GLOBAL ENERGY AND WATER CYCLE EXPERIMENT

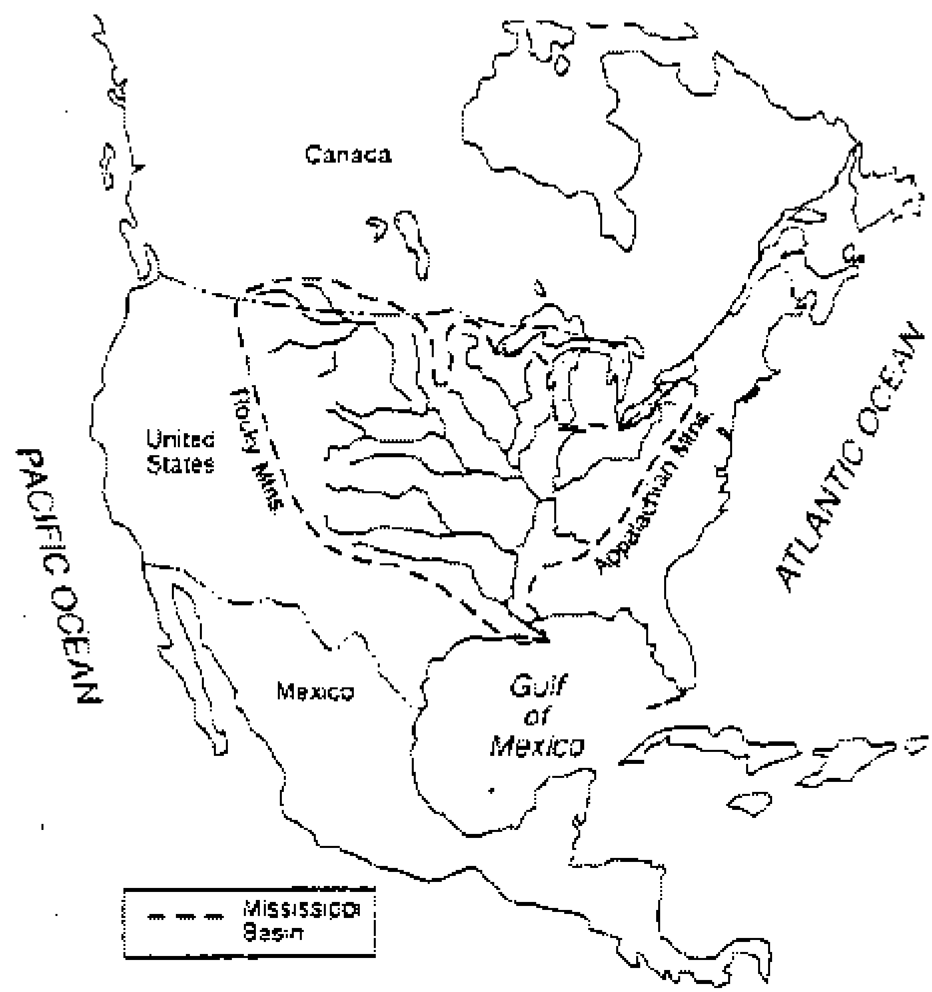
WORLD CLIMATE RESEARCH PROGRAMME (WCRP)

INTERNATIONAL GEWEX PROJECT OFFICE (IGPO)

MAJOR ACTIVITIES PLAN FOR 1997, 1998 AND OUTLOOK FOR 1999

for the

GEWEX CONTINENTAL-SCALE INTERNATIONAL PROJECT (GCIP)



- PART I -

RESEARCH

December 1996

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No. 25

MAJOR ACTIVITIES PLAN FOR

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(GCIP)

- PART I -

RESEARCH

Compiled by

John A. Leese

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MAJOR ACTIVITIES PLAN FOR 1997, 1998 AND OUTLOOK FOR 1999 FOR THE GEWEX CONTINENTAL-SCALE INTERNATIONAL PROJECT (GCIP)

PART I - RESEARCH

PART II - DATA COLLECTION AND MANAGEMENT

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GEWEX CONTINENTAL-SCALE INTERNATIONAL PROJECT (GCIP)

SUMMARY

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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.

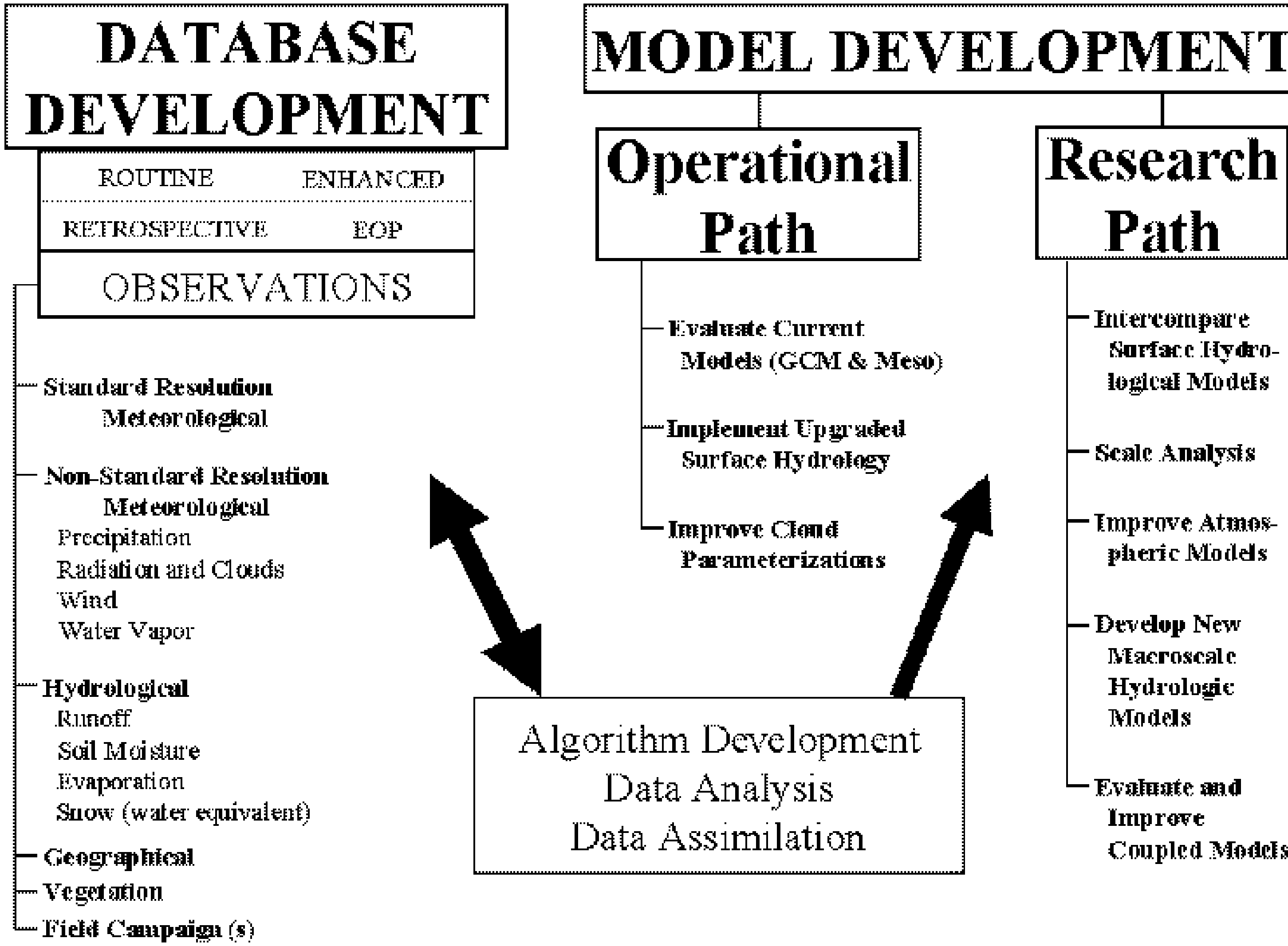
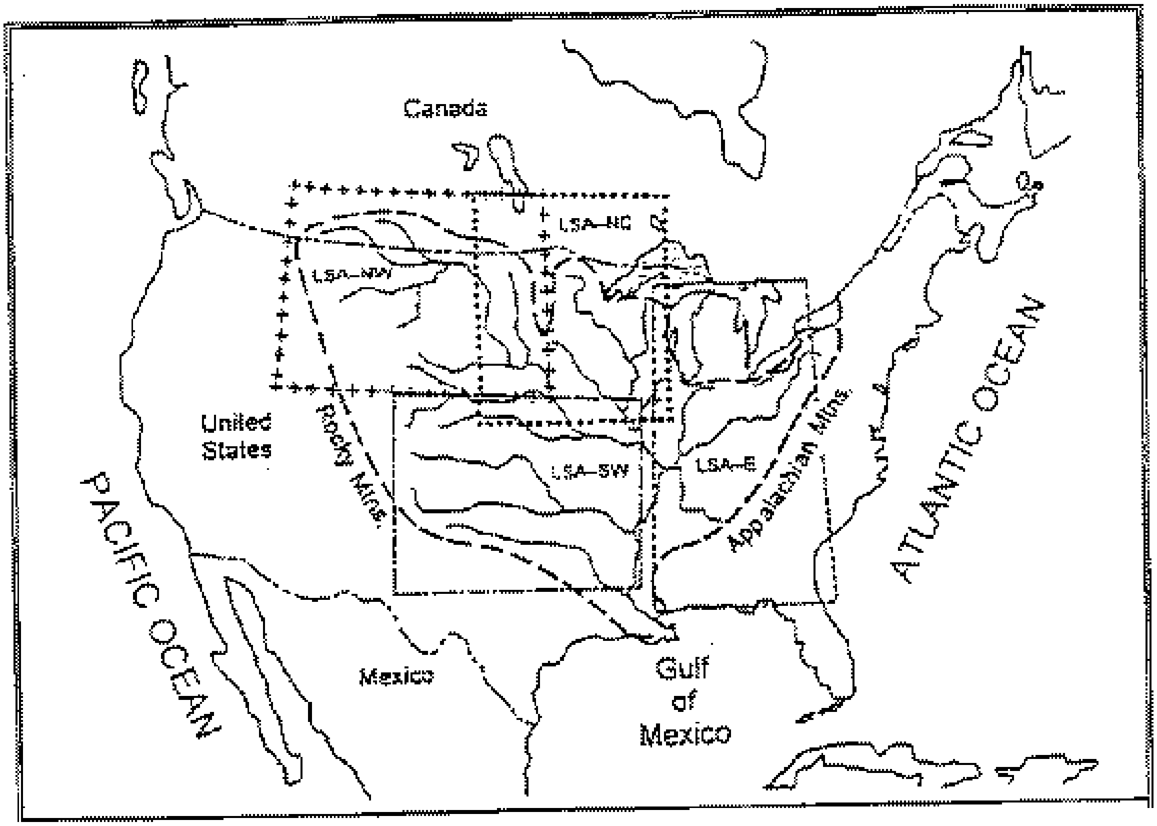


Figure S-1 Strategy Framework for Implementing GCIP.

The understanding and modeling of a continental scale 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, and validation 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. 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.



TIME PHASING OF GCIP RESEARCH EMPHASIS

Multi-Scale Framework	1994 GIST	1995 ESOP	1996 ENHANCED	1997 ENHANCED	1998 OBSERVING	1999 OBSERVING	2000 PERIOD
	FISCAL OR WATER YEAR						
Continental Scale Area	*	*	***	***	***	***	***
Large Scale Areas (LSAs)							
LSA-SW --->	***	***	***	***	**	**	**
LSA-NC --->	*	*	*	***	***	*	*
LSA-E --->	*	*	*	*	***	***	*
LSA-NW --->	*	*	*	*	*	***	***

*** High
** Moderate
* Low

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).

S2. Coupled Hydrologic/Atmospheric Modeling

Model development in GCIP has two paths as was 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 tasks 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 climate model.

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

S2.1 Near-Term Priorities for Coupled Modeling

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

The improved parameterization of land surface processes and warm season convective precipitation in coupled models will be a major focus of interest within GCIP in the next two years, and the intention to begin providing a soil moisture product for at least portions of the Arkansas-Red River basin in Oklahoma during 1997 will provide a critical new resource for such studies. Equally, the planned joint NOAA-NASA call for proposals is an important new opportunity to implement the most essential aspects of an ISLSCP initiative within GCIP. In this context, the basin-wide introduction of advanced representations of the biosphere that are able to exploit remotely sensed data is particularly important, because this will provide a basis for understanding the significance of the seasonal behavior of vegetation in coupled models, and of assessing the biosphere response to extreme conditions of water shortage. The Enhanced Seasonal Observing Period during the winter of 1997 provides the data needs for beginning the studies and modeling of cold season processes with emphasis on the problems of snow cover.

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

Now that complementary studies of ocean-atmosphere interactions within the Pan American climate Studies (PACS) and of land-atmosphere interactions under GCIP are both beginning to make noteworthy progress, it is timely to begin defining and implementing a coordinated US seasonal-to-interannual research program. Consistent with the priorities of the Global Ocean-Atmosphere Land System (GOALS), such a program will have focus on documenting, understanding and modeling the Mexican Monsoon and the indirect impact of this hydroclimatic feature on the summer season climate elsewhere on the North American continent. In this context, the need to correct the weakness of a missing observational interface between PACS and GCIP is a particularly important issue in this planning process.

S2.3 Improvements to Coupled Mesoscale Models

An operational" path (Figure S-1) was started very early in 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.

S2.3.1 Near-Term Priorities for Coupled Mesoscale Models

(1) - Utilize 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 humidty.

(2)- Produce plots and graphs of the monthly Mississippi River Basin water budget components from the ETA, MAPS, and RFE systems. Compare with similar but independently computed budget components from observations.

S2.3.2 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, Mesoscale Analysis and Prediction System (MAPS), and Regional Finite Element (RFE) 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 RFE assimilation and forecast systems. Also study the convective stability index products from these 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 Modeling And Water Resources

One of the eventual aims of the GCIP modeling effort is to generate inputs for operational hydrological and water resources management models over a range of time scales.

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

GCIP plans to increase the level of effort in this area. It has been working with the Office of Hydrology in the area of hydrologic modeling with the hope that some links will be forged with water resource agencies through this initiative. The priority for the Des Moines River Basin in the Upper Mississippi River basin, the first basin in the nation where the Office of Hydrology is installing its Advanced Hydrologic Prediction System, is recognition that links to water resource managers could be strengthened within this area -

In the past, a Water Resources Principal Research Area has considered the issue of climate change and water resources. Since the priorities for GCIP in this area have now broadened with the clarification of the GCIP mission statement by the National Academy of Sciences, a focus on hydrologic modeling and its application to water resources is now taking place in GCIP. Further, it was recognized at the GCIP Workshop for studies and modeling in the Ohio and Tennessee River basins that 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 the Ohio and Tennessee River basins in particular. This has led to some early planning for an experimental streamflow forecast capability for the two river systems.

S4. Data Assimilation

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

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

Based on some initial 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/surface 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). These may include not only new sources of atmospheric moisture information, but also process rates such as rainfall rate, streamflow, and Top-of-Atmosphere radiative fluxes, and various soil- moisture measurements; and,

- understanding of uncertainty in GCIP analyzed data sets.

S5. Diagnostic Studies

The diagnostics studies activities are directed toward deriving quantitative descriptions of the annual, interannual and spatial variability of the water and energy cycles over the Mississippi River basin.

GCIP Objective: *Determine the time-space variability of the hydrological and energy budgets over the Mississippi basin.*

Diagnostics studies 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 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.

