, cloud center height, cloud amount, cloud center temperature, cloud thickness, cloud infrared (IR) emissivity, cloud reflectance, cloud optical depth, cloud top height, cloud IR optical depth, cloud mean IR temperature, and cloud top temperature. In a subsequent ARM IOP, Dr. Charles Whitlock plans to employ a helicopter to measure the spectral bidirectional reflectance of the surface. This measurement will permit a detailed study of the clear as well as cloudy sky effects of the surface and aerosols on the profile of radiative fluxes.

The SARB drives the hydrological cycle, the general circulation, and the global climate change. The SARB computed by GCMs is not regarded to be sufficiently reliable for accurate climate prediction. The state of numerical weather prediction (NWP) model simulations of the SARB limits medium-range weather prediction, too. We lack an adequate observational record of the SARB either in clear or cloudy skies. Cloud feedback is generally considered vital to climate but remains uncertain. More fundamentally, forcing occurs, as well as feedback uncertainties because of the radiative effects due to atmospheric aerosols and the Earth's surface.

An observational SARB record is needed for the validation of GCMs and for diagnostic investigations of low-frequency variability and secular climate change. The development of an observational record of the SARB is one objective of the CERES activity ( Wielicki and Barkstrom 1991) in the EOS and GEWEX. The array of instruments deployed by ARM over the CART site presents a unique opportunity for developing and validating satellite-based retrievals of the SARB. The ARM/CART site is well suited to observing the profile of atmospheric water vapor, the vertical and horizontal structure of clouds, and aerosols; these parameters, as well as the ARM/CART surface and UAV measurements of radiometric fluxes, are critical for testing satellite-based retrievals of the SARB. Activities to support this objective include:

- Retrieval of surface and atmospheric radiation budgets from satellite and meteorological data over the ARM/CART site.

- Comparison of computed fluxes and radiances with ARM-observed fluxes and other satellite data, and NWP model outputs.

- Development of techniques to retrieve aerosol and land-surface radiative forcing with satellite and ground-based measurements.

### 6.4.4 Analyses of Clouds and Radiation

**OBJECTIVE:** *Assess model estimates of clouds and radiation and develop improved parameterizations of clouds and radiation processes.*

Activities to support this objective are:

- Analysis of diurnal variations.

  Observational studies of the diurnal forcing of the land-atmosphere system have been hampered by the lack of good data sets on both clouds and radiation. The derived data sets on clouds and radiation as described in the next section on the continental scale and the high spatial/temporal clouds to be generated for GCIP LSAs will be used to study the diurnal variation of clouds and radiation. Such studies are necessary to achieve the GCIP objective to determine the time-space variability of the hydrological and energy budgets over a continental scale. The satellite radiation measurements will provide information on the top-of-the-atmosphere, surface, and atmospheric radiative energy budgets. The satellite cloud data will provide information on the major modulator of the radiative energy budgets and will permit analyses of cloud radiative forcing on a wide range of time scales.

- Validation of clouds and radiation from regional models.

  Satellite-observed cloud and radiation fields will be compared with clouds and radiation predicted by regional models. Satellite-observed clouds, top-of-the-atmosphere radiative fluxes, and insolation can be used to validate model predictions of these quantities. Particular attention will be paid to diurnal variations.

- Analysis of the effect on mesoscale clouds from vegetation gradients.

  Under certain conditions, large horizontal gradients in surface vegetation can cause mesoscale circulations leading to the development of mesoscale convective cloud systems. These systems can also arise as a result of large-scale irrigation of crops, which introduces surface gradients between the irrigated and nonirrigated land areas. Using the satellite data sets on vegetation index and clouds, GCIP researchers will analyze the impact of such land surface gradients on the development of mesoscale convective clouds.

### 6.4.5 Cloud Data Products

To properly validate the cloud parameterization packages in climate and NWP models, the following cloud products should be developed and delivered on an hourly basis from satellite observations: fractional cloudcover on a resolution of 20 to 50 km, cloud height and type, fraction of each type of cloud (this is difficult) and cloud top temperature.

Several satellite-based cloud data sets will be generated during the course of the EOP, based on both POES and GOES observations: ASOS (GOES), CLAVR (POES), and high-resolution (time and space) clouds (GOES).

A gridded version of the Automated Surface Observing System (ASOS) clouds will be generated for GCIP as a continental-scale product. The ASOS clouds are produced operationally from GOES at weather station locations to supplement the laser ceilometer observations of the ASOS of the modernized weather service. The ASOS clouds are generated from the GOES sounder using the carbon dioxide slicing technique ( Menzel and Strabala 1989; Wylie and Menzel 1989). They can also be generated from the image data by substituting the water vapor channel for the carbon dioxide band. Whether the sounder or imager version is implemented depends on which technique is chosen by the NWS for the operational ASOS product. In addition to cloud information, the ASOS-cloud processing system produces clear sky surface temperature as an intermediate product, which will be evaluated for surface energy budget studies and validation of the Eta and other models.

CLAVR stands for clouds from the advanced very high resolution radiometer (AVHRR) on the POES. NESDIS has developed this cloud product over the last few years, and it is currently being generated on a routine basis from the afternoon POES observations (Stowe et al., 1991). This product includes cloud amount, type, and height of each cloud type at a resolution of one degree in latitude. During GCIP it will be produced routinely on a global basis by NESDIS for day and night from both POES spacecraft. The NESDIS will access the product to produce a CONUS sector for the GCIP database.

The ASOS cloud product produced from the GOES data meets the needs of GCIP users better than the CLAVR cloud product produced from POES data. We shall therefore select the ASOS product as the "best available now" for GCIP with the CLAVR to be used in the event of difficulties with the ASOS product.

### 6.4.6 Radiation Data Products

Radiation data sets are required for the GCIP EOP on a continental scale. This information will include top-of-the-atmosphere, surface, and atmospheric radiation data based on both POES and GOES observations.

### 6.4.7 Outgoing Longwave Radiation (OLR) and Planetary Albedo

The OLR and planetary albedo radiation budget products have been obtained from multispectral, narrowband radiometric scanners for many years. This product is currently being produced using a technique to infer the OLR from four of the channels on the high-resolution infrared sounder (HIRS) flown on the POES(Ellingson et al. 1989; Ellingson et al. 1994a).

The above methodologies for obtaining top-of-the-atmosphere, OLR, and planetary albedo are being applied to GOES-8 data and are being produced for GCIP.

### 6.4.8 Surface and Atmospheric Radiation Budget Components

In addition to the OLR, methods have been developed to infer the downward longwave radiation (DLR) flux at the surface (Lee and Ellingson 1990) and the vertical profile of longwave cooling (LC) (Shaffer and Ellingson 1990; Ellingson et al. 1994b) from POES observations. The DLR and LC estimation techniques require spectral radiance data from the HIRS and the vertical distribution of cloud amount and cloud base height. The NESDIS is implementing the techniques in an experimental operations test in the TOVS sounding system.

Insolation and photosynthetically active radiation (PAR) for the GCIP CSA (and in fact, for the whole U.S.) will be produced from GOES 8/9 imager observations. The insolation algorithm, developed at the University of Maryland (Pinker and Ewing 1985; Pinker and Laszlo 1992) is a physical algorithm that uses GOES imager observations of reflected visible radiation. The algorithm uses target clear radiance, target cloudy radiance, fraction of clouds in the target and atmospheric precipitable water (from the Eta model). Other required input to the model is surface albedo (Matthews 1985) and snow cover. Net solar irradiance at the surface can be derived from the insolation and surface albedo.

This algorithm has been modified at the University of Maryland to use GOES 8/9 data as input. A two threshold cloud detection method has been developed that provides the clear and cloudy radiances and the fractional cloud cover required by the algorithm. Over the past two years the insolation algorithm has been implemented into the

GOES sounding system at NESDIS and routine production has begun. The products are not operational, however, but are currently experimental and generated specifically for GCIP.

Because the insolation algorithm is newly developed for GOES 8/9 data, it is vital that the insolation estimates be compared with ground truth and all aspects of the procedure, from cloud detection through insolation production, and be subject to modification and improvement. This way, the accuracy and reliability of the products will increase, thereby meeting one of the main objectives of GCIP.

Outgoing longwave radiation, DLR at the surface, and atmospheric LC rates will be derived from GOES-8 by applying the methodologies used to generate these quantities from POES-HIRS observations. Some development is needed to apply the techniques to GOES data.

In the case of clear skies, surface temperature will be retrieved from the GOES shortwave radiation budget processing. For the clear radiances for each target a split-window surface temperature will be applied. At first simple algorithms that assume a unit surface emissivity will be used, but research is needed to develop an algorithm that adjusts for the different surface emissivity of a variety of surface types. Estimates of surface temperature can be used to obtain upward longwave radiation fields at the surface. It is also important that land surface temperature be retrieved where it is cloudy by use of microwave (AMSU) window channel data. Such products are being developed at NESDIS for NOAA K-M, and will be available to GCIP.

There is another source of surface temperature that should be considered for GCIP. This is the Derived Product Imagery (DPI) which includes surface skin temperature, lifted index, and total precipitable water. The DPI is a planned operational suite of products from the GOES 8/9 imager that is currently under active development. The resolution of the surface temperature in the DPI is 4 km, so in addition to averages of surface temperature for targets of about 50 km. resolution, histograms of surface temperature could be saved. This could be of considerable interest to the modeling community.

### 6.4.9 SURFRAD Sites for GCIP

Six Surface Radiation (SURFRAD) sites are planned for the contiguous 48 states (three of these are already installed in the Mississippi River basin). This network is intended to provide high quality, long term solar and infrared radiation measurements for a variety of research needs: to validate satellite-derived surface insolation; to provide a long term climatology of surface radiation measurements (at least 25 years); to detect trends in surface radiation; and, to verify radiative transfer models. The basic instrumentation set (see Table 6-1) includes radiometers for upwelling and downwelling solar and INFRARED radiation, a sun-tracking normal incident pyrheliometer (NIP) for measuring direct solar irradiance, and a meteorological tower. Other special sensors may be added.

**Table 6-1. Basic Instrumentation at a Surfrad Site.**

| MEASUREMENT | NAME | COST ($) | ACCURACY |
|---|---|---|---|
| Direct Solar Irradiance | Cavity radiometer (required at BSRN) shadow band radiometer NIP | 18,000<br>10,000<br>1,800 | 2 Wm$^{-2}$<br>5 Wm$^{-2}$ |
| Diffuse Solar | Pyranometer (2(pi) solar flux)<br>(radiation >2.5 pm filtered out) | 1,800 | 5 Wm$^{-2}$ |
| Global Solar<br>(direct and diffuse) | Pyranometer<br>(no tracker) | 1,800 | 10 Wm$^{-2}$ |
| | | | |

| | | | |
|---|---|---|---|
| Reflected Shortwave | Inverted pyranometer<br><br>(shaded from sun) | 2,000 | 10 $Wm^{-2}$ |
| Downward Longwave | Pyrgeometer (filtered pyranometer) | 2,850 | 6-8 $Wm^{-2}$ |
| Upward Longwave | Inverted Pyrgeometer | 2,850 | 6-8 $Wm^{-2}$ |
| Photsynthetically Active Radiation | PAR Instrument<br><br>(filtered silicon detector) | 200 | TBD |
| Surface Meteorology Tower | 10-m height: winds, pressure, temperature, humidity | 6,000 | TBD |

The URL address: ( http://www.srrb.noaa.gov) has detailed information on SURFRAD sites, instrumentation, and access to data. In addition to the instrumentation mentioned in Table 6-1, NOAA has obtained Multi-Filter Rotating Shawdowband Radiometers (MFRSR) for SURFRAD. Operational MFRSR algorithms retrieve column aerosol optical depth, predictable water, and ozone; research algorithms provide cloud optical depth. The SURFRAD combination of broadband and MFRSR measurements will permit the estimation of aerosol direct radiative forcing to climate over GCIP.

SURFRAD sites have been chosen to be representative of extended regions. Each has reasonably uniform and stable surface properties that are representative of the region. This requirement is the primary concern of those doing verification of satellite-based algorithms. Those who will use SURFRAD data to verify the satellite-derived surface radiation data require that the area surrounding the sites be spatially uniform over at least the area of one GOES-8 sounder pixel, which is 10 km (E-W) by 40 km (N-S).

One SURFRAD site in the GCIP region is at Bondville, Illinois, located approximately eight miles southwest of Champaign, Illinois. It is owned by the University of Illinois Electrical Engineering Department and managed by the Illinois State Water Survey. This site consists of six acres of grassland (being updated to 14 acres) and surrounded by 220 acres of soybeans and corn. This site is currently operational and also contains a suite of aerosol measurement systems operating under a separate NOAA funded aerosol monitoring program. A second SURFRAD site in the GCIP region is the Poplar River site (near Fort Peck, Montana). The Poplar River flows south out of Canada and into the Missouri River. This site has good hydrological data available and the Poplar River is not used for irrigation (because of high levels of alkali). The site is on rangeland with no trees in northeastern Montana. This site was operational in the summer of 1994. A third SURFRAD site in the GCIP region is the Goodwin Creek site (near Oxford Mississippi). The Goodwin Creek Experimental Watershed is an ARS site located in northern Mississippi. It is relatively flat, and its land use is about 14 percent agricultural, 26 percent timber, and 60 percent idle pasture land. Four lakes are in the region. This site is operational since the fall of 1994. The data from these sites will be quality controlled by NOAA's Air Resource Laboratory (ARL) in Boulder, Colorado. Data will be archived at the ARL facility in Oak Ridge, Tennessee and accessible via the GCIP *in situ* data source module.

In addition to the usual radiation and hydrological measurements at the three SURFRAD sites identified earlier, funds have been requested to add instrumentation for the following: soil moisture, snowfall measurements (in the northern sites), ground heat flux, and cloud determination via lidar and/or possibly digitized pictures.

Not all the requested instrumentation will be immediately available at all the GCIP SURFRAD sites. It is expected that further implementation of instrumentation will likely occur as more resources become available and become part of the normal operations at the three SURFRAD sites.

## 6.5 Streamflow and Runoff

**OVERALL OBJECTIVE:** *To improve the description of the space-time distribution of runoff over the GCIP study area and to develop mechanisms for incorporation of streamflow measurements in the validation and updating of coupled land/atmosphere models.*

Streamflow is determined from measurements of stream stage at a stream-gauging station. Runoff is the spatially distributed supply of water to the stream network which cannot be measured directly. Both surface and sub-surface components are part of runoff. A delay is also inherent between runoff initiation and the time when the runoff reaches a stream-gauging station. This delay varies spatially depending on the distance to the gauge and on how much runoff is occurring.

This research area is concerned with relationships between runoff as computed by atmospheric models, which is distributed in space, and streamflow as measured at streamgauges. This area includes development of globally applicable routing methods to account for the time lags between occurrence of runoff and occurrence of streamflow. Such routing methods might be used in a model to translate runoff to streamflow or they may be used as part of an analysis system to infer runoff from streamflow. Streamflow data are needed to assist in model development, model parameter estimation, and model testing and validation. Although methods may already exist for making streamflow data useful for each of these purposes, additional studies are needed to improve these methods and make them more useful globally.

Two scales of time delay exist between the initiation of runoff and when the runoff reaches a downstream gauge. The first is the hillslope or landscape scale when runoff is moving above and below the surface into the stream channel network; the second is the stream network scale. Because the hydrological processes that occur at the hillslope scale influence both the amount and timing of runoff, this research area is also concerned with estimating both the amount and timing of runoff at the hillslope scale.

Streamflow data and runoff estimates are required both for the development and for the testing and verification of coupled atmospheric/hydrological models. Testing and verification may be approached in two complementary ways. First, runoff from the coupled models can be verified by routing the runoff from a number of grid points (10 or more) to a streamgauge and comparing the model discharge with the observed discharge on a designated basis. The gauges used for this purpose must be essentially unaffected by upstream regulation or diversion. In practice, most of the continental discharge gauges are influenced by regulation and diversion, and may not be good choices for verification (except perhaps on an annual or climatological basis). Therefore, a second complementary approach to compensate for these upstream effects is needed.

### 6.5.1 Relationships between Runoff and Streamflow

**OBJECTIVE:** *Develop and apply improved techniques for the determination/estimation of runoff and streamflow appropriate to the scales of primary interest to GCIP.*

Activities to support this objective follow:

- Development of globally applicable routing models appropriate for the scale of atmospheric models.

- The runoff routing problem has two components. The first is to account for the time delay for water to flow over and through hillslopes and the ground water system to the stream network and to pass through the upper, highly disperse reaches of the stream network. This time lag is often accounted for in hydrology using a "unit hydrograph." Globally transferrable applicable synthetic unit hydrograph approaches or some mathematically equivalent alternatives must be developed and tested, including nonlinear alternatives.

- The second component of the routing problem is to account for the time that water flows from upstream gauges to those downstream or from the runoff generated from the atmospheric model grid through intervening grids to a streamflow measuring point downstream in the river network. Although the equations describing the unsteady flow of water in river channels are well known, further work is needed on methods of estimating *a priori* parameter values to apply these equations to specific river reaches globally. This estimation could include developing and testing various simplified, globally applicable approaches to the solution of the full unsteady flow equations using geographic information systems to estimate channel slope and other hydraulic parameters. These approaches must handle "leaky rivers" and account for the natural losses in rivers and marsh areas.While routing may not be critical for estimating water budgets over a month this may not be the case for extremes and routing effects cannot always be ignored.

- Identification of tributaries of the Mississippi River basin and/or periods where water management effects can be neglected, and the subsequent evaluation of runoff predictions from atmospheric models by routing to a streamgauge and comparing the data with observed streamflow.

- Improved understanding and description of the effects of hillslopes and stream channel nonlinearities on the amount and timing of downstream discharge for large continental catchments and major tributaries thereof (drainage areas typically greater than 5000 $km^2$).

### 6.5.2 Estimation of Runoff from Streamflow and Climate Data

**OBJECTIVE:** *Apply sensitivity analysis to the error budgets in estimating runoff from streamflow and climate data.*

Activities to support this objective follow:

- Evaluation of the error in methods for estimating gridded runoff fields as a function of catchment area and aggregation period using streamflow measurements independent of those used to estimate the runoff grid.

- Gridded monthly runoff data (on a 30-minute grid) are needed to assess the coupled model validation and diagnostic aspects. The model representation of the surface water budget depends on both local and large-scale processes. To understand how to improve the limitations indicated in model variations at specific streamgauges, additional information on a larger spatial scale is fundamental. For an initial comparison of coupled model gridded runoff, reconstituted runoff that accounts for diversions and ignores reservoir operations would be the simplest approach to developing diagnostic contours of runoff. This approach would enable a more qualitative comparison of the spatial variability of actual and model runoff and would enable the researcher to look more clearly at the various parts of the water budget. Distribution functions could be developed to obtain a better space-time resolution of the water budget components. The emphasis would be on the distribution, not necessarily the actual numbers. If reservoir storage effects are significant, they should be taken into account in developing the reconstituted flows.

- The grid-mapping approach of river discharge was recently reviewed by Arnell (1995). Five methods are considered. These methods and other appropriate approaches need to be evaluated in relation to related activities of agencies in the Mississippi River basin. The Global Runoff Data Centre (GRDC) is coordinating the data for a German-funded project, "Transformation of measured flow data to grid points" as a contribution to World Climate Programme (WCP)-Water Project B.3. The pilot area under study covers the basins of the Rhine, Weser, Elbe, Oder, and Weichsel Rivers within Germany, Czechoslovakia, and Poland. The results of this project and further work with European data by the UK Institute of Hydrology will assist in planning the best approach for the Mississippi River basin.

- Development of algorithms to estimate the uncertainty in gridded runoff fields as a function of drainage network configuration, streamgauge location, and space-time scale for cases with minimal water management effects.

- Development of improved methods for better estimating gridded runoff by evaluating the relative contributions of space-time aggregation, channel network and gauge configuration, and water management effects on the error in gridded runoff fields.

The above activities will be supported by the following specific activities and outputs in 1998-2000.

- Extend the available historical data base for unregulated basins at the SSA and ISA scales (10 to 1000 $km^2$) in the LSA-SW (Arkansas-Red River basin) by updating from 1988 the active streamflow stations on the Wallis-Lettenmaier-Wood CD-ROM and the USGS HCDN CD-ROM. Include additional from the archival record that have shorter periods of records than those on the existing data sets, e.g., by adding two additional categories of unregulated stations which have 10 and 20 years of data. The purpose would be to develop and demonstrate regionalization methods for the estimation of hydrologic model parameters. In addition to allowing the estimation of the land-surface model parameters these data are needed for the development of runoff routing parameters and gridding runoff. This work to quality control and fill in missing data is being undertaken by the University of Washington. Extension to the LSA-NC could be included as part of the NWS WARFS initiative and the work within the NWS/NESDIS Core Project to develop the required historical data bases.

- Develop naturalized streamflow records at key locations in the LSA-SW up to the current time to enable the validation of the atmospheric model predictions. Key locations would include the Red River at Shreveport and the Arkansas River at Little Rock, being the largest basins which can be feasibly considered. This will require agency interaction, particularly with the COE, and the updating of calculated flows by the COE, or the acquisition of the reservoir storage algorithms and the algorithms used in the reservoir operating rules.

- Test a method for estimating gridded runoff data for the LSA-SW to enable the direct validation of atmospheric model runoff predictions. This activity will require research funds and may be supported by the NCGIA, working in conjunction with the USGS and the UK TIGER project supporting GCIP.

As an alternative to naturalized flows, compute the regulated runoff from atmospheric models by using runoff routing and reservoir storage models. The model feasibility has already been demonstrated. Model parameters from the NWS ABRFC are already available, together with their conversion to the application of gridded or distributed models as part of the NWS/NESDIS core Project and the macro-scale model parameters developed over the Arkansas-Red River basin by the University of Washington, the models and parameters will be available in 1996.

### 6.5.3 Surface and Ground Water Measurements

The primary observations of hydrological variables are from *in situ* networks and consist of stream gauges, measuring wells, measurements of water storage in large reservoirs, soil moisture, evaporation and estimates of snow cover. GCIP is treating soil moisture as a separate variable (see Section 6.2) and also estimates of snow cover. (see Section 6.1). There are few measurements of evaporation available. This leaves stream gauges, measuring wells and measurements of water storage which are needed to provide derived information for computing water budgets. In cooperation with many other Federal, state, and local agencies, the USGS collects water data at thousands of locations throughout the nation and prepares records of stream discharge (flow), and storage in reservoirs and lakes, ground-water levels, well and spring discharge and the quality of surface and ground water. The number of stations collecting such data was summarized in Table 1 of the GCIP Implementation Plan, Volume I (IGPO 1993), and is updated for each of the data sets compiled by GCIP.

Most of the gauged streams in the Mississippi River basin are affected by various water management activities such as upstream storage and diversion for human activities and irrigation. The USGS has a hydrological benchmark network of 58 stations virtually unaffected by human activity distributed across the United States (Lawrence 1987). Wallis et al. (1991) prepared a set of 1009 USGS streamflow stations for which long-term (1948-88) observations have been assembled into a consistent daily database and missing observations estimated using a simple "closest station" prorating rule. Estimated values for missing data, as well as suspicious observations, are flagged. The data are retrievable by station list, state, latitude-longitude range, and hydrologic unit code from a CD-ROM. This data set is being updated to include the years since 1988 with primary emphasis on those stations important to GCIP. Landwehr and Slack (1992) compiled measured streamflow data for 1659 stations with at least 20 years of complete records between 1874 and 1988.This data set is available by anonymous ftp at URL: ftp://ftprvares.er.usgs.gov/hcdn92. This data set is also available on CD-ROM and is being updated with post-1988 data. A streamflow data product similar to those described above will be produced for the GCIP EOP.

# 7. AREAL SUMMARY OF PLANNED ACTIVITIES

This section summarizes the activities in each of the LSAs as they relate to the GCIP Objectives and the significant characteristics of each LSA.

The LSA-SW has received high emphasis for the GCIP activities continued to receive a high emphasis through the end of Water Year (WY) 1997 as was shown in Figure 1-2. The LSA-NC (North Central) was added as a high emphasis area starting in the WY 1997 with the LSA-E (East) added in WY 1998, and the LSA-NW added in WY 1999. The CSA is scheduled to have major emphasis during the three Water Years covered by this Major Activities Plan.

## 7.1 LSA-SW

The geographical area of responsibility for the NOAA/NWS River Forecast Center in Tulsa, Oklahoma, is used to define the areas of the Arkansas-Red River basins for the LSA-SW. For atmospheric modeling and other applications, a more regular-shaped area is defined by the boundaries of 33 to 40N latitude and 91 to 107W longitude. This latitude-longitude bounded area, shown in Figure 7-1, is referred to as the LSA-SW.

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[LSASW]

**Figure 7-1** Latitude-longitude boundaries for LSA-SW encompassing the Arkansas-Red River basin.

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### 7.1.1 Significant Features in the LSA-SW

The large east-west gradients of climate variables, especially precipitation, coupled with the unusually diverse mix of atmospheric and surface hydrological data were the principal reasons for selecting the LSA-SW for the GCIP build-up period and the first two years of the EOP. In addition to the large east-west variation in climate, four other environmental features are significant:

- Large water vapor transfer by a low-level jet across the southern boundary.

- Significant warm-season convective contributions to precipitation.
- Large diurnal variability in summer for hydrological components such as water vapor transport and convective regimes.
- Significant seasonal storage of soil and vegetative moisture.

The meteorological and hydrological networks covering the Mississippi River basin are enhanced by new Weather Service Radar 88-Doppler (WSR-88D) radars, wind profilers, and automatic weather stations. Enhancements to these observing networks are also available in the form of mesoscale networks and the ARM Program at the southern Great Plains CART facility (see Figure 7-1).

Commonality of research interests between GCIP, ARM, and ISLSCP form the basis for unique observational and data analysis opportunities within the ARM/CART site. From the GCIP perspective, the ARM/CART site is large enough (almost $10^5$ $km^2$) and is well enough instrumented for approximate closure of the atmospheric energy and water budgets. The size of the ARM/CART area places it at the lower end of the LSA range. Therefore, some LSA studies can be done over the ARM/CART area as well as over the entire LSA-SW area.

Within the ARM/CART site, the opportunities to conduct ISA studies are numerous. At the ISA scale, precipitation and streamflow can be measured accurately and, although the areal average evapotranspiration cannot be measured, extensive *in situ* surface measurements related to evapotranspiration or soil moisture are being made as part of ARM, ISLSCP, the Oklahoma Mesonet, NOAA/NWS observations, and other programs such as CASES. The ARM/CART site also includes a range of climate, soils, and vegetation regimes and is therefore an attractive location for the development and validation of remote-sensing algorithms.

An example of an option for locating an SSA, where significant historical data are available, is the Agriculture Research Service (ARS) Little Washita/Chickasha experimental watershed. This watershed is on the southern boundary of the ARM/CART site (see Figure 7-1). It could be especially important in developing parameterizations of runoff, infiltration, percolation, and soil moisture.

### 7.1.2 LSA-SW Activities during WY'98-WY'00

Since 1993, GCIP has been working in cooperation with other projects and activities in the Arkansas-Red River basin to compile integrated data sets. These include the Department of Energy Atmospheric Radiation Measurement(ARM) program, the Department of Agriculture/Agriculture Research Service and the U.S. Geological Survey Mapping and Water Resources Divisions. GCIP has also supported enhancements to existing observation networks to obtain observations crucial for studying and modeling land surface processes and the coupling of these processes with the atmosphere. The support for soil moisture and soil temperature profile measurements in the Southern Great Plains ARM/CART site and the Little Washita Watershed is particularly noteworthy.

