GEWEX Asian Monsoon Experiment

(GAME)

A sub-programme of
the Global Energy and Water Cycle Experiment
(GEWEX)

Science Plan

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FOREWORD

The human life, economics and agriculture in Asia and Australia region depend deeply upon the monsoon climate and its variability. We should recall that more than 60% of the people on the earth live under the influence of the Asian/Australian monsoon. Droughts and floods associated with the monsoon rainfall variability sometimes cause serious damages for the human activity in these regions. The seasonal forecasting of monsoon rainfall, therefore, has been a matter of great concern for the people and countries in monsoon Asia since the end of the nineteenth century.

As part of WCRP, the TOGA program has been organized, which aims to understand the physical processes of large-scale atmosphere-ocean interaction particularly related to the ENSO, which swings as a major component of the interannual variability of global climate. This project, however, does not explicitly involve the interaction or inter-relation between the ENSO and the Asian monsoon variability.

The Global Energy and Water Cycle Experiment (GEWEX) is now launched as a major part of WCRP after 1995, which aims to understand the basic physical processes, particularly the energy fluxes and hydrological cycle, related to the fast component of the global climate system, covering the time scales of a week to several years.

The Asian summer and winter monsoon, including the Australian summer monsoon, plays a major role in the global energy transport and water cycle, by redistributing the total solar energy input to the earth in the climate system. Without understanding the energy and hydrological processes of the monsoon system and their variability, we are not able to fully understand the global energy and water cycle which functions the fast component of the climate system. The long-term comprehensive observations and modelling effort on the whole Asian monsoon system, including the atmosphere, hydrosphere and land surface conditions are required to answer this purpose, which also will give us the physical bases for long-range forecasting of the Asian monsoon.

The GEWEX Asian Monsoon Experiment (GAME) is proposed to determine the role of the Asian monsoon as a major part of the energy transport and water cycle in the global climate system, and to understand the feedback processes involved in the monsoon system, particularly in radiation, clouds and land surface hydrology, associated with its intraseasonal, seasonal and interannual variability. To determine the impact of the planetary-scale Asian monsoon variability on regional or basin-scale hydrological cycle and water management is another essential part of this program, which is also compatible to one of the main objectives of GEWEX.

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1. Scientific rationale

1-1. Role of Asian monsoon in the global climate system

1-1-1. Global energy and water cycle and Asian monsoon

As a major part of the WCRP, the GEWEX program is initiated to understand the energy fluxes and hydrological cycle and their variability in the global climate system, which plays an important role in the fast component of the climate system. This program also aims to develop the ability to predict the global and regional hydrological processes and water resources and their response to climate change.

The Asian summer and winter (or Australian summer) monsoon system is characterized as a huge atmospheric circulation system in the global atmosphere, which contains the interhemispheric meridional circulation cells as well as the east-west circulation cells along the equatorial belt (Krishnamurti, 1973). Though the net radiation balance of the atmosphere-earth system shows a more or less zonally-uniform distribution as shown in Figure 1-1, the diabatic heating rate of the atmosphere remarkably shows a zonally-asymmetric distribution related to the major land-ocean configuration, as shown in Figure 1-2. The Asian summer and winter monsoon circulation system (Figure 1-3) is really a manifestation of this zonal-asymmetry in the diabatic heating of the global atmosphere.

This monsoon circulation system is forced and maintained fundamentally by latent heat energy supplied and released through the water cycle induced as a result of the ocean-atmosphere-land interaction. This system includes the seasonal migration of gigantic heat source of the global atmosphere over southeast Asia through the warm water pool region of the tropical western Pacific (Johnson et al., 1987). The Asian/Australian monsoon system, thus, consists of a major and key component of energy transport and water cycle in the global climate system. It would be asserted that without understanding the energy and hydrological processes involved in the Asian monsoon system we are not able to fully understand the global energy and water cycle.