The near term priority and strategy is to describe the water budgets over the GCIP domain through utilization of observations in conjunction with model analyses to arrive at a better understanding of the hydrologic cycle. Specific activities over the period covered in this Major Activities Plan include further investigations of the full four-dimensional continental scale water budgets based on radiosonde, wind profiler, precipitation and river discharge observations in comparison to model-based analyses with particular emphasis on the output from the regional mesoscale models producing the output for GCIP. Water budget components will also be examined over the major sub-basins of the Missipi River basin and on some of the Intermediate and Small Scale Areas used as focus study areas for GCIP. The effects of spatial and temporal sampling on 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 no direct measurements that can be used for comparison, in particular regarding radiation terms. The near term approach will be to estimate residual diabatic heating from regional model analyses to check for consistency with other analyses and regions.

S6. Observation Enhancements and Derived Products

S6.1 Precipitation

Overall Objective: *Achieve 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

Near-Term Priorities for Precipitation Research

Investigate over diverse areas of the Mississippi River basin the structure of the subgrid scale variability of rainfall as a function of storm type (e.g., cold vs. warm season rainfall, stratiform vs. convective) and propose schemes for parameterizing this variability in atmospheric models.

Assess the limits of predictability of atmospheric model precipitation as a function of scale and understand the effects of relative patterns of convective/stratiform rainfall and of subgrid scale spatial rainfall variability on rainfall prediction and on the surface water and energy partitioning via coupled modeling.

Inputs are needed on the degree of sensitivity of coupled models to rainfall spatial variability to enable precipitation investigators to assess the utility and degree to which this variability is worth resolving. Also, based on the premise that two-way coupling (atmosphere to land to the atmosphere feedbacks) will not only improve hydrologic predictions but also rainfall predictions themselves, we need collaboration on the best hydrologic modules that should be used to examine the sensitivity of rainfall predictions to this two-way coupling and determine how rainfall predictability can be improved through this coupling.

A timely provision of a range of data sets is needed (especially routine WSR-88D, GOES satellite, rain- gauge-network data, soundings and frequent observations of standard surface meteorological variables) to test the performance of atmospheric model rainfall predictions and investigate how these predictions can be further improved.

Precipitation Research Long Term Items To Be Initiated In Next Two Years

As some issues are resolved in specific settings, e.g. effect of subgrid scale rainfall variability on surface fluxes, we should move also towards the direction of extremes and especially, heavy precipitation producing systems in the Mississippi River Basin.

Also, include orography and understanding of how the resolution of orography affects rainfall predictions that determine forecasts of hydrologic balances and flooding over the whole basin, and develop methods for better use of WSR-88D scans over complex terrain (especially use of information obtained in higher elevation angle scans, and possibly modifying the scans over complex topography to take advantage of this information.)

S6.1.2 Precipitation Measurement and Analysis

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 four to 50 km.*

Near-Term Priorities for Precipitation Measurement and Analysis

Evaluate if current precipitation products (e.g., hourly 4x4 km composites) meet GCIP requirements for atmospheric model verification studies and for analysis of space-time precipitation structures. Also work towards improving the availability and quality of WSR-88D and concurrent atmospheric observations (e.g., GOES satellite data, soundings, etc.) for GCIP precipitation research.

GCIP is making use of the national stage IV precipitation analysis being produced by NOAA/NCEP. Near-term priority improvements for this product include:

(1) - Adapt and apply Stage III-type automated quality assurance algorithms for filtering and/or "flagging" such analysis problems as anomalous propagation, bright bands, and grossly erroneous gauge reports. Utilize the rich NCEP and NESDIS centralized hourly databases of atmospheric analyses (e.g. temperature, freezing level) and satellite retrievals (e.g. cloud cover and hourly precipitation estimates) to apply filtering algorithms beyond those feasible at the local RFC.

(2) - Develop a terrain-height database for the national 4-km "HRAP" grid. Use this terrain database and known elevations of WSR-88D radar sites to identify and flag beam blockage prone regions in the Stage IV analysis.

(3) - Investigate the feasibility of a GCIP archive of operational hourly RFC Stage III precipitation analyses to build a national mosaic of Stage III for GCIP research studies.

Longer term improvements to Stage IV precipitation analysis for GCIP research which should be initiated in the next two years include:

(1) - Perform a retrospective 24-hour gauge-only precipitation analysis using the GCIP composite gauge data set. Consider applying gauge correction algorithms for wind exposure effects, etc.

(2) - At NCEP, develop a realtime "final" 24-hour gage/radar precipitation analysis by using the vastly more spatially dense set of realtime 24-hour gage reports. Merge this latter set with a derived set of 24-hour summations of the realtime hourly, 3-hourly, and 6-hourly gauge reports.

(3) - Evaluate the hourly, 3-hourly, 6-hourly, and 24-hourly precipitation gauge reports routinely available to the RFC Stage III and NCEP Stage IV analyses and develop practical and reproducible automated quality control and filtering algorithms for the gauge data.

S6.1.3 Snow Measurements

A GCIP study is underway to design techniques for correcting the in-situ snow measurements for systematic biases due to exposure and wind losses. These techniques will be used to prepare a corrected set of snowfall measurements on a daily and monthly timescale for the Enhanced Seasonal Observing Period in the Upper Mississippi River basin during Water Year 1997. Such corrections will also be applied to the same region during Water Year 1998.

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

A validated soil moisture product will be developed for at least a portion of the Arkansas-Red River basin at a spatial scale of about 40 km and a daily temporal scale for four depths corresponding to the regional mesoscale model output archived for GCIP studies. This should start in 1997 to take advantage of the planned aircraft campaign over a portion of the ARM/CART site in June and July 1997. 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, and remote sensing.

A large scale (~ 10,000 sq km) aircraft remote sensing data collection campaign to provide a relatively long term data set approaching the type of data one would get with satellite remote sensing. Selecting and carrying out a series of imbedded experiments that address issues of model derived soil moisture, scaling and uncertainties.

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.

Longer term items that should be started in 1997 include:

- Analysis of existing remote sensing data (RADARSAT, ERS-1&2, SAR , SCAT,and SSM/I) to estimate the information content that can be used to achieve the goals for the soil moisture contributions to GCIP.

- Develop procedures to extrapolate or assimilate point data to basin and regional scales.

S6.3 Land Surface Characteristics

The goal of land surface characterization research within GCIP is to 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 use and evaluation of existing land surface characteristics data sets at the continental scale. Although several key land surface characteristics data sets are now available for GCIP researchers, considerable efforts are still needed to apply and test these new data sets. Specific efforts are needed to expand the use of these land surface characteristics data bases. For example, atmospheric modelers need to incorporate the new soils data base into their analysis, especially within the land surface parameterizations for mesoscale models.

Evaluation and/or validation of these land surface data sets by the data-providers and GCIP researchers is needed. In most cases, these data sets are aggregated to a coarser resolution for use in the land surface parameterizations, for example, 20-50 km grid cells for continental scale analysis. The method of aggregation is typically based on the use of the "predominant" class within the model grid cell.

Deliver enhanced land surface characteristics data sets and place them on-line for easy access. The NASA- led ISLSCP/GEWEX Initiative Number 2 could provide enhanced biophysical land cover land cover parameters at a 0.5 degree grid size by late 1997.

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

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

Conduct land surface characterization research on rules for aggregation of land surface data in grid cells, scaling of point processes to the landscape level, and investigation of multiresolution interrelationships among land cover, soils, and topographic characteristics data sets.

Conduct advanced land surface characterization research using physically-based models and remote sensing algorithms. For example, atmospherically corrected satellite reflectance data are needed to 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.

Develop plans to review and incorporate 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 scientific algorithms under development by the MODIS Land Science Team are of particular relevance to GCIP. In addition, current 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 Streamflow/Runoff

Over 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.

Near-Term Priorities for Streamflow/Runoff

Extend the available historical data base for unregulated basins at the intermediate and small scales (10 to 1000 km2) 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.

S6.5 Clouds and Radiation

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 offline 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 snowcovered 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, snowcover, 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 models in the Eta and other regional and global models need improvement and 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.

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.ncdc.noaa.gov/gcip/gcip_home.html

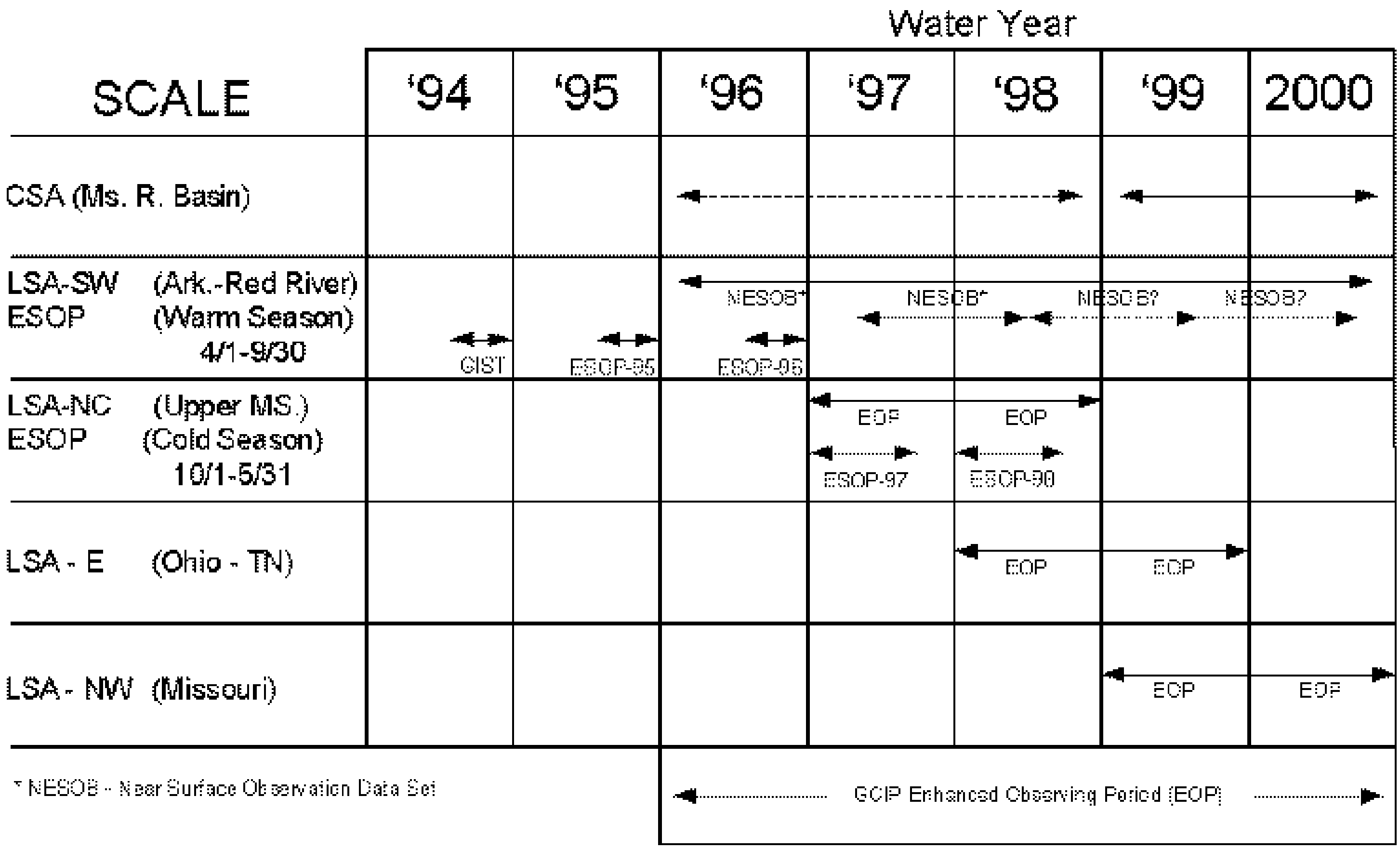


Figure S-3 Compiled and Planned Standard Data Sets for GCIP Research.

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 June 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).

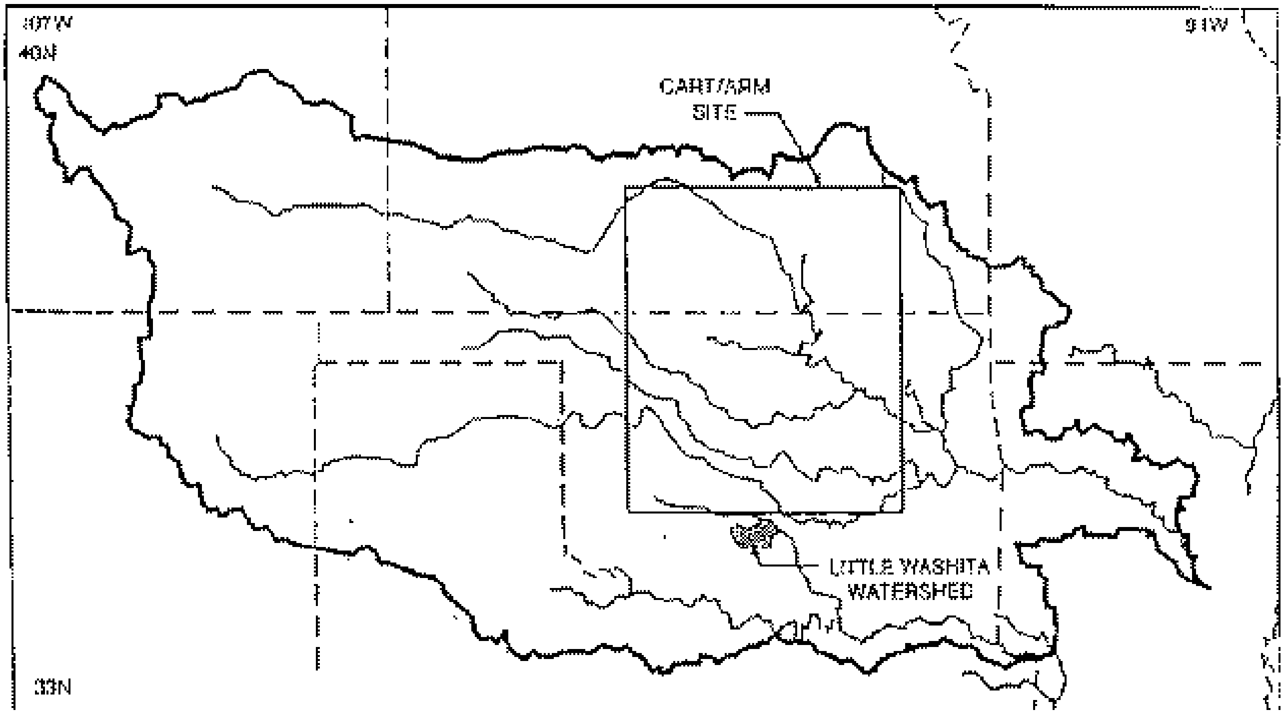


Figure S-4 The LSA-SW Encompasses the Arkansas-Red river basin. GCIP Focus Study Areas in the LSA-SW Include the CART/ARM Site Operated by the Department of Energy and the Little Washita Watershed Operated by the USDA/Agriculture Research Service.

S7.2 Data Sets for Cold Periods

The data collection activities for Water Years(WY) 1997 and 1998 will include the cold season in the Upper Missipi River basin identified as the LSA-NC in Figure S-5. The details of the data to be collected during the first period are given in the Tactical Data Collection and Management Plan for the 1997 Enhanced Seasonal Observing Period (ESOP-97).