The full complement of observing systems needed for the Near-Surface Observation Dataset , described in Section 10 were operating by the end of March 1997. A second phase of data collection for this special data set began on 1 April 1997 and will continue for at least one full year. As in the first phase the data collection effort is concentrating on the ARM/CART site and the Little Washita Watershed.

The implementation strategy given in Volume II of the GCIP Implementation Plan (IGPO 1994a) envisioned that the LSA-SW activities will continue although at somewhat less intensity beyond 1997. This continuing effort will provide GCIP investigators with a 5-yr data set for the LSA-SW and with the same length data set for some of the ISAs and SSAs within the area. The five years of effort in the LSA-SW will also enable the GCIP investigators to benefit from this data rich subregion to the maximum extent possible during the EOP.

## 7.2 LSA-NC

The second year of the EOP in WY 1997 marked the start of focused studies within the Upper Mississippi River basin, identified as LSA-NC (see Figure 7-2). This LSA extends into southern Canada and provides an opportunity for cooperative efforts with the Canadian GEWEX Program. A regular-shaped area is defined by the boundaries of 37 to 50N and 85 to 99W longitude as shown in Figure 7-2.

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[LSANC]

**Figure 7-2** Latitude-longitude boundaries for LSA-NC encompassing the Upper Mississippi River basin.

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### 7.2.1 Characteristics of the LSA-NC

The features important to GCIP in this LSA include the following:

- Winter snow accumulation and spring snowmelt and their roles in the annual water budget.
- Large natural inertia in the water runoff system due to lakes.
- Minimal orographic effects for precipitation.

Cold-season hydrology involves consideration of the dormant state of vegetation, the nature of evaporation-sublimation loss, the effect of soil conditions (especially frozen soil) on runoff, infiltration, and most importantly, the snow cycle. A prerequisite for the improvement of the parameterization of snow hydrological processes is an improved database of relevant variables. A program for improved documentation of snow cover, water content, and albedo over the LSA-NC is exploiting all available information from *in situ*, aircraft, and satellite observations from the region. The SSAs established within the Upper Mississippi River basin for study are providing additional data on the vertical variation of snow thermal properties and on the hydrological and thermal conditions of the underlying soil layer that are relevant to the development of improved snow hydrology and soil moisture parameterizations. Several locations are suitable for SSA in the LSA-NC. The USGS operates an interdisciplinary research institute for hydrological research in the Shingobe River headwaters area of northern Minnesota. The USDA/ARS operates an experimental station in Morris, Minnesota and the University of Minnesota operates an experimental agriculture area near St. Paul, Minnesota. Other areas include the Illinois Climate Network operated by the Illinois State Water Survey.

### 7.2.2 LSA-NC Activities

The Major Activities Plan for 1996, 1997, and Outlook for 1998 for GCIP (IGPO 1995a) contained two appendices relevant to planning for research in the LSA-NC:

> Appendix J - Summary of Results from Workshop on Cold-Season/Region Hydrometeorology. A more complete summary report and proceedings for the Workshop held in May 1995 at Banff, Alberta, Canada is also available (IGPO 1995b).
>
> Appendix K - Summary of Results from LSA-NC Detailed Design Workshop

Following this Detailed Design Workshop in Minneapolis, MN in October 1995, the GCIP Project set up a LSA-NC Science/Implementation Taskgroup to take the results of these two workshops as initial input to recommend a specific set of research activities which will best utilize the existing infrastructure and other relevant research projects in the LSA-NC with due consideration of both the future GCIP plans for research in other LSAs in the Mississippi River basin .

These results were used by a LSA-NC Science/Implementation Taskgroup to develop recommendations for specific activities during WY'97. A second meeting of the Taskgroup in February 1997 reviewed the status of the earlier recommendations and recommended further actions during WY'98. The report of the LSA-NC Science/Implementation Taskgroup is given in Appendix D. The Data Collection and Management (DACOM) Committee has used this Taskgroup report as a basis for the Tactical Data Collection and Management Plan for the ESOP-98. A summary of data collection plans is given in Section 10.

## 7.3 LSA-E

Focused studies within the Ohio River basin, identified as LSA-E (see Figure 7-3) will be emphasized by GCIP starting in Wy- 98 as the third year of the EOP. This LSA extends eastward to encompass most of the Appalachian Mountains. A regular-shaped area is defined by the boundaries 33-43 N. latitude and 78 to 89 W. Longitude.

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[LSAE]

**Figure 7-3** Latitude-longitude boundaries for LSA-E encompassing the Ohio and Tennessee River basins.

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### 7.3.1 Characteristics of the LSA-E

The features important to GCIP in this LSA include the following:

- Topographic effects of the Appalachian Mountains
- Heaviest precipitation in the entire Mississippi River basin
- Winter-spring precipitation maximum
- Winter-spring floods
- Synoptic weather systems as major precipitation cause
- Some snowmelt effect
- Rivers in deep valleys (gulleys)
- Dominant contribution to Mississippi River runoff
- Few large natural reservoirs, but many manmade [e.g., Tennessee Valley Authority (TVA)]

The characteristics of the major river basins in the LSA-E are:

- Upper Ohio River provides semi-humid, Appalachian headwater signature in Mississippi River hydrograph

- Tennessee-Cumberland River provides semi-humid southeast tributary, representative of hydrology in this region. Hydrology is highly affected by TVA and the U.S. Army Corps of Engineers (USACE) reservoirs.

### 7.3.2 LSA-E Activities

In preparation for this new focus study region, NASA scientists at the Marshall Space Flight Center in Huntsville, Alabama worked with scientists from neighboring institutions to organize some GCIP-related activities in the Tennessee Valley region. Focus of the work is on establishing a SSA within the Tennessee Valley region and defining the important hydrometeorological, biophysical and landscape science issues that need to be addressed to support GCIP activities within this SSA. Foremost will be to expand cooperative relationships between institutions such as the Global Hydrology Climate Center (GHCC), the Tennessee Valley Authority (TVA) and the Oak Ridge National Laboratory (ORNL) to better draw upon the rich data and science expertise resources available within the Tennessee Valley region for conducting GCIP-related investigations within the LSA-E. One of the real advantages in working in the Tennessee Valley is the ability to explore the interrelationships of GCIP science issues with the applied interests of the TVA in reservoir operations, management, and electric power production.

A discussion paper was compiled by Dale Quattrochi as a precursor to the GCIP/LSA-E Detailed Design Workshop held in November 1996 at Huntsville, AL. The discussion paper presents both opportunities and challenges for conducting research to better understand how hydrologic, atmospheric, and hydrometeorological processes are manifested and operate in the eastern portion of the Mississippi River basin. A final version of this paper is available on the World Wide Web through the GCIP Home Page. The LSA-E region offers an opportunity to compare and contrast hydrologic processes operating within a temperate, humid climatic region, with the same processes operating in very different climatic environments in the LSA-SW, NC and NW. The comparative differences with the other three LSAs offers an opportunity to learn something about the atmospheric-hydrologic linkages within the GCIP region as well as to extend and validate the methods and models used in the LSA-SW and LSA-NC to the LSA-E. Moreover, the LSA-E provides a challenging environment to develop and test nested modeling approaches for addressing atmospheric, hydrologic, hydrometeorologic, and land surface scaling issues. The LSA-E region also offers the opportunity to address the human dimensions of climate change on hydrology within the Mississippi River basin, particularly those impacts associated with the operational or long-term management of water resources.

The workshop recommended a number of research activities that should be accomplished in the LSA-E as major contributors to the successful accomplishment of the GCIP Science Objectives. In particular, the hydrometeorological prediction and water resources management group recommended a set of experimental activities for both the Ohio and Tennessee River basins. A summary report of the LSA-E Detailed Design Workshop is given in Appendix C. This report forms the basis for the definition of specific implementation tasks to be carried out during Water Years 1998 and 1999.

## 7.4 LSA-NW

The LSA-NW encompassing the Missouri River basin is the fourth and last LSA for focused studies in the Mississippi River basin . This region was the last to receive the WSR-88D radar systems and also is the most data sparse region in the Mississippi River basin.

### 7.4.1 Significant Features in the LSA-NW

The general characteristics of this region, especially the northwestern portion, are, that it is snowmelt dominated and is mostly semi-arid. Some important characteristics are thin winter snowpacks and short vegetation amenable to aircraft and satellite remote sensing. Additional features important to GCIP in this LSA include the following:

- Large year to year variability in water cycle components.
- Significant regulation of streamflow through dams.
- Major terrain effect from Rocky Mountains.
- Relatively small normal runoff amounts.
- Snow measurement a significant problem.
- Snowmelt timing a problem in water budgets.
- Nebraska sandhill as unique hydrology problem.

A regular shaped area is defined by the boundaries of 39 to 51 N latitude and 90 to 114 W longitude as shown in Figure 7-4.

The LSA-NW offers an excellent test of the transferability of developed models and retrieval algorithms from the other three LSAs. The transferability of results is a very significant issue in determining the success of GCIP results with respect to worldwide applications and to climate modeling on a global scale.

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[LSANW]

**Figure 7-4** Latitude-longitude boundaries for LSA-NW encompassing the Missouri River basin.

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### 7.4.2 LSA-NW Activities for WY'99

An early start on planning and proposing GCIP relevant studies in the Upper Missouri River basin is being made by a group led by the South Dakota School of Mines and Technology. This group is proposing a plan for a collaborative pilot research project to integrate scientific resources in the Upper Missouri River basin to address questions of fundamental importance related to orographic effects on precipitation, especially in the cold seasons; coupled modeling to include "deep" groundwater in subsurface aquifiers; and the effects of spatial and temporal variability on the ISA scale on atmospheric water budgets in complex terrain. An IOP to acquire intensive observations of atmospheric components of the water budget is planned for the spring of 1998; accompanying surface and subsurface data will be provided by the ongoing Black Hills Hydrology Study directed by the USGS Water Resources Division. Significant episodes from the IOP will then be simulated using a high-resolution mesoscale coupled model developed by scientists at the South Dakota School of Mines from existing mesoscale atmospheric , surface and subsurface models. A detailed design workshop to plan activities for the LSA-NW EOP is planned for the fall of 1998.

## 7.5 CSA Activities for 1998 to 2000

The implementation of GCIP research is focusing initially on sub-basins of the Mississippi River basin leading to an integrated continental-scale capability by the end of the five year enhanced observing period in the year 2000.

The CSA data requirements in the early years of the EOP are primarily for the application of energy and water budget studies with a secondary application of model evaluation for the regional model output. The specific CSA activities during 1998 and 1999 will depend upon the support for regional activities in the LSA-E and the LSA-NW during these years. Some early plans are being formulated for a Mississippi River Basin Experiment (MIRBEX) starting as early as 1999. These plans will be further developed after the LSA-E and LSA-NW research support issues are better defined.

# 8. COLLABORATIVE RESEARCH ACTIVITIES

GCIP has evolved from its beginning as largely an international project to a largely national project with participation from many different agencies in the USA. This evolution has fostered the development of cooperative and collaborative activities in many different areas.

## 8.1 Collaboration with Other GEWEX Projects

The GCIP applied research project has connectivity to GEWEX as a whole and to its components through a commonality of scientific objectives. For example the Project for the Intercomparison of Land-Surface Parameterizartion Schemes (PILPS) is partially supported by the NOAA/OGP GCIP Program. The mesoscale convective cloud modeling tasks are coordinated with the theoretical and observational tasks of the GEWEX Cloud Systems Study, and surface flux studies and modeling of the atmospheric planetary boundary-layer research will be carried out in close collaboration with ISLSCP.

During 1995, GCIP and other similar continental-scale projects were combined under a Hydrometeorology Panel within GEWEX. The principal research task for this panel is to assist GEWEX in demonstrating skill in predicting changes in water resources and soil moisture on time scales up to seasonal and annual as an integral part of the climate system. GCIP will benefit from this coordination of continental-scale experiments. The results of the Canadian Mackenzie GEWEX Study (MAGS) will contribute to an improved understanding of cold-region, high-latitude hydrological and meteorological processes, and the role they play in the global climate system. An essential goal of the GEWEX Asian Monsoon Experiment (GAME) is to understand the physical basis of the seasonal forecast of the Asian monsoon and to improve the modeling techniques related to predicting and assessing the regional hydrometeorological conditions under anthropogenic as well as natural climate changes. The key scientific issues in the Baltic Sea Experiment (BALTEX) relate to coupling between the atmosphere and hydrological processes over relatively complicated terrain, sea, and ice.

Adequate description of hydrologic processes is required in global models of the ocean-atmosphere-land system to improve the prediction of weather and climate at all time scales. Research is required to make best use of the data available from GCIP and other GEWEX large-scale observational programs to guide the formulation and validation of such hydrologic submodels. Improving the description of hydrologic processes in global models is a priority issue for GCIP which will be best addressed in collaboration with PILPS, ISLSCP, and the GEWEX Hydrometeorology Panel.

### 8.1.1 Research relating to the GEWEX Cloud Systems Study

The goal of the GEWEX Cloud Systems Study (GCSS) is to improve the parameterization of cloud systems in climate and NWP models. This objective will be achieved through a better quantitative knowledge of the physical processes involved in cloud systems as well as a quantification of their large-scale effects ( GCSS 1994). Key issues are described in Browning (1994). The investigation of continental cloud systems is part of the long-term objectives of the GCSS Working Group on Precipitating Convective Cloud Systems (Moncrieff et al. 1997).

One of the aims of GCIP is to improve the treatment of surface and hydrologic processes in NWP and climate models, but clouds have an important impact on these processes. GCSS involvement would contribute to the cloud component to GCIP, by way of cloud-resolving modeling and related activities. In turn, the GCIP data sets would be used to evaluate these models against observations.

#### Cloud Resolving Models

Cloud resolving models, identified by their ability to resolve cloud dynamics, are the approach of choice of the GCSS. These models derive from traditional nonhydrostatic cloud models but their scope is more ambitious. The effects of convection on the environment and the interaction among physical processes (boundary layer, surface layer, radiation, and microphysics) are the pacing issues, rather than individual processes per se. Since the time scales of some interactions (e.g., cloud--radiation) can be weeks, this is not only demanding on model design but also requires large computer resources.

When used to study precipitating convection (e.g. Grabowski et al. 1996a, b) or frontal cloud systems (Dudhia 1994) grid lengths of about 1km can be successfully employed to calculate bulk effects. Consequently, the domains of cloud resolving models span many NWP grid volumes. The time scales examined by 2D models is up to several weeks and these models are poised to address issues on intraseasonal time scales. An example is the effect of cloud-radiation interactions on the atmospheric and surface energy budgets (Wu et al. 1995b).

Cloud-resolving models also explicitly resolve convection-mean flow interactions that are impossible to accurately observe and since cloud-scale dynamics is explicitly simulated, one key uncertainty is minimized. Data sets from cloud resolving models can be used to evaluate single-column climate models - the testbeds for convective parameterization schemes. These data sets are also a key element in formulating new and more comprehensive approaches to parameterization.

Models need to be evaluated against atmospheric data sets. The GCIP region features several cloud system types, ranging from deep precipitating convection during the warm season, to frontal clouds dominated by ice processes in winter. GCIP will provide data sets for evaluating cloud resolving models, noting the relatively high density of routine observations over the U.S., not to say the special long-term observations available from the ARM/CART site.

Two different types of evaluation are required. First, an evaluation of the physical parameterizations used in cloud-resolving models (e.g., microphysics, turbulence, surface processes and radiation) is needed. However, this requires detailed cloud-scale observations, as well as intensive observation periods involving airborne platforms. Neither is available from GCIP.

Second, the effect of clouds on the environment directly relates to convective parameterizations in GCMs and is, in principle, an area to which GCIP can contribute. It is, however, far from a simple matter to utilize data collected during the GCIP Enhanced Seasonal Observing Periods (ESOPs) to evaluate the models.

A basic issue is: what is the minimum observational detail required to evaluate cloud resolving models? An ultimate answer will involve data assimilation in both regional and global models to "fill in" missing or data-void areas. However, present assimilation methods are neither a panacea nor even practicable on cloud resolving model grids. GCSS will therefore focus on basic problems such as the ensemble response of clouds (deep and shallow) to spatially-averaged, time-dependent forcing applied over scales comparable to or exceeding, climate model grid scales.

**Strategy**

The GCSS has a cloud-resolving model intercomparison component. Modeling workshops have been conducted by the Working Group on Boundary Layer Clouds. Non-precipitating stratocumulus clouds in idealized environments were examined using Large Eddy Simulation models (Moeng et al. 1995).

The GCSS Working Group on Precipitating Convective Cloud Systems has an ongoing model intercomparison based on convection over the tropical western Pacific. The data set used in the model evaluation is from the Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE). To identify scientific and numerical issues as well as to minimize the complications and difficulties of modeling precipitating cloud systems, prototype numerical experiments were conducted (e.g. Grabowski et al. 1996a). This working group intends to move on to continental cloud systems in due course. The GCIP ESOP in 1996, that focused on the GCIP Large Scale Area-South West (LSA-SW) during the warm season, is an opportunity to study organized precipitating systems. A prototype experiment relating to GCIP could start as soon as adequate resources are available and the ESOP data have been analyzed.

**GCSS/GCIP Projects**

The following are candidate projects. Additional projects may arise; for example, noting that the 1997 GCIP ESOP will concentrate on wintertime processes, a GCSS initiative on frontal clouds is a possibility (Ron Stewart, private communication).

**Project 1:** Investigate the coupling of surface and boundary layer processes with convection under the influence of evolving large-scale forcing.

Comprehensive modeling studies of convection over the tropical oceans have been performed. Grabowski et al. (1996a) and Xu and Randall (1996) demonstrated, in simulations of convection during the GARP Atlantic Tropical Experiment (GATE), that realistic life cycles and transports could be achieved using two-dimensional cloud resolving models. This has been extended to three dimensions by Grabowski et al. A 39-day simulation of TOGA COARE convection (Wu et al. 1996) is equally encouraging.

Since the convective life cycle over land is quite different from that over the ocean, 2D modeling should be undertaken over the GCIP region (e.g. a domain of ~900km in the horizontal by ~40km in the vertical) to examine the coupling of convection with the boundary layer and surface processes--- that is to add a precipitating cloud component to existing GCIP studies. A key issue will be the treatment in these coarse-grid models of the atmospheric boundary layer in convectively-disturbed conditions. This could involve two GCSS Working Groups (Boundary Layer and Precipitating Convective Cloud Systems). The precipitating convection study could progress to three-dimensional simulations (e.g. domain of ~400km in the horizontal by ~400km by ~40km in the vertical).

**Project 2:** Quantify uncertainties in NWP models associated with precipitating convective cloud systems.

An issue to be explored is the large-scale effect of organized cloud systems, which are ubiquitous over the U.S. Southern Great Plains. These systems are copious (but intermittent) producers of precipitation over a large-area because of their longevity and propagation. Consequently, they have a significant hydrologic impact; they affect the surface fluxes; and they are likely to be responsive to changes in the large-scale circulation (e.g., through the influence on convection of vertical shear which may change in response to variability, on various time scales, in the low-level nocturnal jet originating from the Gulf of Mexico).

These organized systems violate the scale-separation assumption underpinning present parameterization methods. Organized fluxes are not adequately treated in existing convective parameterization schemes. For example, it has been shown that large mesoscale systems in the tropical western Pacific cause uncertainties in a medium-range NWP model (Moncrieff and Klinker 1997), mainly because the part-resolution causes an over-prediction of the thermodynamic and momentum tendencies.

**Project 3**: Quantify the large-scale effects of organized convection

Cloud-resolving models have been successfully employed to determine the transport properties by organized convection in idealized tropical western Pacific environments (Wu and Moncrieff 1996). A modeling and analysis study over the continental U.S., recognizing the very different role of the boundary layer over continental land masses from over the ocean, would be a valuable addition to existing knowledge. Interactively-nested, three-dimensional models (e.g. Clark and Farley 1984), containing microphysical and surface flux parameterizations would be used to simulate organized convection over the GCIP/ARM domain.

The CSU Regional Area Modeling System (RAMS) is another interactively-nested model being used to devise parameterizations of mesoscale convective systems (MCSs). The mesoscale parameterization is tied to a version of the Arakawa-Schubert convective parameterization scheme which is modified to employ a prognostic closure. One of the two MCS case studies being used is from the central U.S. ( Alexander and Cotton 1995).

Moncrieff (1992) addressed the poorly-understood issue of convective momentum transport at a basic level by formulating a dynamical model of the mass and momentum fluxes, and also pointed the way to its parameterization in large-scale models. LeMone and Moncrieff (1994) evaluated the fluxes predicted from this model against observations. Liu and Moncrieff (1996) added the effects of shear and buoyancy to the archetypal model. As far as GCIP is concerned, a possible course of action is to evaluate how well these dynamical models represent the mass and momentum fluxes by squall line convection over the Southern Great Plains. This could be a stand-alone project but, preferably, should be conducted as part of the analysis of cloud-resolving model data sets.

### 8.1.2 ISLSCP/GCIP Surface Flux Measurements

The purpose of the ISLSCP initiative within GCIP is to provide data sets that can be used to complement the operational and other research data sets being collected in the Mississippi basin. Particularly needed are sensible and latent heat fluxes and related measurements. The basic science question that the ISLSCP initiative will address is: Can the application of more complete bio-physical models and the development and application of relevant remote sensing algorithms be used to improve the quality of the continental-scale description of surface and water exchanges?

The strategy of the ISLSCP initiative will be to use flux towers to study temporal variability of fluxes at a point over an extended period of time and to use aircraft measurements to study spatial variability near the flux towers for selected times representing different seasons. This strategy will support investigations of scaling properties of land surface models and processes and the development and testing of approaches to estimate effective parameters for large areas.

The GCIP science plan (WMO 1992) identified one particular field campaign that cut across several GCIP scientific objectives. The year long field effort (with embedded IOPs) would be used to validate the largescale application of surface-atmosphere flux calculation models forced by remote sensing data, standard meteorological observations, and analyses thereof. This project would provide the following missing components, which are directly relevant to the large-scale objectives of GCIP:

- Time-series fields of evaporation, with a spatial-resolution on the order of a few kilometers and temporal resolution of hours to days.
- Time-series fields of the surface radiation budget (same spatial-temporal resolution as above).
- Time-series fields of soil moisture, with a spatial resolution of a few kilometers and a temporal resolution of days to weeks.

The provision of these additional quantities would not only close the water and energy budget equations for the region but would also provide more detailed information on the spatial distributions of moisture and energy sinks and sources within the experimental area. Measurement and modeling techniques developed with ISLSCP over the last five years could be used to address these missing components.

NOAA has already started a contribution to this effort with a new flux tower operating since May, 1995 in the Little Washita area of Oklahoma. Also augmentation of a flux tower at Oak Ridge, Tennessee has occurred and a third flux tower was added in 1996 at Bondville, Illinois.

In keeping with the philosophy of an effective, directed but economic field effort the following measurements are proposed.

(*i)* Four to six flux towers should be located within the GCIP area. These will be sited on the basis of a land cover/climatological classification of the GCIP area, conducted well ahead of time, using AVHRR data among other sources. The flux towers should be located near the (monitoring) radiation rigs and should measure:

Latent heat flux
Sensible heat flux

Shear stress
Soil heat flux

These measurements should be made throughout one experiment year, preferably several years.

(*ii)* Airborne eddy correlation

Eddy correlation aircraft (preferably twin engine aircraft like the NCAR King Air or the NAS/NRC Twin Otter) will be used during a series of Intensive Field Campaigns (IFC); perhaps three or four IFC's each of 10-20 days during the experimental year.

The aircraft will be used to conduct the following tasks:

- Measurement of fluxes over 30x30 km areas of homogeneous surface conditions centered on the flux sites.
- Measurement of fluxes over long low-level transects across gradients of soil moisture/vegetation conditions; preferably between flux sites and in conjunction with Landsat/SPOT/AVHRR acquisitions.
- Measurement of divergence/gradient terms using 'box pattern' flight lines centered on the flux sites.

These airborne eddy correlation data will be used to validate the large-scale application of surface-atmosphere flux calculation models forced by remote sensing data and meteorological observations or analyses.

(*iii)* Airborne soil moisture measurements

Aircraft equipped with gamma-ray or microwave sensors should be used to make soil moisture transect measurements. In some cases, these should be validated by a compact ground measurement exercise.

The routinely-acquired satellite data and the combined surface observations/analysis fields of meteorological conditions will be used to drive regional scale models that will calculate continuous time-series fields of the following quantities:

<u>Radiation:</u>

Insolation, PAR
Absorbed insolation, Absorbed PAR, Albedo
Downward longwave
Emitted longwave
Net radiation

<u>Heat Fluxes:</u>

Latent heat flux (evapotranspiration)
Sensible heat flux
Ground heat flux

<u>Momentum:</u>

Shear stress (roughness length)

<u>Surface conditions:</u>

Soil moisture
Vegetation state (FPAR)

## 8.2 Collaboration with the Atmospheric Radiation Measurement Program

Since 1993, GCIP has been coordinating many of its data collection activities with the Atmospheric Radiation Measurement (ARM) to achieve synergistic benefits from the outstanding observation facilities established by ARM at the southern great plains Clouds and Radiation Testbed (CART) in Oklahoma and Kansas. In this regard, the soil water and temperature system (SWATS) is a joint venture between the GCIP and ARM. The GCIP has provided the SWATS and data loggers, and supported their installation. The ARM Program is supporting the operation of the system.

Given the fact that the ARM program is investigating radiative transfer processes in the atmosphere as its highest priority at a site within the GCIP study area, GCIP will continue to collaborate with ARM via the existing ARM/GCIP/ISLSCP working group. However, there is a need for GCIP to take a more active role in developing a new joint focus of interest between ARM and GCIP in the area of measuring and modeling the warm season convective production of clouds and precipitation. This is an emerging joint interest of high priority to both scientific programs that should be addressed as a collaborative initiative over the next few years.

## 8.3 Collaboration with NASA Initiatives in the Mississippi River Basin

Several aspects of the NASA program relate direct to priority science of GCIP. The field studies on soil moisture in the ARM/CART region in 1997 relate directly to some of the science discussed in Section 6, and active collaboration should be sought between GCIP coupled modeling scientists and NASA observational scientists to secure maximum scientific benefit from that study. Equally, NASA and NOAA share an interest in providing improved management of water resources in the GCIP LSA-E, most probably through the Tennessee Valley Authority. Both agencies also share an important common interest in documenting, understanding and, to the extent possible, predicting seasonal-to-interannual variability in the southwest monsoon season, and evaluating the consequences of that variability on the vulnerable human management systems in that region.

## 8.4 Collaboration with PACS and GOALS

Prediction of weather and climate is made with models which include description of the entire global domain and which, in consequence of technical constraints, necessarily operate with a level of spatial and temporal precision that is inconsistent with the hydrological interpretation of their predictions over continents. Increased specificity in space and time is possible using regional models which operate over a more limited continental domain. In order to allow hydrological interpretation of weather predictions at seasonal-to-interannual time scales, research is required to foster and demonstrate effective coupling between regional models of atmospheric and hydrologic systems on the one hand and global models of atmospheric and oceanic systems on the other.

GCIP is working with the Pan-American Climate Studies (PACS) portion of the GOALS Program to develop a plan for joint studies centered on the North American monsoon system. Such research will include interfacing regional coupled atmosphere-land system models with global coupled ocean-atmosphere models as an important scientific focus.