1-1-2. Role of Asian monsoon in the interannual variability of the global climate system

It should be noted here that not only the basic state and the mean seasonal cycle, but also the interannual variability of this monsoon system plays an essential role in the anomalous state of the climate system both in the tropics and the extratropics. It has been pointed out and partly revealed that the monsoon variability of this region is closely related to the variability of the atmosphere/ocean coupled system in the tropical

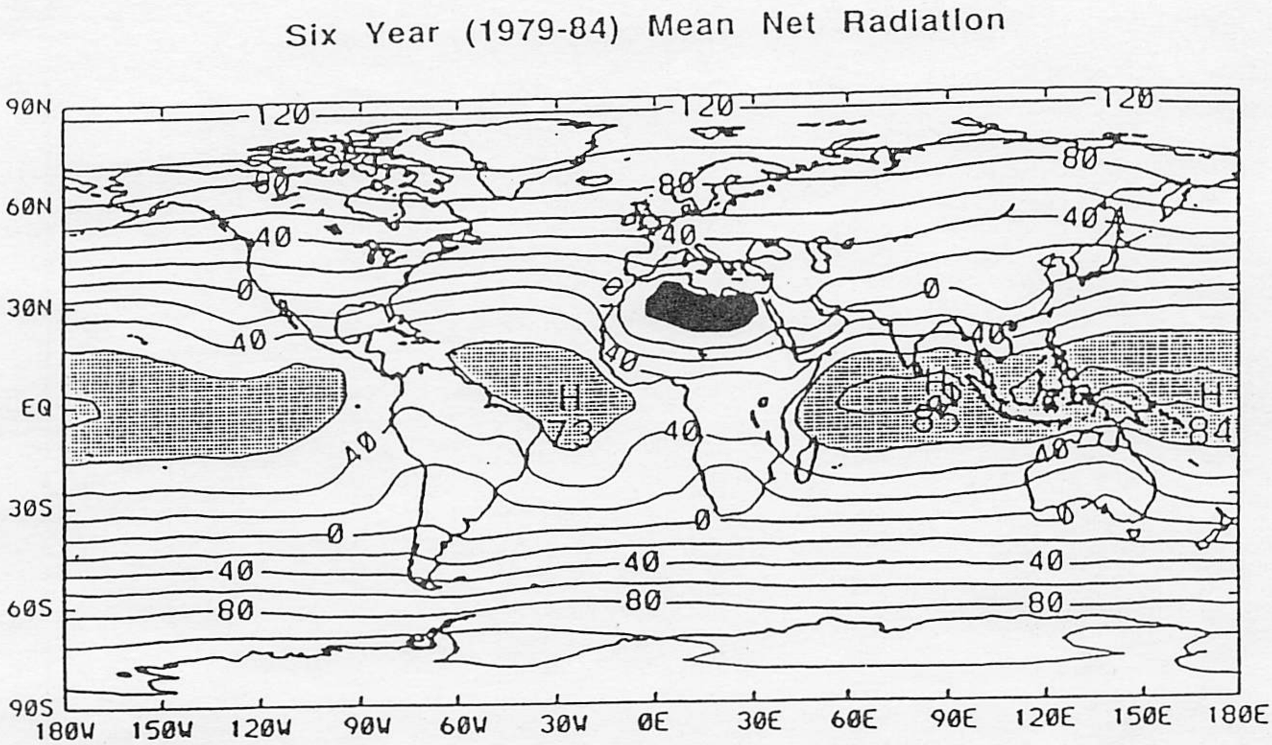


Figure 1-1: Global distribution of the 6-year mean net radiation at the top of atmospheric (in Wm-1) using a 20 Wm-1 contour interval. Area whose fluxes are larger than 60 Wm-1 are shaded. Black shading indicates the North African deficit region. (Sohn and Smith, 1992).