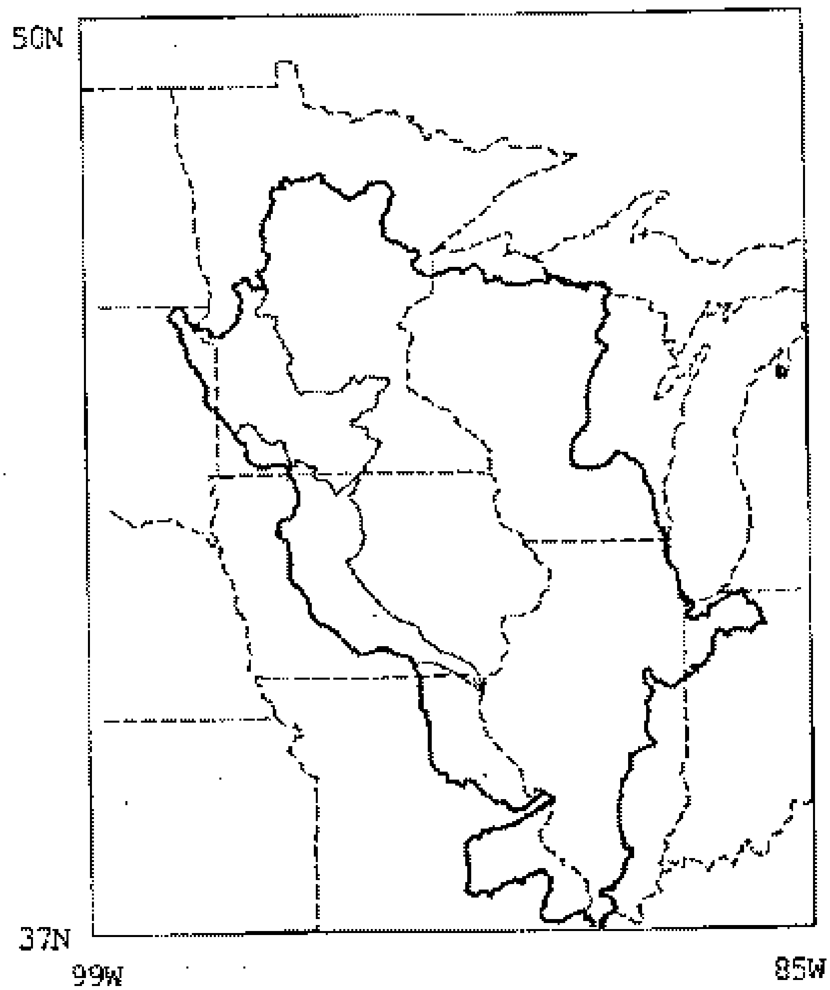


Figure S-5 The LSA-NC encompasses the Upper Mississippi River basin. GCIP Focus Study Areas in the LSA-NC include the Des Moines River and Minnesota River basins outlined in the western part of the basin and the State of Illinois.

S7.3 Data Sets for 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 there are plans to compile a Near Surface Observation (NESOB) Data set for at least one 12-month period beginning 1 April 1997. This special dataset 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.

This integrated dataset will be compiled for the geographical area which includes both the ARM/CART site and the Little Washita Watershed in the Arkansas-Red River basin. The vertical dimension will include from 3000 meters above the surface to two meters below the surface with the specific types of observations listed in Table S-1.

The preparation of the archive data for streamflow by the U.S. Geological Survey is done on a Water Year (1 October to 30 September) 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 will remain largely distributed among different data centers through WY 1998. It was shown in Figure S-3 that composite data sets for the Mississippi River basin are planned to be compiled beginning in 1999.

TABLE S-1. Types of Observations in each Layer of Near Surface Observation Data Set

---

1. Boundary Layer Z < 3000 meters

- 1.1 Temperature profiles
- 1.2 Water vapor profiles
- 1.3 Wind profiles
- 1.4 Clouds

2. Surface (0 < Z <10 meters)

- 2.1 Temperature, Specific Humidity, Wind Component, and Surface Pressure
  - U & V component wind speed at 10 m
  - Temperature at 2 m
  - Specific humidity at 2 m
  - Surface pressure
- 2.2 Surface momentum flux
  - Surface U wind stress
  - Surface V wind stress
- 2.3 Surface sensible and latent heat fluxes
  - Surface latent heat flux
  - Surface sensible heat flux
  - Soil heat flux to Surface
- 2.4 Surface skin temperature
- 2.5 Precipitation (including snow)
- 2.6 Surface Radiation
  - Downward shortwave
  - Upward shortwave (albedo)
  - Downward longwave
  - Upward longwave
  - Net radiation (measured)
  - Photosynthetically Active Radiation (PAR)
- 2.7 Surface and ground water
- 2.8 Vegetation type and characteristics
- 2.9 Site Description

3. Sub-surface (-2 < Z < 0 meters)

- 3.1 Soil moisture (profiles)
- 3.2 Soil temperature (profiles)
- 3.3 Soil physical and hydraulic properties
- 3.4 Wilting point
- 3.5 Rooting zone
- 3.6 Field capacity

Note: A hard copy of the complete Plan is available in two parts:

> **PART I - RESEARCH**
> **PART II - Data Collection and Management**

Copies can be ordered from the GCIP Project Office at:

> **e-mail-** gcip@ogp.noaa.gov
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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.

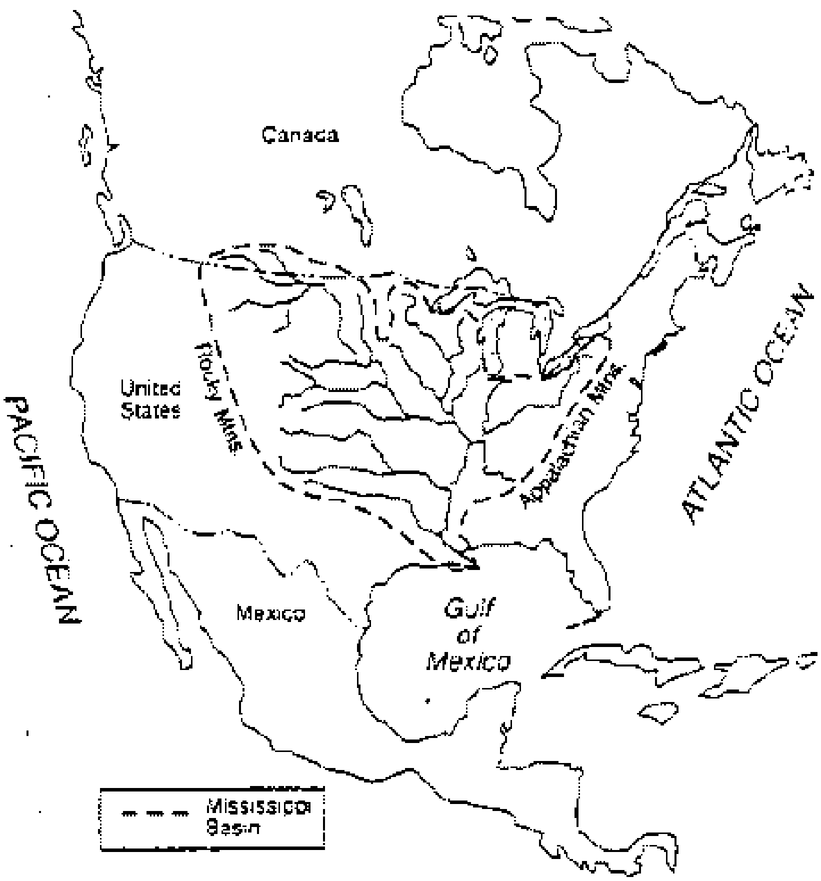


Figure 1-1 The Mississippi River basin, the focus of GCIP activities.

1.2 GCIP Objectives

A recently completed review by the NAS/NRC GEWEX Panel recommended that GCIP should focus more on the seasonal to interannual prediction problem and recommended the following scientific mission for GCIP:

*"**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.**"*

The Panel further recommended some restatement of the original science objectives to more clearly focus on the seasonal to interannual prediction problem and to add an objective pertaining to data management. GCIP has adopted these modified objectives to better reflect the emphasis of the Project which has evolved over the past five years since the completion of the GCIP Science Plan (World Meteorological Organization, 1992). The GCIP objectives are:

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.

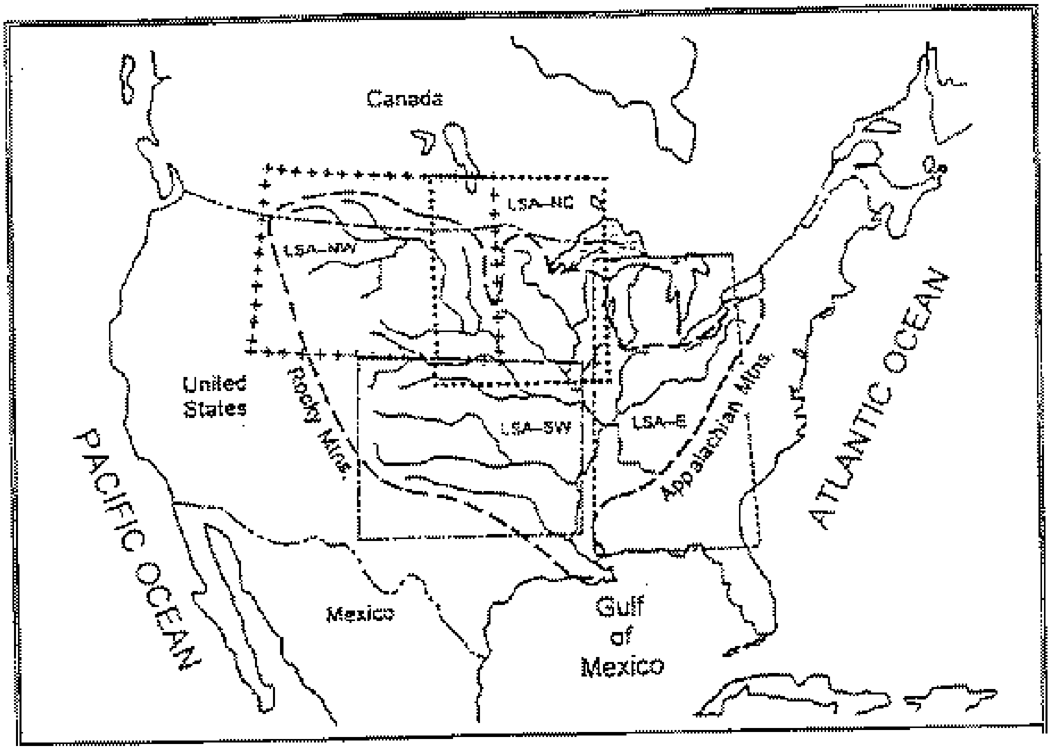
The understanding and modeling of a continental scale require, from the outset, consideration of nonlinear-scale interactions in the aggregation of smaller processes to the larger scale and vice versa. Progress in this area requires that methodologies be developed to represent the coupling of processes 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.



TIME PHASING OF GCIP RESEARCH EMPHASIS

	FISCAL OR WATER YEAR						
Multi-Scale Framework	1994 GIST	1995 ESOP	1996 ENHANCED	1997	1998 OBSERVING	1999	2000 PERIOD
Continental Scale Area	*	*	***	***	***	***	***
Large Scale Areas (LSAs)							
LSA-SW ——>	***	***	***	***	**	**	**
LSA-NC ——>	*	*	*	***	***	*	*
LSA-E ——>	*	*	*	*	***	***	*
LSA-NW ——>	*	*	*	*	*	***	***

*** High
** Moderate
* Low

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

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 will be 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 will be 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 will be 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 will continue to be the main focus in the near- term. In fact, as the EOP proceeds, the GCIP-derived budgets based on regional mesoscale models will likely be 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 four 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).

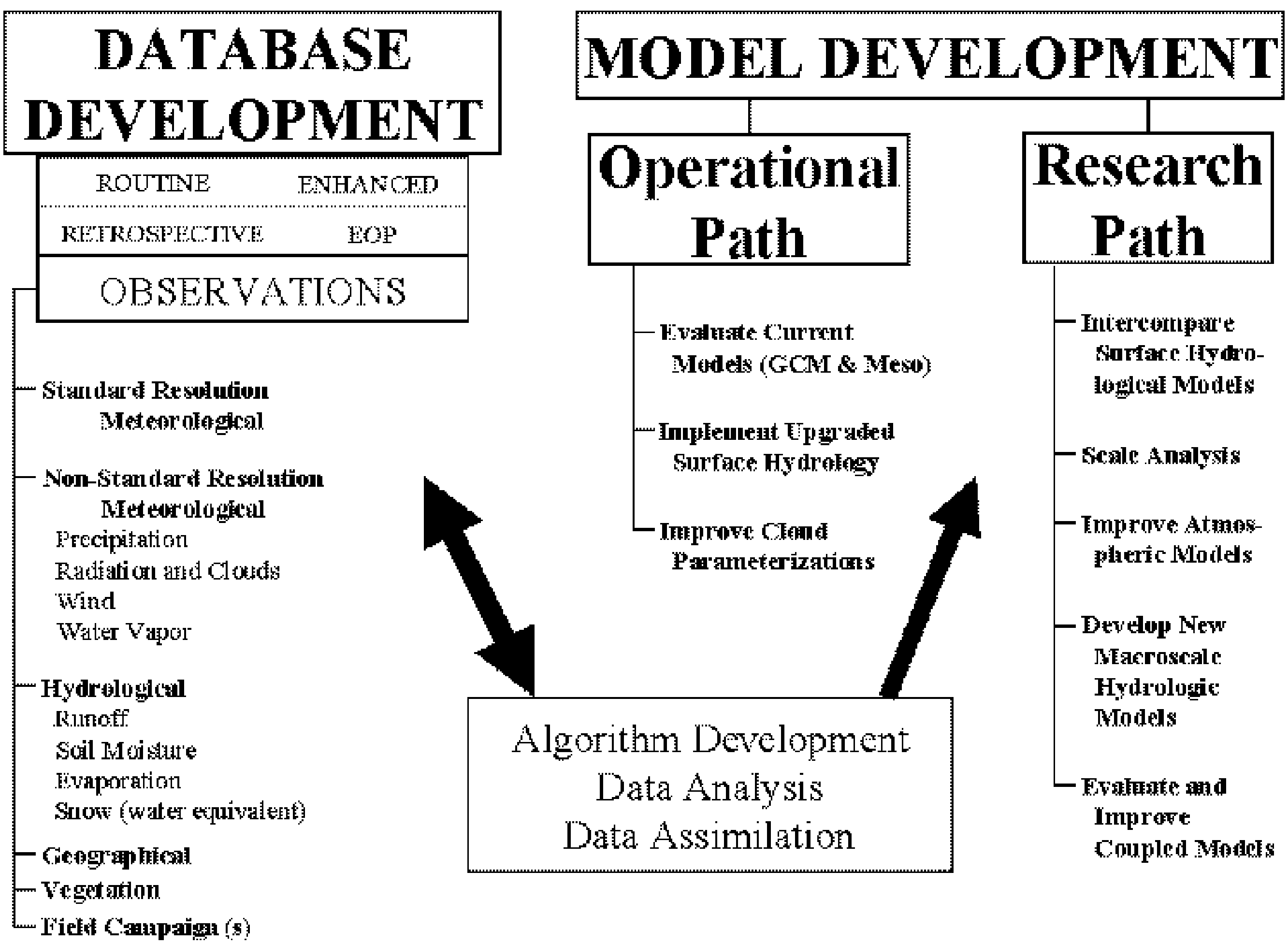


Figure 1-3 Strategy framework for implementing GCIP.

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.