## 8.5 Collaboration with the US Weather Research Program

The US Weather Research Program (USWRP), which is jointly funded by NOAA and NSF, has as one of its major goals the development of techniques to improve quantitative precipitation forecasts over short time scales. As part of this process the USWRP has been holding small workshops on relevant issues including precipitation prediction. GCIP is exploring areas of common interest to the USWRP with a view to initiating some joint studies in precipitation estimation and prediction. The data collection for ESOP-95 was carried out as a joint undertaking with the USWRP WAVE project.

## 8.6 FAA Collaboration - The Water Vapor Sensing System (WVSS) for Commercial Aircraft

Water vapor is ubiquitous, energetically important and volatile, highly variable in space and time, and unfortunately, poorly measured by current methods. The water vapor information from the twice-per-day radiosonde sites will be marginal for the diagnostic budget studies to be performed for GCIP. Two major systems can be used during GCIP to augment these radiosondes. The first of these is to add ascent and descent profiles from commercial aircraft. The second approach is to make greater use of the water vapor channel information from geostationary satellites. Here, however, one needs to continuously calibrate the satellite information because of its vertical-error structure. The horizontal gradient structure in water vapor as seen by the satellite is quite good; however, the data from the commercial aircraft is needed to calibrate the satellite data and provide both the vertical consistency and the missing lower tropospheric water vapor information that the satellite cannot see.

The commercial aircraft high resolution sounding will provide winds, temperature, and water vapor (discussed below). Such profiles will aid the research goals stated in Section 5 concerning the ability to improve water balance calculations with soundings at a far greater frequency than twice per day. Such water vapor profiles will also contribute to the precipitation research discussed in Section 6.

The development of a water vapor sensing system (WVSS) for commercial air carriers was funded by the FAA under the Commercial Aviation Sensing Humidity (CASH) Program. NOAA's Office of Global Programs (GCIP) is now co-funding the procurement phase with the FAA (which is now called the WVSS program). A competitive contract was awarded to Lockheed Martin Corporation (LMC) in July 1995.

**1998 Activities**

Data from the first commercial aircraft with the WVSS was continuously available for the last four months of WY97. We are achieving an excellent dynamic range of mixing ratio information, the data comparison between ascent and descent from the same air terminal has been consistent, and comparisons against radiosondes (when possible) have been quite good with consistent vertical changes in degrees of wetness. All of our error quality control checks also appear to be working as we gave them to Allied Signal.

This first aircraft was a United Parcel Service (UPS) B-757. FAA certification for all B-757 was finally granted in August 1997. Installation for the next five WVSS units on UPS aircraft began in September 1997 and is expected to be completed in November 1997. The government exercised an option in the LMC contract for 60 additional units in September 1997.

A radiosonde intercomparison test of the six WVSS units and radiosondes launched at Louisville, KY (there is currently no radiosonde site at the UPS hub), will occur in November 1997. This is being co-funded by this project and the National Weather Service. The UPS labor strike, other FAA delays, and the reduced GCIP budget for this program have all contributed to a delay in the government's decision on the next 60 units. Subsequently, the production team for the WVSS must be reassembled and the delivery of the next 60 units can only begin in February 1998 and be completed by the end of fiscal year 1998. However, considerable work can be accomplished with the first six WVSS units (they provide 24 ascents and 24 descents per day) toward data evaluation and new 4DDA algorithms for water vapor information being combined with satellite data. By the end of the year the 66 WVSS units will be providing 264 new water vapor profiles each day, primarily over the GCIP region. The descent and en route data will also contribute to the satellite calibration and water vapor flux calculations.

Evaluation of the data will be performed by NOAA Forecast Systems Laboratory (FSL) for GCIP and the FAA. Quality-controlled data sets of wind, temperature, and water vapor from the commercial aircraft will be made available through the GCIP in situ data source module described in Section 9.

**1999 and 2000 Activities**

A second contract option for an additional 100 WVSS units will be made in FY98 as originally planned; however, due to GCIP budget decreases for this program, the full amount of money for this option is not available. The current price for this option is approximately $9K per unit and $6K for installation. The FAA has agreed to continue their share in FY99 and thus pay

back a lender of funds in FY98. If GCIP continues to fund this program at the current rate (including a similar FY99 commitment), then approximately 80 of the 100 units can be procured. This would provide the last two years of GCIP with water vapor information from 146 aircraft. Moreover, the WVSS can be continued into the future for a continued GCIP/PACS project as once the capital costs for the WVSS have been paid, the operational and maintenance cost are trivial.

## 8.7 Cooperative Atmospheric-Surface Exchange Study (CASES)

CASES is a facility of about 5000 $km^2$ to study mesoscale processes of and linkages among meteorology, hydrology, climate, ecology and chemistry, in the upper Walnut River watershed, north of Winfield, Kansas. This is located within the ARM/CART site. Boundary layer instrumentation, in conjunction with WSR-88D radars, stream gauges, soil moisture data, topographical and land use data, mesonet surface data, and coupled atmospheric-hydrologic models, will produce data sets useful to GCIP SSA and ISA studies when this facility is fully implemented.

CASES will provide seasonal and interannual information on precipitation, soil moisture, runoff, vegetation, evapotranspiration, and atmospheric thermodynamics, which will allow modelers to not only define the surface hydrology but approach closure on the hydrologic cycle between the atmosphere and the watershed as well. CASES will provide a comprehensive data set on a scale which will allow aggregate testing of model structure and model parameters derived from studies of the Little Washita watershed and the FIFE experiment.

Initial activities are ongoing to prepare a retrospective data set for the Walnut River basin. Further plans exist for implementing some of the sensor systems identified above, and these will be implemented as resources become available.

# 9. DATA COLLECTION AND MANAGEMENT

Accomplishment of the GCIP major science objectives involves the development of a comprehensive and accessible database for the Mississippi River basin. Volume I of the GCIP Implementation Plan (IGPO 1993) contains information that (1) identifies the sources of observations from existing and planned networks; (2) further enhances those networks where necessary; and (3) assists in developing data sets accumulated from existing observational systems and derived from operational model outputs, such as the NOAA/NCEP Eta regional mesoscale model. The strategic portion of the data management planning (IGPO 1994b) establishes the implementation strategies needed to achieve the data collection and management objective:

***** Provide access to comprehensive in-situ, remote sensing and model output data sets for use in GCIP research and as a benchmark for future studies.***

The GCIP Data Management and Service System (DMSS) is shown in Figure 9-1 as a user service configuration based on accessing the GCIP Home Page on the World Wide Web through the URL address:

http://www.ogp.noaa.gov/gcip/

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[user_services]

**Figure 9-1** GCIP DMSS user services configuration.

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The GCIP Data Management and Service System (DMSS) implementation strategy makes maximum use of existing data centers which are made an integral part of the GCIP-DMSS through four data source modules that specialize by data types (i.e., *in situ*, model output, satellite remote sensing, and GCIP special data). These four data source modules are connected to a GCIP central information source that provides "single-point access" to the GCIP-DMSS. The primary responsibilities for the data source modules along with their major functions and activities were described in Volume III of the GCIP Implementation Plan (IGPO 1994b).

## 9.1 Overall Objectives

The goal of the DMSS is to make GCIP data available to GCIP investigators and to the international scientific community interested in GCIP. The data services are provided through a system which will have multiyear data set information that will be of continuing research use after GCIP is completed. These two items led to the following overall objectives for the DMSS:

> (1) *During the course of GCIP, the GCIP data management system will compile information on the data that are collected in the data centers to produce special data sets for GCIP users and to provide a single-point access to service user requests for GCIP data.*
>
> *(2) At the completion of GCIP, the GCIP data management system will turn over the composite data set documentation (metadata) to a permanent archiving agency for continuing use in climate-related studies.*

The topic of GCIP data management is divided into strategic and tactical planning efforts. The strategic portion of the GCIP data management plan is covered in Volume III of the GCIP Implementation Plan (IGPO 1994b). A tactical data management plan is prepared for each definable data set produced by the DMSS.

## 9.2 Data Availability and Costs

The GCIP Science Plan (WMO 1992) recognized that the success of the Project depends on scientists and agency participants sharing their data with each other. The timely archival of data collected or processed by GCIP researchers, along with mechanisms to ensure open and minimal-cost distribution to all researchers, requires a clearly stated and implementable data policy. Such a GCIP data policy concerning access to GCIP data was given in the GCIP Science Plan (WMO 1992).

Data management will incur costs primarily for the collection of information on the data and the reproduction costs to compile data sets. The costs incurred for the initial compilation of information on the data will be borne by the Project. Costs for data sets that are compiled for general use by researchers involved in the Project will also be borne by the Project. Costs for data sets to individual specifications will, in general, be borne by the user making the request for the data. This topic is described further in Section 10 and was also described in Section 3 of Volume III of the GCIP Implementation Plan (IGPO 1994b).

## 9.3 System and Services Approach

To the extent possible GCIP relies upon existing or planned operational, or, at least, systematic observing programs operating over the Mississippi River basin, including space-based observations. The essential task is to assemble information about relevant data sets and implement a data management system to support the scientific program. The DMSS takes advantage of the ongoing data management activities of related projects and programs such as Atmospheric Radiation Measurement (ARM), Earth Observing System Data and Information System (EOSDIS), U.S. Weather Research Program (USWRP), and others. Data sets and data management infrastructure under development for these programs are being used by the DMSS to the fullest extent possible. Each of these programs has, or is developing, data management systems with GCIP-relevant data to access through the GCIP-DMSS.

## 9.4 DMSS Overall Design

The data management strategy of GCIP relies fundamentally on working with and through existing data centers. A variety of organizations, including the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) and the National Water Information System (NWIS), of the USGS already have extensive capabilities for processing, validating, storing, cataloging, retrieving, and disseminating environmental data.

The DMSS in use during the first two to three years of the EOP is labeled the Prototype system and will not contain all the features that are technically feasible. The DMSS will incorporate improvements and new developments as these become operational at the existing centers to evolve to an Advanced system. It is envisioned that once the system is more fully operational, users will be able to sign onto a central computer and examine the GCIP master catalog to determine the data set(s) that best meet their requirements. If they desire additional information on a selected data set, the access software will route them to the data source module for the particular data type for more specific information. They will then be able to examine detailed data guides or discuss their data needs with someone knowledgeable about the GCIP data sets who can assist them in searching and ordering the data from the correct existing data center. The users can, if desired, go directly from the master catalog to the existing data center to place an order for data.

To develop the distributed data management system envisioned for GCIP in the most cost effective manner the DMSS Data Source Modules will strive to make the best use of current and planned capabilities of each pertinent data center. The DACOM recognized that the specific data service policies and procedures can vary among the existing data centers and the Project will need to adapt its "GCIP specific" portion of the DMSS, shown in Figure 9-1, to these variations.

The principal GCIP data centers form the backbone of the data management system. A principal data center is responsible for a significant volume of data pertinent to GCIP and has the capability to provide on-line access to data catalogs, inventories, and ordering systems. The center's on-line access system will be connected to and accessible through an electronic link to the DMSS. Since a center's designation as a principal data center is dependent upon its technical capabilities, under GCIP some supplementary centers will be changed to principal centers as GCIP evolves during the EOP.

## 9.5 Near-Term Improvements

The flexibility of the DMSS configuration shown in Figure 9-1 makes it possible for each of the modules to evolve at different rates which can be closely related to the specific data centers connected to the module. A summary of the projected improvements by each of the modules is given in the following paragraphs:

**GCIP Central Information Source**

Responsible Agency: GCIP Project Office hosted by NOAA Office of Global Programs Silver Spring, MD

Contact: Adrienne Calhoun

The GCIP Central Information Source (GCIS) is responsible for a variety of major functions as listed in Section 5, Volume III of the GCIP Implementation Plan. The DACOM will be asked to review these functions and make recommendations on how they can best be implemented in light of the experience gained from using the World Wide Web as a communications media for information about GCIP data.

The World Wide Web enables the GCIS to make use of this medium for providing information about all the significant items in GCIP in addition to providing the central contact for information about the DMSS. The GCIP Project Office is compiling information about GCIP to provide through the GCIP Home Page.

The GCIS will provide a mechanism for feedback from the users and incorporate these suggestions in its attempts to make this new medium a useful tool for the GCIP users.

***In Situ* Data Source Module**

Responsible Agency: Joint Office for Science Support (JOSS) UCAR Boulder, CO

Contact: S. Williams

The In-situ Module is responsible for providing data management and information resources for surface, upper air, radar, and land surface characteristics data of interest to GCIP. The Module uses the UCAR/JOSS Data Management System (CODIAC) which has been the GCIP DMSS "on-line" demonstration" system. A number of activities are planned for the DMSS In-Situ Module during the next two years:

1) Continue in-situ data collection for the 5-year GCIP Enhanced Observing Period (EOP), scheduled which began in October 1995. Also select and publish appropriate subsets of EOP data using CD-ROM media.

2) Complete the in-situ data collection process for the 1997 Enhanced Seasonal Observing Period (ESOP-97), October 1996 through May 1997 in the Arkansas-Red River Basin. Also select and publish appropriate subsets of ESOP data using CD-ROM media.

3) Continue to provide and add preliminary GCIP "Quick Response" data sets (i.e. 2 month lag) to the GCIP Scientific Community via CODIAC. These data sets would be available for both the EOP as well as the Enhanced Annual and Seasonal Observing Periods.

4) Continue to provide GCIP Initial Data Sets (GIDS) to the GCIP Scientific Community via on-line access and CD-ROM media.

5) Continue development of World Wide Web (WWW) enhancements to the Module and data access links to CODIAC as well as coordination of such development with the other Modules.

6) Continue establishment of on-line data links to other in-situ GCIP primary data centers as well as improved links to other NCDC data sets (i.e. WSR-88D Level II radar data).

7) Set up and execute the in-situ data collection process for the ESOP-98, October 1997 through May 1998 in the LSA-NC. Also select and publish appropriate subsets of ESOP data using CD-ROM media.

8) Set out and execute the in-situ data collection for the Enhanced Annual Observing Period (EAOP-98), October 1997 through September 1998 in the LSA-E/ Also select and publish appropriate subsets of EAOP data using CD-ROM media.

**Model Output Data Source Module**

Scientific Data Services; NCAR; Boulder, CO

Contact: R. Jenne

The Model Output Data Source Module is responsible for providing data management and information resources for GCIP-relevant model output data and products. The Module uses the NCAR Scientific Data Services as the infrastructure and expertise for GCIP support.

During the next three years this Module will concentrate on establishing a data archive for the output from three different regional models:

Eta Model output from NOAA/NMC
RFE (now GEM) Model output from AES/CMC
MAPS Model output from NOAA/FSL

The data management plans for this large volume of model output are evolving as an ongoing effort to balance the investigator needs with the resources available as described in Section 2.4 and Appendix B.

**Satellite Remote Sensing**

Responsible Agency: Global Hydrology and Climate Center (DAAC); NASA/MSFC Huntsville, AL

Contact: A. Ritchie

The GCIP Satellite Remote Sensing Data Source Module is responsible for providing data management and information resources for GCIP-relevant satellite data and products. The satellite module participates in several coordinating functions within the GCIP project primarily through DACOM.

The WWW is the implementation choice of the DMSS and allows the satellite module to provide information and easily link to other existing information at the various data centers. The satellite module continues to compile information about the GCIP data requirements to coordinate readily available data sets as specified by the Principal Research Areas, the DACOM, and other GCIP-related inputs.

The evolution of the satellite home page begins with the initial prototype configuration. The prototype provided an overview, high-level data access to existing archives, CD-ROM information, and links with the other active modules. The prototype home page provides a mechanism to solicit inputs from the entire GCIP science community.

# 10. COMPILATION OF DATA SETS

The intent of GCIP researchers to rely as much as possible on existing data centers as the archive location of GCIP data means that data sets will be geographically distributed among these data centers. The GCIP-DMSS is compiling a centralized set of information on the data sets. In some cases, this set consists of a directory and inventory of the data set, and in other cases it consists of only directory information with the inventory information available from the data center where the data set is stored. A tactical data collection and management plan is prepared for each definable data set compiled by the Project. This plan is converted to a data summary report when the compiled data set is completed.

A number of GCIP initial data sets (GIDS) were prepared to provide the data services support during the build-up period before the Five-year Enhanced Observing Period (EOP). Preparation of the GIDS started in 1993, and the data sets were compiled for on-line access by GCIP investigators to the extent that is technically feasible. They were also published on a CD-ROM for wide distribution, especially to international persons interested in performing initial diagnostic, evaluation, and modeling studies on GCIP-related topics. A summary description of the four composite data sets which comprised the GIDS series is given in Appendix E.

The EOP started on 1 October 1995 and is continuing for five years. The start date of 1 October was in part chosen to correspond to the start of a "water year" as used by the Water Resources groups in organizations such as the U.S Geological Survey. The availability of water data including streamflow data from the USGS National Water Information System is based on the water year. Such data are normally available from this system about six to nine months after the end of the water year. The availability date of these data becomes a primary determining factor in the schedule for the completion of EOP data sets by the GCIP data management system. The data collected during each EOP year are being compiled into a number of standard and custom data sets.

## 10.1 Compiled Data Sets

The compiled data sets are any GCIP data compiled for a GCIP user or set of users in such a way as to facilitate ease of accessing and using the data. For purposes of organizing the data compilation activity, three different types of compiled data sets are recognized:

- Standard Data Sets
- Custom Data Sets
- As Requested Data Sets

A *standard data set* is one with specifications that are agreed to before the data collection period starts so that standing orders can be provided to the data centers. Agreement on the specifications will be reached at the project level and funded on a year-by-year basis.The primary purpose of the *standard data sets* is to give wide distribution to specific GCIP data to encourage analysis, research, and modeling studies. The current plans for compiling GCIP standard data sets are summarized in Figure 10-1. Further details about each of the standard data sets are given in the remainder of this section.

[datasets]

**Figure 10-1** Compiled and Planned Standard Data Sets for GCIP Research.

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A *custom data set* is one that is either distributed or compiled at a central location and made easily accessible for a group research effort. Applications of custom data sets include validation and/or comparison of algorithms, energy and water budget studies, and model evaluation studies. The primary purpose is to facilitate "group" research efforts. The group requesting the data set will agree to the specifications for the custom data sets. Requests will be submitted to the GCIP office for funding the preparation of the custom data set. Funds will be identified by the Project for each custom data set at the time the request is approved.

The primary purpose of the *as requested data set* is to enable any user to order a data set with individual specifications from any of the individual data sets listed in the GCIP master catalog or data set guides. The GCIP-DMSS will provide assistance to the user to compile information about data availability to facilitate ordering data sets to specification. Incremental costs for compiling and distributing an *as requested data set* will in most cases be borne by the user making the request.

## 10.2 Near Surface Observation Data Set

Since 1993, GCIP has been working in cooperation with other projects and activities in the Arkansas-Red River basin to compile datasets for GCIP research activities. These include the Atmospheric Radiation Measurement (ARM) program, the USDA/Agriculture Research Service in El Reno, OK and the Oklahoma Climate Survey. GCIP has also supported enhancements to existing observation networks to obtain observations crucial for studying and modeling land surface processes and the coupling of these processes with the atmosphere. The support for soil moisture and soil temperature profile measurements in the ARM/CART site and the Little Washita Watershed (shown in Figure 7-1) is particularly noteworthy.

The implementation of this enhanced observation capability has advanced to where it is now feasible to compile a special dataset for land surface and boundary layer studies and modeling. The GCIP/DACOM has compiled a set of data requirements that will be suitable for:

- Land surface process studies
- Validation and verification of land surface processing schemes
- Detailed validation and verification of model output from regional land-atmosphere coupled models.
- Derivation of surface energy and water budgets.

It was pointed out in Section 2.4 that one of the three objectives for model output is - to produce a quantitative assessment of the accuracy and reliability of the model assimilated and derived variables for applications to energy and water budgets. The successful achievement of this objective entails an extensive evaluation of both the model output and the derived variables. All of the evaluations require a lengthy series of observed data for those variables considered significant . As a start on this evaluation effort, GCIP is compiling a special data set of observations for as many of the variables as reasonably available.

### 10.2.1 Summary Description of a Near-Surface Observation Dataset

The vertical dimension will include from 3000 meters above the surface to two meters below the surface. The specific types of observations are listed in Table 10-1 which is divided into three parts:

1. Boundary Layer (Z < 3000 meters)
2. Surface Layer (0 < Z < 10 meters)
3. Subsurface Layer (-2 < Z < 0 meters)

| **Table 10-1: Near Surface Observation Types in each Layer** |
|---|
| **1. Boundary Layer Z < 3000 meters**<br><br>1.1 Temperature profiles<br>1.2 Water vapor profiles<br>1.3 Wind profiles<br>1.4 Clouds |
| |
| **2. Surface (0 < Z <10 meters)**<br><br>2.1 Temperature, Specific Humidity, Wind Component, and Surface Pressure<br>U & V component wind speed at 10 m<br>Temperature at 2 m<br>Specific humidity at 2 m<br>Surface pressure<br>2.2 Surface momentum flux<br>Surface U wind stress<br>Surface V wind stress<br>2.3 Surface sensible and latent heat fluxes<br>Surface latent heat flux<br>Surface sensible heat flux<br>Soil heat flux to Surface<br>2.4 Surface skin temperature<br>2.5 Precipitation (including snow)<br>2.6 Surface Radiation<br>Downward shortwave<br>Upward shortwave (albedo) |

| |
|---|
| Downward longwave<br>Upward longwave<br>Net radiation (measured)<br>Photosynthetically Active Radiation (PAR)<br>2.7 Surface and ground water<br>2.8 Vegetation type and characteristics<br>2.9 Site Description |
| **3. Sub-surface (-2 < Z < 0 meters)**<br><br>3.1 Soil moisture (profiles)<br>3.2 Soil temperature (profiles)<br>3.3 Soil physical and hydraulic properties<br>3.4 Wilting point<br>3.5 Rooting zone<br>3.6 Field capacity |

The land surface studies and models can use the data at point locations to force land surface models or can make use of the observations to complete an area analysis for different size areas within the ARM/CART site and the Little Washita Watershed. The difficulty in achieving a consensus on the techniques for an area analysis has necessitated a decision to compile data as close as possible to an observational measurement. This will enable an investigator to use whatever analysis techniques are deemed appropriate for their specific research.

#### 10.2.2 Data Collection Schedule for Near Surface Observation Data Set

In order to maximize the number of observed variables this special data set is focused on the region of the ARM/CART site and the Little Washita Watershed during the period April 1, 1996 through March 31, 1998. If data exchange issues can be resolved with the Oklahoma climate survey, the NESOB data sets will also include data from the Oklahoma Mesonet. Plans to continue compiling NESOB data sets beyond March 1998 are indicated in Figure 10-1.

## 10.3 Model Output During the EOP

The plans for model output data are remaining fairly constant during the five year EOP as indicated in Table 10-2. There are no plans to subset the model output data by geographical coverage. Emphasis is on the atmospheric regional model output as given in the top part of Table 10-2. The regional model output is divided into three types:

(1) One-dimensional vertical profile and surface time series at selected locations referred to as Model Location Time Series (MOLTS)

(2) Gridded two-dimensional fields, especially ground surface state fields, ground surface flux fields, top-of-the-atmosphere (TOA) flux fields, and atmospheric fields referred to as Model Output Reduced Data Sets (MORDS)

(3) Gridded three-dimensional atmospheric fields containing all of the atmospheric variables produced by the models.

Further details on the regional model output is given in Appendix B.

| **Table 10-2. Model Output Data for CSA During the EOP** | |
|---|---|
| **DATA DESCRIPTION** | **DATA AVAILABILITY** |

| MODEL DATA | | |
| --- | --- | --- |
| **Atmospheric Regional Models** | **Module** | **Center** |
| Eta Data Assimilation System (EDAS) (3-hrly) | X | |
| Eta Model Forecast (12-hrly) | X | |
| Eta Model Initialization Analysis GIF Imagery (daily; UTC) | | UCAR/JOSS |
| Eta Model Location Time Series (hrly) (MOLTS) | X | |
| Eta Model Reduced Data Set (3-hrly) (MORDS) | X | |
| Eta Fixed Fields (including land surface) | X | |
| RFE Model Analyses (8-hrly) (MORDS) | X | |
| RFE Model Forecasts (12-hrly) (MORDS) | X | |
| RFE 3-D Fields | | AES/CMC |
| RFE Model Location Time Series (hrly) | X | |
| RFE Fixed Fields (including land surface) | X | |
| MAPS Model Output 3-D Fields | | NOAA/FSL |
| MAPS Model Output (MOLTS & MORDS) | X | |
| **Atmospheric Global Models** | | |
| NMC Medium Range Forecasts (MRF) (12-hrly) | | NCAR/DSS |
| CMC Global Spectral Model (12-hrly) | | AES/CMC |
| ECMWF Medium Range WX Fost Model (Daily) | | ECMWF |
| NMC Climate Data Assimilation System (CDAS) (Daily) | | NCAR/DSS |
| **Hydrology Models** | | |
| RFC Hydrology Model Data (8-hrly) | TBD | TBD |
| **Derived Data Products** | | |
| National Precipitation Analysis (Daily) | X | NCAR/DSS |

## 10.4 Data Collection for ESOP-96

The ESOP-96 data can be divided into three major data categories: *In situ*, satellite, and model. The responsibility in data collection will fall under each module of the GCIP Data Management and Service System (DMSS) described in Section 9. Although most of the data sources are operational in nature, special arrangements were made to obtain these data in the highest resolution possible. Table 10-3 summarizes the individual datasets comprising the ESOP-96. In addition, an initial phase of compiling a near surface observational data set from the Little Washita Watershed and the ARM/CART site was completed for the period of April to September 1996 (see Section 10.2 for further details). The ESOP -96 Tactical Data Collection and Management Plan provides more details including a brief description of each dataset with information regarding data collection, processing, and final archival and information on dataset dissemination after the compilation is completed in December 1997. Information on the final ESOP-96 datasets will be provided in the ESOP-96 Tactical Data Collection and Management Report to be completed after the data compilation is complete.