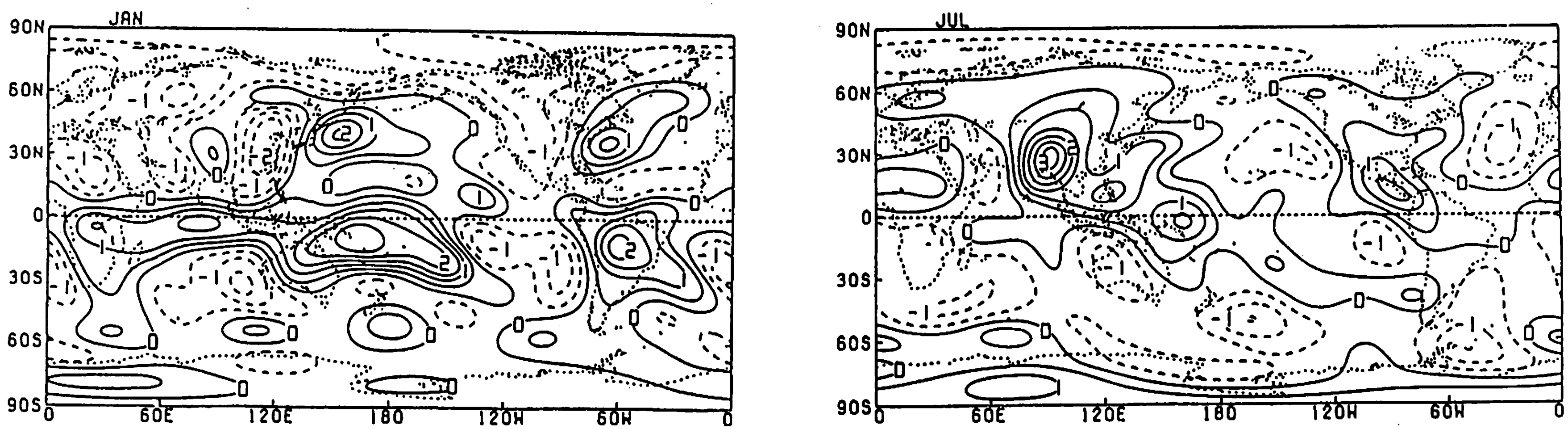


Figure 1-2: Mass-weighted vertically averaged diabatic heating rates (K per day) for January an July of 1979. Negative values are shown with dashed lines. (Johnson et.al., 1987)