1.4.2 Research Path Achievements

The GCIP research activities got underway in 1993 with primary support from NOAA. The achievements to date can be grouped under four headings of data analysis, model development, diagnostics of model output, and observing system enhancements. A more comprehensive review of this activity was published in a special issue of the Journal of Geophysical Research Volume 101, Number D3, March 20, 1996.

i. Data Analysis
- Precipitation variability and extreme events: Implications for climate models and climate change
- Physically-based subgrid scale statistical parameterization of rainfall: Coupling mesoscale meteorology with small scale statistical descriptions
- Characterization and modeling of snow distribution and associated land surface hydrology over mountainous watersheds
- Snow cover as an indicator of anthropogenic change
- Analysis and modeling of the hydrological cycle using Russian data

ii. Model Development
- Dynamic land surface/atmosphere parameterization at different spatial scales for the South Platte River Drainage
- Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS)
- Coupled boundary-layer formulation and land surface processes
- Using the Mesoscale Kinetic Energy (MKE) to Parameterize Subgridscale (Mesoscale) Processes in General Circulation Models
- Evaluation of GCM Land-Surface Schemes in GCIP

iii. Diagnostics of Model Output
- Summaries of North American continental-scale hydrology using ETA Model analysis/forecast products
- North American land surface/atmosphere hydrological cycle
- Prediction and diagnosis of atmospheric moisture and surface hydrology variations over North America

iv. Observing System Enhancements
- Aircraft Water Vapor Sensing System
- Automated soil moisture and temperature profile measurements at the DoE ARM/CART Southern Great Plains Site for GCIP
- Surface flux measurements in the Little Washita Watershed in Oklahoma and Bondville, Illinois
- Surface Radiation (SURFRAD) measurements at three sites in the Mississippi River basin.

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 Environmental Prediction Center [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 NMC Eta Model and the NOAA Forecast Systems Laboratory MAPS Model are both high resolution nested regional models, the ECMWF and NMC operate global models at coarser resolution while the CMC uses a variable grid approach with the Regional Finite Element (RFE) imbedded within a global model. All these model outputs 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 Section 11.

Improved land surface schemes were implemented in the three regional models prior to the Enhanced Seasonal Observing Period from 1 April to 30 September 1996.

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. Each of these items is summarized in Part II of this Major Activities Plan.

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) as depicted in Figure 1-4. 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).

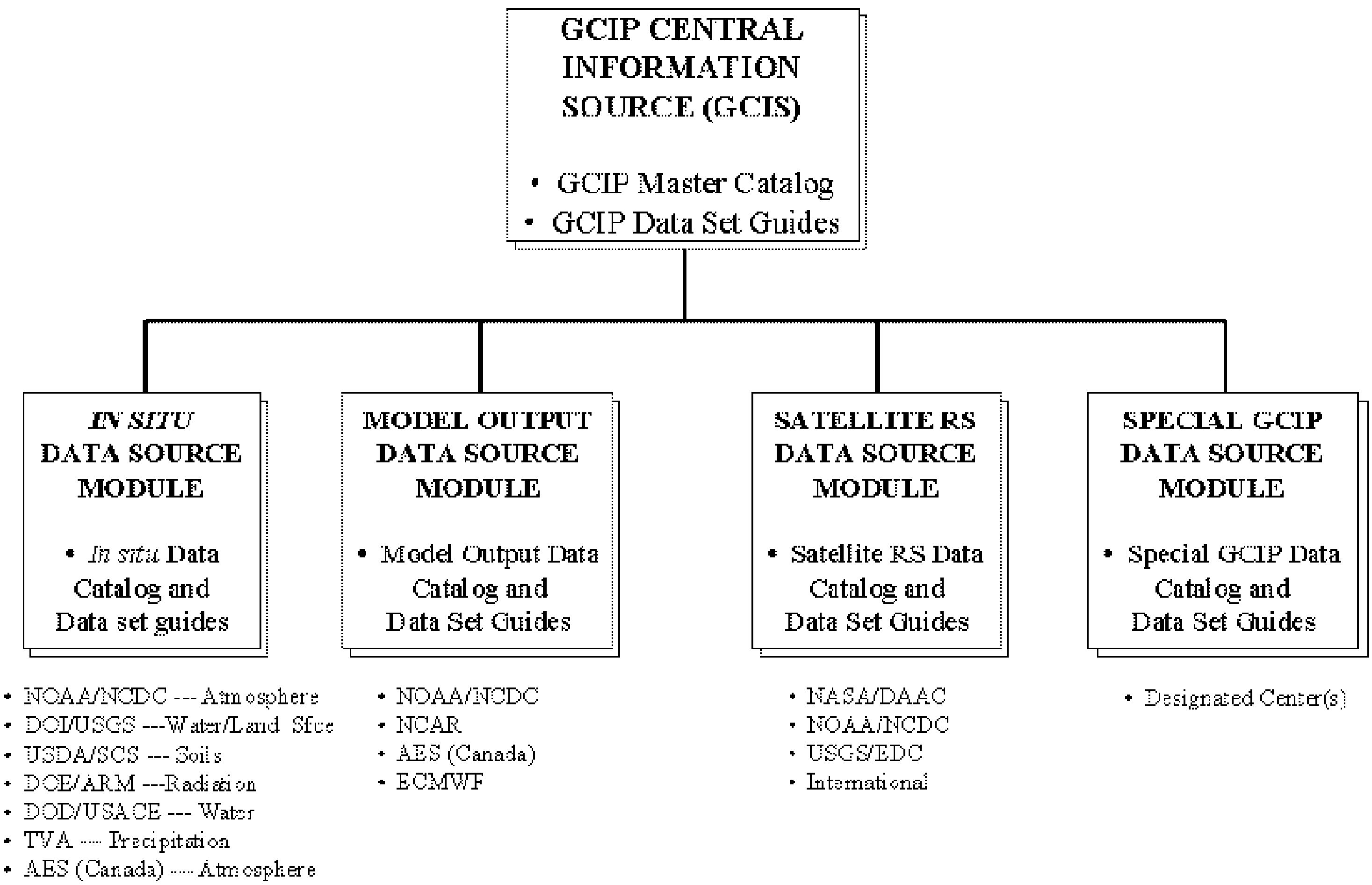


Figure 1-4 Organization of GCIP Data Management System.

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 last year (IGPO, 1995).

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 1997, 1998 and outlook for 1999. 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. The structure of the Major Activities Plan during the first two years was to concentrate on the activities in each of the LSAs. Since activities are planned for each of the four LSAs, this will spread out the descriptions pertaining to specific objectives. For this reason the Plan is divided into two parts. Part I entitled Research devotes a section to each of the four science objectives and is described in Sections 2,3,4, and 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, streamflow and runoff, 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 Part II of this plan entitled Data Collection and Management.

2. COUPLED MODEL DEVELOPMENT AND EVALUATION

Goal: *Develop a coupled hydrologic/atmospheric model with an initial validation focus on the Mississippi River basin at a time scale of days to seasons increasing to an interannual time scale.*

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.

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 objective:

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

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 held in May 1996 resulted in a number of recommendations which are incorporated in this and other sections of the Major Activities Plan for 1997, 1998 and Outlook for 1999.

An "operational" path was started in 1993 during in 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 11 of this plan.

The activities for each of these paths are described in the remainder of this section.

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 Recommended by the GCIP Coupled Modeling Workshop

---

1. "*To what extent is meterological 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:**

- Exploratory 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 Biospheric Processes

- ISLSCP's Proposed Vegetation Studies within GCIP

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 Seasonal Predictability Evidence and Mechanisms

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 during the subsequent months. Atmospheric general circulation model runs are required with improved representation of interactive moist processes to test this hypothesis and to determine the conditions and limitations under which it might apply. Diagnostic studies are also needed. 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.

2.2.1.2 Coupling importance over an 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. Understanding this seasonal variation will aid in defining the relative complexity required in the representation for different hydrologic-atmospheric coupling processes when used for meteorological 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 Exploratory seasonal-to-interannual predictions

Although there are unresolved scientific issues regarding the optimum representation of physical processes in coupled hydrologic-atmospheric models, the viability of the land-surface schemes presently being used at operational forecast centers is such that 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 skill should be limited to capturing modest indications of regional-scale monthly or seasonal anomalies in precipitation and temperature.

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 12. 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 as a priority in GCIP. 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. To assess 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.

(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

Within the climate system, near-surface soil moisture possesses a memory due to 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. Preliminary modeling investigations (e.g. Avissar and Liu, 1996) indicate that naturally occurring soil moisture heterogeneity (acting through land-atmosphere coupling processes) significantly influences the behavior of the overlying atmosphere. Progress in understanding the effect of area-average soil moisture, understanding the effect of 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 measurement

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.

Exploratory installation of automatic soil moisture sensors within the ARM-CART array is underway, and plans are being made to extend deployment to the Oklahoma Mesonet and similar distributed data collection networks elsewhere in the Mississippi River basin. GCIP has an interest in deploying a set of soil moisture (and temperature) profile measurements along a north-south transect in the North-Central study area to make observations over the annual cycle, but with emphasis on documenting freezing and thawing episodes during the cold season. Meanwhile, there is investigation of the value of installing soil moisture measurements along a transect from the Little Washita watershed in Oklahoma to the Shingobee watershed in northern Minnesota. Pending 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 satellite 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 would greatly illuminate this issue. The coupled modeling community is aware of and applauds upcoming NASA-sponsored field studies within the ARM-CART study area in the Mississippi River basin that fulfill many of these observational needs, and look forward to working with the data that will result (see next section).

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

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 and latent-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.

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.

(3) Improved parameterization of hydrologic submodels

Model parameter estimation is closely tied to model development. Model parameters in the hydrologic part of coupled models vary spatially and may also vary seasonally. Local model parameters are estimated on the basis of information about vegetation, soils and geology, and gridded fields of soils and vegetation characteristics are needed at various scales to provide such estimates. Many such gridded maps have been developed for the GCIP study area, but this process needs to continue. Procedures for estimating model parameters from these gridded data have been developed and have been used to calculate distributed fields of model parameters for some schemes, but the parameter estimation procedures used are largely untested, and it is known that there are wide margins of uncertainty in the ensuing estimates of parameters, such as rooting depth and the hydraulic characteristics of soils. Because model performance is highly sensitive to the value of these parameters, validation and improvement of methods for parameter estimation are needed. Hydrologic schemes might be improved by selecting a model structure which minimizes the effect of parameter uncertainty on model output. There are already a wide range of models available, and the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) has shown that the available schemes can indeed produce a wide range of different results, given the same parameterization data. No doubt part of this difference is due to model structure differences, but part is due to the way model parameters are estimated from the same basic parameterization data.

One factor which limits tests of the credibility of model parameter estimation techniques is the fact that validation data are not readily available. However, streamflow data can be used together with observations of precipitation and estimates of meteorological forcing from surface observations to validate the performance of hydrologic models and, hence, the procedures used to select the parameters applied within them. As a possible GCIP initiative, historical data series of these variables which last at least 10 years (to sample interannual variability) could be organized for some river basins over a wide range of climatic settings, and these then could be made available to the scientific community for the purpose of model parameter validation. Such data could be used to test the parameter estimation schemes used in a selection of hydrologic models as a precursor to their possible inclusion in coupled models.

A general approach and overall strategy for parameter estimation and testing as a precursor to coupled model experiments is illustrated in Figure 2-1. This figure is a process diagram that illustrates how activities fit together to produce the primary outputs expected from the off-line experiments. Locations of the primary outputs are shown in Figure 2-1. These primary outputs are:

- Model test results from both stand-alone and coupled modeling;
- Improved methods for making estimates of parameter values everywhere in a model domain;
- Model parameter values and model outputs for limited test areas.
- The tasks required to produce these outputs are:
    - **a.** Investigate potential new surface hydrological parameterizations.
    - **b.** Acquire test data sets (historical precipitation, streamflow, surface meteorological observations and land surface characteristics) for a large number of basins (at least 100) for model calibration and testing. These data sets should be for long periods; at least 10 and preferably 50 years. **c.** Calibrate model parameters.
    - **d.** Investigate relationship between model parameters and land surface characteristics of the basins (topography, soils, vegetation, etc.).
    - **e.** Evaluate possible dependence of model parameters on climate.
    - **f.** Estimate model parameters using land surface properties (and climate characteristics if needed).
    - **g.** Operate parameterization in off-line mode using GCM and observed data to test performance over the GCIP study area.
    - **h.** Implement parameterization in Regional NWP Models and GCMs and evaluate results.

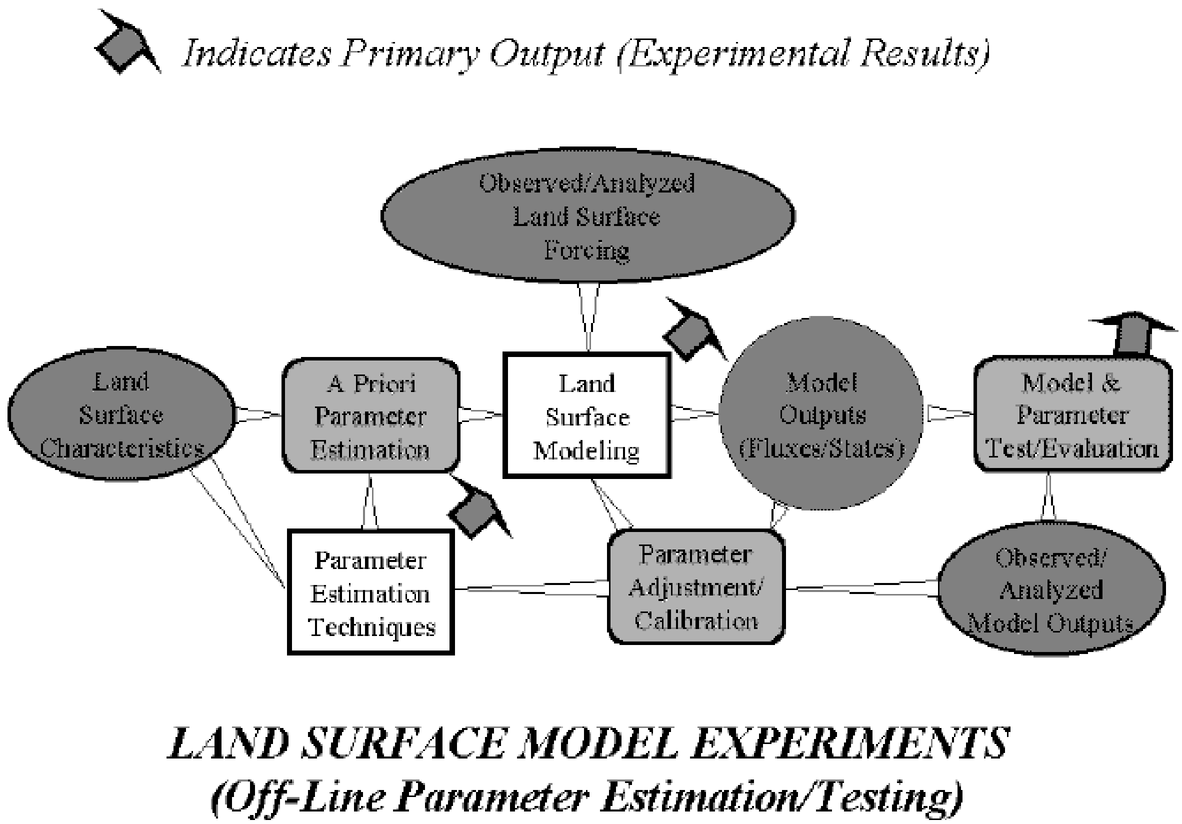


Figure 2-1 Strategy for Coupled Model Experiments.

The parameter estimation strategy will be to build on existing experience with a priori parameter estimation using available land surface characteristics information, previous investigations of "effective" parameters that account for sub-grid variability of the actual parameters, and parameter calibration techniques that have been developed by the hydrology modeling community. As illustrated in Figure 2-1, this strategy involves beginning with existing a priori parameter estimates, using them in test watersheds to see how well they function over many years. The primary variable for the long term tests will be runoff, but soil moisture and surface flux data are available for limited periods at a few places. Adjustments can be made in the a priori parameters to get improved model performance. The basis for these adjustments might include theoretical analyses of scaling relationships or analyses of parameter sensitivity and uncertainty. Then, new relationships (some may be empirical) between adjusted parameter values and climate, soils and vegetation characteristics that can be known globally will be developed. These will be applied to other test watersheds and evaluated.