**TABLE 10-3 Datasets comprising the ESOP-96**

***IN-SITU* DATA**

Surface Data
- Automated Surface Observing System (ASOS) Data
- FAA Automated Weather Observing System (AWOS) Data
- Surface Aviation Observations (SAO) Hourly Data
- SAO Special Observation Data
- High Plains Climate Network (HPCN) Data
- Oklahoma Mesonet Data
- USDA/Agricultural Research Service (ARS) Little Washita Watershed Micronet
- CoAgMet Hourly Data
- Missouri Commercial Agriculture Weather Station (CAWS) Network Data
- Missouri Department of Conservation Fire Weather Network Data
- NMSU Monitored Climate Station Network Data
- NOAA Profiler Network (NPN) Surface Observations
- DOE ARM/CART Surface Meteorological Data
- DOE ARM/CART Radiation Data
- DOE ARM/CART EBBR and ECOR Data
- DOE ARM/CART SWATS Data
- USDA/ARS Little Washita Soil Moisture Data
- USDA/NRCS Soil Moisture Data
- NOAA/GEWEX Long-term Flux Monitoring Site Data
- NWS Cooperative Observer Daily Observations
- NWS Cooperative Observer Precipitation Data
- ABRFC Precipitation Data
- US Army Corps of Engineer (USACE) Precipitation and Streamflow Data
- USGS Precipitation and Streamflow Data
- USGS Reservoir Data
- ESOP-96 Hourly Surface Composite
- ESOP-96 5-min Surface Composite
- ESOP-96 Hourly Precipitation Composite
- ESOP-96 15-min Precipitation Composite
- ESOP-96 Daily Precipitation Composite

Upper Air Data
- NWS Upper Air Rawinsonde Data (6-sec vertical levels)
- NWS Upper Air Rawinsonde Data (mandatory/significant levels)
- DOE/ARM CART Site Upper Air Data
- NOAA Profiler Network Data
- UW AERI Data

Radar Data
- WSR-88D Data
- WSR-88D NIDS Data
- WSI Reflectivity Composite Imagery
- ABRFC Stage III WSR-88D Data (including daily GIF imagery)
- NASA/MSFC National Reflectivity Composite

Land Characterization Data
- PSU 1-km Multi-Layer Soil Characteristics Dataset
- Little Washita River Basin Soils and Land Cover

**SATELLITE DATA**

GOES-8/9 Satellite Imagery (Infrared, Visible, and Water Vapor)
GOES-8/9 VAS Data/Derived Products
NOAA POES AVHRR Imagery
NOAA POES TOVS Data
DMSP SSM/I Data/Imagery
NOAA Weekly Northern Hemisphere Snow Cover Analysis
GOES/ASOS Cloud Observations
CLAVR Clouds
Satellite Radiation Datasets
EDC Bi-weekly Vegetation Index
CAGEX Products

**MODEL OUTPUT**

Atmospheric Model Output
- AES/CMC RFE Model Output
- NOAA/NCEP Eta Model Output
- NOAA/NCEP Eta Model 12 UTC Initial Analysis Daily GIFs
- NOAA/FSL MAPS Model Output
- MOLTS Output
- MOLTS Derived Sounding Output
- MORDS Output

Hydrologic Model Output
- ABRFC Hydrologic Model Output

## 10.5 EOP-2 Data Collection During WY 1997

The plans for data collection for the second year of the EOP took account of the following general requirements.

(i) The ESOP-97 was held for the period 1 October 1996 through 31 May 1997 in the geographical region identified as the LSA-NC for data to conduct focused studies on cold season/region hydrometeorology.

(ii) The CSA data requirements are continuing for energy and water budget studies with an increase in emphasis on model evaluation for the regional model output.

(iii) Annual data sets for the LSA-SW and LSA-NC are required for energy and water budgets over an annual cycle plus model evaluations of the regional model output.

**Data Collection for ESOP-97**

A summary listing of the data collection plans for ESOP-97 is given in Table 10-4.

The ESOP-97 Tactical Data Collection and Management Plan provides more details including a brief description of each dataset with information regarding data collection, processing, and final archival and information on dataset dissemination after the compilation is completed in June 1998.

**TABLE 10-4. Datasets comprising the ESOP-97**

***IN-SITU* DATA**

Surface Data

National

- Automated Surface Observing System (ASOS) Data
- Automated Weather Observing System (AWOS) Data
- Surface Airways Observations (SAO) Hourly Data
- SAO Special Observation Data
- NOAA Profiler Network (NPN) Surface Data
- Long-Term Ecological Research (LTER) Site Data
- Canadian Surface Observations
- NWS Cooperative Observer Daily Observations
- NWS Cooperative Observer Precipitation Data
- United States Army Corps of Engineer (USACE) Precipitation and Streamflow Data
- United States Geological Survey (USGS) Streamflow Data
- United States Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS) Soil Moisture Data
- USDA/NRCS Soil Moisture/Soil Temperature (SM/ST) Data
- USGS Reservoir Data
- SURFRAD Data

Regional

- High Plains Climate Network (HPCN) Data
- Deparment of Energy (DOE) ARM/CART Surface Meteorological Data
- Great Lakes Meteorological Data
- Management Systems Evaluation Areas (MSEA) Project Data
- North Central River Forecast Center (NCRFC) Precipitation Data
- NCRFC Winter Graphical Products and Data
- DOE ARM/CART Soil Water and Temperature System (SWATS) Data
- Wisconsin and Illinois Gravediggers Network Data
- DOE ARM/CART Radiation Data
- DOE ARM/CART Energy Balance Bowen Ratio (EBBR) and Eddy Correlation (ECOR) Data
- USGS/Scientific Assessment and Strategy Team (SAST) Data
- National Ice Center (NIC) Great Lakes Ice Data
- ESOP-97 Hourly Surface Composite
- ESOP-97 Hourly Precipitation Composite
- ESOP-97 Daily Precipitation Composite

Illinois

- Illinois Department of Transportation (DOT) Network Data
- Chicago Deicing Project Mesonet Data
- Illinois Climate Network (ICN)Data
- Cook County, Illinois Precipitation Network Data
- Imperial Valley Water Authority Precipitation Network Data
- Illinois State Water Survey (ISWS) Soil Moisture Data
- ISWS Wells Data

Indiana

- Indiana Department of Environmental Management (IDEM) Air Quality Network Data

Iowa

- Walnut Creek Watershed (Iowa) Meteorological Data
- Walnut Creek Watershed Precipitation Data
- Davenport Iowa ALERT Network Data
- Iowa State University (ISU) Soil Moisture Survey Data
- Walnut Creek Watershed Surface and Groundwater Data
- Walnut Creek Watershed Energy Balance and Evapotranspiration Monitoring Network Data

Kansas

- Overland Park Kansas ALERT Network Data

Michigan

- Michigan State University Automated Weather Station Network Data

Minnesota
- Minnesota Department of Natural Resources (DNR) Fire Weather Network Data
- Minnesota Road Research Project (Mn/ROAD) Data
- Minnesota Extension Climatology Network Data
- University of Minnesota (UM) Watershed Project Data
- Minnesota Pollution Control Agency (MPCA) Watershed Project Data
- UM Rosemount Experiment Station Data
- Other UM Experiment Station Data
- USGS Interdisciplinary Research Initiative (IRI) Site Data
- Minnesota Precipitation Network Data

Missouri
- Missouri Commercial Agriculture Weather Station (CAWS) Network Data
- Missouri Department of Conservation Fire Weather Network Data
- Missouri Air Pollution Control Program Network Meteorological Data

Nebraska
- Papio Basin ALERT Network Data

North Dakota
- Grand Forks Air Force Base Network Data
- North Dakota Atmospheric Resources Board Cooperative Rain Gage Network Data

Wisconsin
- University of Wisconsin (UW) Agricultural Weather Observation Network (AWON) Data
- Wisconsin Department of Transportation (DOT) Network Data
- Wisconsin DNR Fire Weather Network Data
- Wisconsin DNR Air Quality Network Data
- Wisconsin Tower Flux Measurement Data
- USDA/NRCS Wisconsin Dense Till (WDT) Data

Upper Air Data
- NWS Upper Air Rawinsonde Data (6-sec vertical levels)
- NWS Upper Air Rawinsonde Data (mandatory/significant levels)
- DOE ARM/CART Site Upper Air Data
- Canadian Upper Air Rawinsonde Data (10-sec vertical levels)
- Canadian Upper Air Rawinsonde Data (mandatory/significant levels)
- NOAA Profiler Network Data
- Boundary Layer Profiler Data

Radar Data
- WSR-88D Data
- WSR-88D NIDS Data
- WSI Reflectivity Composite Imagery
- NCRFC Stage III WSR-88D Data
- NASA/MSFC National Reflectivity Composite

Land Characterization Data
- PSU 1-km Multi-Layer Soil Characteristics Dataset
- Walnut Creek Watershed Soil Characterization Data

**SATELLITE DATA**

- GOES-8/9 Satellite Imagery and Derived Products
- NOAA POES AVHRR Imagery
- NOAA POES TOVS Data
- DMSP SSM/I Data/Imagery
- NOAA Weekly Northern Hemisphere Snow Cover Analysis
- GOES/ASOS Cloud Observations
- CLAVR Clouds
- Satellite Radiation Datasets

EDC Bi-weekly Vegetation Index
NOAA Airborne Gamma Snow Survey Data
NOAA/NOHRSC Satellite-Derived Snow Extent Data

**MODEL OUTPUT**

Atmospheric Model Output
- AES/CMC RFE Model Output
- NOAA/NCEP Eta Model Output
- NOAA/NCEP Eta Model 12 UTC Initial Analysis Daily GIFs
- NOAA/FSL MAPS Model Output
- MOLTS Output
- MOLTS Derived Sounding Output
- MORDS Output

Hydrologic Model Output
- NCRFC Hydrologic Model Output

## 10.6 EOP-3 Data Collection During WY 1998

The data collection plans during WY 1998 takes account of the following known requirements :

(i) The ESOP-98 is scheduled for the period 1 October 1997 through 31 May 1998 in the geographical region identified as the LSA-NC for data to continue focused studies on cold season/region hydrometeorology. The specific data requirements are expected to be very similar to those for ESOP-97 with some modifications based on items learned during the ESOP-97.

(ii) The CSA data requirements continue for energy and water budget studies with increasing emphasis on interseasonal and interannual variability. Coupled modeling validation and evaluation will begin for the CSA.

(iii) An annual data set for the LSA-NC and LSA-E is required for energy and water budgets over an annual cycle plus model evaluations of the regional model output.

(iv) Data collection requirements for the LSA-SW are projected to continue but the specific requirements are not yet defined.

The proposed data sets for the LSA-E are shown in Table 10-5 for in-situ data and Table 10-6 for satellite remote sensing data. The current plans for model output data for the LSA-E are the same as that given in Table 10-2 for the CSA.

**Table 10-5. Proposed In-Situ Data for LSA-E During WY 1998 and WY 1999.**

***IN-SITU* DATA**

Surface Data
- National
  - Automated Surface Observing System (ASOS) Data
  - Automated Weather Observing System (AWOS) Data
  - Surface Airways Observations (SAO) Hourly Data
  - SAO Special Observation Data
  - NOAA Profiler Network (NPN) Surface Data
  - Long-Term Ecological Research (LTER) Site Data
  - Canadian Surface Observations

NWS Cooperative Observer Daily Observations
NWS Cooperative Observer Precipitation Data
United States Army Corps of Engineer (USACE) Precipitation and Streamflow Data
United States Geological Survey (USGS) Streamflow Data
USDA/NRCS Soil Moisture/Soil Temperature (SM/ST) Data
USGS Reservoir Data
SURFRAD Data

Regional

Tennessee Valley Authority (TVA) Precipitation and Streamflow Data
TVA Nuclear Power Plant Meteorological Station Data
Regional Atmospheric Monitoring and Analytical Network (RAMAN) Data
USDA/Agricultural Research Service (ARS) Meteorological and Soils Data
Great Lakes Meteorological Data
NOAA River Forecast Center (RFC) Precipitation Data
RFC Graphical Products and Data
Wisconsin and Illinois Gravediggers Network Data
USGS/Scientific Assessment and Strategy Team (SAST) Data
National Ice Center (NIC) Great Lakes Ice Data
LSA-E Hourly Surface Composite
LSA-E Hourly Precipitation Composite
LSA-E Daily Precipitation Composite

Alabama

Alabama Weather Observing Network Data
Redstone Arsenal Mesonet Data

Georgia

Auburn University Mesonet Data
Georgia Automated Environmental Monitoring Network Data
Georgia Forestry Commission Automated Weather Station Network Data

Illinois

Illinois Department of Transportation (DOT) Network Data
Illinois Climate Network (ICN) Data
Cook County, Illinois Precipitation Network Data
Imperial Valley Water Authority Precipitation Network Data
Illinois State Water Survey (ISWS) Soil Moisture Data
ISWS Wells Data

Indiana

Indiana Department of Environmental Management (IDEM) Air Quality Network Data

Kentucky

Kentucky Division for Air Quality Meteorology and Air Quality Station Data
University of Kentucky Research Farm Meteorological Data

Michigan

Michigan State University Automated Weather Station Network Data

North Carolina

North Carolina State University Experiment Station Weather Network Data

Pennsylvania

Pennsylvania Department of Environmental Protection/Bureau of Air Quality Network Data

Tennessee

NOAA/GEWEX Long Term Flux Monitoring Site Data
Walker Branch Watershed Meteorological and Hydrological Data

Virginia

Virginia Department of Environmental Quality Air Monitoring Station Data

Wisconsin

University of Wisconsin (UW) Agricultural Weather Observation Network (AWON) Data
Wisconsin Department of Transportation (DOT) Network Data
Wisconsin DNR Fire Weather Network Data
Wisconsin DNR Air Quality Network Data
Wisconsin Tower Flux Measurement Data
USDA/NRCS Wisconsin Dense Till (WDT) Data

Other State Surface Meteorological and Hydrological Network Data
TBD following Data Survey

Upper Air Data
NWS Upper Air Rawinsonde Data (6-sec vertical levels)
NWS Upper Air Rawinsonde Data (mand/sig levels)
Canadian Upper Air Rawinsonde Data (10-sec vertical levels)
Canadian Upper Air Rawinsonde Data (mand/sig levels)
Redstone Arsenal Rawinsonde Data
NOAA Profiler Network (NPN) Data
Boundary Layer Profiler Data

Radar Data
WSR-88D Data
WSR-88D NIDS Data
WSI Reflectivity Composite Imagery
RFC Stage III WSR-88D Data
NASA/MSFC National Reflectivity Composite

Land Characterization Data
PSU 1-km Multi-Layer Soil Characteristics Dataset

**Table 10-6. Proposed Satellite Remote Sensing Data During WY 1998 and WY 1999 Applicable for the LSA-E**

| DATA DESCRIPTION | DATA AVAILABILITY | |
|---|---|---|
| | MODULE | DATA CENTER |
| Composite Daily Snow Depth Grid | | NCDC |
| Composite Daily Snow Cover (GOES, POES, DMSP) | X | NESDIS, NOHRSC |
| 3-Day Composite DMSP SSM/I Snow Cover | X | NOHRSC |
| Composite Weekly Snow Cover Extent | | NESDIS |
| Monthly DMSP SSM/I Snow Cover in Percent | X | NCDC |
| | | |
| Hourly GOES-8 1 km Visible (for LSA-E) | | UCAR OFPS |
| Daily POES AVHRR 1 km (Land Cover/Vegetation) | | NOHRSC, EDC |
| | | |
| Daily DMSP SSM/I Brightness Temperatures | X | MSFC DAAC |
| Daily DMSP SSM/T2 Radiances | X | MSFC DAAC |
| | | |

| | | |
|---|---|---|
| Daily DMSP OLS Visible Imagery | | NGDC |
| Daily DMSP OLS IR Imagery | | NGDC |
| | | |
| POES Radiation Budget Data (4-Day) | | NCDC |
| POES Radiation Budget Data (hourly) | | NCDC |
| ISCCP 30 km Cloud Data | | |
| | | |
| Composite Gridded Snow Water Equivalent* | X | NOHRSC |
| Composite Gridded Soil Moisture* | X | NOHRSC |
| | | |
| Landsat Thematic Mapper Imagery | | EDC |

*Data from aircraft, satellite and surface sources.

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## 10.7 EOP-4 Data Collection During WY 1999

The data collection plans for EOP-4 are expected to be very similiar to those for EOP-3 given in the previous section with the addition of LSA-NW.

A preliminary listing of data sets for the LSA-NW is shown in Table 10-7 for in-situ data . The current plans for satellite remote sensing data for the LSA-NW are similiar to those shown in Table 10-6 for the LSA-E. The current plans for model output data for the LSA-NW are the same as that given in Table 10-2 for the CSA.

| **TABLE 10-7 Preliminary In-Situ Data for LSA-NW During WY 1999 and 2000** |
|---|
| ***IN-SITU* DATA**<br><br>**Surface Data**<br><br>National<br>Automated Surface Observing System (ASOS)<br>Automated Weather Observing System (AWOS)<br>Surface Airways Observations (SAO) Hourly<br>SAO Special Observation<br>NOAA Profiler Network (NPN) Surface Sites<br>Fire Weather Network<br>Long-Term Ecological Research (LTER) Sites<br>Canadian Surface Observations<br>NWS Cooperative Observer Daily Observations<br>NWS Cooperative Observer Precipitation Observations<br>US Army Corps of Engineer (USACE) Precipitation and Streamflow Sites<br>USGS Streamflow Network<br>USDA/NRCS Soil Moisture/Soil Temperature (SM/ST) Network<br>USGS Reservoir Network<br>SURFRAD Network<br><br>Regional |

High Plains Climate Network
US Bureau of Reclamation AgriMet Network
DOE ARM/CART Surface Meteorological Network
Great Lakes Buoy, C-MAN, and Coast Guard Sites
NOAA River Forecast Center (RFC) Precipitation Sites
Management Systems Evaluation Areas (MSEA) Project
USGS/Scientific Assessment and Strategy Team (SAST)
Wisconsin and Illinois Gravediggers Network
USDA/NRCS SnoTel Network
DOE ARM/CART Soil Water and Temperature System Network
DOE ARM/CART Radiation Sites
DOE ARM/CART Energy Balance Bowen Ratio and Eddy Correlation Networks
Hourly Surface Composite
Hourly Precipitation Composite
Daily Precipitation Composite

<u>Colorado</u>

Colorado Agricultural Meteorological Network (CoAgMet)

<u>Illinois</u>

Illinois Department of Transportation Network
Illinois Climate Network
Cook County Precipitation Network
Imperial Valley Water Authority Precipitation Network
Illinois State Water Survey Soil Moisture Network
Illinois State Water Survey Wells Networks

<u>Iowa</u>

Walnut Creek Watershed Meteorological Sites
Walnut Creek Watershec Precipitation Sites
Davenport ALERT Network
Iowa State University Soil Moisture Survey
Walnut Creek Watershed Surface and Groundwater Sites
Walnut Creek Watershed Energy Balance and Evapotranspiration Network

<u>Kansas</u>

Overland Park ALERT Network

<u>Minnesota</u>

Minnesota Department of Natural Resources (DNR) Fire Weather Network
Minnesota Road Research Project (Mn/ROAD)
Minnesota Extension Climatology Network
University of Minnesota Watershed Project
Minnesota Pollution Control Agency (MPCA) Watershed Project
University of Minnesota Rosemount Experiment Station
Other University of Minnesota Experiment Stations
USGS Interdisciplinary Research Initiative (IRI) Site
Minnesota Precipitation Network

<u>Missouri</u>

Missouri Commercial Agriculture Weather Station Network
Missouri Department of Conservation Fire Weather Network
Missouri Air Pollution Control Program Network

<u>Nebraska</u>

Papio Basin ALERT Network

<u>North Dakota</u>

Grand Forks Air Force Base Network
North Dakota Atmospheric Resources Board Cooperative Rain Gage Network

u> Utah

Utah Mesonet

<u>Wisconsin</u>

University of Wisconsin Agricultural Weather Observation Network
Wisconsin Department of Transportation Network
Wisconsin Department of Natural Resources Fire Weather Network
Wisconsin Department of Natural Resources Air Quality Network
Wisconsin Tower Flux Measurement Site
USDA/NRCS Wisconsin Dense Till Network

Upper Air Data
- NWS Upper Air Rawinsonde Data (6-sec vertical levels)
- NWS Upper Air Rawinsonde Data (mandatory/significant levels)
- DOE ARM/CART Upper Air Sites
- Canadian Upper Air Rawinsonde Data (10-sec vertical levels)
- Canadian Upper Air Rawinsonde Data (mandatory/significant levels)
- NPN Data
- Boundary Layer Profiler Data

Radar data
- WSR-88D Data
- WSR-88D NIDS Data
- WSI Reflectivity Composite Imagery
- NOAA/RFC Stage III WSR-88D Data
- NASA/MSFC National Reflectivity Composite

Land Characterization Data
- PSU 1-km Multi-Layer Soil Characteristics Dataset

## 10.8 EOP-5 Data Collection During WY2000

The data collection plans for EOP-5 are expected to be very similiar to those for EOP-4 given in the previous section.

## 10.9 EOP Data Collection Plans for Continental Scale Areas (CSAs)

The list of data to be collected for the complete CSA during WY-99 and WY 2000 of the EOP are given in Table 10-8 for In-Situ data, and Table 10-9 for Satellite Remote Sensing data.

**Table 10-8. In-Situ Data Sets for CSA During the EOP**

| DATA TYPE | DATA AVAILABILITY | |
|---|---|---|
| **Surface** | **Module** | **Center** |
| EOP Hourly Surface Composite | X | JOSS |
| EOP Hourly Precipitation Composite | X | OFPS |
| EOP Daily Precipitation Composite | X | OFPS |
| 1-hr data from the ASOS Network (both comissioned and non-comissioned sites) | X | OFPS |
| 1-hr data from SAO Stations (NWS and FAA) | | NCDC |
| 1-hr data NOAA Wind Profiler Demonstration Network (WPDN) Stations | | NCDC |
| 1-hr data from the Oklahoma Mesonet Network | | OCS |

| | | |
|---|---|---|
| 1-hr data from the Illinois Climate Network (ICN) | | ICN |
| 1-hr data from the High Plains Climate Network (HPCN) | | HPCC |
| 1-hr data from the USDA SNOTEL Network | | USDA |
| 1-hr and daily precipitation data from the NWS Cooperative Observer Network | | NCDC |
| Daily data from the NWS Cooperative Observor Network | | NCDC |
| Daily streamflow data from the USGS and USACE Networks | | USGS |
| Daily stramflow and precipitation data from TVA | | TVA |
| 1-hr data from the USDA/Agricultural Research Service (ARS) | | OCS |
| 1-hr radiation data from the NOAA SURFRAD Network | | FSL |
| Available Soil Moisture data from USDA/SCS, USDA/ARS, DOE/ARM/CART, and ICN | X | OFPS |
| 1-hr surface observations from the DOE Southern Great Plains ARM/CART site | | DOE |
| **will be others from other LSAs to be determined** | | |
| **Upper Air** | | |
| 1-hr data from the NOAA Wind Profiler Demonstration Network (WPDN) | | NCDC |
| 12-hr high-resolution (6-sec vertical level) rawinsonde data from the NWS | | NCDC |
| 12-hr Eta Model MOLTS Soundings (state parameters only) | | NCAR |
| ACARS and CASH flight data from commercial aircraft | | FSL |
| **Radar** | | |
| 1-hr NIDS 2-km radar reflectivity composite | X | OFPS |
| 1-hr NASA/MSFC 8-km National precipitation composite (derived from reflectively) | | MSFC |
| 1-hr and daily WSR-88D Stage III product composite (all available RFC's) | X | OFPS |
| WSR-88D Site Level II Archive Data | | NCDC |

**Table 10-9. Satellite Remote Sensing Data for CSA during the EOP**

| DATA DESCRIPTION | DATA AVAILABILITY | |
|---|---|---|
| SATELLITE DATA | MODULE | CENTER |
| POES Radiation Budget Data (4/day) | | |
| - Outgoing longwave (AVHRR) | | NCDC |
| - Planetary albedo (AVHRR) | | NCDC |
| - Downward longwave (HIRS) | | NCDC |
| - Longwave cooling rate (HIRS) | | NCDC |

| | | |
|---|---|---|
| - Outgoing longwave (HIRS) | | NCDC |
| | | |
| GOES Radiation Budget Data (hrly) | | |
| - Outgoing longwave (Sounder) | | TBD |
| - Downward longwave (Sounder) | | TBD |
| - Longwave cooling rate (Sounder) | | TBD |
| - Insolation/PAR | | NCDC |
| - Clear sky surface temperature | | NCDC |
| | | |
| POES/AVHRR Vegetation Index (Weekly/Monthly) | | NCDC |
| DMSP/SSM/I Snowcover (Daily) | | NCHRSC |
| POES/CLAVR Clouds (2/day) | | NCDC |
| GOES/ASOS Clouds (hrly) | | NCDC |
| GOES Conus Sector Imagery (IR, VIS, WV) (hourly) | | UCAR/JOSS |
| Gridded Areal Snow Cover (Weekly) | | NCHRSC |
| Gridded Areal Snow Cover (Daily) | | TBD |
| Gridded Snow Water Equivalent (Weekly) | | NCHRSC |
| Gridded Snow Water Equivalent (Daily) | | TBD |

## 10.10 Retrospective Data Sets

**OBJECTIVE:** *Develop high-quality retrospective databases of surface observations, especially precipitation observations, surface meteorological observations, and streamflow for use in calibration of key surface parameters in atmospheric and hydrological models.*

Historical hydrometeorological data are needed to develop, validate, and estimate parameters in improved surface parameterizations for atmospheric models. The required period of hydrological data must include several extreme wet and extreme dry periods in which soil moisture levels reach maximum and minimum values. Usually this period ranges from 10 to 30 years, depending on the local climate and actual occurrence of events. At least 30 years is needed to put the EOP in a climatological context. Spatially, all available precipitation measurements are needed to obtain the best possible water budgets over areas of $10^3$ to $10^4$ $km^2$.

The data types required include precipitation, air temperature, streamflow, and meteorological observations to estimate water and energy fluxes between the surface and the atmosphere. The primary source of historical data is surface observations, but archived NWP model outputs and some historical satellite data may be required as well.

The preparation of historical data sets is directly linked to the development of the NOAA Hydrological Data System which was described in Appendix E of the GCIP Major Activities Plan for 1995, 1996 and Outlook for 1997 (IGPO 1994c).

For GCIP, long periods of retrospective, high-quality hydrometeorological data are critical because the statistical variability of extremes (that is, flood and drought) is essential in assessing the impact of climate variability on water resources. A portion of the total retrospective data needs is being compiled within the NWS/OH as part of the NOAA Core Project for GCIP. Retrospective data are a critical input to the NWP model upgrades. At present, models of surface hydrology must be calibrated using historical precipitation, evaporation, temperature, and other climatological data, together with streamflow data. Similar calibrations using 30 to 50 years of data are needed to run the models from which will be determined the key hydrological parameters of soil moisture capacity and runoff formulation required by the upgraded NWP models and required to global models.

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# APPENDIX A

## A POST-2000 IMPLEMENTATION STRATEGY FOR GCIP

The GEWEX Continental-scale International Project (GCIP) has made tremendous strides in several of its science objectives during the past five years while others, such as the water resources objective, have not yet started. It is clear that a more balanced effort is needed in the future if GCIP is to make progress toward its long-term goal of demonstrating skill in predicting changes in water resources on time scales up to seasonal, annual, and interannual as an integral part of the climate prediction system. GCIP also needs to develop its strategy for contributing to the overall program for the GEWEX Hydrometeorological Panel as well as contributing to the joint GCIP/PACS studies of the variability of warm season precipitation over North America.

### A.1 GCIP Implementation and Progress

After the GCIP Project was conceived in 1990; its Science Plan was published in 1992; and its implementation Plan was completed in 1994. With primary funding from the NOAA's Office of Global Programs, early research activities were undertaken in 1993 in analysis of observational and model output data and in model development. Results of this research were published in a special issue of the Journal of Geophysical Research of the American Geophysical Union in March 1996.

A major phase of GCIP is the five-year Enhanced Observing Period that started on 1 October 1995 and is scheduled to be completed on 30 september 2000. This initiative is providing a comprehensive observational database needed for GCIP research and as a benchmark for future studies. GCIP research involves a systematic multiscale approach to accommodate physical process studies, model development, data assimilation, diagnostics, and validation topics. These research activities occur in a phased timetable and emphasize a particular region of the Mississippi River Basin with special characteristics for a period of about two years (see Figure A-1). Initial research emphasis has been on warm season processes using data from the Arkansas-Red River Basin in the southwestern part of the Mississippi River Basin. Cold season processes using data from the Upper Mississippi River Basin are being added to the ongoing research activities. These research activities, although initiated in limited regions, are leading toward an integrated continental-scale capability. Contributions to GCIP by the NASA Mission to Planet Earth Program are augmenting the level of GCIP research activities. Further details are available on the GCIP Home Page at the URL address: http://www.ogp.noaa.gov/gcip/

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[LSAs]

**Figure A-1** The Mississippi River basin with boundaries defining the Large Scale Areas (LSAs) for GCIP Focused Studies (top). Temporal emphasis for each LSA from 1994 through 2000 (bottom).