2.2.3.3 Biospheric processes

Vegetation influences several aspects of the hydrological cycle. There is long-standing evidence that vegetation cover affects catchment runoff. Foliage is known to exert active biological control on transpiration by regulating the stomatal pores through which water vapor leaves the plant. The morphology of plant canopies also influences the absorption of solar energy and the generation of turbulence. These factors together influence the partitioning of available energy into sensible heat and latent heat, and the heat flow into and out of the soil. The sensitivity of stomata to soil moisture change is small at high soil moisture values, but it is ultimately a strongly limiting control on transpiration flux at low soil moistures.

The International Satellite Land Surface Climatology Project (ISLSCP) has proposed NASA-sponsored observations and modeling studies to define the coupling between the biosphere and atmosphere across the GCIP study area. Long-term and continuous measurements of mass and energy fluxes and planetary boundary-layer characteristics are proposed for selected sites in the GCIP domain. These continuous tower-based measurements will allow documentation of diurnal, seasonal, and interannual variations in surface energy fluxes and PBL growth and also capture unexpected but important meteorological events such as drought and storms. The proposed sites would be established over representative land surfaces in the GCIP domain, such as crops, rangeland, and broadleaf forests. They will provide information on meteorological and biological variables needed to test and parameterize the soil-vegetation-atmosphere models which will be the repository of understanding of biosphere-atmosphere coupling in this ISLSCP initiative. Flux measurements at individual tower sites measure surface fluxes only over a limited upwind area and would be augmented with short-term studies over a larger area to determine how representative the towers are. Experimental campaigns with instrumented aircraft are the proposed mechanism to assess the spatial statistics associated with surface characteristics and with surface energy fluxes.

A hierarchy of models, including the most advanced biosphere-atmosphere models currently available, would then be tested against these observations. These would be used as the basis for developing simpler, mechanistically-based models that can be implemented by forecast meteorologists, hydrologists, and climatologists. Scientific foci of this proposed ISLSCP study would be the better determination of seasonality in leaf cover and ensuing changes in biospheric parameters; the biospheric response to seasonal changes in atmospheric demand, with particular attention to changes in the response of vegetation in extreme conditions; and the extension of current understanding on biospheric processes to the dominant land covers within the GCIP domain. Such scientific issues are important aspects of the GCIP coupled modeling research agenda, and the recent Coupled Modeling Workshop strongly supported this NASA-sponsored initiative.

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

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/RFE) 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 initial Mississippi River Basin water budget studies based on these Eta model GCIP archive products (Berbery et al., 1996; Yarosh et al. 1996).

NCEP, over the last three years with GCIP support, has accelerated ETA/EDAS improvements in the following three key areas:

- Coupled land-surface/hydrology model
- 4DDA Assimilation techniques and data sources
- Explicit cloud physics for precipitation and radiation

These three improvement areas have resulted in the following specific items implemented in the ETA/EDAS system:

- October 1995: Explicit microphysics for cloud water and ice was added, with attendant improvements in the accuracy of precipitation and radiation (Zhao and Carr, 1996).

- October 1995: Realtime, routine assimilation of SSM/I total column water vapor over oceans in the EDAS.

- January 1996: The new NCEP/OSU land-surface package was implemented, with two soil layers, time-dependent soil moisture, seasonally varying vegetation, and snowpack (Chen et al., 1996a, Chen et al., 1996b, Betts et al., 1996, (Janjic, 1994).

- May 1996: Realtime generation and archive of National Stage IV gage/radar hourly 4-km precipitation analysis (an important prerequsite for assimilation of precipitation in the EDAS).

Following three years of NCEP/EMC focused effort as a key participant in the NOAA-sponsored, land-surface related, GCIP project (in collaboration with the NWS Office of Hydrology), EMC operationally implemented in January 1996 a new multi-layer soil/vegetation scheme in the Eta model (see Secs 3.1.1 and 3.1.2 of Chen et. al. 1996a, also Chen et. al. 1996b). This land-surface physics package includes two soil layers, time dependent soil moisture and temperature, spatially varying vegetation and soil types, a seasonal vegetation cycle, snowpack physics, and runoff. A related land-surface scheme was implemented in the NCEP/EMC global model and its continuous global data assimilation system, which includes continuous cycling of soil moisture and soil temperature. The Eta model soil moisture and soil temperature are initialized from the latter global data assimilation system with improvements planned for a continuous cycling as identified late in this section. The snowdepth is initialized from a daily 47-km Northern Hemisphere Air Force snowdepth analysis.

The following is a list of ongoing GCIP-focused ETA/EDAS developments now underway with a projected implementation in the next 24 months or less:

Dynamics:
(a) - quasi Lagrangian advection of water vapor/cloud water
(b) - non-hydrostatic numerics

Physics:
(a) - improve land-surface scheme including increase from 2 to 4 soil layers, allow non-uniform root distribution, upgrade snowpack and frozen soil physics, refine key hydraulic, infiltration, and runoff parameters, refine vegetation and soils specification
(b) - test alternative deep and shallow convection schemes, such as Kain-Fritsch to include explicit treatment of the low-level cold outflow and convection initiation due to downdrafts
(c)- upgrade the radiation scheme and its interaction with clouds, including reduction of positive surface solar insolation bias

Data Assimilation:
(a) - a continuously cycled 24-hour EDAS (including soil moisture)
(b) - assimilate NCEP hourly 4-km U.S. gage/radar precip analysis (should significantly improve cycled soil moisture)
(c) - 3-D and 4-D variational assimilation
-- assimilate WSR-88D radar products (e.g. radial winds)
-- assimilate satellite radiances directly

A 4-dimensional Variational Assimilation (4-D VAR) System is in advanced development and testing, using the adjoint of the Eta model. The 4-D VAR methodology allows easier incorporation of non-traditional data sources such as direct use of satellite radiances, cloud cover, precipitation, radar reflectivities, profilers, WVSS, ACARS, and ASOS. The assimilation of one to three hourly precipitation fields and satellite estimates of atmospheric water vapor has shown significant promise in tests to date. The satellite water vapor estimates have included GOES 8/9, SSM/I, and SSM/T2.

The current ETA/EDAS system operates at a resolution of 48-km and 38 layers. The companion mesoscale Eta system operates on a 29-km resolution with 50 layers. Routine realtime testing of 10-km nested Eta grids (Eastern U.S.) was successfully accomplished for 4 months during May-Aug 96 in a special Olympic support effort. Once-a-day prototype 10-km nested Eta runs are expectedto continue at NCEP as a demonstration of concept to be evaluated by NWS field forecasters.

2.3.2 Regional Model Upgrade at CMC

It is expected that the quality of the Regional Finite Element (RFE) model outputs 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.

Surface temperature and wind forecasts should become slightly more accurate due to modifications to the surface layer formulation which will affect the free convection limit and the roughness length. More realistic surface temperature and dew point predictions should result from refined treatments of surface evaporation, snow melt, and soil humidity analysis over North America. A 35-km resolution version of the model with 28 vertical levels was implemented at the end of 1995. Improvements are being tested for its stratiform clouds (the Sundqvist scheme with explicit prediction of cloud fraction and cloud water) which are expected to have a significant impact on precipitation and three-dimensional humidity forecasts. Energy budget calculations are expected to benefit from more sophisticated solar and infrared radiation parameterizations.

Within the coming year it is expected that a meso-scale convective parameterization (perhaps Fritsch-Chappell) and a fully interactive radiation/cloud water scheme will become available. The recent installation of a NEC SX-4 supercomputer should permit a further upgrade of the model resolution to approximately 20 km, with a corresponding increase in the number of vertical levels.

By the end of the three-year period it is likely that the regional forecast model will have been converted to the non-hydrostatic variable-resolution global finite-element based model that was described in the GCIP Major Activities Plan for 1995, 1996 and Outlook for 1997 (IGPO, 1994c).

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.

Projected changes during the early part of 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

Plans for FY97 -

- 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 FY98 -

- 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.

Outlook for FY99.

- 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.

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.

3.1 Background

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.

GCIP plans to increase the level of effort in this area. It has been working with the Office of Hydrology in the area of hydrologic modeling with the hope that some links will be forged with water resource agencies through this initiative. The priority for the Des Moines River Basin in the LSA-NC is recognition that links to water resource managers could be strengthened within this area - the first basin in the nation where the Office of Hydrology is installing its Advanced Hydrologic Prediction System. Other potential links between GCIP and the Office of Hydrology will become clearer as the program is implemented.

In the past, a Water Resources Principal Research Area has considered the issue of climate change and water resources. Since the prioirties for GCIP in this area have now broadened with the clarification of the GCIP mission statement by the National Academy of Sciences, a focus on hydrologic modeling and its application to water resources is now taking place in GCIP. The results from the LSA-E detailed Design Workshop provide an excellent start along these lines. A complete summary report of this workshop is given in Appendix B. Recommendations prepared by the work session on hydrometeorological prediction and water resources management is given in the remainder of this section.

3.2 Water Resources Research in the LSA-E

The water resources working group at the LSA-E Detailed Design Workshop focused on how GCIP LSA-E activities could contribute to GCIP's evolving goals with respect to water resources. The working group focused its recommendations on those LSA-E activities which would have the greatest "spinoff" benefits for water resource systems operations. It was clear that 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 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.

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 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 would provide an excellent test site for evaluation of ensemble hydrologic forecasts derived from coupled land-atmosphere models.

3) Opportunities for diagnosis of NWP models (especially NCEP/Eta, but longer range forecast models as well as their land surface schemes are updated) 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) 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.

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 Near-Term Priorities

- Research into improved atmospheric assimilation techniques and incorporation into regional mesoscale models.
- Research into soil property assimilation
- Evaluation of assimilation data sets
- Use of soil and hydrological model adjoints for assimilation of process rate variables (This is an item which requires a significant amount of research before it can be used as an applied data assimilation technique. However, it shows sufficient potential that such research activity needs to be included as a priority item to get started during the next two years.)

5. DIAGNOSTIC STUDIES

OBJECTIVE: *Provide a better description and understanding of the factors which control the mean annual cycle and 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

A description of the activities within each of these program elements is given in the following sections.

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 (ESOP-97), 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 during the WY 1997 and for the LSA-NC during WY 1997 and WY 1998.

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 study of cold season hydrological processes (ESOP-97) and adapt the methodology to the study of hydrological processes over 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 "core" activities is on combined 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 viewed in the context of model output discussed in chapter 11.

The overall activities for budget studies include the following:

1) Water and energy budget studies over the GCIP area will be performed using both operational analyses/forecast systems and free running GCM's.

2) Intercomparisons will be performed among several regional models including the Eta, MAPS, LFE and NCEPs Regional Spectral Model.

3) Intercomparisons will be performed of model simulated precipitations and observational estimates.

4) The NCAR Climate Model CCM3 simulations will be compared to GCIP observations and model assimilated fields.

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 Budgets Variables: Atmospheric Profiles CSA & LSA Scales

VARIABLE	MEASURED	REMARKS	DERIVED	REMARKS	MODEL OUTPUT	REMARKS
Water Vapor (q)	X	RWS			X	Sec. 5.1
Dry Static Energy (CpT+qZ)			X	Investigator Derived	X	Sec. 5.1
Wind	X	RWS & Profilers			X	Sec. 5.1
Water Vapor Flux	X	Investigator Derived			X	Sec. 5.1
Dry Static Energy Flux	X	Investigator Derived			X	Sec. 5.1
Vapor Flux Divergence			X	Investigator Derived	X	Sec. 5.1
Energy Flux Divergence				Investigator Derived	X	Sec. 5.1
Longwave Flux			X	NESDIS	X	Sec. 5.1
Shortwave Flux			X	NESDIS	X	Sec. 5.1
TOA Flux			X	NESDIS	X	Sec. 5.1
Cloudiness	X	ASOS & GOES			X	Sec. 5.1
Net Radiative Heating			X	NESDIS	X	Sec. 5.1
Condensation Heating (Vertically Integrated)			X	Investigator Derived	X	Sec. 5.1

Table 5.1b Energy and Water Budget 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	Sec. 5.1
Dry Static Energy (CpT+qZ)				X	X	Investigator Derives	X	Sec. 5.1
Wind	X	X	RWS-NWS,ARM include IOP Profilers; NEXRAD					Sec. 5.1
Water Vapor Flux				X	X	Investigator Derives	X	Sec. 5.1
Dry Static Energy Flux				X	X	Investigator Derives	X	Sec. 5.1
Vapor Flux Divergence				X	X	Investigator Derives	X	Sec. 5.1
Energy Flux Divergence				X	X	Investigator Derives	X	Sec. 5.1
Longwave Flux				X	X	NESDIS;CAGEX ARM database	X	Sec. 5.1
Shortwave Flux					X	NESDIS;CAGEX ARM database	X	Sec. 5.1
TOA Flux					X	NESDIS;CAGEX ARM database	X	Sec. 5.1
Cloudiness	X	X	GOES-ASOS;Sfc Composite ARM database				X	Sec. 5.1
Net Radiative Heating					X	NESDIS;CAGEX ARM database	X	Sec. 5.1
Condensation Heating					X	Houze (WSR-88D)		
Aerosol Concentration		X	ARM Central Site database		X			

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* R. - Routine
* E. - Enhanced

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				USGS/EDC		
Vegetation (NDVI)			X	NESDIS		
Precipitation	X	Ppt. Composite obs.	X	NMC Mesoscale Analysis	X	Sec. 5.1
Storage Snow Water Equivalent			X	NOHRSC	X	Sec. 5.1
Stream Discharge	X	USGS				
Reservoir Storage	X	USGS				
Water Table (Wells)	X	Not Applicable				
Soil Moisture		Not routinely	X	GCIP/ISLSCP joint project in 1977.	X	Sec. 5.1
Surface Temperature	X	Surface Composite	X Clear sky	NESDIS	X	Sec. 5.1
Albedo			X	NESDIS	X	Sec. 5.1
"Surface" Specific Humidity	X	Surface Composite	X	NESDIS	X	Sec. 5.1
"Surface" Wind	X	Surface Composite			X	Sec. 5.1
Sensible Heat Flux			X	GCIP ISLSCP joint project in 1977.	X	Sec. 5.1
Latent heat Flux			X	GCIP ISLSCP joint project in 1977.	X	Sec. 5.1
Longwave Radiation			X	NESDIS	X	Sec. 5.1
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. 5.8 Task 5.8.5		
Vegetation (NDVI)				X		Sec. 5.8 Task 5.8.2		
Precipitation (Liquid)	X		ESOP-96 Precip Composite 15min,hrly,daily) Sec. 5.4 Task 5.4.2	X		Sec. 5.4 Task 5.4.1	X	Sec. 5.1
Stream Discharge	X		USGS & USACE daily stream flow Sec. 5.9 Task 5.9.1					
Reservoir Storage	X		Sec. 5.9 Task 5.9.1					
Water Table (Wells)	X		Sec. 5.9 Task 5.9.1					
Soil Moisture			Sec. 5.7 Task 5.71 Little					
Total Column		X	Washita & ARM/CART data				X	Sec. 5.1
Profile		X	OK Mesonet					
Surface Temperature	X		ESOP-96 Hrly. Sfc. Composite Table 7.5	X Clear sky		NESDIS & CAGEX	X	Sec. 5.1
Albedo		X	ARM/CART Sec. 5.6 Task 5.6.1		X	2-D Grid ARM/CART	X	Sec. 5.1
"Surface" Specific Humidity	X		ESOP-96 Hrly. Sfc. Composite Table 7.5				X	Sec. 5.1
"Surface" Wind	X		ESOP-96 Hrly. Sfc. Composite Table 7.5				X	Sec. 5.1
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	Sec. 5.1
Longwave Radiation		X	Sec. 6.4 ARM/CART		X	NESDIS & CAGEX 2-D Grid ARM/CART	X	Sec. 5.1
Shortwave Radiation		X	Sec. 6.4 ARM/CART	X	X	NESDIS & CAGEX 2-D Grid ARM/CART	X	Sec. 5.1

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* R - Routine
* E - Enhanced

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 LSA and CSA Budgets

OBJECTIVE: *Develop a 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 LSA budget time series is a continuing activity, and will produce a continuous time series of mean monthly budget variables. Although the temporal and spatial resolution of these "bulk" budgets is limited, much can be learned about continental hydrological processes by deriving budgets and validating 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 validation activities that address the major objectives of the GCIP program.

The basic time scale for the LSA and CSA budgets is monthly. The evaluation of the individual variables will depend heavily on operational data and operational 4DDA variable fields. Mesoscale resolution is required to adequately resolve the effects of terrain and to accurately resolve the irregular boundaries of a specific drainage basin. This can be provided by the data assimilation systems of regional mesoscale forecast models e.g. NMC Eta model, the FSL MAPS analyses and the Canadian RFE model. However, to fully utilize all available data and information, and meet the objectives for the budget studies, it will be necessary to improve the 4DDA capabilities of the operational model output available to GCIP investigators. This requires a program of intercomparison and validation studies.

The competing methods 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. Intercomparison of rawinsonde/profiler line integral results with the 4DDA fields will provide information on the quality of the 4DDA flux fields and the impact of changes in the data assimilation system. The choice of areas for comparison is limited by the relatively sparse distribution of rawinsonde and profiler stations. Two areas have been chosen for ongoing intercomparison; (1) the continental-scale geographical area 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 The ongoing intercomparison over the profiler array will be limited to winds and velocity divergence fields. Intercomparisons will also be done between the MOLTS and the radiosondes in the CART/ARM hexagon since these were not included in the data assimilation schemes of the models.

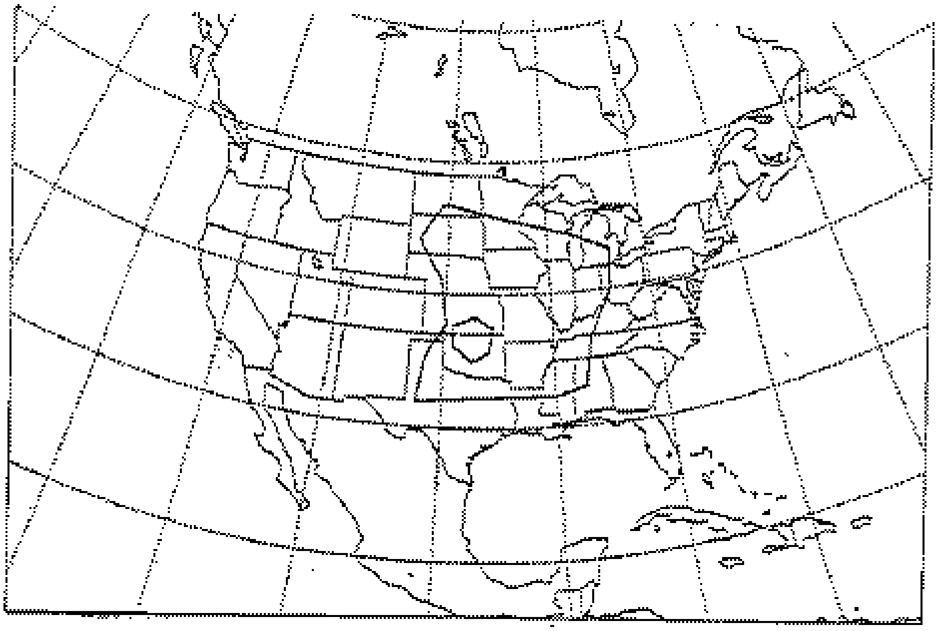

Figure 5-1 Continental Scale Area for intercomparison of atmospheric flux-diveregence results.

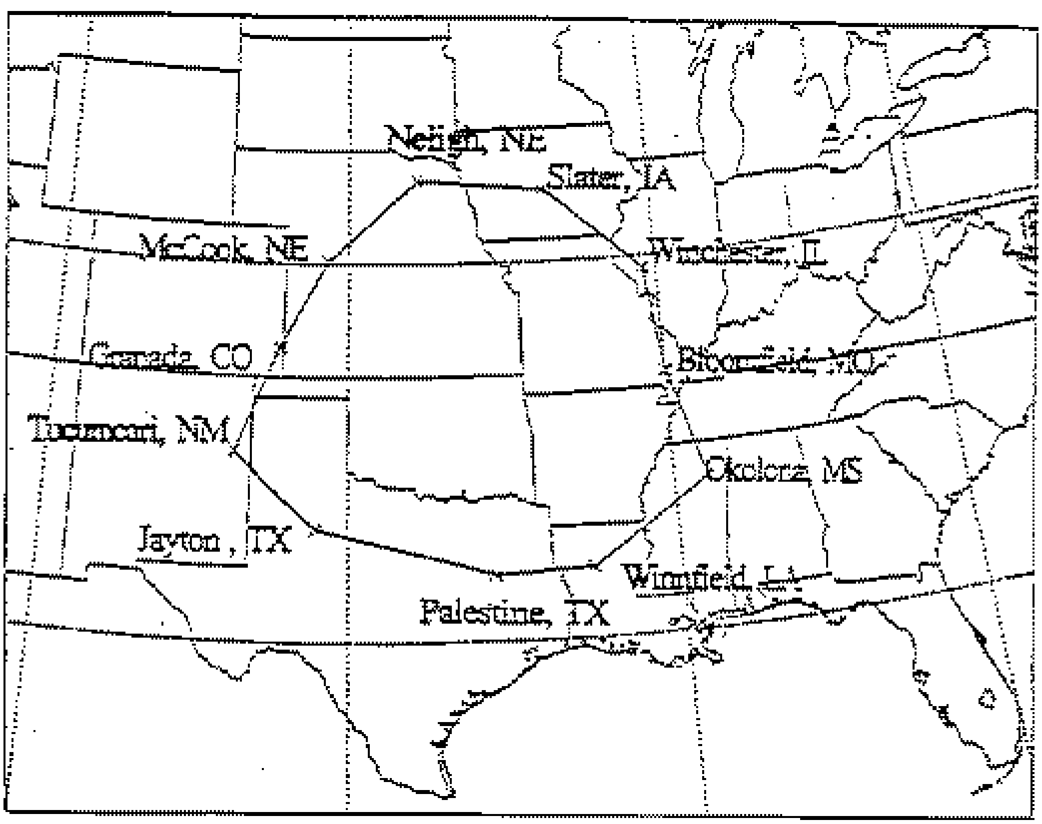

Figure 5-2 Large-scale profiler array in the Central U. S.

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 was summarized earlier in Section 1. The ISA/SSA budgets will be of a more specialized nature than the routinely computed LSA budgets. They will be computed for limited areas and in many cases for limited periods of time. They will 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 will usually be more process oriented e.g. seasonal aspects of the hydrological cycle; 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 WY97 the geographical focus will be on the LSA-NC. The phenomenological emphasis will be on various aspects of the cold season hydrological cycle. It will include studies on the LSA, ISA and SSA scales. Many of the ISA activities will 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 97 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).

b) Conduct ongoing intercomparisons of atmospheric budgets obtained directly from observations and those computed from operational analyses for areas shown on Fig. 5-2.

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

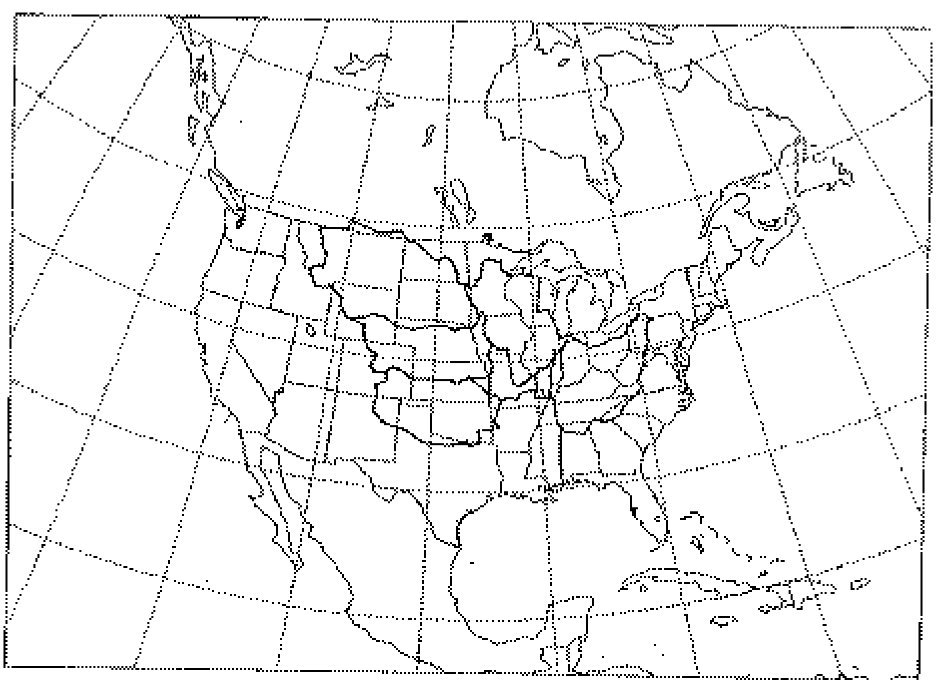

Figure 5-3 Subbasins of Mississippi River to be used in Computing Energy and Water Budgets.

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 areas.

b) Continue development of area averaged surface/atmosphere energy and water budgets during the three-week 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 of soil moisture and surface meteorological parameters for the Little Washita Watershed. Compare these values with output from operational mesoscale models.

d) Complete implementation of a program of ISA/SSA budget computations over the LSA-NC during ESOP-97.

5.1.4 WY 98 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 97 annual cycle of the land surface and atmosphere hydrological and energy cycles over each LSA and the CSA drainage area. Such descriptions can serve as "benchmarks" forstudying interannual variability and for validation of model simulations.

c) Continue ongoing intercomparisons between atmospheric budgets obtained directly from observations and those computed from operational analyses for the areas shown on Fig. 5-2.

2) ISA/SSA Budgets.

a) Continue compilation of area averaged surface/atmosphere energy and water budgets for the area within the LSA-NC ISA/SSA and continue four station ARM/CART rawinsonde array during the seasonal three week intensive observational periods.

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) Continue evaluation of available surface/atmosphere budget information acquired during ESOP-97 in the ISA/SSA basins of the LSA-NC.

d) Complete planning and implementation of a program of ISA/SSA budget computations over the LSA-E during WY 98.

5.1.5 Outlook for WY 99

1) LSA Budgets. Mean monthly LSA budget time series will be extended into WY 98. The third year (WY 99) annual cycle will be analyzed and compared with the first years' results. Results of diagnostic studies will be used to develop improved estimates of budget variables and to upgrade earlier budget estimates.

2) ISA/SSA Budgets. Continue evaluation of ISA/LSA budgets within the LSA-SW and LSA-NC. Began similar evaluation of ISA/SSA budgets for specified areas in the LSA-E. Begin planning and implementation of focused studies over 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 the ESOP-96 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 will provide 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 will be available from the ARM/CART area are the following:

1) Data for the evaluation of the surface radiation balance and surface fluxes. These data will be provided from a number of different ARM instrument systems and sites. Emphasis will be 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 will be established over the Little Washita Watershed. This will provide a more dense network of soil moisture profile measurements than will be available from the ARM/CART network. The existing meteorological observations over the basin will also beevaluated 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 the regional focus will shift to the LSA-NC where the phenomenological focus will be 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, will be developed during WY 96 for the LSA-NC. The enhanced winter observing period (ESOP-97) will include 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. The enhanced observational program will supplement routinely available information from in-situ, aircraft and satellite observations from the basin.

5.2.3 Near Term Activities

WY 97 Activities:

1) Perform diagnostic analyses of continental-scale features of the cold season circulation as they relate to hydrological processes over the LSA- NC and the ISA/SSA within this region. Since twice daily rawinsonde observations are not adequate to study the diurnal cycle, the diagnostic studies will 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 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-97 diagnostic studies over the LSA-NC region and formulate plans for a second ESOP, as needed, during the winter of WY 98.

WY 98 Activities:

1) Continue diagnostic studies of the data collected over LSA-NC and subareas during ESOP 97.

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

3) Begin implementation of plans for diagnostic studies over the LSA-E in WY 98.

WY 99 Outlook:

Emphasis will be placed on a synthesis of the results from the warm season and cold season analyses. New studies will be undertaken in the LSA-E, and planning for studies over the LSA-NW will be completed.

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 more recent 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 be a focus of these studies during WY 97 and WY 98.

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, they will be carried out as a joint effort of GCIP and the PACS Program. The effort will bring together global and regional mesoscale modeling groups and the land surface parameterization communities.

The development of large-scale anomaly patterns will be examined in the context of the annual cycle; e.g. what was 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 and remote forcing in the perpetuation and intensity of the anomalous regime and 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 97 Activities:

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

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

WY 98 Activities:

Diagnostic studies of the 1988 and 1993 anomaly regimes will extend into WY 98 and new studies of large-scale anomaly regimes which occurred during the 1995 to 1997 WYs will be initiated.

WY 99 Outlook:

Continuation of the new studies of large-scale anomaly regimes which occurred during 1995-1997 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.

6.1. Precipitation

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

The hypothesis behind GCIP precipitation research is that improved high-resolution precipitation prediction from atmospheric models is expected to result (via coupled land- atmosphere modeling) in better predictions of other hydrologic variables (e.g., soil moisture and runoff) at the small basin scale and over storm to daily to seasonal time scales. Such improved predictions will be useful for water management decisions and basin interpretations of climatic changes.

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 subgrid scale precipitation downscaling algorithms (from large to small scales) to be used in atmospheric models.*

Activities to support this objective are:

- A comprehensive study of the statistical subgrid scale rainfall variability over the Mississippi river basin (MRB) as function of storm type (e.g., cold vs. warm season precipitation, statisfrom vs. concective) and other relevant meteorological parameters of the storm environment (e.g., convective available potential energy -- CAPE). 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 e.g., represented through certain atmospheric instability indices such as CAPE. 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, for the purpose of continuous-time rainfall downscaling. 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.

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 3D 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 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, and (d) the vertical distribution of heating associated with the precipitation process.

- 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 vertical distribution of heating.

- Develop and test convective precipitation parameterizations.

- Understand the effects of orographic influences on the spatial structure of the produced precipitation structures, develop methods of parameterization, and test the performance of available orographic precipitation models for the Mississippi River basin.

6.1.3. 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.

- Understand how the resolution of orography affects precipitation predictions,which affect hydrologic balances and flooding over the Mississippi river basin.

- Under the premise that two-way coupling (atmosphere to land to the atmospherefeedbacks) will not only improve hydrologic predictions but also precipitation predictions themselves, investigate the sensitivity of the precipitation predictions to the two-way coupling processes (parameterization and resolution) in coupled models.

- Develop methods of atmospheric and coupled model verification, paying special attention to proper ways of integrating atmospheric and hydrologic information at different scales, i.e., point observations, model output products, and larger scale measurements.

6.1.4. Data for GCIP Precipitation Research

Objective: *Improve the availability and quality of data that are neeeded to support the research activities descibed 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 structures. 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 WRS-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.

6.1.5 Snow

Objective: *Produce gridded snow water equivalent data sets for the upper Mississippi River basin by integrating ground-based, airborne and satellite snow cover data sets.*

Activities to support this objective are:

- Develop algorithms for cloud detection for GOES data over land and AVHRR scenes over land.
- Develop prototype ice versus sea ice algorithms.
- Obtain GOES-8 (and GOES-9) data in the appropriate GVAR format and adopt the GOES-7 processing to handle GVAR data.
- Identify suitable Landsat data, contemporaneous with available AVHRR data for validation/modification of the prototype snow detection algorithm.
- Enhance implementation to ingest and process ground-based snow data from Regional Forecast Centers (RFC) for incorporation into the Snow Estimation and Upadating System (SEUS) for the Upper Midwest.