A rewriting of the GCIP Objectives by the NAS/NRC Gewex Panel in 1996 contributed to more focus of the GCIP research activities and near-term plans (IGPO 1996a):

- Determine and explain the annual, interannual, and spatial variability of the water and energy cycles within the Mississippi River basin. "***Diagnostics***"
- Develop and evaluate coupled hydrologic-atmospheric models at resolutions appropriate to large-scale continental basins. "***Modeling***"
- Develop and evaluate atmospheric, land and coupled data assimilation schemes that incorporate both remote and in-situ observations. "***Data Assimilation***"
- Improve the utility of hydrologic predictions for water resources management up to seasonal and interannual time scales. "***Water Resources***"
- Provide access to comprehensive in-situ, remote sensing, and model output data for use in GCIP and other seasonal-to-interannual climate studies and as a benchmark for future hydrology and climate studies. "***Data Management***"

The GEWEX Hydrometeorology Panel (GHP) was formed in 1995 and is the principal group within GEWEX for considering scientific issues associated with water cycle processes involved in the coupling of the atmosphere and the land surface, including the distribution of water and potential impacts on water resources. The main task of the GHP is to improve the collective contribution of the GEWEX Continental Scale Experiments (CSEs) and ensuring their regional results contribute to improvements in global scale prediction models. The CSEs , in addition to GCIP, consist of the Baltic Sea Experiment (BALTEX), the GEWEX Asian Monsoon Experiment (GAME), the Large-scale Biosphere-Atmosphere experiment in Amazonia (LBA), and the Mackenzie River Basin GEWEX Study (MAGS). The premise of the GHP is that the prediction of regional precipitation and runoff anomalies over period of several months is a possibility with improved understanding of water cycle processes. In this regard, the GHP will work toward the following scientific milestones:

- By the year 2000 quantify evaporation, precipitation and other hydrological processes as required to improve prediction of regional precipitation over periods of one to several months.
- By the year 2005 predict changes in water resources and soil moisture on time scales of seasonal to annual as an element of the World Climate Research Program's goals for the climate system.

GCIP and the Pan American Climate Studies(PACS) projects recently developed a prospectus as an initial step toward an integrated study of warm season predictability of precipitation and temperature over North America. It is predicated on the hypothesis that there is a deterministic element in the year-to-year variability of summertime precipitation and temperature over North America. The GCIP/PACS studies will address three major objectives:

1. Describe, explain and model the North American summer climate regime and its associated hydrologic cycle in the context of the evolving land surface- atmosphere-ocean annual cycle.

2. Describe, explain and model North American warm season precipitation and temperature variability with emphasis on seasonal and interannual time scales.

3. Describe, explain and model the spatial variability of summertime precipitation over North America on mesoscale to continental scale.

The brief summary given above shows that the environment for GCIP research has changed significantly over the past five years since the GCIP Implementation Plan was written. Some changes were foreseen while others were not and the Preface to Volume I (IGPO 1993) states -- "These volumes of the implementation plan will evolve during the course of the project and each will be updated as required". It is apparent that updating should be done to accommodate the knowledge gained during the past five years. GCIP could benefit most from the updating of Volume II - RESEARCH- portion of the GCIP Implementation Plan. This proposal for a post-2000 implementation strategy is a first step in this process. It is also provides a framework for updating the GCIP Major Activities Plan for the period 1998, 1999 and Outlook for 2000.

## A.2 Phased Objectives

GCIP is completing the first two research phases since the Science Plan was published in 1992. The Buildup Period from 1992 to 1994, which was largely devoted to implementation planning and the compilation of several initial data sets also included some early research studies which culminated in 25 papers published in a special issue of the Journal of Geophysical Research in March 1996. The Data Management Objective was emphasized in this early stage because it was recognized in the GCIP Science Plan (WMO 1992) that the success of the science objectives were heavily dependent on the availability of suitable data sets for the GCIP investigators.

The beginning of the five-year EOP in 1995 also initiated a three-year phase concentrated on budget studies and some early experience with coupled mesoscale NWP models (IGPO 1995). The early years of the Enhanced Observing Period through 1997 are emphasizing the water budgets of the Mississippi River basin and diagnostic studies of regional model output with emphasis on the variables needed to compute water budgets.

The results of the research during the past five years,especially the successes with the mesoscale NWP models show that GCIP can now increase the time scale for predictions and should focus on developing an initial version of a coupled hydrologic/atmospheric climate model. Also, GCIP needs to increase the priority of its efforts in water resources applications to provide a contribution to the strategic objective for the GEWEX Hydrometeorology Panel.

A composite assessment of the priorities for each of the five GCIP objectives (listed in Section A.1) is shown in Table A-1. The ranking for the objectives during phases 0 and I are based on the actual efforts expended during these six years. The rankings for Phases II, III and IV indicate the relative priorities that GCIP needs to give to each of the objectives assuming that the GHP strategic objective for 2005 is also a primary objective for GCIP. This assumption was used to design the implementation strategy described in the remainder of this paper. Consideration was also given to the GCIP/PACS prospectus described earlier.

[datasets]

**Table A-1** GCIP Objectives Ranked in Project Phases.

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The period from 1998 through the year 2000, identified as phase III in Table A-1 will focus on process and budget studies, some initial coupled modeling experiments and studies of precipitation predictability during the warm season. This phase of GCIP research will be entitled the Process, Early Coupled Modeling and Predictability studies phase or **PRECOMP** . The overall objective for the PRECOMP Phase is--- ** By the end of the year 2000 demonstrate an initial version of a regional coupled hydrologic/atmospheric climate prediction model capable of carrying out prediction experiments up to annual time scales*.

The period after the year 2000 through the year 2003 will focus on the applications of regional coupled models in climate prediction. Emphasis will be on Embedded Regional Modeling and Seasonal Prediction Experiments and will be given the shortened name of the **ERMOSPE** phase. Successful completion of the overall objective for the PRECOMP phase will enable GCIP to begin to implement a more complete climate prediction system focusing on water resources during the period 2001 through 2003. The overall objective during the **ERMOSPE** Phase is proposed as --- ** By the end of the year 2003 demonstrate an initial climate prediction system capable of carrying out experiments to predict variabilities in water resources and soil moisture on time scales of seasonal to annual*.

The last phase will include the years 2004 and 2005 and will concentrate on the applications of climate predictions in water resources management. Emphasis during this phase will be on Seasonal to Annual Water Resources Prediction EXperiments and will be labeled the **SAWRPEX** phase . It is envisioned that GCIP along with the other four CSEs (BALTEX, GAME, LBA and MAGS) will all be focused on demonstrating a capability and successful achievement of the GHP strategic objective --- ** By the end of the year 2005 predict changes in water resources and soil moisture on time scales of seasonal to annual as an element of the World Climate Research Program's goals for the climate system*.

## A.3 Critical Activities in the PRECOMP Phase

An increasing emphasis is needed on regional climate modeling and predictability studies during the period 1998 through 2000 to provide the capability needed for the climate prediction experiments after the year 2000. Some of the critical activities during the PRECOMP Phase are summarized in terms of accomplishments needed to achieve the overall PRECOMP objective given in the previous section. A more specific description of the plans for all of the Principal Research Areas in GCIP is given in the GCIP Major Activities Plan for 1998, 1999 and Outlook for 2000.

### A.3.1 Coupled Modeling

The function of the coupled modeling is to foster research which creates, calibrates and applies coupled models of the atmospheric and hydrologic system, with priority on research to improve prediction of weather and climate at time scales from days to seasons. The research focus is on determining , understanding and modeling those processes which are demonstrably important in coupling atmospheric and hydrological systems, rather than those processes which are separately important within these two systems.

#### A.3.1.1 Coupled Climate Model Research

The research activities in coupled climate modeling will focus on predictability studies for precipitation during different seasons in the annual cycle. These will be concerned with :

- Seasonal predictability and sensitivity to hydrologic-atmospheric coupling processes.

- Relative importance of hydrologic-atmospheric coupling in summer and winter

- Exploratory seasonal-to-interannual predictions

The exploratory work on seasonal to annual predictions needs to be emphasized and carried through to the extent that regional climate predictions can be produced in an on-line operational mode as well as off-line hindcast experiments.

#### A.3.1.2 Macroscale Land Surface/Hydrology Models

The research activities relevant to land surface schemes within the GEWEX Program have literally exploded during the past five years. The ISLSCP Workshop held at Columbia, MD in 1992 created the impetus for these later activities within the GCIP, ISLSCP and PILPS components of GEWEX. The PILPS Project is focusing on evaluating and improving land surface schemes for climate and weather prediction models and the results from the early phases have been published (Henderson-Sellers et al. 1995). ISLSCP has published an Initiative I global data set for land-atmosphere models formatted on a one by one degree grid and covering a one-year period in 1987-88 (Sellers et al. 1996). Support is now being sought for an ISLSCP Initiative II data set covering the period 1986 to 1995. GCIP is supporting research on land/hydrology models as well as compiling data sets for experiments with such models (IGPO 1996). Research is also underway in several of the other CSEs and is expected to become a major emphasis area in the next several years within the GHP.

The results from the GCIP, ISLSCP and PILPS activities during the past five years have enhanced the understanding of the performance of land/hydrology models and just as critically have made significant progress toward compiling more complete datasets for initialization/boundary conditions, forcing and validation of land/hydrology models.

GCIP needs to focus its efforts in this area on evaluating, selecting and implementing a macroscale land/hydrology model as a critical element of its PRECOMP objective of demonstrating an initial version of a regional coupled hydrologic/atmospheric climate prediction model . In particular, this emphasis needs to be placed on the land surface and hydrology components of a climate model which is focused on providing predictions at the seasonal to interannual time scale.

### A.3.1.3 Regional Mesoscale Models

The implementation plan for GCIP(IGPO 1993) incorporated the operational numerical weather prediction models and associated 4DDA systems as fundamental systems for both the description and modeling of the energy and water cycles. GCIP is concentrating on three regional mesoscale models (IGPO 1995):

- Eta model operated by NOAA/NCEP
- MAPS model operated by NOAA/FSL
- RFE (now GEM)model; operated by AES/CMC

The regional mesoscale models are supporting GCIP research in the following manner:

- Provide model assimilated and forecast data products for GCIP diagnostic studies including energy and water budget studies.
- Test and validate components needed to develop a coupled hydrologic-atmospheric climate model.
- Demonstrate the validity and performance characteristics of a coupled hydrologic - atmospheric model during the assimilation and early prediction time periods as a precursor to developing and testing a coupled hydrologic-atmospheric climate model.

The progress over the past four years in the demonstrated success by these three regional modeling efforts, especially with the initial land-physics components implemented in each of the models are enabling GCIP to accelerate its efforts in developing and testing an initial version of a coupled hydrologic-atmospheric climate model. It is anticipated that the three functions listed above can be essentially completed by the end of the PRECOMP phase. The requirements for model assimilated and forecast data products after the year 2000 have not yet been determined.

### A.3.2 Water Resources

The overall objective in water resources is to improve the utility of hydrologic predictions for water resources management up to seasonal and interannual time scales. A recent coupled modeling workshop "... revealed a lack of understanding of how best to give seasonal-to-interannual predictions hydrological interpretation and a failure in communication between the atmospheric and hydrological communities on this issue." It was concluded that research is required to determine what type of hydrological prediction is possible from seasonal-to-interannual meteorological predictions and at what spatial and temporal scales hydrological interpretation can have worth while credibility and utility (IGPO 1996b).

The research activities in the PRECOMP phase will focus on the following:

- Evaluation of regional model short term predictions for utility as input to hydrological models.
- Sensitivity studies on accuracy and precision requirements for precipitation predictions as useful input to hydrological applications.
- Utility of probabilistic meteorological predictions to hydrological applications.

It is especially critical that GCIP develop a consensus among interested investigators on an action plan for water resources in time for inclusion in the GCIP Major Activities Plan for 1998, 1999 and Outlook for 2000.

### A.3.3 Data

A number of GCIP initial data sets (GIDS) were prepared to provide the data services support during the build-up period before the 5-year EOP. Preparation of the GIDS started in 1993, and the data sets were compiled for on-line access by GCIP investigators to the extent that is technically feasible. They were also packaged and distributed on CD-ROMs for wide distribution especially to international persons interested in performing initial diagnostic, evaluation and modeling studies on GCIP-related topics. The compiled and planned standard datasets for GCIP research are summarized in Figure A-2. Further details about each of these standard datasets are available (IGPO 1996a)

[datasets]

**Figure A-2** Compiled and Planned Standard Data Sets for GCIP Research.

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The major data collection and management activities during the PRECOMP phase are:

- Complete the Compilation and Distribution of GCIP Initial Data Sets

- Compile/Distribute LSA data sets with emphasis on Enhanced Seasonal Observing Periods.

- Compile 5-yr data set for LSA-SW

- Assure available data are archived for CSA data during first three years of the EOP (WY'96 - WY'98).

- Compile CSA data sets for last two years of Enhanced Observing Period (WY'99 and WY2000).

The current plans for data collection and management need to be reviewed and modified as needed in light of the developing plans for GCIP research after the year 2000.

## A.4. Strategy and Guidelines for ERMOSPE Phase

The coupled modeling and prediction experiments for seasonal to annual time scales envisioned for the ERMOSPE phase from 2001 through 2003 will entail closely coordinated efforts among the five GEWEX CSEs and also closely coordinated/joint experiments with CLIVAR/GOALS and particularly with the PACS project.

The specific nature of these activities will depend on results achieved during the PRECOMP phase particularly with reference to the question - To what extent is meteorological prediction at daily to seasonal time scales sensitive to hydrologic- atmospheric coupling processes? They will also depend on the early result for the GCIP/PACS hypothesis that -- there is a deterministic element in the year-to-year variability of summertime precipitation and temperature over North America.

The activities during the ERMOSPE phase are described in the following section in terms of the GCIP objectives as was done earlier for the PRECOMP phase.

### A.4.1 Coupled Hydrologic-Atmospheric Modeling

It is envisioned that the coupled modeling activities during the ERMOSPE phase will involve activities in the following areas:

- Seasonal to interannual predictability experiments as part of GCIP/PACS and GHP coordinated research using 25-year data set from 1976 to 2000.
- Experimental seasonal to interannual predictions as joint effort with NCEP and other prediction centers.
- Test and validate "next generation" components needed to improve performance of a coupled hydrologic-atmospheric climate model.
- Provide model assimilated and forecast products for GCIP diagnostic studies including energy and water cycles.

### A.4.1.1 General Approach for Climate Modeling and Prediction

The emphasis during the ERMOSPE phase will be on developing and carrying out regional modeling and prediction experiments with priority on the applications to water resources management. The costs for such experiments, especially for computer time and data sets needed, make it critical to lay out a GCIP strategy that is both affordable and provides sufficient opportunity for participation by interested investigators.

The implementation strategy will consist of a four-stage scenario for regional climate modeling and applications as summarized in Figure A-3:

> ***I. Land/Hydrology component only to consolidate the efforts in this research area through a GCIP - Modular Land/Hydrology Model Infrastructure (GCIP-MLH).***
>
> ***II. Hindcasts and simulations using a global reanalysis , such as the NCEP reanalysis to provide "perfect boundary conditions" for embedded/coupled regional climate models.***
>
> ***III. Seasonal to Annual Predictions, primarily through the operational facilities of NCEP.***
>
> ***IV. Applications of seasonal to annual hydrometeorological forecasts with emphasis on water resources management.***

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[datasets]

**Figure A-3** GCIP 4-Stage Scenario for Regional Climate Modeling and Applications.

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The general approach will consist of on-line realtime predictions and off-line non-real time hindcasts and simulations. The former will be carried out primarily through NCEP by making use of both the operational regional climate model output and the parallel (non-operational) regional climate model output.

The off-line non-realtime hindcasts and simulations will consist of the following activity areas:

- Climate prediction experiments to the extent that Agency support permits.
- Cooperative model transferability experiments with other Continental Scale Experiments (CSEs) through the GEWEX Hydrometeorology Panel.
- GCIP/PACS prediction experiments as mutually agreed by the two projects and supported by the Agency Programs.
- Case studies for model component development, test and evaluation.
- Research and sensitivity experiments using modular macroscale land surface/hydrology models infrastructure (GCIP-MLH ).

**A.4.1.2 Infrastructure Guidelines**

Figure A-4 provides a schematic of the infrastructure needed to support a regional NWP or Climate model. GCIP will make use of the following guidelines for infrastructure support during the ERMOSPE phase:

- On-line predictions:
  - GCIP Project will support the archiving of model output data as provided by NCEP for meeting research requirements to the extent that agency resources are provided for such purposes.
  - Principal Investigators are responsible for any reproduction charges by the archiving facility.
- Off-line hindcasts and simulations:
  - GCIP Project will make provisions for an agreed upon composite data set for input data and model monitoring and evaluation data.
  - GCIP Project will make provisions for an agreed upon set of global model reanalysis data to

conduct regional climate model simulations.
- Principal Investigators are responsible for all the other support requirements needed for their research.
- Principal Investigators will make model output data available to GCIP as mutually agreed by the PI and the Project.
- Modular macroscale land surface/hydrology model infrastructure support to be defined.

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[datasets]

**Figure A-4** Infrastructure for Regional Model (NWP or Climate).

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### A.4.1.3 Modular Land/Hydrology Model Infrastructure

A schematic depicting the role of land models coupled to atmospheric models is shown in Figure A-5 (Sellers et al. 1996). The current focus in GCIP is on the models used to calculate the exchanges of water and energy between the land surface and the atmosphere on different time scales from hours to seasons. These components represent unique portions of a completely coupled climate model which GCIP and the other CSEs in the Gewex Hydrometeorology Panel are being asked to contribute to the overall goal of the WCRP. The GCIP concentration in the Mississippi River basin, with its varied climatic regimes combined with a relatively data rich sets of observations and model assimilated data sets available provides an opportunity for GCIP to make a significant contribution to global climate modeling and prediction by developing the infrastructure needed to accelerate the research and development of a community land/hydrology model. The infrastructure needed for a potential GCIP - Modular Land/Hydrology Model Infrastructure is depicted schematically in Figure A-6. Setting up such an infrastructure in an appropriate institution will provide an opportunity for interested investigators from universities, national research laboratories and private research laboratories to readily contribute to such an accelerated research effort.

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[datasets]

**Figure A-5** Schematic for Land and Atmosphere Models.

[datasets]

**Figure A-6** Infrastructure for Potential GCIP-Modular Land/Hydrology Models (GCIP-MLH).

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The significant advantages for a GCIP- MLH will accrue for the activities outside the Mississippi River basin, especially in carrying out the GCIP role within the GEWEX Hydrometeorology Panel on transferability of results. In the context of GHP, transferability is defined as : "The demonstration that techniques (including models) developed in particular regions to account for critical water and energy cycles will adequately represent those of other regions without tuning when provided with appropriate initial conditions and background fields".

Setting up the infrastructure needs to consider this as a long-term effort that will extend beyond the life of the GCIP Project. The elements of Land Models shown in Figure A-5 (Carbon, Biogeochemistry and Terrestrial Ecology) are not yet quantified for inclusion in climate models in any meaningful way but are projected to be part of the next advances in coupled climate modeling.

**A.4.2 Water Resources**

Some initial indications point to the GCIP water resources activities such as the following:

- Evaluation of climate predictions for annual periods as input to annual operating plans for river basins and sub-basins.
- Simulation and evaluation of alternative river basin management scenarios emphasizing 25-year period from 1976 to 2000.
- Evaluation of ongoing experimental seasonal to interannual climate predictions for hydrological applications.

It is anticipated that the activities will become better defined for water resources by the end of 1997 .

**A.4.3 Data**

It is envisioned that a few seasonal to annual prediction experiments can be conducted with the operational centers such as NCEP. However, it is assumed that the bulk of the coupled modeling research and prediction experiments will necessarily make use of historical data sets. A preliminary assessment indicates that most of the data requirements can be met by using the 25-year period from 1976 to 2000. This makes use of the model reanalysis from the period when the global models were first implemented for operations by the NOAA/NMC through the buildup period for The Global Weather Experiment (1979) and will provide the optimum global data set for the ERMOSPE phase.

- Compile and archive the composite data set documentation for the five-year Enhanced Observing Period.
- Contribute to the compilation of 25-year data set for the period 1976 to 2000 for use by GCIP/PACS and GHP seasonal to interannual prediction studies.
- Contribute to compilation of custom data sets for diagnostic studies and coupled modeling experiments.
- Compile a custom data set to support the GCIP - Community Land/Hydrology modeling development, test and evaluation efforts.

## A.5 Preparations for SAWRPEX Phase

It is envisioned that GCIP will be ready to conduct Seasonal to Annual Water Resources Prediction Experiments (SAWRPEX) by the year 2003. Achieving such a capability will entail some complex preparatory research and analysis during the period 1998 to 2003.

It was recognized during the implementation planning for GCIP that the task of predicting the consequences of climatic variability and change on regional hydrological and water resources is a formidable one (IGPO 1994). At some point the capability developed by GCIP to model water and energy cycle variability needs to be integrated into models that gauge societal impacts from climate variability and change. This testing must demonstrate consistency in local and regional as well as continental skill.

Presently, the uncertainty associated with estimates of how managed and uncontrolled watersheds may respond to a variety of climatic scenarios is enormous. What is called for, and what GCIP has the opportunity to provide, is an evaluative framework composed of methods and procedures for translating the output of climate models to a form appropriate and meaningful for use in water management models. Thus, GCIP water resource research activities during the next five years needs be organized around two distinct focuses:

(1) Diagnostic evaluation of coupled atmospheric and hydrological model output as applied specifically in watershed and water management models. Associated with this is the development of methods for generating climatic data streams using climate model-simulated variations and changes in climate over the Continental United States and Mississippi River basin.

(2) Development and testing of water resources models and fully integrated data management systems designed to help water resource managers and water users improve the utilization of water and the management of water-related infrastructure in the Mississippi River basin.

### A.5.1 Diagnostic Evaluations for Water Resources

Although the body of information dealing with the hydrological and water resource effects of climate variability and change is growing rapidly (especially case studies of hydrological impacts), few water resource policy and management insights have been produced in these efforts. This lack of intuitive knowledge is due largely to the reality that the analyses are based on GCM outputs that simply do not provide the information required for management and policy activities. However, a concerted effort at understanding the principal strengths as well as weaknesses of the different types of climate models *vis-à-vis* water resources assessment has never been undertaken. Clearly, GCIP research presents a unique opportunity for identifying ways to make climate model output, especially at the mesoscale, more useful as input to water resources simulations and to water resources management decision-making.

Initial studies will focus on the larger space and longer time scales and then work down to greater spatial and temporal detail. Thus, the first activity will be to assess the performance of operational models over the entire Mississippi River basin domain at an annual time step. Subsequent efforts will move to the LSAs and then to the smaller study areas, and down to seasonal and then monthly time steps. Questions of importance to water resources assessment and management to be addressed in these evaluations include:

- Can the model reproduce the timing, amount, and regional distribution of snow across the Mississippi River basin?
- How well are snowmelt-generated spring flows simulated, and how variable is model skill in simulating runoff over monthly to annual time scales?
- Are there significant regional differences in model skill at simulating runoff and related variables across the Mississippi River basin?

### A.5.2 Transfer of Research Results to Water Resource Managers

Another important consideration of the water management element relates to the presence of an incongruity between the research and modeling outputs of the GCIP effort and the practical problems (e.g., organizational constraints and liabilities) faced by water resources managers. This is not to say that GCIP information is not of potential significant benefit, but, rather, to note that such information cannot be directly transformed or transferred into water management activities without a lengthy process of institutional validation and without reconstituting it into a complex series of models, engineering regulations, manuals, and conventional practices. Thus, while the water management community may immediately see the long-range value of GCIP scientific information and products, that value may not be readily translated into operational payoffs. As a result, the practical benefits of the GCIP effort should be viewed in a long-term context.

*To ensure that GCIP scientific research output is effectively evaluated and utilized in water management activities within the Mississippi River basin, a coordination function with the responsible regional and local water management organizations will be established and maintained.*

As part of this liaison activity several distinct actions are planned. First, an implementation plan will be developed for incorporating GCIP products into each management organization's procedures. Second, the GCIP Water Resources PRA, or some working group thereof, will undertake the coordination of ongoing agency activities that complement GCIP objectives. Many organizations will not be funded specifically to conduct GCIP activities, but they do conduct operations that support GCIP objectives. A mechanism for incorporating these related activities is essential to the success of the water resource assessment component of the overall project. Third, most water management agencies also conduct research on the design of hydrological models. It is appropriate, therefore, to ensure that these modeling efforts, as well as the testing of existing models using GCIP data, are incorporated into the overall hydrological modeling component of the Mississippi River basin project.

There is also a need to describe clearly what operational improvements water resources managers should anticipate in what timeframe. In this regard, it is instructive to consider the water management perspective. Although a wide range of water models is available, two generic types may be considered: hydrological process models and water management models. The former type is designed to understand how changes in precipitation, the land surface, and soils affect runoff (discharge) and recharge. The latter type, which includes such schemes as simulation and optimization, tends to utilize statistical series of precipitation and streamflow and focus on resolving issues such as how to design, control, and distribute the water supply.

In general, process models are not directly used in water management operations, although certain features are incorporated for special problems. Rather, a number of specialized models have been developed for application to different decision needs, such as operations, planning, and design. Some examples of these models, along with the time scale at which they operate, appear in Figure A-7.

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[LSAs]

**Figure A-7** Models for Different Decision Needs in Water Resources Management.

Shorter term needs (days to several months), focused on operations, are depicted on the left side of the vertical dashed line in Figure A-7. Longer term needs (several months to more than 100 yr), aimed at planning and design, appear to the right of this line. The types of models that support operational issues include those designed to assist in decisions related to flood warning and evacuation, reservoir operation, water supply allocation, navigation, and the development of reservoir operating rules. At the longer time scales, planning and design-oriented models address issues such as interannual storage, safe yield, supply reliability, hydropower, drought, design flood, probable maximum flood, structural integrity, dam safety, and project lifespan. GCIP needs to focus on the establishment of an infrastructure for the improved management of water resources in the Mississippi River basin, across the range of decision needs, by ensuring that the gains in understanding hydrological processes and modeling techniques are linked with the appropriate water management organizations.

# APPENDIX B

## REGIONAL MESOSCALE MODEL OUTPUT PRODUCTS

One of the principal functions of the regional mesoscale models, as was noted in Section 2, is to produce the model assimilated and forecast output products for GCIP research, especially for energy and water budget studies. The production of such data sets was an important part of the GCIP Implementation Plan (IGPO 1993). A major thrust area for the production of such data sets from three different regional models was initiated in 1995 with the following objectives:

(*i)* To produce model assimilated and forecast data products for GCIP investigators with an emphasis on those variables needed to produce energy and water budgets over a continental scale with detailed emphasis in 1997 on the LSA-SW and the LSA-NC and beginning the application of such detailed emphasis capability to the LSA-E during 1998, and to the LSA-NW during 1999.
(*ii)* To produce a quantitative assessment of the accuracy and reliability of the model assimilated and forecast data products for applications to energy and water budgets.
(*iii)* To conduct the research needed to improve the time and space distribution along with the accuracy and reliability of the model assimilated and forecast data products.