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 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 or 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, instu soil moisture observations, and remote sensing. 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 is to be developed for the LSA- SW because this is the area where the most in situ data are available and the region where remote sensing can provide the best information because of the relativly 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 need to be addressed with this data set.

6.2.2 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 anything like that what we can measure?*

Activities that are needed or support this objective are:

- Comparison of the model representation of the soil volume to the potential sources of measured soil moisture data This activity involves examining how the model represents the profile (i.e., number of layers) as well as how the model represents the horizontal variability. It also involves comparing the model sensitivity to changes in soil moisture to the precision capabilities of point and remote measurements. Current models will likely have to be modified to use measured soil moisture as input data or as a state variable. These studies link directly to PILPS phases l(c) and 2(b) (see Figure 8) and will draw upon PILPS intercomparison results.

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

- 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.

6.2.3 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 or support his 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, and 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.

6.2.4 Remote Sensing of Soil Moisture

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

Activities that are needed or support this objective are:

- Conducting a large scale (~ 10,000 sq km) aircraft remote sensing data collection campaign to provide a relatively long term data set approaching the type of data one would get with satellite remote sening. Selecting and carrying out a series of imbedded experiments that address issues of model derived soil moisture, scaling and uncertainties.

- 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 to10 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 any relationship between direct measurements of the surface (the composite of soil and various vegetation types) with microwave data 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 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 specific target areas (i.e., Little Washita) for comparisons of soil moisture or wetness product with Eta and MAPS model output.

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 databases that will meet the immediate requirements of GCIP's Principal Research Areas. The first priority is to supplement the GCIP Implementation plan by further documenting the specific multiresolution land surface data requirements of GCIP researchers, with provisions for updating the land surface characterization research plan based on regular feedback from GCIP modelers, as well as research results concerning land process modeling activities of PILPS and ISLSCP. The near- term strategy also includes adapting and testing promising 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 land datasets recently 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 are also key factors in this near-term strategy. GCIP's longer-term strategy for land surface characterization research will focus on the SSAs and ISAs to develop high-resolution land data sets; to collect field data that are necessary to develop, adapt, test, and validate promising remote sensing algorithms for land cover characterization and model parameterizations; to conduct advanced remote sensing research, for example, canopy reflectance modeling; and to investigate landscape heterogeneity as related to land process parameterizations.

Multiresolution land characterization research in the near-term will be directed toward 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. The initial project regions and their associated gridding intervals include the CSA and LSA-SW (40-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 are currently available throughout the conterminous United States to potentially meet some of GCIP's immediate requirements for land data within these four regions include 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 will focus 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 characterization research will focus on meeting changing land data requirements, developing data sets for new regions, and facilitating the use of geographic information systems (GIS) technology and other appropriate tools for land surface data analysis. For example, model sensitivity analysis from GCIP and PILPS investigators will help to more clearly identify requirements for specific types of land surface characteristics including accuracy specifications. Detailed analysis of multiresolution satellite data for the ARM/CART region will lead to remote sensing algorithms that can be applied within the LSA- and CSA-scale regions. GCIP would also significantly benefit from remote sensing algorithms developed and tested under the proposed ISLSCP Initiative No. 2 project.

Additional regions will be defined and higher resolution land data sources will be investigated and developed, as required. Candidate regions include the Upper Walnut River watershed located within the ARM/CART as related to the proposed Cooperative Atmosphere-Surface Exchange Study (CASES); the LSA-NC; and SSAs within the LSA EAST, for example, 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. Organization of the LSA-NC and LSA-East is underway.

Some of the key secondary land data sources will 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 (see the World Wide Web at the URL address: http://edcwww.cr.usgs.gov/sast-home.html).

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 modelers. 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.

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. To meet the requirements of GCIP's other Principal Research Areas, the highest priority activities within this land surface characterization plan was initiated during 1996. Tailoring available multiresolution AVHHR land cover characteristics data for multiresolution model test and evaluation, preparing preliminary soils data sets from STATSGO for the Mississippi River basin, and evaluating high resolution land cover classifications and obtaining Landsat TM images for the ARM/CART and Little Washita regions are the top priorities for 1996 and early-1997.

Land surface characterization research is a highly interdisciplinary effort. Therefore, an equally important high-priority task is to develop Federal agency participation and resource support for beginning and working cooperatively on the accomplishment of these 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 such as Penn State University, Colorado State University and Texas A&M University. The coordination of this research with potential contributions by GEWEX/ISLSCP presents an outstanding opportunity, especially for biophysical remote sensing algorithm development, operational database development, and scaling research.

6.3.2 Land Cover Characteristics

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 landcover 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 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 vegetation/land cover characteristics data include the global one- degree latitude-longitude modeling data sets recently published on CD-ROM by NASA/GSFC under GEWEX/ISLSCP Initiative No. 1 and various AVHRR data sets produced by NOAA/NESDIS and USGS. For example, NASA's ISLSCP CD-ROM includes monthly one- degree by one-degree calibrated, continental NDVI data (1982 to 1990); 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 (SiB) Model 2 land surface parameterization (LSP) with FPAR as the key model input. The CD-ROM also includes a one-degree global land cover data set.

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 inverting an LSP to derive the land cover characteristics will guide efforts to similar use of higher resolution AVHRR and LANDSAT TM data. NASA/GSFC is currently planning ISLSCP Initiative No. 2 which would focus on enhanced global land cover characteristics data sets at a 1/2-degree latitude-longitude grid. The ISLSCP No. 2 data are planned for release during late 1997.

The NOAA/NESDIS has developed 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 product. Recently, NOAA/NESDIS produced a five-year climatology of the GVI data, and is now working to derive vegetation fraction from the GVI. The NOAA/NESDIS is also working with NASA/GSFC on the AVHRR Global Area Coverage (GAC) Pathfinder project to develop calibrated 8-km AVHRR data with a period of record beginning in 1981.

The USGS EROS Data Center (EDC) has developed 1-km AVHRR databases for the conterminous United States and is now processing global 1-km AVHRR data for land areas. The databases for the conterminous United States include biweekly AVHRR time-series image composites on CD-ROM (1990-1995) and a prototype land cover characteristics database for 1990 on CD-ROM. This 1990 land cover characteristics database is currently undergoing validation based on field survey data. Ongoing USGS activities also include the preliminary 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 landcover database development activity, the USGS is currently processing global, 10-day AVHRR image composites for land areas. A proto-type 1-km AVHRR land cover data for the North American continent was recently made available for test and evaluation. These land cover data (for example, the BATS, Sib2, IGBP, and other land cover classification schemes), ten-day global AVHRR data, and a 1-km digital elevation model (DEM) for North America can be obtained via ftp through the EDC Distributed Active Archive (DAAC) Homepage (http://edcwww.cr.usgs.gov/landdaac/). 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 will be produced from data collected by the MODIS, MISR, ASTER, and CERES sensors on board the AM1 Platform. These data will be subsequently available for GCIP research through the EOS Data and Information System. For example, atmospherically- corrected reflectance and vegetation index data will 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.

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 to support this objective in order of priority follow:

a. Definition of the requirements of GCIP modelers for multiresolution land cover characteristics data, documentation of available data sources, and assessment of the adequacy of available data for GCIP Principal Research Areas.

As a first priority, the requirements of GCIP's scientific investigators for multiresolution land cover characteristics data must be determined, specifically, requirements for land cover classes, agricultural crop and land use categories, and seasonally variable biophysical properties (i.e., vegetation attributes or characteristics). The potential sources for land cover and land use data will be identified and documented. This effort includes published data on vegetation characteristics and biophysical attributes such as those prescribed for Biosphere-Atmosphere Transfer Scheme (BATS), Simple Biosphere Model 2 (SiB2), Land-Ecosystem-Atmosphere Feedback (LEAF), and other land cover classification schemes. The adequacy of available data sources for GCIP modeling, especially in terms of detailed agricultural land use classes and attributes, will be assessed.

Ongoing feedback is needed from GCIP, PILPS, and ISLCSP activities concerning requirements for land cover characteristics data and the results of model sensitivity analysis concerning land cover characteristics. (Note: The requirements for multiresolution land surface characteristics data on land cover, soil, and topography identified under this and subsequent objectives will be used to prepare a matrix gridding plan showing regions versus land surface characteristics data requirements.)

b. Tests and evaluation of AVHRR-derived land cover data in GCIP models and assessment of data accuracy limitations.

Available 1-km and coarser resolution AVHRR-derived land cover data sets (i.e., the BATS, SiB2, USGS Anderson Level II-modified, Olson, and similar vegetation and land use classifications) will be tailored for test and evaluation in the land surface parameterization component of atmospheric GCMs, nested mesoscale meteorological models, and multiscale watershed hydrological models. The sensitivity of GCIP models to potential data accuracy limitations will be assessed.

c. Facilitation of 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.

d. Facilitation of the adaptation, development, and use of biophysical remote sensing algorithms to estimate seasonally variable land cover characteristics data needed to parameterize, initialize, and validate GCIP's models; validation of the remote sensing algorithms and tests to evaluate the biophysical data in GCIP's atmospheric and hydrological models.

This effort is focused on facilitating the use of multitemporal AVHRR channel reflectance, NDVI greenness, and GVI data to develop and evaluate seasonally variable, time-dependent biophysical land cover characteristics data that are required by GCIP investigators for development, initialization, test and evaluation, and validation of their land process models and parameterizations. For example, NOAA/NESDIS has developed 5-year climatologies of the GVI including derived estimates of vegetation fraction from the GVI. Another potential data resource is the experimental 1-km resolution vegetation seasonality characteristics data set now under development by the USGS from biweekly, 1-km AVHRR NDVI greenness temporal profile data (1989-1994). Following the application of temporal smoothing algorithms, calculated seasonality data for each 1-km pixel of each year and the five-year averages include the NDVI Julian dates and associated numerical values for onset, peak, and end of greenness; rates of NDVI change; duration of greenness season; greenness curve modality; and seasonally integrated total NDVI.

Some of the biophysical characteristics to be potentially developed and tested from these types of seasonality data include estimated LAI, ratio of vegetation to bare soil (i.e., vegetation fraction), greenleaf fraction, vegetation height, and FPAR. Research on the interannual variability of satellite vegetation indexes, for example, due to the effects of the atmospheric water vapor and aerosols or due to year-to-year weather variations or other factors is a key requirement to ensure the proper use of seasonality data. These atmospheric corrections are also essential to the use of channel reflectance data to estimate land surface albedo and other derived parameters. This biophysical remote sensing research is impeded by the lack of operational algorithms to correct satellite reflectance data for the effects of atmospheric water vapor and aerosols.

e. Development of high-resolution land cover classifications (i.e., vegetation type and land use) including preliminary land cover characteristics data sets for the ARM/CART site and selected SSAs, for example, based on 30-m resolution LANDSAT TM data.

Facilitating the use of relatively inexpensive LANDSAT TM data by Federal agencies and state university remote sensing centers to develop digital land cover classification maps is one possible strategy to meet this need. Comparisons with AVHRR-derived land cover characteristics data are needed.

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.

f. Exploration of multiresolution relationships among land cover/vegetation, soil, and topographic characteristics data, as well as relationships with microclimatic and hydrometeorological data, ranging from the landscape and watershed scales up to the ISA and LSA regions.

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.

g. Conductance of advanced land cover characterization research within SSAs and ISAs to meet GCIP's requirements for more detailed land cover characteristics data and information.

Several types of advanced land cover characterization research activities are needed. For example, a strategy is needed for collecting essential ground-based data and field observations that will be used in combination with published research results to develop, adapt, test, and/or validate remote sensing algorithms at the ISA/SSA-scales. In addition to basic remote sensing algorithms for making atmospheric corrections or other image processing, applications could also involve remote sensing algorithms for making regional extrapolations of land surface processes such as seasonal evapotranspiration or net primary productivity, or the validation of satellite-derived land cover characteristics data such as LAI. Field-based data sets are also needed to develop land surface parameterizations or to properly use satellite remote sensing data, such as multitemporal NDVI greenness data, as part of special studies to investigate how vegetation controls evapotranspiration.

Research on state-of-the-art canopy reflectance modeling is needed, especially as related to the estimation of canopy characteristics for agricultural crops. Model-based approaches for estimating key canopy parameters need investigation, for example the inversion of a land surface parameterization such as was done by NASA/GSFC with SiB2 as part of the ISLSCP Initiative No. 1 CD-ROM development. Advanced remote sensing research is also needed to investigate the potential use of other remote sensing data in GCIP, for example, the use of Airborne Visible Infrared Imaging Spectrometer (AVIRIS), Thermal Infrared Multispectral Scanner (TIMS), ERS-1, or RADARSAT data.

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.

Elements of land characterization research will focus on the use of remote sensing algorithms and geostatistical analysis tools to investigate the estimation and analysis of land surface energy fluxes and scaling issues, especially as related to comparisons with tower flux site, SSA, ISA ARM/CART observations, and GCIP model outputs. Scaling research issues involve remote sensing, for example, concerning the use of the NDVI or the simple ratio in canopy conductance modeling based on LANDSAT TM and AVHRR data inputs. The use of satellite-based remote sensing technology to directly or indirectly estimate surface energy fluxes is still an open research topic. This land surface characterization research will also contribute to efforts by GCIP researchers to investigate how landscape spatial heterogeneity contributes to surface flux distribution and parameterizations.

These aspects of land characterization research will use digital image processing, GIS, and various geostatistical tools for spatial and temporal analysis. Examples of geostatistical tools include autocorrelation analysis, kriging, variograms, and potentially other types of spatial analysis which may be useful in characterizing the impact of landscape pattern, arrangement, type, and distribution as a forcing function in hydrometeorological processes within the Mississippi River basin.

h. Organization of an annual joint GCIP/ISLSCP workshop on the development, test and evaluation, and validation of remote sensing algorithms for land cover characterization and regional estimation of biophysical processes.

6.3.3 Soils and Geology

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 land surface-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 database 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 databases 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 databases at three scales. The familiar county-level soil survey is being converted to a digital database for use primarily in local-level planning. This database 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 third soil map product being created is the National Soil Geographic Database (NATSGO). This product is being compiled at a scale of 1:7,500,000 and is not yet available.

The STATSGO database provides the most useful resource for characterizing the role of soil in mesoscale atmospheric and hydrological models. This database 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.

The STATSGO database will be useful for regional-scale analysis; however, GCIP researchers will require, on a selective basis, SSURGO data for detailed watershed studies and intense field observation programs. Although this database 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 STATSGO databases are linked through their mutual connection to the NCSS Soil Interpretation Record (Soil-5) and Map Unit Use File (Soil-6). A further description of soil characteristics data set derived from the STATSGO data base is given in Section 10.

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 to support this objective in order of priority follow:

a. Definitions of the requirements of GCIP modelers and scientific investigators for multiresolution soil physical and derived hydraulic properties data.

Ongoing feedback is needed from GCIP, PILPS, and ISLCSP activities concerning data requirements for soil properties and the results of model sensitivity analysis to these properties.

b. Use of the STATSGO soils database to develop multiresolution gridded soil physical and hydraulic properties data for the entire GCIP domain to include soil texture, available water-holding capacity, vegetation rooting depth, and other soil physical and hydraulic properties that help to determine the soil thermal and moisture conditions.

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 database development (soil science) communities must consult on the nature of these needs.

c. Facilitated development of SSURGO databases for selected watersheds within the GCIP domain. This information will be vital for support of intense field observations and campaigns during the EOP.

d. Tests and evaluations of the STATSGO and SSURGO data in GCIP modeling activities.

e. Improve quantitative understanding of STATSGO and SSURGO 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 STATSGO 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.

f. Explore need for and availability of geologic databases 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.

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-arcsecond 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 to support this objective follow:

a. Definitions of 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.

b. Organization of 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.

c. Facilitation of 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.

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

e. Investigation of 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 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.

6.4.1 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 upstreamgauges 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 km2).

6.4.2 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 1997-1999.

- Extend the available historical data base for unregulated basins at the SSA and ISA scales (10 to 1000 km2) 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. Subject to some funding to support a post-doctoral fellow this work could be undertaken at the University of Washington.

- 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 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 IRC. 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.*

6.5.1 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 follow:

- 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). These products are being produced as part of the derived data products described in Section 10. 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 operational GOES ASOS cloudiness product will be generated for GCIP. Cloud information will also be available from the polar-orbiting environmental satellite (POES). The GOES and POES 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. For many studies related to mesoscale convective systems and their relationships to land surface-atmospheric interactions on small horizontal scales, higher spatial and temporal cloud information is needed. A high- resolution cloud algorithm for GOES-8 will be developed. The algorithm will be based on GOES-8 imager observations and could provide cloud analyses with spatial resolutions as fine as a 4X4 pixel retrieval box or visible imagery and temporal resolutions of 30 minutes. Funding for the development of satellite radiation budget products for ARM/CART will be from the NASA EOS project.

6.5.2 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 previous Section 1).

(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://info.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. An expanded CAGEX run will span approximately one half of the GCIP region for six continuous months in 1996; this will be used to test Land Data Assimilation Systems (LDAS) and the within-the-atmosphere fluxes in the Eta model (Section 5.2).

One surprising result in CAGEX is the demonstration of a significant discrepeancy 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 (August 1997; possible delay to January 1998) 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.

The dense coverage of measurements over the ARM site are presently supplemented with the geographically dispersed SURFRAD (Section 10.4). 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 in 4 channels), the LW window directional radiance, and the broadband SW and LW fluxes (i.e., Purgold et al., 1994) will be made over the ARM site in 1996. 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 of 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 will measure 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.

6.5.3 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 from the Eta model data base. 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 with 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 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 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 withj satellite and ground-based measurements.

6.5.4 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 Section 5 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.

6.5.5 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. 1996).

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. 1995a). 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. (Note GCSS looks to the GCIP Data Management and Service System to provide data sets in the desired form).

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 1996), 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 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 (1995) 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.

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 to date as was shown in Figure 1-2 and will continue to receive a high emphasis through the end of Water Year (WY) 1997. The LSA-NC (North Central) is 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 will 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 National Oceanic and Atmospheric Administration (NOAA)-National Weather Service (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.

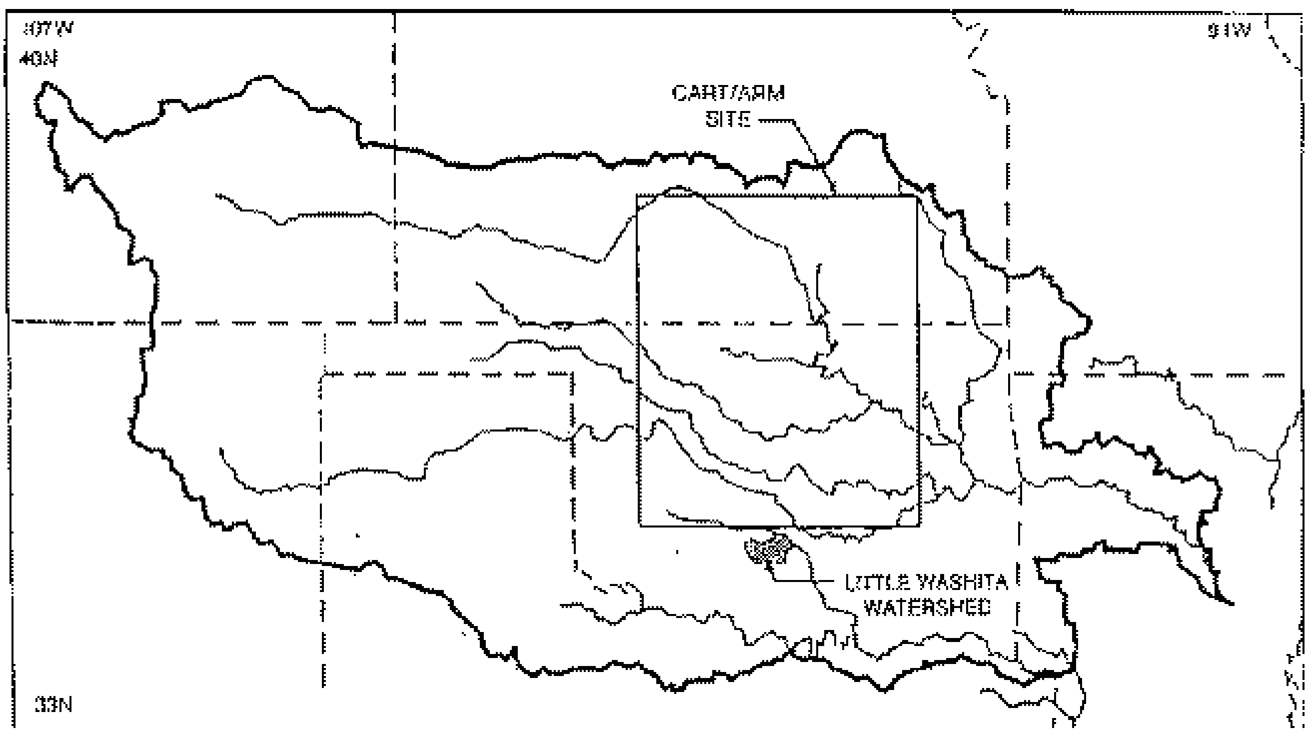

Figure 7-1 Latitude-longitude boundaries for LSA-SW encompassing the Arkansas-Red River basin.

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 forms 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 105 km2) 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 and soil moisture cannot be measured, extensive in situ surface measurements related to evapotranspiration or soil moisture will be 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'97-WY'99

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 are scheduled to be operating by the end of March 1997. A second phase of data collection for this special data set will begin on 1 April 1997 and continue for one full year. As in the first phase the data collection efforts will concentrate 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 marks 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 will provide 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.

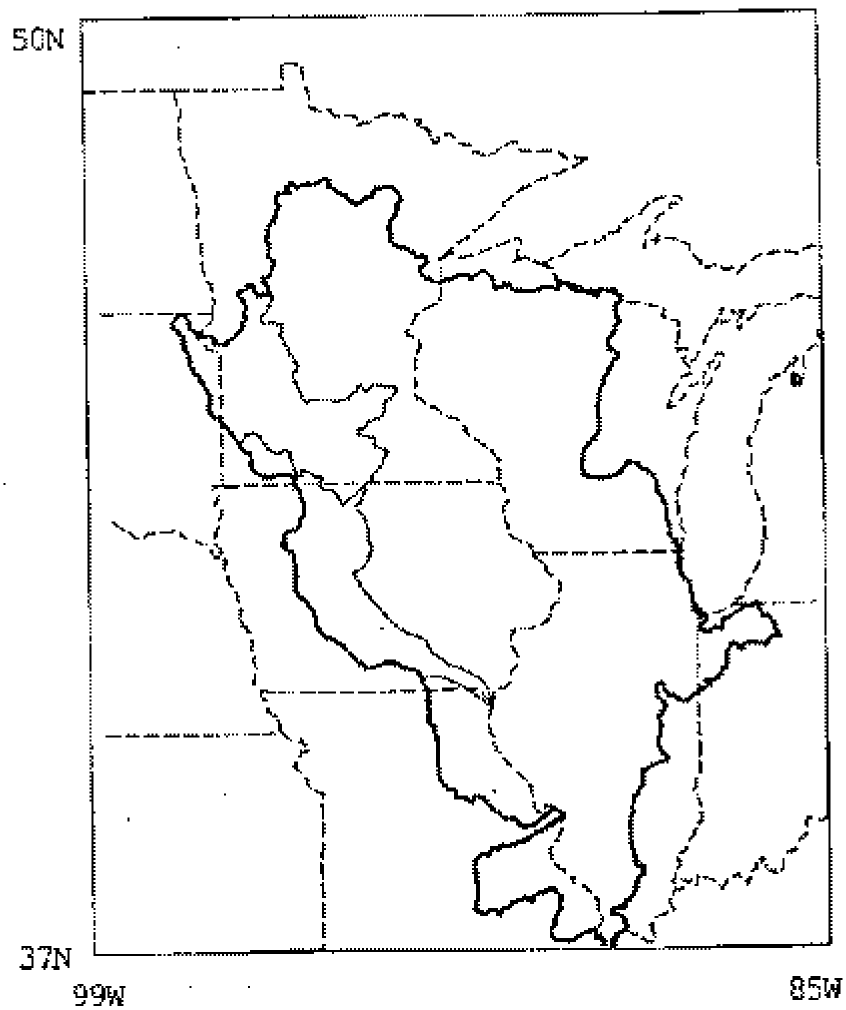

Figure 7-2 Latitude-longitude boundaries for LSA-NC encompassing the Upper Mississippi River basin.

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 will exploit all available information from in situ, aircraft, and satellite observations from the region. The SSAs to be established within the Upper Mississippi River basin for study will provide 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 candidates for an SSA in the LSA-NC. The USGS operates an interdisciplinary research institute for hydrological research in the Shingobel 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 during WY'97-'WY'99

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.

The report of the LSA-NC Science/Implementation Taskgroup is given in Appendix A. 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-97. The data collection plans are described further in Section 12 which is in Part II of the GCIP Major Activities Plan.

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 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 30-45 N. latitude and 78 to 89 W. Longitude.

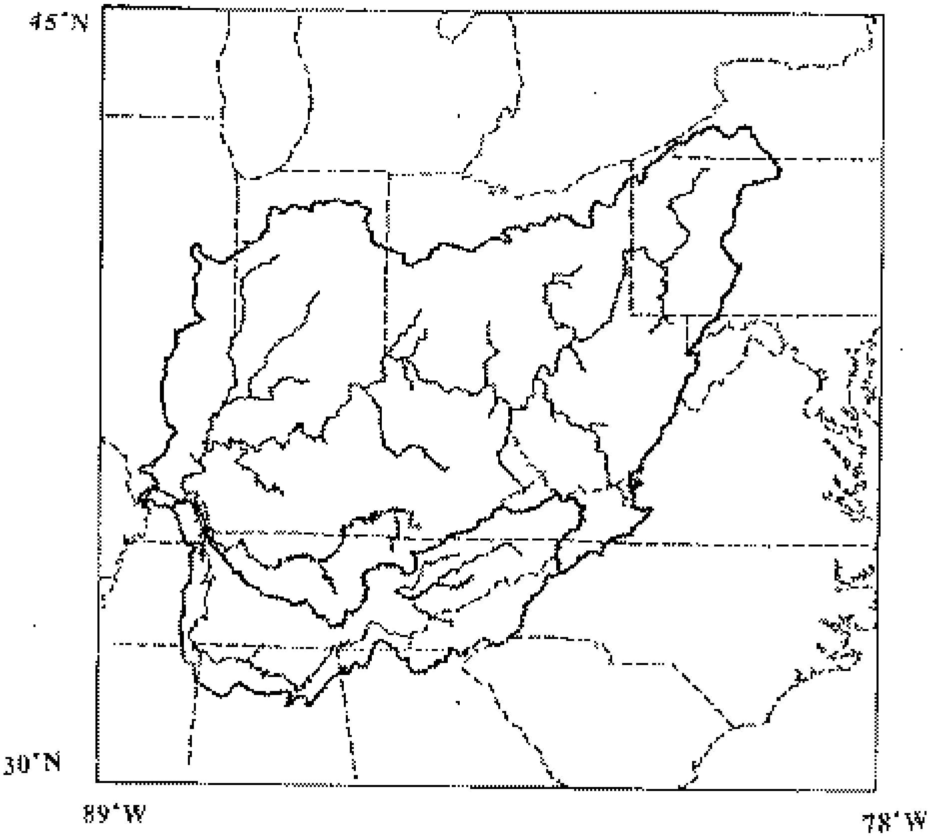

Figure 7-3 Latitude-longitude boundaries for LSA-E encompassing the Ohio and Tennessee River basins.

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 during WY'98-WY'99

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. 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 as given in Section 3. A summary report of the LSA-E Detailed Design Workshop is given in Appendix B. This report will form 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 is 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 steamflow through dams .
. Major terrain effect from Rocky Mountains.
. Relatively small normal runoff amounts.
. Snow measurement a significant problem.
. Snowmelt timing as problem in water budget regions.
. Nebraska sandhill as unique hydrology problem.

A regular shaped area is defined by the boundaries of 40 to 51 N latitude and 95 to 115 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.

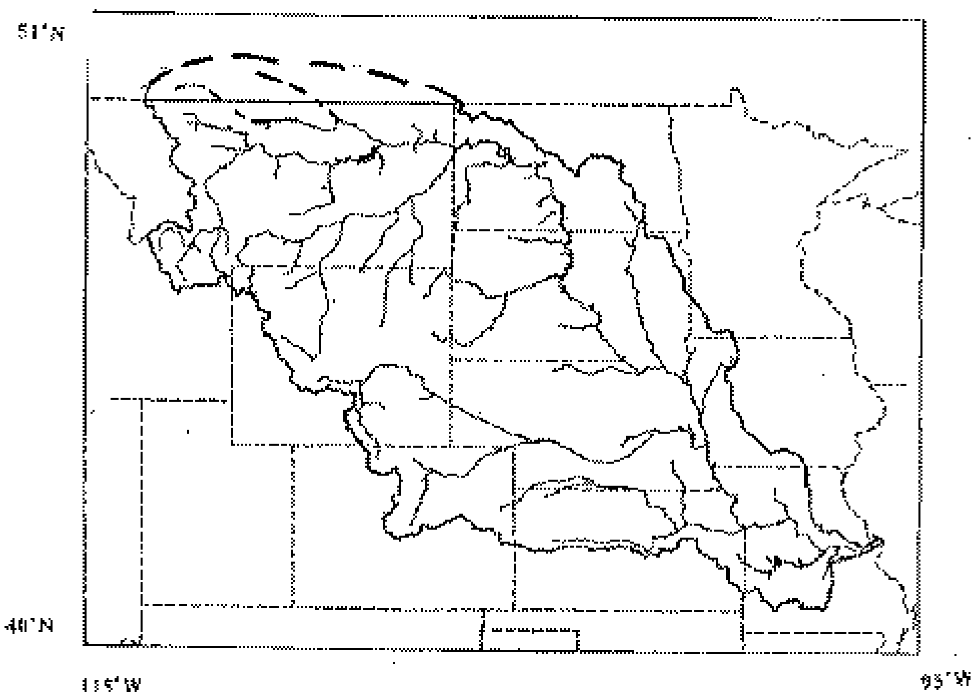

Figure 7-4 Latitude-longitude boundaries for LSA-NW encompassing the Missouri River basin.

7.4.2 LSA-NW Activities Outlook 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 Schools of Mines and Technology. This group is proposing a long-term plan for a collaborative research project to integrate scientific resources in the Upper Missouri River basin to address questions of fundamental importance related to hydrology, land cover, exchange processes, climate variability, and sustainability. The goal of the proposed effort is to monitor, describe, explain and predict seasonal and interannual variations of land cover and precipitation over the Upper Missouri River basin. The primary objective of the proposed research is to develop and improve representations of atmospheric and land surface processes, and their interactions, in coupled system models that simulate the major hydrologic processes of concern over the basin. The central hypothesis of the investigation is that variations in atmospheric circulations and land-surface characteristics are mutually interactive and can generate significant variations of weather and climate in the region on temporal scales up to seasonal and interannual. NOTE to Draft - The Group preparing the proposal summarized above is preparing to submit the proposal to NASA for funding. Given that this proposal is supported it is likely that the research proposed could start as early as 1997.

7.5 CSA Activities for 1997 to 1999

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 research program 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 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 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.

8.2 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 ARM will install and operate 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 GCIP-ARM 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 upcoming field studies on soil moisture in the Little Washita catchment 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 project 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.