The activities relevant to the second and third objective above were described in Section 2. The details of the regional model output to satisfy the first objective above is given in the remainder of this Appendix.

### B.1 Regional Mesoscale Model Output

The list of model output fields needed by GCIP researchers was given in Table 3, Volume I of the *GCIP Implementation Plan* (IGPO 1993). From the beginning of GCIP, it has been the intent to acquire model output from several different models of varying resolution, physics and data assimilation systems. The large volume of data produced by the current generation of atmospheric models has forced a number of compromises in order to achieve a tractable data handling solution for model output data. The data volume is further enlarged by the GCIP need to enhance the traditional model output to include additional fields needed by researchers to perform meaningful studies of the water and energy cycles. The near-term GCIP needs for model output data will be met by concentrating on three regional mesoscale models:

- Eta model operated by NOAA/NCEP
- MAPS model operated by NOAA/FSL
- RFE (now GEM) model operated by AES/CMC

The model output is divided into three types:

(1) One-dimensional vertical profile and surface time series at selected locations referred to as Model Location Time Series (MOLTS)
(2) Gridded two-dimensional fields, especially ground surface state fields, ground surface flux fields, top-of-the-atmosphere (TOA) flux fields, and atmospheric fields referred to as Model Output Reduced Data Sets (MORDS)
(3) Gridded three-dimensional atmospheric fields containing all of the atmospheric variables produced by the models.

Each model output type is described in the following sections.

### B.2 Model Location Time Series

Results from the GCIP Integrated Systems Test (GIST) in 1994 and ESOP-95 demonstrated that the vertical and surface time series at selected points is a very useful type of output for a number of applications. Indeed, some energy and water budget computations are making use of this type of model output data. GCIP labels this type of model output as Model Location Time Series (MOLTS) which is produced as an enhanced output containing a complete set of the "surface" type of state and flux data needed by GCIP in addition to the basic atmospheric data which operational centers produce for normal monitoring use and other applications.

The output variables for the MOLTS are listed in Table B-1. The variables listed under 2) Surface Variables and 3) Atmospheric Variables are considered a"fundamental" list. The MOLTS list from a specific model may add other variables depending on choice of physics package or other non-GCIP user requirements. Some examples for the surface variables could include turbulent kinetic energy and other diabatic heating and moistening rates, such as those due to vertical and horizontal diffusion. Some examples of the non-profile variables could include canopy water content, boundary layer depth, convective storm stability indices, precipitation type (frozen?), etc.

An assessment of the MOLTS requirements for GCIP, MAGS and other investigators indicates that a maximum number of 300 locations will satisfy these requirements during the EOP. The specific number could be less than this maximum number depending on resources available to the data producers and the changes in requirements for GCIP during the Enhanced Seasonal Observing Periods and outside of these periods. GCIP will provide inputs to the requirements as part of its annual update of the GCIP Major Activities Plan. The distribution of 300 MOLTS locations is shown in Figure B-1.

| Table B-1 Output Variables for the Model Location Time Series (MOLTS) |
| --- |
| **1) Identifiers**<br><br>Location ID<br>Valid Date/Time<br>Forecast Length<br>Latitude<br>Longitude<br>Location Elevation (in model) |
| **2) Surface Variables**<br><br>Mean sea level pressure<br>Ground surface pressure<br>Total precipitation in past hour<br>Convective precipitation in past hour<br>U wind component at 10 m<br>V wind component at 10 m<br>2-meter specific humidity<br>2-meter temperature<br>Skin temperature<br>Soil temperature (all soil layers)<br>Soil moisture (all soil layers)<br>Latent heat flux (surface evaporation)<br>Sensible heat flux<br>Ground heat flux<br>Surface momentum flux<br>Snow phase-change heat flux<br>Snow depth (water equivalent)<br>Snow melt<br>Surface runoff<br>Sub-surface runoff |

Surface downward short-wave radiation flux
Surface upward short-wave radiation flux (gives albedo)
Surface downward longwave radiation flux
Surface upward longwave radiation flux
Top-of-atmosphere net longwave radiative flux
Top-of-atmosphere net shortwave radiative flux
Top-of-atmosphere pressure for above fluxes

**3) Atmospheric variables at each model vertical level**

pressure
geopotential height
temperature
specific humidity
U wind component
V wind component
Omega (vertical motion -- Dp/Dt)
convective precipitation latent heating rate
stable precipitation latent heating rate
shortwave radiation latent heating rate
longwave radiation latent heating rate
cloud water and/or cloud fraction

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[LSAs]

**Figure B-1** Geographical Distribution of 300 MOLTS Locations.

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## B.3 Model Output Reduced Data Set

An analysis of the different GCIP requirements for the gridded two- and three-dimensional fields indicates that most of the requirements can be met by a selected set of two-dimensional gridded fields. [NOTE: Some of the requirements for three-dimensional fields can be met with the MOLTS , e.g. by placing the locations around the boundaries of a river basin to do budget studies.] Some of the other 3-D field requirements can be met by a vertical integration through the atmosphere, e.g. vertically integrated atmospheric moisture divergence needed to calculated water budgets. GCIP will make use of this concentration of requirements to further the tractability of the model output data handling problem. A Model Output Reduced Data Set (MORDS) will continue to be produced as two-dimensional fields with the expectation that the MORDS can meet most of the GCIP requirements at a significantly reduced data volume over that needed to provide the information as three-dimensional fields. GCIP is proposing a total of 60 output variables for MORDS separated into the following four components:

A. Near-surface fields which will include all the sub-surface and surface land characteristics and hydrology variables plus the surface meteorological variables including wind components at 10 meters.

B. Lowest-level atmospheric fields which includes the lowest model level and the mean value in a 30 hpa layer above the surface.

C. Upper atmosphere fields at a few standard levels plus the tropopause height and the top-of-atmosphere radiation as a time average.

D. Metadata fixed fields as one-time companion file to the MORDS.

The specific model output variables in each of the four components are listed in Table B-2.

Output from the regional mesoscale models on the AWIPS 212 Lambert Conformal Map base at a 40 km resolution constitutes about 30 Kilobytes per field for each output step. The 55 fields from the list of variables shown in Table B-2 will produce about 1.5 Mb for a single forecast or analysis valid time. The MORDS output of analysis, assimilation, and forecast fields for both 0000 UT and 1200 UT cycles comes to a daily total of about 40 Mb per day from each of the regional mesoscale models or about 1.2 Gb per month. This is significantly less than the data volume generated from each of the regional models output in three-dimensional fields.

## B.4 Gridded Three-Dimensional Fields

The descriptions given in Section B.2 on MOLTS and Section B.3 on MORDS are aimed primarily at reducing the need to handle the full three-dimensional output fields from each of the regional models. This should make the model output more readily accessible for the GCIP investigators. It is also, in part, needed due to the limitations in the data handling capacity for the full model output by the Model Output Data Source Module in the GCIP Data Management and Service System. These limitations mean it will be possible to collect the three-dimensional fields at this location for the Eta model only. GCIP encourages the producers of the three-dimensional fields for the other two regional models to store them locally to the extent possible.

The description given above on how GCIP plans to meet the model output data requirements within the data handling limitations experienced is applicable for the near-term requirements. It is expected that these requirements will evolve as the land physics packages of these models demonstrate their utility. GCIP will reevaluate this area on an annual basis as part of preparing updates to the GCIP Major Activities Plan.

**Table B-2 Output Variables for the Model Output Reduced Data Set**

**A. Near-Surface Fields**

1 - Mean sea level pressure
2 - Surface pressure at 2 meters
3 - Temperature at 2 meters
4 - Specific humidity at 2 meters
5 - U component wind speed at 10 meters
6 - V component wind speed at 10 meters
7 - Surface latent heat flux (time avg)
8 - Surface sensible heat flux (time avg)
9 - Ground heat flux (time avg)
10 - Snow phase change heat flux (time avg)
11 - Surface momentum flux (time avg)
12 - Vertically integrated moisture convergence (time avg)
13 - Vertically integrated energy convergence (time avg)
14 - Total precipitation (time accumulated)
15 - Convective precipitation (time accumulated)
16 - Surface runoff (time accumulated)
17 - Subsurface runoff (time accumulated)
18 - Snow melt (time accumulated)
19 - Snow depth (water equivalent)
20 - Total soil moisture (within total active soil column)
21 - Canopy water content (if part of surface physics)
22 - Surface skin temperature
23 - Soil temperature in top soil layer
24 - Surface downward shortwave radiation (time avg)
25 - Surface upward shortwave radiation (time avg)
26 - Surface downward longwave radiation (time avg)
27 - Surface upward longwave radiation (time avg)
28 - Total cloud fraction (time avg)
29 - Total column water vapor
30 - Convective Available Potential Energy (CAPE)

**B. Lowest level Atmospheric Fields**

31 - Temperature (lowest model level)
32 - Specific humidity (lowest model level)
33 - U component wind speed (lowest model level)
34 - V component wind speed (lowest model level)
35 - Pressure (lowest model level)
36 - Geopotential (lowest model level)
37 - Temperature (mean in 30 hpa layer above ground)
38 - Specific humidity (mean in 30 hpa layer above ground)
39 - U component wind speed (mean in 30 hpa layer above ground)
40 - V component wind speed (mean in 30 hpa layer above ground)

**C. Upper Atmospheric Fields**

41 - 1000 hpa height
42 - 700 hpa vertical motion (omega -- Dp/Dt)
43 - 850 hpa height
44 - 850 hpa temperature
45 - 850 hpa specific humidity
46 - 850 hpa U component wind speed
47 - 850 hpa V component wind speed

48 - 500 hpa height
49 - 500 hpa absolute vorticity
50 - 250 hpa height
51 - 250 hpa U component wind speed
52 - 250 hpa V component wind speed
53 - Tropopause height (or pressure)
54 - Top-of-atmosphere net longwave radiation (time avg)
55 - Top-of-atmosphere net shortwave radiation (time avg)

**D. Meta Data Fixed Fields (as one-time companion file to MORDS)**

a - model terrain height
b - model roughness length
c - model max soil moisture capacity
d - model soil type
e - model vegetation type

# APPENDIX C

## LSA-NC Science /Implementation Task Group Session II Report and Recommendations

The Task Group met on February 19 , 1997 at the Holiday Inn Express in St. Paul, MN. The group focused on the progress since its last report and on those areas which may need enhancements for the second Enhanced Seasonal Observing Period during the cold season of 1997/98 (ESOP-98).

### C.1 Background

The GCIP Implementation Plan (IGPO 1994a) identified the following features of the LSA-NC as important to GCIP:

- Role of winter snow accumulation and spring snowmelt in the annual water budget.
- Large natural inertia in the water runoff system due to lakes.
- Minimal orographic effects for precipitation.
- Soil freezing and thawing.

The results from the LSA-NC Detailed Design Workshop held in October 1995 (IGPO 1995a) were used by the first meeting of the LSA-NC Science/Implementation Task Group held in March 1996 (IGPO 1996a) to develop more specific recommendations for GCIP activities in the LSA-NC during 1997 and 1998. The Task Group recommendations primarily addressed those scientific issues that relate to snow and frozen ground processes and that can take advantage of the existing infrastructure and ongoing projects. These scientific issues were organized around three themes with specific activities recommended for each theme:

- Land Surface Model Physics
- Land Surface Modeling of SubGrid- Scale Heterogeneity Effects
- Monitoring of the Land-Surface State

These three themes along with the specific activities recommended for each theme and the status of these recommendations are described in later sections.

### C.2 LSA-NC Implementation

The Task Group received reports on the status of the implementation of the LSA-NC activities with emphasis on the specific activities recommended in the first report and listed in the previous section.

The GCIP activities in the LSA-NC were initiated on 1 October 1996 as the beginning of the data collection period for ESOP-97 and continuing through 31 May 1997. S. Loehrer summarized the data collection and management plans for ESOP-97. Details are available in the Draft Document entitled Tactical Data Collection and Management Plan for the 1997 Enhanced Seasonal Observing Period (ESOP-97) which was printed in September 1996. This document will continue in draft form until the composite data set is compiled at which time it will be converted to a summary report on the ESOP-97 data set. The scheduled completion of the ESOP-97 data set is June 1998.

R. Lawford reviewed a number of new developments in the GCIP program and recent funding decisions that will affect the LSA-NC program in FY97. Five new projects are being either fully or partially funded in FY97. It is felt that these new initiatives, when combined with research relevant to the LSA-NC in on-going projects, will constitute a substantial research effort in the LSA-NC during 1997, 1998 and into 1999.

The five projects that have been approved for FY97 will make contributions to coupled model development and to the measurement of solid precipitation. One project (PI: G. Liston) will use the RAMS model over the LSA-NC area at 40-km resolution to test out a new snow-cover sub-model. The new sub-model will include the effects of sub-grid snow cover variability. This modeling study which will produce runoff estimates as well as tracking snow cover will complement other on-going work in cold season coupled modeling by D. Lettenmaier and E. Wood using the VIC-2L model and by Y. Xue using the SSiB model.

A related new project (PI: K. Kunkel) involves a study of the heterogeneity of snow cover with an emphasis on its evolution prior to and during snow melt events. The study will examine patterns at spatial scales ranging from the field scale to regional model grid scales and their associated scaling relationships. The study will be based on measurements being taken in Eastern Illinois.

Two studies will provide unique data sets for facilitating analysis of the interactions between land surfaces and the atmosphere during winter and early spring. The first study (PI: J. Baker) will provide data sets from Rosemount, Waseca and Lamberton, Minnesota which will be used to validate models of vertical heat fluxes and the disposition of meltwater. The second study (PI: K. Davis) will focus on observing and analyzing regional scale exchanges of water and energy over agricultural landscapes during winter and snowmelt. Considerable effort will be directed at the Rosemount site with radiosonde and tethersonde measurements being taken and modeling studies being carried out, as needed, to fully understand the processes governing the development of the planetary boundary layer.

A fifth study (PI: A. Super) will accelerate the development of a snow accumulation algorithm for use with NEXRAD radars. This funding will support real-time testing of an algorithm in Minneapolis and the adaptation of this algorithm for application to the "NIDS" 5 dBZ resolution product. This work is expected to complement other data-related studies being carried out in the LSA-NC by Steve and Tom Carroll to develop better algorithms for estimating snow on the ground and work by G. Peck and P. Groisman aimed at improving the estimates of snow amount derived from climate station data.

## C.3 Land Surface Model Physics

This primarily includes frozen soil processes, snowpack maturation and melt, and the energy budget at the snow-atmosphere interface. The recommendations from the first meeting in March 1996 are identified with the notation Rx.y ,e.g. R3.1 is given below together with a current status report.

R3.1--- During ESOP-97, the data sets for the variables identified in Table C-1 should be collected at one or more sites. Based on information presented at the first task group meeting, the Rosemount Experimental site and the Bondville, Illinois Climate Network site were identified as particularly suitable and with minor improvements in measurement capabilities could meet all of the data requirements given in Table C-1.

**Status:** J. Baker reported on the Status of the Rosemount Site measurements for ESOP-97. The Rosemount Experiment Station is located 24 km south of St. Paul. All measurements described below are made in a 17 ha (40 acre) field located on the south side of 160th Street, approximately 0.8 km east of the station office. The field is currently planted with maize, and there is a permanent mast installed in the center, so fetch exceeds 180 m in all directions. Precipitation gauges are installed within a Wyoming-type enclosure located 80 m north of the main mast. Data are transmitted via buried cable to a computer housed in a nearby building, and subsequently retrieved via telephone for archival at the St. Paul campus of the University of Minnesota. Routine meteorological data (averaged or summed on 30 minute intervals) that are collected with automated instrumentation include the following variables:

| VARIABLE | INSTRUMENTATION |
|---|---|
| Air temperature (2m)<br>Relative humidity (2m)<br>Windspeed (0.4, 0.8, 1.4, and 2m) | Vaisala HMP35<br>Vaisala HMP35<br>RM Young cup anemometers |

| | |
|---|---|
| Solar Radiation (incoming and reflected)<br>Longwave radiation (incoming and outgoing)<br>Net radiation<br>Precipitation quantity<br>Precipitation quantity<br>Snow depth | Kipp & Zonen pyranometers<br>Eppley pyrgeometers<br>REBS Q7.1 net radiometer<br>Qualimetrics heated tipping bucket<br>Belfort weighing gauge<br>CSI Ultrasonic sensor |

The following soils data (averaged or sampled on 30 min intervals) are collected:

| | |
|---|---|
| Soil heat flux (2.5cm)<br>Soil temperature (8 depths from 2.5 cm to 1 m)<br>Water content (8 depths, from 2.5 cm to 1 m) | REBS heat flux plate & thermocouple<br>thermistors<br>time-domain reflectometry |

The following data are collected manually (approximately weekly, more frequently as needed):

- Snow depth by visual observation of 37 snow sticks arrayed in a circle of 90 m radius.
- Snow density by gravimetric sampling
- Soil water content by neutron probe (20 cm depths to 160 cm)

Turbulent flux data are also collected. Sensible and latent heat flux measurements were made during spring 1997 snowmelt by eddy covariance, with a CSI 1-D sonic anemometer and Krypton hygrometer. For winter 1997-1998, continuous measurements of each will be made by conditional sampling and/or eddy covariance.

S. Hollinger reported on the status of the Bondville Site measurements for ESOP-97 including the new surface flux measurement site near to the Bondville site. A Campbell Scientific snow depth sensor was installed at the Illinois Climate Network station near Bondville, IL in early January. There were three significant snow events, and two snow melts after the installation of the sensor. These were the major snow events of the winter of 1996-1997 in the region. The first snow event began on 10 January resulting in a snow accumulation of approximately 5 cm. A second snow event occurred on 15 January resulting in a final total snow pack of 16 cm. The snowmelt occurred as a result of a warm front and warm air rain. All of the snow was melted in a period beginning at 1200 on 20 January through 1200 on 22 January when the snow pack decreased from 15 cm to 0 cm. On 26 January the third snow event began resulting in a snow accumulation of approximately 2.5 cm. This snow cover remained until 31 January when it melted as a result of a bright sunny day when air temperatures increased to 5C. At the flux station located east of Bondville, soil temperatures were colder in the no-till soybean residue than at the Bondville site which was under a heavy grass cover.

R3.2 ---The above datasets should also be collected during ESOP-98 at the same sites. Other suitable sites such as the Walnut Creek and Shingobee River watersheds can be considered for additional data collection efforts.

**Status**: Plans are proceeding to include both the Rosemount and Bondville sites for special data collection efforts during ESOP-98.

D. Rosenberry reported on the status of the measurements at the Shingobee River watershed and the site at Bemidji, MN. Soil-temperature and soil-moisture sensors were installed January 31, 1997 at the Bemidji Toxic Substances Hydrology site in northern Minnesota to complete a data-collection package that represents soil conditions in the center of a 2 ha field in a jack pine forest. Time-domain reflectometry (TDR) sensors and thermocouple thermometers already were installed at the Bemidji site in a related effort by the U.S. Geological Survey at depths of 50, 100, 150, 200, 250 and 300 cm below land surface. The January installation of identical probes at depths of 10, 20 and 30 cm below land surface meets the needs of GCIP by providing shallow soil-moisture data. This also will allow documentation of soil-moisture changes as the snowpack melts this spring. TDR probes and thermocouple thermometers also will be installed this June at the U.S. Geological Survey Interdisciplinary Research Initiative (IRI) site 65 km south of the Bemidji Site. These sensors will be installed in a mixed coniferous-deciduous forest at depths of 5, 15, 25, 35, 50, 100, 150, 200, 250 and 300 cm below land surface. In addition, a thermocouple will be installed at land surface at both the Bemidji and IRI sites. All sensors will be connected to Campbell Scientific dataloggers which will compute hourly and daily average values for soil moisture and soil temperature. TDR probes will be connected to a Tektronics cable testor, which when combined with the datalogger will process and convert TDR-probe signals to soil-moisture data. Calibrations will be made with a neutron soil-moisture probe inserted in neutron access tubes installed adjacent to the sensor strings, and with bulk-density measurements of nearby soil samples.

The measurements at the Walnut Creek watershed are made by the USDA/ Soil Tilth Laboratory. A NOAA wind profiler site is on the southern edge of this watershed. In addition, the Des Moines WSR-88D radar is nearby and could provide wind information. These data are part of the ESOP-97 data set. Further investigation is needed to determine whether all the critical measurements shown in Table C-1 will be available during ESOP-98.

R3.3 --- An evaluation of land surface models should be undertaken, possibly as part of a PILPS initiative, based on the data collected at all of the selected sites.

**Status**: No action has yet been taken on this recommendation.

| **Table C-1. Variables Required for Land/Hydrology Model Studies** |
|---|
| Forcing measurements (30 min res)<br><br>U component wind speed at 10 m<br>V component wind speed at 10 m<br>Temperature at 2 m<br>Specific humidity at 2 m<br>Surface pressure<br>Surface skin temperature<br>Precipitation quantity and type<br>Surface Radiation - downward shortwave<br>Surface Radiation - downward longwave |
| Validation<br><br>Surface Radiation - upward longwave<br>Surface Radiation - net radiation (measured)<br>Streamflow<br>Soil moisture (profiles)<br>Soil temperature (profiles)<br>Surface latent heat flux<br>Surface sensible heat flux |
| Set up for Experiment<br><br>Vegetation type and characteristics Site<br>Site Description<br>Surface Radiation - upward shortwave (albedo)<br>Soil characteristics<br>Wilting point<br>Rooting zone<br>Field capacity |

## C.4 Land Surface Modeling of SubGrid- Scale Heterogeneity Effects

During the cold season this is most relevant during snowmelt when the change in albedo can exert a profound influence on the surface-atmospheric energy exchange. Specific activities recommended include:

R4.1---The GCIP should investigate the suitability of several sites, including the Le Sueur and Cottonwood River Basins, for a study of subgrid-scale variability.

**Status**: No action has yet been taken on this recommendation.

R4.2 ---During ESOP-98, the data collection effort for studies of subgrid-scale variability should be undertaken with an emphasis on the spring snowmelt period.

**Status**: ESOP-98 data collection plans were not available at the time of the meeting.

R4.3 --- A second model intercomparison study focusing on sub-grid scale heterogeneity should be conducted and validated against areally-averaged values of relevant variables.

**Status**: No action has yet been taken on this recommendation.

## C.5 Monitoring of the Land-Surface State

Studies of the LSA-NC region as a whole require accurate measurements of the condition of the land-surface, particularly soil moisture, soil temperature, and snowpack characteristics. Specific activities recommended include:

R5.1--- A corrected set of the cooperative observer data of snowfall, snowdepth , and snow water equivalent (SWE) should be developed for the LSA-NC both for ESOP-97 and ESOP-98 and for the historical record. It should be feasible to extend it back to 1948. This set should be compatible with the corrected Canadian snow data (i.e., contours should match at the international boundary).

**Status**: It was noted that several activities recommended at the first meeting of the Taskgroup dealt with the issue of obtaining valid data about snowfall and the water equivalent of the snowfall or the use of such data for research and modeling studies.

GCIP supported an investigation by Gene Peck of the snow measurement issue as it pertains to GCIP investigations and provided recommendations to improve the measurement of snowfall. A report prepared by Gene Peck entitled "Review of Snowfall and Snow Cover Measurement Programs in GCIP North Central Large Scale Area" was sent to each participant prior to the meeting. A special meeting on Snow Measurements Adjustments was held at the NOAA Operational Hydrologic Remote Sensing Center in Chanhassen, MN on 18 February to consider the report . A second report by P. Groisman entitled "The procedure to adjust the data in the NCEP atlas of gridded hourly precipitation over the contiguous United States for the period 1964-1993" was also considered at this special meeting. The results of this special meeting resulted in the recommendations by Peck being sorted into three action groups:

(1) Actions to improve records during the two year period for GCIP data collection in the LSA-NC.

(1.1) The relationship of Groisman's and Peck's factors for determining the exposure effect of wind on a snow measurement gauge should be investigated.

(1.2) Arrangements should be made to adjust observed snowfall observations from selected climatological stations in near-real time and both the observed and adjusted values should be part of the archive record.

(1.3) Complete a test study to determine the utility of using Eta model winds for adjusting snowfall records at climatological stations and for evaluating the reliability of wind records at synoptic stations in the LSA-NC.

(2) Actions to improve historical records

(2.1) Conduct a study to investigate the relationship of the NWS airborne gamma radiation measurements of the water equivalent of the snow cover with in-situ measurements of adjusted precipitation and of the water equivalent of the snow cover.

(2.2) Develop isohyetal information in map and gridded formats for the winter months and for the year for the northern part of the LSA-NC area. This information should be developed using adjusted snowfall values for selected Hydroclimate Network and synoptic stations.

(2.3) For at least those portions of Canada within the LSA-NC, arrange for adjustment of Canadian synoptic and climatological records on a daily basis and publish both the observed and adjusted values.

(3) Action by GCIP and others to improve all US long-term snowfall records

(3.1) Work with the operational agencies responsible for snowfall measurements to have all snowfall records in the US adjusted in real and near-real time on an operational basis and publish both observed and adjusted records.

The discussion and conclusions of the Taskgroup resulted in the follow-up recommendations given in Section C.6.

R5.2 --- Optimal methods to combine cooperative observer, satellite, and airborne gamma radiation snow data should be developed. These methods should produce snow fields with acceptable accuracy both for research studies (when all data can be used) and for operational applications (when only a subset of cooperative observer data are available).

**Status:** T. Carroll gave the special meeting on snowfall measurements adjustments a presentation and demonstration of the operational procedures and the developments in process to prepare maps of snowfall and snow water equivalent from an integrated set of data.

R5.3 --- The GCIP office should investigate whether more applicable radar algorithms like those to be used at the Minneapolis WSR-88D radar can be implemented operationally before ESOP-98 for those radar systems covering the LSA-NC.

**Status**: A report by A. Super and E. Holroyd III entitled "Snow Accumulation Algorithm for WSR-88D, Version 1" was sent to the participants at the Snow Measurement Adjustment meeting.. In addition, A. Super participated in the special meeting on snow measurement adjustments and presented a report on his work. It was agreed that there was little or no chance that a WSR-88D algorithm would be implemented operationally before ESOP-98 in any portions of the WSR-88D operational network.

R5.4 --- WSR-88D radar data from the Minneapolis site should be archived for ESOP- 97 and ESOP-98. Studies of snow water variability using these and other relevant data should be encouraged.

**Status**: The Level II data from each of the WSR-88D sites in the operational network are routinely archived at the NCDC in Asheville, NC. However, the cost to retrieve these data is such that GCIP could only afford to retrieve limited samples from this archive.

The GCIP/Data Collection and Management (DACOM) committee has taken the initiative to collect the data from the operational NEXRAD Information Dissemination Service (NIDS) for nine sites in the LSA-NC. However, there is some concern about the utility of the reflectivity data to derive estimates of snowfall.

A. Super agreed to use some NIDS data samples from the Minneapolis site to be supplied by S. Loehrer to derive estimates of snowfall for cases in which such estimates were previously derived from the full reflectivity data.

R3.5 --- The development of methods to combine remotely sensed and in situ soil moisture should be encouraged. Of particular interest are methods that are accurate at the beginning of the cold season, just before the soil freezes and snow cover commences, and just after snow cover has disappeared.

**Status**: T. Carroll showed results of soil moisture comparisons between aircraft and in-situ measurements made at the beginning of the cold season. It was agreed that GCIP should continue to encourage the development of methods to combine these two types of measurements.

R3.6--- To the extent possible within fiscal constraints, the GCIP should encourage and support routine soil moisture measurements at several sites within LSA-NC.

**Status**: J. Leese reported on some GCIP activities to support soil moisture measurements in the LSA-NC. Partial support was provided to the Water Resources Division of the USGS to install soil moisture sensors at the Shingobee River watershed. The surface flux site installed near Bondville, IL includes soil moisture sensors. J. Baker informed the meeting about plans to install soil moisture sensors at Lamberton and Waseca, MN.

J. Leese also reported on the GCIP activity to establish a North - South Transect of soil moisture and other measurements along or near 96W longitude. He particularly noted the contribution from the USDA/NRCS to make the data from their Soil Moisture/Soil Temperature Pilot Project available to GCIP. Noteworthy, for the N-S Soil Moisture Transect was the fact that the NRCS Project replaced the soil moisture sensors for three sites along the transect at a high priority in their schedule. The N-S transect will start at Plainview , TX (~30N latitude ) and continue North to Shingobee Watershed (~47N latitude) . Although sparse in the LSA-NC portion, the temporal variability of the soil moisture and soil temperature profiles over the course of an annual cycle should still be informative , especially during the cold period of the ESOP-98 from October 1997 to May 1998.

R 3.7 --- Satellite estimates of fractional snowcover should be obtained for the surface sites of interest (Rosemont, Bondville, Walnut Creek, Shingobee, etc.)

**Status**: Such estimates can be made from the operational meteorological satellite data acquired from either the NOAA polar-orbiting or the GOES satellites. However, the resolution is likely not sufficient to derive estimates of fractional snowcover for specific sites.

J. Leese reported on a Winter Cloud Experiment (WINCE) conducted by W. Smith at the University of Wisconsin. WINCE made use of the NASA ER-2 aircraft to fly the MODIS Airborne Simulator (MAS) for calibration checks. Arrangements were made with W. Smith to schedule some of the flights between Madison, Wisconsin and Bondville, IL during a two-week period in February, 1997. MAS data from the flights over Bondville are expected to become available in the near future. The MAS is an airborne sensor which has most of the remote sensing characteristics of the Moderate resolution Imaging Spectroradiometer , or MODIS to be flown aboard the EOS AM-1 satellite scheduled for launch in 1998. The MODIS data could be important for GCIP in the later stages of the five-year Enhanced Observing Period.

## C.6 Recommendations

The following recommendations primarily address collection and monitoring efforts to enhance ESOP-98 data sets, and are identified as Recommendation 98-x.

### C.6.1 Data Collection to Support Land-Surface Model Development.

Enhanced data collection efforts are planned for the Rosemount and Bondville sites. This will provide a core set of data for model development. However, there are opportunities for enhancement. In particular, there are ongoing data collection efforts in the Walnut Creek watershed that may meet many, if not all, the requirements shown earlier in Table C-1. It may be possible to meet all requirements with little effort and funds. Its location, roughly intermediate in latitude between Rosemount and Bondville, would provide a worthwhile enhancement to the GCIP data base.

**Recommendation 98-1**: The GCIP office should investigate whether all of the critical measurements in Table C-1 will be available from the Walnut Creek watershed. If only minor enhancements are needed to meet all requirements, we recommend that the GCIP office explore options to achieve those enhancements.

### C.6.2 Data Collection Efforts for Modeling of Subgrid-Scale Heterogeneity.

Enhanced data collection efforts to document subgrid-scale heterogeneity are planned for Bondville, an area of generally ephemeral cold season snow cover. It would be desirable to also have suitable data collection efforts in the northern portions of the basin with longer lasting snow cover. Such data collection efforts would need to be on the scale of numerical weather prediction (NWP) grid and hydrologic model scales. We recognize that this can be costly and difficult and may not be possible within fiscal constraints. Nevertheless, its importance in accurate modeling of the land-surface state is sufficiently great that we make the following recommendation.

**Recommendation 98-2**: The GCIP office should investigate options for the collection of data on the subgrid-scale heterogeneity of snow cover at one or more sites in the northern portions of the basin. It may be most economical to utilize remotely sensed observations from satellites and aircraft. However, for purposes of model development, it would be advantageous to incorporate some high spatial resolution ground-based measurements of snow cover and water equivalent.

### C.6.3. Monitoring of Snow Water Equivalent

The report by Eugene Peck on the snow measurements program in the LSA-NC included a number of recommendations. The Taskgroup generally agrees with these recommendations. Thus, the recommendations of the Taskgroup, largely adapted from the Peck report, are as follows:

**Recommendation 98-3.1**: The GCIP program office should take actions to improve snow records for ESOP-97 and ESOP-98. In order of priority, these actions are as follows:

98-3.1.1. A comparison of the Groisman and Peck factors to characterize site exposure should be undertaken. It would be advantageous if the two approaches provided comparable results because the Groisman approach only requires station history information and can be applied to many more stations than the Peck approach which requires a detailed knowledge of the site. However, the Peck approach is presumably the more accurate.

98-3.1.2. An application of any method for making exposure adjustments to snow records requires a reasonably accurate estimate of the wind. This presents a serious problem for climatological stations not near a synoptic station and may also be a problem when a synoptic station's data quality is suspect, an example of which is reported in the Peck report. The NOAA ETA model provides wind movement at a 10 meter height at a grid resolution of 40 km. This internally consistent wind data set at an adequate spatial resolution provides a potential solution. The Taskgroup recommends that GCIP support or arrange for a test study that would use ETA model winds to adjust snow records at climate stations and to evaluate the reliability of wind records at synoptic stations in the LSA-NC region.

98-3.1.3. The GCIP office should arrange that observed and adjusted values of snowfall for selected climate stations in the LSA-NC be released in near real-time.

98-3.1.4. The GCIP office should encourage activities to improve mapping of snow depth, coverage, and water equivalent, using a combination of airborne gamma and in situ measurements.

**Recommendation 98-3.2**. The GCIP project office should foster actions to improve historical snow records in the following priority order:

98-3.2.1. The GCIP office should encourage the development of isohyetal winter and annual maps of snowfall in map and gridded data format for the northern portions of the LSA-NC. Current maps are inadequate.

98-3.2.2. In order to provide for a consistent record and avoid discontinuities at the international boundary, it is recommended that the Canadian snow records be adjusted on a daily basis using similar techniques. Both observed and adjusted values should be published.

**Recommendation 98-3.3**. The problems associated with snow records in the LSA-NC also affect records for other areas of the U.S. The GCIP office is encouraged to work with the NWS, NCDC, and other relevant organizations to improve all U.S. snowfall records. Specifically, snowfall records should be adjusted in near-real-time on an operational basis. Both observed and adjusted values should be published.

### C.6.4 Monitoring of Soil Moisture

**Recommendation 98-4.1**. The GCIP office should continue to encourage the development of methods to combine remotely sensed and in situ soil moisture measurements.

**Recommendation 98- 4.2**. The Taskgroup supports the GCIP office's initiative to establish a north-south transect of soil moisture monitoring sites and encourages its continued development.

### C.6.5 Monitoring of Surface Albedo

Despite the importance of albedo in determining the coupling between the land surface and the atmosphere and the large albedo changes associated with snow accumulation and melt, there are no operational plans to measure this variable on an area-averaged basis, because of the high costs associated with airborne platforms. However, this is an important component to address.

**Recommendation 98-5**. The GCIP office should investigate opportunities to obtain large area observations of albedo, such as was done during the ESOP-97 with ER-2 flights of the MODIS Airborne Simulator.

# APPENDIX D

## SUMMARY OF RESULTS FROM GCIP/LSA-E DETAILED DESIGN WORKSHOP

The GCIP/LSA-E Detailed Design Workshop was held in Huntsville, Alabama on 20 - 22 October, 1996 at the Holiday Inn - Research Park. The primary purpose of this workshop was to provide inputs to the design of the overall experiment for the LSA-E during the water years 1998-1999. The Workshop made use of the document entitled "GCIP Studies in the LSA-E - A Discussion Paper" compiled by Dale Quattrochi as a starting point in developing recommended research activities.This document is available through the WEB on the GCIP Home Page or at the URL address: (http://wwwghcc.msfc.nasa.gov/GCIP/). This Appendix contains an abbreviated summary of the results from the work sessions.

The characteristics of the major river basins in the LSA-E are:

- Upper Ohio River provides semi-humid, Appalachian headwater signature in Mississippi River hydrograph

- Tennessee-Cumberland River provides semi-humid southeast tributary, representative of hydrology in this region.

The features of the Ohio and Tennessee River basins important to the GCIP continental-scale studies include the following:

- Topographic effects of the Appalachian Mountains
- Heaviest precipitation in the entire Mississippi River basin
- Winter-spring precipitation maximum
- Winter-spring floods
- Synoptic weather systems as major precipitation cause
- Some snowmelt effect
- Rivers in deep valleys (gulleys)
- Dominant contribution to Mississippi River runoff
- Few large natural reservoirs, but many manmade [e.g., Tennessee Valley Authority (TVA)]

The features and characteristics listed above led to the emphasis on research studies and modeling for this region to focus on the annual hydrometeorological cycle dynamics and water resources management.

### D.1 LSA-E Infrastructure and Related Research

A significant part of the Workshop was a series of presentations on the existing facilities and current research activities in the region which are potentially useful for collecting data needed by GCIP and/or for cooperative research studies with GCIP. A summary of these presentations was given in last year's edition of the GCIP Major Activities Plan (IGPO 1996a).

### D.2 Work Sessions

Work Sessions were held in two phases. The first phase addressed three specialized topics while developing an approach to the major research questions on the annual hydrometeorology and water resources that are significant to the success of GCIP. The three topics were:

1. Coupled Hydrologic/Atmospheric Modeling
2. Diagnostic Studies/Energy and Water Budgets
3. Hydrometeorological Prediction and Water Resources Management

The second phase then further developed the specific research and data issues defined during these initial Work Sessions.

GCIP research addresses activities on two scales in each Large Scale Area (LSA). Intermediate-scale area (ISA) activities at spatial scales on the order of 1,000 to 10,000 sq km are phased in with those for each LSA. Small-scale area (SSA) activities at a spatial scale on the order of 100 sq km typically involve efforts requiring intensive observing periods over a concentrated region to study focused issues. The Work Sessions were asked to identify candidate ISA and SSA activities in the LSA-E.

## D.3 Coupled Hydrologic/Atmospheric Modeling Work Session

The development and validation of coupled hydrological-atmospheric models is a major scientific objective for GCIP that includes improving the representation of land surface components in models. This Work Session was asked to consider how GCIP can make use of the unique features, infrastructure and data available in the LSA-E to develop and evaluate regional coupled hydrologic/atmospheric models for weather and climate prediction. In particular, it addressed questions such as what coupled modeling issues can be addressed in the LSA-E?; what processes pertaining to characteristics inherent to the LSA-E need to be emphasized?; how can we evaluate the capability of coupled models to simulate the causal mechanisms for interseasonal and interannual variability over the LSA-E?; and what is needed to estimate model parameter values over the annual hydrologic cycle?

The Work Session was also asked to identify the types of data needed for hydrological and atmospheric modeling research; to identify where such data are available in the LSA-E; and to recommend enhancements to assure sufficient data are available for the Water Years 1998 and 1999.

The coupled hydrologic-atmospheric modeling Work Session recommended research tasks in four areas and summarized in the remainder of this section.

### D.3.1 Model Grids and Coordinate Systems

The current status of the three regional models being used by GCIP to provide model output data for budget studies and other applications was reviewed with emphasis on the capability to produce the model output needed during the Water Years 1998 and 1999.

The three regional models producing output for GCIP are archived on a 40 km resolution grid using a Lambert Conformal Map projection true at 100W longitude. However, the "native" grid system resolution varies among the three models. These variations provide an opportunity to investigate the extent to which each of the three regional model grid and coordinate systems are adequate to model the effect of orography on precipitation and the effect of heterogeneous vegetation in the LSA-E.

In addition, these evaluations should include comparisons with higher resolution grids. The Eta model produced model output at 10 km resolution over a portion of the LSA-E during the period of the 1996 Olympics in Atlanta, GA. A model output data set such as this is well suited for comparative evaluation on the effects of grid resolution in capturing orographic effects on precipitation and the effect of heterogeneous vegetation.

### D.3.2 Model Initiation

The Work Session considered there is little data available in the LSA-E for coupled hydrologic/atmospheric modeling in both the operational and the research mode. It was recommended that sensitivity studies be conducted on the effects of improved initiation of coupled mesoscale models in very complex regions (such as the LSA-E) with special attention to orography, vegetation, groundwater, and heavily managed runoff.

It was suggested that a coupling between the Land Data Assimilation System (LDAS) and hydrological models and applied in the Ohio and Tennessee river basins could be a test bed for some of these sensitivity studies.

### D.3.3 Modeling Clouds

The Work Session recognized that all aspects of cloud parameterization in atmospheric models could be improved. However, it was recommended that some emphasis should be placed on the problem of representing low-level cumulus clouds. The feedback on the surface energy balance needs to be included in coupled mesoscale models and the parameterization of such clouds evaluated using detailed, satellite based estimates of cloud cover.

### D.3.4 Compatibility of Regional and Global Models

It was considered that the relative value of output from regional and global models is largely an open question in the case of LSA-E, and that this may have seasonal characteristics. The Work Session recommended that some priority be given to the evaluation of global model output using regional data sets from the LSA-E. In this regard, it was recommended that GCIP give consideration to the following questions.

(a) Should global model output products be a formal part of the GCIP data base?
(b) Should the model physics be consistent between the regional and global models used at NCEP to produce operational output products?
(c) Is the soil moisture initiation in regional and global models adequate?

## D.4 Diagnostic Studies/Energy and Water Budgets Work Session

Determining the time and space variations of the energy and water budgets from daily to seasonal and interannual periods for the continental scale is one of the scientific objectives for GCIP. This Work Session was asked to consider the types of energy and water budget studies that could best be done in the LSA-E that could contribute to the successful achievement of this scientific objective for GCIP. This Work Session was also asked to identify the data requirements needed to conduct energy and water budget studies; to consider how the existing facilities could contribute to these budget studies; and to recommend enhancements to the existing facilities which the GCIP Project should make during the two-year data collection period of Water Years 1998 and 1999.

The Work Session was focused on energy and water budgets and their variations on seasonal to interannual time scales. The primary questions it addressed were:

What types of energy and water budgets are required over the LSA-East?
What are the data requirements to support these studies?
How can existing facilities contribute to meet these data requirements?

The Working Group was asked to make specific recommendations with respect to:

(i) Candidate list of small-scale area basins(SSAs)within the LSA-East,

(ii) Candidate intermediate scale area basins(ISAs) within the LSA-East,

(iii) Identification of existing sources to meet data requirements in the LSA-East, and

(iv) Data collection enhancements to existing facilities for the 1998 and 1999 Water Years.

The Group in the Work Session noted that given the overall complexity and heterogeneity of the LSA-E it would be exceedingly difficult to design an observational program that could sample data representative of each micro-climate and ecosystem niche. Thus the group suggested that it would be prudent to suggest the minimum number of SSAs that would sample two major ecosystem types, forests versus cultivated land areas, and regions with distinctive climates, northern versus a southern areas. A survey of existing instrumented sites resulted in recommending that the following sites be considered as candidates for SSA sites:

(1) Goodwin Creek Watershed; Oxford, MS USDA/ARS/NSL

(2) Walker Branch Experimental Watershed; Oak Ridge, TN

(3) North Appalachian Experimental Watershed;Coshocton, OH USDA/ARS

(4) Alabama A&M Experiment Station and Remote Sensing Center; Huntsville, AL

(5) Redstone Arsenal; Huntsville, AL U.S. Army

(6) Panola experimental watershed near Atlanta, GA USGS and NOAA/ERL

The Working Group recommended augmenting or changing locations for the current MOLTS array produced by the coupled mesoscale models to include the candidate SSA sites listed above.

As in all GCIP study areas, precipitation was identified as the most critical variable. It was recommended that the current GCIP mosaic precipitation data set be checked to insure that it was obtaining all of the precipitation networks within the LSA-E. Given the complex terrain and potentially large amounts of data it was suggested that the WSR-88D estimated rainfall would be most useful in conjunction with SSA and ISA study areas.

## D.5 Hydrometeorological Prediction and Water Resources Management

The water resources working group focused on how GCIP LSA-E activities could contribute to GCIP's evolving goals with respect to water resources. The group started by identifying some of the most important characteristics of LSA-E with respect to water resources:

1) For water resources purposes, LSA-E consists of the Tennessee-Cumberland and Ohio River systems. The two systems have hydroclimatological similarities, but from a water resource systems standpoint they are much different. The Tennessee River system is highly regulated, via the TVA reservoir system, whereas the Ohio system is largely unregulated. From an institutional standpoint, TVA is a focal point for Tennessee (and, to some extent, Cumberland) system operations and planning issues. For the Ohio River, no one agency has comparable responsibility, although the U.S. Army Corps of Engineers (USACE) does have system-wide responsibility primarily as a result of its ownership of navigation works.

2) For the Tennessee River system, TVA operations and planning models such as PRYSM define a clear modeling framework and corresponding boundary conditions/forcings which could be provided by GCIP products. Essentially this information includes future reservoir inflows over a wide range of future time scales, ranging from a few days to months and seasons. Also, temperature forecasts would be important to the operation of the energy systems.

3) Opportunities to support water management in the Ohio River appear to include navigation interests on the main stem and a variety of reservoir operations on some of the tributaries. These opportunities need to be explored in more detail. Benefits to navigation of improved forecast information appear to exist for forecast periods up to about two weeks.

### D.5.1 Relationship to Ongoing NWS Activities

Present operational hydrologic forecast models in use at the two NWS RFCs in LSA-E and by water management agencies do not include new representations of vegetation that have been developed by the land surface community, do not model the surface energy budget, and generally make limited use of available soils, land use and remote sensing information. On the other hand the land surface models are beginning to include hydrologic components that account for infiltration, surface runoff, and subsurface runoff and water storage. As GCIP begins to focus on the LSA-E, subsurface storage and runoff processes will need to be represented well in the land surface models. This will be required for these models to represent the surface moisture conditions that actually exist in the LSA-E and that are important for surface forcing of the atmosphere in climate models as well as weather prediction models. On the other hand, operational hydrologic prediction models would be significantly improved if they included better and more physically based representations being developed by GCIP for application in atmospheric models and for use in LDAS to provide initial soil moisture and temperature information for NWP models.

NWS is developing an ensemble precipitation forecasting capability. This will use ensemble forecasts from regional and global numerical prediction models, but it will include a range of statistical approaches to processing model output information, for simulating fine scale space-time characteristics of precipitation not represented in model output, and for accounting for short-term forecast uncertainty that may not be included in NWP ensemble products. This also includes development of a precipitation snalysis system to be used at RFCs that will include various statistical tools for combining all of the information from different sources and for producing the final precipitation ensembles for the hydrologic models.

### D.5.2 Relevance of GCIP Plans to Water Resources Operations in LSA-E

TVA has an interest in streamflow forecasts with two lead times: a) for operational purposes (up to about a week); and b) for planning purposes (months to seasonal). At present, TVA uses probabilistic (10, 50, 90 percentile) forecasts derived from NCEP products; these are used as forcings in the Lettenmaier/Grygier/Stedinger model streamflows (Sacramento model for five index catchments disaggregated stochastically to 42 inflow nodes). For planning purposes, an analogue approach is used, wherein historical observed streamflows for selected years are routed through a reservoir system model. In addition to inflows to the reservoir system, TVA has an interest in forecasts of surface air temperature, which affect both water temperature, which is a key operating constraint, and power demand.

The PRSYM model was implemented by a research group, and is not currently used operationally by TVA. The ESP approach is not used operationally at present in LSA-E, either by the NWS River Forecast Centers, or by TVA. There is a potential TVA interest in ESP-type forecasts over a range of time scales from several days (for power operations purposes) through seasonal (for power planning).

The NWS scheme(s) for producing QPF are evolving. For short lead times (out to about two days), forecasts will be produced from Eta model output. Because the source of forecast uncertainty is not entirely clear at short lead times (probably a combination of uncertainty in model initialization, parameter error, and residual error due to subgrid effects) it will be necessary to develop schemes to represent, possibly via rescaling, forecast error probability density functions. At longer time scales (up to two weeks), ensemble forecasts will be produced using the NCEP's global model. At these lead times, ensemble predictions are expected to represent more realistically the range of likely forecast errors. Finally, at seasonal time scales, ensemble forecasts will be developed from NCEP's coupled ocean-atmosphere model.

### D.5.3 Recommendations

Improvements in short and long-range weather forecasting represent the strongest tie between the GCIP research community and water resources operations, both generally and for LSA-E in particular. As a means to direct the LSA-E water resources activity in this direction, the feasibility of developing an experimental water resources forecast capability for part or all of LSA-E was recommended, as follows:

1) GCIP should develop an experimental streamflow forecast capability for the two major river systems within LSA-E: The Tennessee-Cumberland, and the Ohio River systems. It is important that this activity

be implemented with parallel research and operational pathways, the latter of which would incorporate the involvement of the two RFCs that operate in LSA-E. This capability may well encompass multiple modeling systems, but should have the following general attributes:

a) For the Tennessee-Cumberland River systems, produce streamflow at inflow points to existing TVA reservoir systems models, such as the PRSYM system developed collaboratively between TVA, USGS, and other cooperators;

b) For the Ohio River System, forecast points should be selected to match those used by NWS/OHRFC;

c) The system should have the capability of using off-line (e.g., observational) forcings, as well as forecast products produced by the NCEP models.

d) Hydrologic developments should be undertaken as a cooperative effort with the two NWS River Forecast Centers, as well as the key operating agencies (TVA in the case of the Tennessee-Cumberland system; USACE in the case of the Ohio);

2) An ensemble approach to hydrologic forecasting is needed for several reasons. First, PRYSM-type water resources systems models are designed to process ensembles of events to evaluate the implications of alternative operating decisions when the future reservoir inflows are not known exactly. In other words, PRYSM-type models need ensemble forecasts of reservoir inflows. In addition, ensemble prediction methods allow uncertainty in future precipitation patterns throughout a river basin to be analyzed in a way that is statistically consistent for all forecast points in the basin. The TVA system could provide an excellent test site for evaluation of ensemble hydrologic forecasts derived from coupled land-atmosphere models. In this context, analysis of precipitation climatologies should be undertaken to support verification and testing of precipitation forecasts, including ensemble precipitation forecasts. In addition, hydrologically relevant verification methods are needed to assess precipitation forecasts. This includes techniques to assure that the climatology of precipitation forecasts (including ensemble forecasts) matches climatology (i.e. the forecasts are statistically unbiased). Also, hydrologically relevant approaches are needed to measure the skill in these forecasts over a range of space and time scales.

3) Opportunities for diagnosis of NWP models' soil moisture should be exploited using the parallel simulations produced using observed forcings. The potential for updating for NWP model soil moisture using streamflow prediction errors should be evaluated as well.

4) Consideration should be given to broadening the scope of the proposed GCIP/Tennessee River workshop to include some aspects of the Ohio River as well, especially synergisms in the operation of these two systems with respect to effects on the Lower Mississippi River.

5) Attention should be given to the role of biases in both meteorological forecasts (forcings to hydrologic forecast models) and in the hydrologic models themselves. Every hydrologic model includes at least some seasonal bias in the statistical properties (e.g., means and variances) of model outputs when the models are operated in a simulation mode using historical observations. Some method of correcting for these biases is essential for water resource applications of the forecasts. The required corrections usually must be accomplished through post processing of model outputs. Experiments are needed to demonstrate that the climatology of hydrologic forecasts agree with the climatology of historical streamflow events. In addition, useful methods to measure the skill in these forecasts need to be demonstrated to develop the appropriate level of confidence among water resource managers.

## D.6 Research Issues Work Session

This Work Session used the results from the first set of Work Sessions to develop an overall listing of the research topics which GCIP should concentrate on during the period of 1997 and 1998 for focused studies on cold season/region hydrometeorology in the LSA-NC. It was agreed that:

1) LSA -E has a wide array of precipitation regimes influenced by orography, soil moisture, and land use.

2) A large question for coupled modeling within the LSA -E is how can models be applied to such things as areal averaging across the region.

3) The LSA-E has high temporal variability in precipitation as well as the highest precipitation within the GCIP region as a whole. Additionally, the LSA-E has systemic wet and dry periods that have a pronounced effect on hydrometeorology.

4) Surface energy balance/radiation data are sparse across the LSA-E, but could be very useful for coupled modeling if the existing sites are augmented.

The following items were recommended:

- Augment surface flux capabilities within the LSA-E at specific sites selected for focus studies.
- Investigate the availability of aircraft measurements within the LSA-E.
- Develop an action plan for evaluating and improving WSR- 88D and gauge precipitation data sets for model prediction (e.g., topography, snow cover)

One other aspect that needs to be undertaken is to evaluate and improve GOES and polar orbiting data for surface radiation budgets, radiative flux estimates, and to develop data sets for flux profiling of surface fluxes. It was suggested there be development of the LDAS concept, both for operational and research uses, and, to develop a strategy to validate with streamflow gauging with emphasis on focus study areas.

It was recommended that GCIP/DACOM include the following sites in their inventory of data available in the LSA-E.

1. Walker Branch Watershed at Oak Ridge

2. Bondville, IL SURFRAD site/Reifsteck farm in situ site

3. USDA-ARS Hydrologic Experiment Station at Coshocton, OH

4. Alabama A&M University research farm and U.S. Army Redstone Arsenal Meteorological station, Huntsville, AL

5. Panola experimental watershed near Atlanta, GA

6. Giles County, TN -- TVA Land Between the Lakes site

7. Coweta Experimental Watershed, Otto, NC

Additionally, land-grant universities within the LSA-E (i.e., agricultural schools) should be contacted to find out if they monitor any flux tower sites and instrumented watersheds within the LSA-E. Potential schools are: University of Tennessee, Knoxville; University of Kentucky; University of Georgia; Auburn University; Mississippi State University; Ohio State University; West Virginia University; Virginia Tech as well as possibly others.

## D.7 Data Issues Work Session

This Work Session used the results from the first set of Work Sessions to develop a consolidated list of data requirements for the LSA-E. The Work Session started with the "strawman" list of data requirements which had been developed prior to the workshop. Several possible additions of data from states within and just outside the LSA-E were discussed. This included the Georgia Forestry Commission (28 meteorological stations), the Alabama Weather Observing Network (several automatic meteorological stations) and Alabama Redstone (18 meteorological stations), the North Carolina State Network (14 meteorological stations). Possible additions to upper-air data include profiler data from Redstone Arsenal, University of Alabama-Huntsville (UAH) and Oak Ridge, Tennessee.The consolidated list which resulted from a discussion in a Plenary Session at the Workshop was given in Section 10 of this report.

The group recommended the following actions for GCIP in preparation for research activities in the LSA-E:

- Perform a survey to find out what data products are available and what instrumentation is available within the LSA-E. Focus on existing data sources and data sets within the LSA-E.
- Produce a detailed survey of in situ data availability within the LSA-E
- Identify researcher requirements for WSR-88D data (i.e., volumes, cost, browse availability).

The group raised a number of questions pertaining to the availability and use of satellite remote sensing data in the LSA-E.

> What is the future of the satellite data source module as part of the Data Management and Service System? What happens to data availability after the MSFC DAAC closes?
>
> What are the satellite data requirements for GCIP researchers?
>
> What is the quantity of data available? (How accessible are these data and at what cost?)
>
> Is there a need for a satellite data source module and what role should it play in LSA-E research? (e.g., as a provider/pointer?)

The Session was informed that the MSFC/DAAC as the current satellite remote sensing data source module Work is developing a detailed survey of data availability through remote sensing satellites affecting the LSA-E.

# APPENDIX E

## SUMMARY OF GCIP INITIAL DATA SETS COMPILED

A number of GCIP initial data sets (GIDS) were prepared to provide the data services support during the build-up period before the EOP. The GCIP researchers considered the availability of existing data sets from special experiments and/or reanalysis periods in selecting time periods for these initial data sets.

Preparation of the GIDS started in 1993, and the data sets were compiled for on-line access by GCIP investigators to the extent that is technically feasible. They were also packaged in a manner (e.g., use of CD-ROM) for wide distribution especially to international persons interested in performing initial diagnostic, evaluation, and modeling studies on GCIP-related topics.

### E.1 GIDS-1 Winter-Early Spring Season

The first GCIP data set served as both a scientific data set and a GCIP static data system test that made use of existing experimental and operational capability to provide a composite observing and model output data set derived from the new observation and assimilation schemes. The period for this data set is from 1 February to 30 April 1992. This data set includes data from STORM-FEST, conducted from 1 February to 15 March 1992, and was augmented by hydrological, geographical, and vegetation data for the Mississippi River basin. An additional six weeks of atmospheric, hydrological, and land surface data were added from existing data centers.

The GIDS-1 data set became available online through the CODIAC system operated by the UCAR/OFPS in April 1994. A CD-ROM containing a selected portion of GIDS-1 data was distributed in August 1994. A summary report for this data set was completed in September 1996.

### E.2 GIDS-2 Abnormal Climate Events

The compilation of this data set was postponed due to lack of resources.

### E.3 GIDS-3 Initial Warm Season

The observations and model output data collected during a GCIP Integrated Systems Test (GIST), provided the third of the initial data sets. This data set was completed in June 1995 and is available on line through the CODIAC system operated by the UCAR/OFPS. A CD-ROM containing a selected portion of the GIDS-3 data was distributed in October 1995. The data summary report was completed in September 1996.

The GIST data collection period extended from 1 April 1994 to 31 August 1994, with a concentrated effort during the summer season of June, July, and August. The GIST took place in the LSA-SW which was shown in Figure 7-1. A listing of the data types to be included in the GIDS-3 data set is given in Table E-1.

| Table E-1 Data Sets Collected During GIST |
| --- |
| **Surface Data** |
| Gist Hourly Surface Composite*<br>Gist Hourly Precipitation Composite*<br>GIST Daily Precipitation Composite*<br>NWS ASOS Data<br>FAA AWOS Data |

| |
|---|
| NCDC Surface Aviation Observations (SAO) Data<br>High Plains Climate Network (HPCN) Data<br>Oklahoma Mesonet Data<br>DOE/ARM CART Surface Data<br>NWS Cooperative Observer Data<br>Tulsa River Forecast Center (TRFC) Precipitation Data<br>U.S. Army Corps of Engineer Precipitation and Streamflow Data<br>USGS Precipitation and Streamflow Data<br>USDA/ARS Precipitation Data<br>USDA/Natural Resources Conservation Service Soil Moisture Data |
| **Upper Air Data** |
| NWS Upper Air Rawinsonde Data (MicroART 6-see diskettes)<br>NWS Upper Air Rawinsonde Data (Mandatory/Significant Levels)<br>DOE/ARM CART Site Upper Air Data<br>NOAA Demonstration Network Profiler Data |
| **Satellite Data** |
| GOES-7 Satellite Imagery (IR, Visible 6.7 pm)<br>GOES-8 Satellite Imagery (preliminary)<br>NOAA POES AVHRR Imagery<br>NOAA POES TOVS Data<br>DMSP OLS Imagery<br>MDSP SSM/I Data |
| **Radar Data** |
| WSR-88D LEVEL II Data<br>WSI Reflectivity Composite Imagery |
| **Model Data** |
| AES/CMC RFE Model<br>NOAA/NMC Eta Model<br>NOAA MAPS Model<br>Oklahoma Local Analysis and Prediction System (OLAPS) Model<br>GCIP can access global model output produced by AES/CMC, ECMWF, and NOAA/NMC and hydrology model output produced by NOAA and shown in Table 1. |

*Contains data from ASOS, AWOS, NCDC SAOs, HPCN, Oklahoma Mesonet, DOE/ARM CART, NWS Cooperate Observer, TRFC, USGS, USACE, and USDA

## E.4 GIDS-4 Second Warm Season

The Enhanced Seasonal Observing Period of 1995 (ESOP-95) was conducted from 1 April 1995 to 30 September 1995 to initiate the ongoing program of observations in support of the LSA-SW focus and to concentrate the buildup in the six months prior to the start of the EOP. The ESOP-95 data collection was done in cooperation with the VORTEX II and a US Weather Research Program campaign labeled Weather Analysis and Verification Experiment (WAVE) conducted in the first three months of the ESOP-95 period.

The ESOP-95 provided the basis for the fourth initial data set (GIDS-4). The GIDS-4 contains many of the same data types as was collected during GIST in 1994. The data set was completed in Sepatember 1996 and the data summary report is in preparation.

A listing ot the data types to be included in the GIDS-4 data set is given in Table E-2.

| **Table E-2 Data Sets Contained in the GIDS-4 Database** |
|---|
| **IN-SITU DATA** |
| **Surface**<br><br>GIDS-4 Hourly Surface Composite*<br>GIDS-4 Hourly Precipitation Composite*<br>GIDS-4 Daily Precipitation Composite*<br>NWS ASOS Data<br>FAA AWOS Data<br>NCDC Surface Aviation Observations (SAO) Data<br>High Plains Climate Network (HPCN) Data<br>Oklahoma Mesonet Data<br>DOE/ARM CART Surface Data<br>NWS Cooperative Observer Data<br>Arkansas-Red Basin River Forecast Center (ABRFC) Precipitation Data<br>U.S. Army Corps of Engineer Precipitation and Streamflow Data<br>USGS Precipitation and Streamflow Data<br>USDA/ARS Surface and Soil Moisture<br>USGS Reservoir Data |
| **Upper Air Data**<br><br>NWS Upper Air Rawinsonde Data (6-sec vertical levels)<br>NWS Upper Air Rawinsonde Data (Mandatory/Significant Levels)<br>DOE/ARM CART Site Upper Air Data<br>NOAA Demonstration Network Profiler Data |
| **Radar Data**<br><br>WSR-88D LEVEL II Data<br>WSI Reflectivity Composite Imagery |
| **Land Characterization Data**<br><br>Vegetation/Data Products |
| **SATELLITE DATA**<br><br>GOES-8 Satellite Imagery (IR, Visible 6.7 pm)<br>NOAA POES AVHRR Imagery<br>NOAA POES TOVS Data<br>DMSP OLS Imagery<br>DMSP SSM/I Data NOAA Weekly Northern Hemisphere Snow Cover Analysis ASOS Cloud Observations CLAVR Clouds Satellite Radiation Datasets Vegetation Index Little Washita River Basin Soils and Land Cover |
| **MODEL DATA**<br><br>AES/CMC RFE Model<br>NOAA/NMC Eta Model |

| |
|---|
| Eta Model Initialization Analyses GIF Imagery (daily; 12 UTC) Eta Enhanced Model Output Profiles NOAA/FSL MAPS Model |

*Contains data from ASOS, AWOS, SAOs, HPCN, OK Mesonet, DOE/ARM CART, NWS Cooperative Observer, ABRFC, USGS, USACE, USDA/ARS)

## E.5 GCIP Reference Data Set

The USGS supported the preparation of a CD-ROM containing a number of different data sets which is expected to have wide use among GCIP investigators. One of the major criteria for including a specific type of data on the CD-ROM was that the data are expected to change little if any during the next two to three years. A CD-ROM containing the GCIP Reference Data Set (GREDS) was published in August 1995. A description of the data sets on this CD-ROM is included as part of the documentation for each CD-ROM. The list of data sets for the GCIP Reference Data Sets CD-ROM is given in Table E-3.

| **Table E-3 GCIP Reference Data Sets CD-ROM** |
|---|
| 1. Two ASCII files of USGS, reservoir and NOAA meteorological sites plus Canadian hydrometric and meteorological stations for the Mississippi River basin.<br><br>2. An ASCII file inventory of daily values for the USGS sites.<br><br>3. A 500-m Digital Elevation Model.<br><br>4. Geology of the conterminous United States, from 1:2,500,000-scale King and Beikman map.<br><br>5. Land use from 1:7,500,000-scale map of conterminous US.<br><br>6. River-Reach File, Version 1 (RF1). Data set derived from original EPA files, with attributes, for the conterminous US.<br><br>7. Large Reservoirs of the US. (Hitt 1990). Locations and selected characteristics of approximately 2,700 reservoirs and controlled natural lakes that have normal capacities of at least 5,000 acre-feet or maximum capacities of at least 25,000 acre-feet and that were completed as of January 1, 1988.<br><br>8. Average Annual Runoff. (Gebert et al. 1987). This is an isoline map of average annual runoff in the conterminous United States, 1951-1980, base scale 1:7,500,000.<br><br>9. Climatography of the US, No. 81 -- Supplement No. 3: Contour maps of Annual 1961-90 Normal Temperature, Precipitation, and Degree Days, from NCDC.<br><br>10. LANDSAT nominal row and path boundaries and center points. An index to LANDSAT scenes.<br><br>11. Grid node locations and complete descriptions of model parameters for the ETA model. Projected to Lambert Azimuthal Equal Area, to match with the other data sets.<br><br>12. State and county boundaries from the 1:2,000,000 Digital Line Graph format.<br><br>13. Quadrangle index maps for USGS 1:250,000-, 1:100,000-, and 1:24,000-scale quadrangle map series. Including quad name, states, index numbers needed for ordering quad maps from USGS. Useful for determining list of quads needed for a particular study area.<br><br>14. Hydrological units of the conterminous United States. Boundaries for the 8-digit hydrological unit codes, digitized from 1:250,000-scale base map. |

15. An ASCII listing of sites identified as having long-term records useful for climate studies, including the USGS hydro-climatic data network (Slack and Landwehr 1993).

16. Graphic interface format images of the above data sets for browsing. Each image is 1024 x 768 pixels.

17. Software -- PC executable and C source code for Lambert Azimuthal Equal Area projection to Latitude/Longitude, and vice versa. FORTRAN source distribution (USGS version) for entire Global Coordinate Transformation Package (GCTP).

# APPENDIX F

## ACRONYM LIST

| | |
|---|---|
| 2-D | Two-Dimensional |
| 3-D | Three dimensional |
| 4-D | Four-Dimensional |
| 4DDA | Four-Dimensional Data Assimilation |
| 4-D VAR | 4-Dimensional Variational Assimilation System |

## A

| | |
|---|---|
| ABRFC | Arkansas-Red Basin River Forecast Center |
| ACARS | Aircraft Communication and Recording System |
| AERI | Atmospheric Emitted Radiance Interferometer |
| AES | Atmospheric Environmental Service |
| AFGWC | Air Force Global Weather Central |
| AIRS | Advanced Infrared Studies AIRS |
| AM1 | First Earth Observing System Orbital Platform |
| AMIP | Atmospheric Modeling Intercomparison Project |
| AQP | Avionics Qualification Policy |
| ARESE | ARM Enhanced Shortwave Experiment |
| ARL | Air Resource Laboratory |
| ARM | Atmospheric Radiation Measurement |
| ARS | Agriculture Research Service |
| ASCII | American National Standard Code for Information Exchange |
| ASTER | Atmosphere Surface Turbulent Exchange Research facility |
| ASOS | Automated Surface Observing System |
| ATSR | Along-Track Scanning Radiometer |
| AVHRR | Advanced Very High Resolution Radiometer |
| AVIRIS | Airborne Visible Infrared Imaging Spectrometer |
| AWDN | Automated Weather Data Network |
| AWIPS | Advanced Weather Interactive Processing System |
| AWON | Agricultural Weather Observation Network |
| AWOS | Automated Weather Observing System |

## B

| | |
|---|---|
| BALTEX | Baltic Sea Experiment |
| BATS | Biosphere-Atmosphere Transfer Scheme |
| BOREAS | Boreal Ecosystem Atmosphere Study |
| BRDF | Bidirectional Reflectance Distribution Function |

| | |
|---|---|
| BSRN | Baseline Surface Radiation Network |
| BUFR | Binary Universal Form for Representation of meteorological data |

# C

| | |
|---|---|
| CAC | Climate Analysis Center |
| CAGEX | CERES-ARM-GEWEX Experiment |
| CAPE | Convective Available Potential Energy |
| CART | Clouds and Radiation Testbed |
| CASES | Cooperative Atmosphere-Surface Exchange Study |
| CASH | Commercial Aviation Sensing Humidity |
| CAWS | Commercial Agriculture Weather Station |
| CCA | Canonical Correlation Analysis |
| CD-ROM | Compact Disk, Read-Only Memory |
| CDAS | Climate Data Assimilation System |
| CERES | Clouds and the Earth's Radiant Energy System |
| CLAVR | Clouds from the Advanced Very High Resolution Radiometer |
| CLIVAR | Climate Variations |
| CMC | Canadian Meteorological Centre |
| CODIAC | Cooperative Distributed Interactive Atmospheric Catalog |
| COE | Corps of Engineer |
| CONUS | Continental United States |
| CSA | Continental-Scale Area |
| CSIRO | Commonwealth Scientific and Industrial Research Organization |

# D

| | |
|---|---|
| DAAS | Data Acquisition and Archive Center |
| DACOM | Data Collection and Management |
| DEM | Digital Elevation Model |
| DIAL | Differential Absorption Lidar |
| DLG | Digital Line Graph |
| DLR | Downward Longwave Radiation |
| DMA | Defense Mapping Agency |
| DMSP | Defense Meteorological Satellite Program |
| DMSS | Data Management and Service System |
| DNR | Department of Natural Resources |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DOI | Department of Interior |
| DOT | Department of Transportation |
| DPI | Derived Product Imagery |
| DRADAP | Digital Radar Precipitation |

# E

| | |
|---|---|
| EBBR | Energy Balance Bowen Ratio |
| ECMWF | European Centre for Medium-Range Weather Forecasting |
| ECOR | Eddy Correlation |
| EDA | Eta Data Assimilation |
| EDAS | Eta Model Data Assimilation System |
| EDC | EROS Data Center |
| EMC | Environmental Modeling Center in NCEP |
| EMEX | Equatorial Mesoscale Experiment |
| EOP | Enhanced Observational Period |
| EOS | Earth Observing System |
| EOSDIS | EOS Data and Information System |
| EPA | Environmental Protection Agency |
| EROS | Earth Resources Observation Satellite |
| ERL | Environmental Research Laboratories |
| ERS | Earth Resources Satellite |
| ESA | European Space Agency |
| ESDIM | Environmental Services Data and Information Management |
| ESOP | Enhanced Seasonal Observing Period |
| ESOP95 | Enhanced Seasonal Observing Period of 1995 |
| ESOP96 | Enhanced Seasonal Observing Period of 1996 |
| ESOP97 | Enhanced Seasonal Observing Period of 1997 |
| ESP | Extended Streamflow Prediction |
| ESTAR | Electronically Scanned Thinned Array Radiometer |
| Eta | (Traditional name of an NMC model using Greek letter for the vertical coordinate) |
| ETL | Environmental Technology Laboratory |

# F

| | |
|---|---|
| FAA | Federal Aviation Administration |
| FIFE | First ISLSCP Field Experiment |
| FNOC | Fleet Numerical Oceanographic Center |
| FPAR | Fractional of Absorbed Photosynthetically Active Radiation |
| FSL | Forecast Systems Laboratory |
| FTP | File Transfer Protocol |

# G

| | |
|---|---|
| GAC | Global Average Coverage |
| GARP | Global Atmospheric Research Program |
| GATE | GARP Atlantic Tropical Experiment |
| GCDIS | Global Change Data and Information System |
| GCIP | GEWEX Continental-Scale International Project |
| GCIS | GCIP Central Information Source |

| | |
|---|---|
| GCM | General Circulation Model |
| GCMD | Global Change Master Directory |
| GCSS | GEWEX Cloud Systems Study |
| GCTP | Global Coordinate Transformation Package |
| GEF | Global Finite Element |
| GEM | Global Environmental Multiscale Model |
| GEOS | Goddard Earth-Observing System |
| GEWEX | Global Energy and Water Cycle Experiment |
| GFDL | Geophysical Fluid Dynamics Laboratory |
| GHCC | Global Hydrology Climate Center |
| GHP | GEWEX Hydrometeorology Panel |
| GIDS | GCIP Initial Data Sets |
| GIS | Geographic Information Systems |
| GIST | GCIP Integrated Systems Test |
| GMT | Greenwich Meridian Time |
| GNEG | GEWEX Numerical Experimental Group |
| GNEP | GEWEX Numerical Experiment Panel |
| GOALS | Global Ocean Atmosphere Land Surface |
| GOES | Geostationary Operational Environmental Satellite |
| GPCP | Global Precipitation Climatology Project |
| GPS | Global Positioning System |
| GRDC | Global Runoff Data Centre |
| GREDS | GCIP Reference Data Set |
| GRIB | Grid point values expressed in Binary form |
| GSFC | Goddard Space Flight Center |
| GVI | Global Vegetation Index |
| GVaP | GEWEX Water Vapor Project |
| GVAR | GOES Variable data format |

# H

| | |
|---|---|
| HAPEX | Hydrological-Atmospheric Pilot Experiment |
| HCDN | Hydrology Climate Data Network |
| HH | Horizontal Send-Horizontal Receive |
| HIRS | High-Resolution Infrared Sounder |
| HPC | Hydrometeorology Prediction Center of NCEP |
| HPCN | High Plains Climate Network |
| HSCaRS | Hydrology, Soil Climatology, and Remote Sensing |

# I

| | |
|---|---|
| IAV | Interannual Variability |
| ICN | Illinois Climate Network |
| IDEM | Indiana Department of Environmental Management |
| IFC | Intensive Field Campaign |

| | |
|---|---|
| IGBP | International Geosphere Biosphere Project |
| IGPO | International GEWEX Project Office |
| IOP | Intensive Observing Period |
| IR | Infrared |
| IRI | Interdisciplinary Research Initiative |
| ISA | Intermediate-Scale Area |
| ISCCP | International Satellite Cloud Climatology Project |
| ISLSCP | International Satellite Land Surface Climatology Project |
| ISWS | Illinois State Water Survey |

# J

| | |
|---|---|
| JERS | Japanese Earth Resources Satellites |
| JPL | Jet Propulsion Laboratory |

# L

| | |
|---|---|
| LAI | Leaf Area Index |
| Lake-ICE | Lake Induced Convection and Evaporation |
| LBA | Large Scale Biosphere-Atmosphere Experiment in Amazonia |
| LANDSAT | Land (Remote Sensing) Satellite |
| LAPS | Local Analysis Prediction System |
| LC | Longwave Cooling |
| LDAS | Land Data Assimilation System |
| LEAF | Land-Ecosystem-Atmosphere Feedback |
| LFM | Limited Fine Mesh |
| LLJ | Low-Level Jet |
| LSA | Large-Scale Area |
| LSA-E | Large-Scale Area-East |
| LSA-NC | Large-Scale Area-Northcentral |
| LSA-SW | Large-Scale Area-Southwest |
| LSP | Land Surface Parameterization |
| LTER | Long Term Ecological Research |
| LW | Long Wave |
| LWW | Little Washita Watershed |

# M

| | |
|---|---|
| MAC | Multi-Sensor Aircraft Campaign |
| MAGS | Mackenzie GEWEX Study |
| MAPS | Mesoscale Analysis and Prediction System |
| MCC | Mesoscale Cloud Complex |
| MCS | Mesoscale Convective Systems |
| MFRSR | Multi-Filter Rotating Shawdowband Radiometers |
| MIRBEX | Mississippi River Basin Experiment |

| | |
|---|---|
| MISR | Multi-angle Imaging Spectroradiometer |
| MIT | Massachusetts Institute of Technology |
| MKE | Mesoscale Kinetic Energy |
| MM4 | Mesoscale Model (NCAR) |
| MM5 | Mesoscale Model (NCAR) |
| MODIS | Moderate Resolution Imaging Spectrometer |
| MOLTS | Model Location Time Series |
| MORDS | Model Output Reduced Data Set |
| MOS | Model Output Statistics |
| MPCA | Minnesota Pollution Control Agency |
| MRF | Medium-Range Forecast |
| MSEA | Management Systems Evaluation Areas |
| MSFC | Marshall Space Flight Center |
| MSP | Minneapolis St. Paul Airport |
| MSS | Multi-Spectral Scanner |
| MTPE | Mission to Planet Earth (NASA) |

# N

| | |
|---|---|
| NASA | National Aeronautics and Space Administration |
| NASDA | National Space Development Agency |
| NASS | National Agricultural Statistics Service |
| NATSGO | National Soil Geographic Database |
| NCAR | National Center for Atmospheric Research |
| NCDC | National Climate Data Center |
| NCEP | National Centers for Environmental Prediction |
| NCGIA | National Center for Geographic Information and Analysis |
| NCRFC | North Central River Forecast Center |
| NCSS | National Cooperative Soil Survey |
| NDVI | Normalized Difference Vegetation Index |
| NESDIS | National Environmental Satellite Data and Information Service |
| NESOB | Near Surface Observation |
| NetCDF | Network Common Data Format |
| NEXRAD | Next Generation Radar |
| NFS | Forecast System for the Nile River |
| NGM | Nested Grid Model |
| NIC | National Ice Center |
| NIP | Normal Incident Pyrheliometer |
| NIR | Near Infrared |
| NOAA | National Oceanic and Atmospheric Administration |
| NOHRSC | National Operational Hydrologic Remote Sensing Center |
| NPA | National Precipitation Analysis |
| NPN | NOAA Profiler Network |
| NRC | National Research Council |
| NRCS | National Resource Conservation Service |

| | |
|---|---|
| NSF | National Science Foundation |
| NSL | National Sedimentation Laboratory |
| NWIS | National Water Information System |
| NWP | Numerical Weather Prediction |
| NWS | National Weather Service |
| NWSRFS | National Weather Service River Forecast System |

# O

| | |
|---|---|
| OFPS | Office of Field Project Support |
| OH | Office of Hydrology |
| OLAPS | Oklahoma Local Analysis and Prediction System |
| OLDS | On-Line Demonstration System |
| OLR | Outgoing Longwave Radiation |
| ORFC | Ohio River Forecast Center |
| ORNL | Oak Ridge National Laboratory |
| OSU | Oregon State University |

# P

| | |
|---|---|
| PACS | Pan American Climate Studies |
| PAR | Photosynthetically Active Radiation |
| PBL | Planetary Boundary Layer |
| PILPS | Project for Intercomparison of Land Surface Parameterization Schemes |
| POES | Polar Orbiting Environmental Satellite |
| PNE | Prototype Numerical Experiments |
| PPS | Precipitation Processing System |
| PPT | Precipitation |
| PRA | Principal Research Area |
| PRAC | Principal Research Area Coordinator |
| PRE-STORM | Preliminary Regional Experiment for Storm-Central |
| PRISM | Precipitation-development Regressions on Independent Slopes Model |
| PRYSM | Power and Reservoir Model |

# Q

| | |
|---|---|
| QPF | Quantitative Precipitation Forecast |

# R

| | |
|---|---|
| RADARSAT | Radar Satellite |
| RAMAN | Regional Atmospheric Monitoring and Analytical Network |
| RAMS | CSU Regional Area Modeling System |
| RASS | Radio Acoustic Sounding System |
| RFC | River Forecast Centers |

| | |
|---|---|
| RFE | Regional Finite Element |
| RPCA | Rotated Principal Components Analysis |
| RPN | Recherche en Prévision Numérique |

# S

| | |
|---|---|
| SAO | Surface Aviation Observations |
| SAR | Synthetic Aperture Radar |
| SARB | Satellite Radiation Budget |
| SAST | Scientific Assessment and Strategy Team |
| ScaRab | French-Russian Scanner for Earth Radiation Budget |
| SCAT | Scatterometer |
| SEUS | Snow Water Estimations and Updating System |
| SGP | Southern Great Plains |
| SiB | Simple Biosphere |
| SiB2 | Simple Biosphere Model 2 |
| SIR | Shuttle Imaging Radar |
| SMA | Soil Moisture Accounting |
| SM/ST | Soil Moisture/Soil Temperature Project |
| SNOTEL | SNOpack TELemetry |
| SNR | Signal-to-Noise Ratio |
| SOLRAD | Solar Radiation |
| SPOT | System Pour l'Observation de la Terre |
| SRB | Surface Radiation Budget |
| SSA | Small-Scale Area |
| SSG | Scientific Steering Group |
| SSM/I | Special Sensor Microwave Imager |
| SSTA | Space Science and Technology Alliance |
| SSURGO | Soil Survey Geographic Database |
| STATSGO | State Soil Geographic Database |
| STC | Supplement Type Certificate |
| STORM-FEST | Storm-Scale Operational and Research Meteorology-Fronts Experiment Systems Test |
| SVAT | Soil Vegetation-Atmospheric Traveler |
| SWATS | Soil Water and Temperature Systems |
| SWE | Snow Water Equivalent |
| SURFRAD | Surface Radiation Monitoring Network |

# T

| | |
|---|---|
| TBD | To Be Determined |
| TBRG | Tipping Bucket Raingauge |
| TDR | Time Delay Reflectometry |
| TIGER | Terrestrial Initiative in Global Environment Reseach |
| TIMS | Thermal Infrared Multispectral Scanner |

| | |
|---|---|
| TM | Thematic Mapper |
| TOA | Top-of-the-Atmosphere |
| TOGA-COARE | Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment |
| TOP | Topography-Based |
| TOVS | TIROS Operational Vertical Sounder |
| TRFC | Tulsa River Forecast Center |
| TRMM | Tropical Rainfall Measuring Mission |
| TVA | Tennessee Valley Authority |

# U

| | |
|---|---|
| UAH | University of Alabama, Huntsville |
| UAV | Unmanned Aerospace Vehicles |
| UCAR | University Corporation for Atmospheric Research |
| UK | United Kingdom |
| UM | University of Minnesota |
| UPS | United Parcel Service |
| URL | Uniform Resource Locator |
| U.S. | United States |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USGCRP | United States Global Change Research Program |
| USGS | U.S. Geological Survey |
| USRA | Universities Space Research Association |
| USWRP | U.S. Weather Research Program |
| UW | University of Wisconsin |

# V

| | |
|---|---|
| VAD | Velocity Azimuth Display |
| VAS | VISSR Atmospheric Sounder |
| VIL | Vertically Integrated Liquid |
| VV | Vertical Send-Vertical Receive |

# W

| | |
|---|---|
| WARFS | Water Resources Forecasting System |
| WARM | Illinois Water and Atmospheric Resources Monitoring Network |
| WAVE | Weather Analysis and Verfication Experiment |
| WBW | Walker Branch Watershed |
| WCP | World Climate Programme |
| WCRP | World Climate Research Programme |
| WDT | Wisconsin Dense Till Project |
| WFOV | Wide Field of View |

| | |
|---|---|
| WMO | World Meteorological Organization |
| WPMM | Window Probability Matching Method |
| WRD | Water Resources Division |
| WSI | Weather Services International |
| WSR-88D | Weather Service Radar 88-Doppler |
| WVSS | Water Vapor Sensing System |
| WY | Water Year |