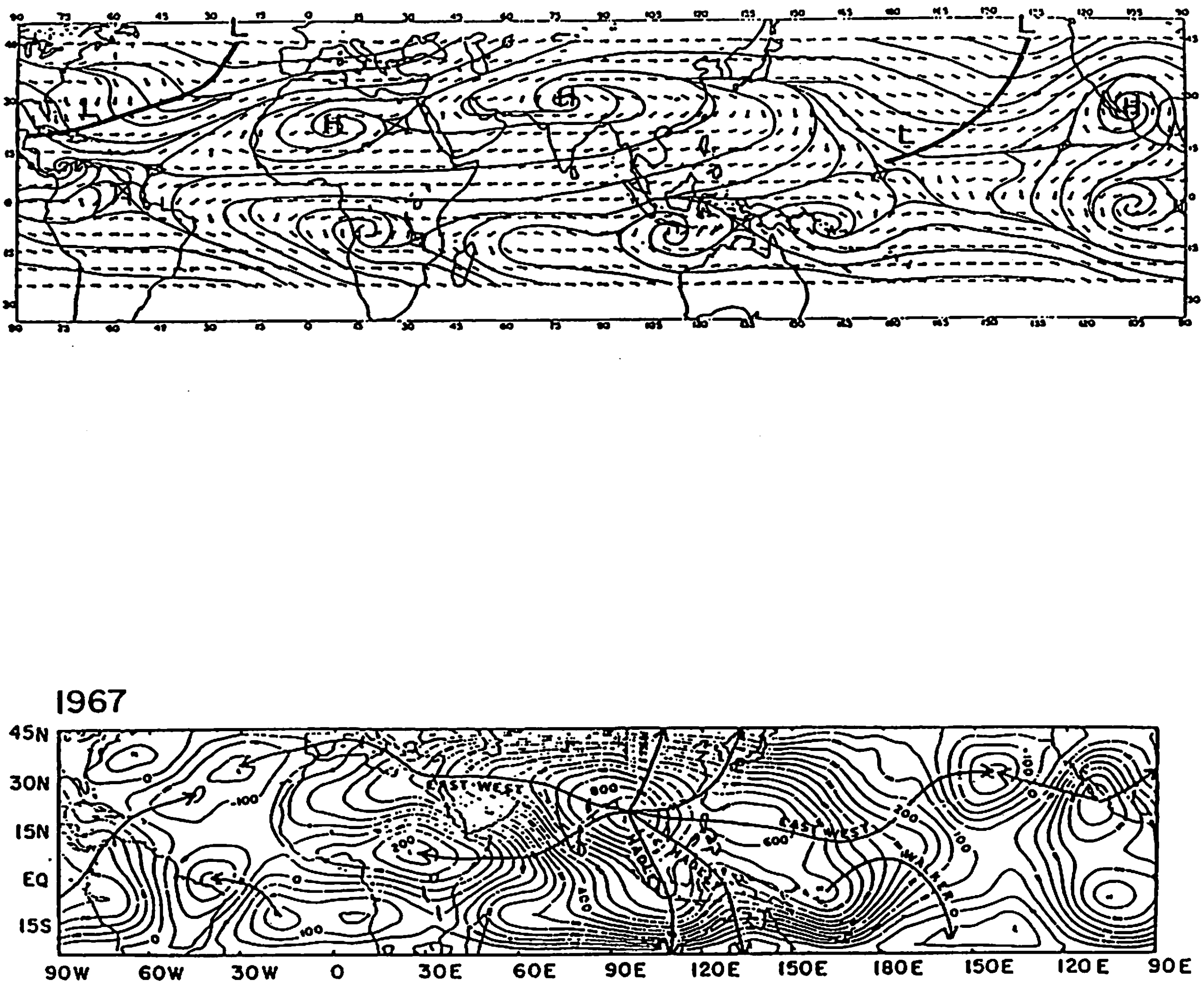


Figure 1-3: (Upper) Wind vector and streamline at 200 mb averaged for June - August, 1967.(Krishnamurti, 1971). (lower) velocity potential field for the same period (Kanamitsu and Krishnamurti, 1978).

Pacific/Indian Ocean typically known as ENSO (Rasmusson and Carpenter, 1983; Shukla and Paolino, 1983; Nicholls, 1984; Tian and Yasunari, 1992 etc.). The TOGA, implemented as a major subprogram of WCRP, has been revealing various aspects both in the large and local scales, of this atmosphere/ocean coupling in the equatorial Pacific.

Recent diagnostic and model studies have revealed that the seasonal cycle and interannual variabilities of the Asian summer monsoon activity has a more active rather than a passive role on the atmosphere/ocean coupled system in the equatorial Pacific (Meehl, 1987, 1993; Yamagata and Masumoto, 1989; Yasunari, 1990, 1991: Webster and Yang, 1992). That is, a weaker (stronger) than normal condition of the Asian summer monsoon seems to lead one anomalous state of the atmosphere/ocean system favorable for the El Ninõ (non-El Ninõ or La Ninã) in the equatorial eastern Pacific, presumably through the modulation of east/west atmospheric circulation along the equatorial belt of the Indian/Pacific Ocean sectors. Although the physical processes underlined in this ENSO/monsoon connection have not fully be understood yet, the seasonal and interannual modulation of heating contrast between the Eurasian continent and the surrounding two oceans is likely to have a clue for this issue. This heating contrast is, undoubtedly modulated by some feedback processes in the energy and water cycle of the ENSO/monsoon system itself.

1-2. Uncertainties in seasonal prediction of Asian monsoon in the climate models

1-2-1. Activity of MONEG

The seasonal prediction of the monsoon circulation and rainfall has been an essential task for the operational meteorological agencies in the countries in monsoon Asia and Australia. The recent rapid progress in the GCMs and numerical forecast models has been leading it to be successful in simulating and forecasting the overall feature of Asian monsoon (e.g., Palmer et al., 1992). However, all the models still have large systematic errors not only in the regional scale but also in the planetary-scale feature, mostly related to large uncertainties in the physical processes. The recent TOGA-MONEG report (WCRP, 1992) has concluded that the systematic errors in simulating the seasonal monsoon circulations were found to be sensitive to four physical processes, i.e., convection, surface heat fluxes in the warm water pool region, land surface processes and the representation of subgrid-scale orography. In other words, the change of these processes, or the integration of slightly different processes result in a great change in the distribution of latent heat transport and convergence in the monsoon region, which in turn is easily fed back to the distribution of diabatic heating and monsoon circulations.

The recent model comparison study in the MONEG activity has also shown that considerably large discrepancies and systematic errors still exist between the models even when the same SST conditions are prescribed to all the models. This result suggests the relative importance of cumulus convection and land surface processes (and possibly, their interactions) in producing large systematic errors and discrepancies between the models. In fact, all the models have adopted considerably or delicately different parameterization schemes for these processes, either of which are not fully validated by the observations over the land area. More specific problems related to the cloud and the land surface processes and their parameterization in the climate models are described in the following subsections.

1-2-2. Role of cloud systems and cumulus convection in monsoon Asia

It is well known that in the tropical Pacific the hierarchy structure of the cloud system is apparent both in time and space field, which seems to plays an important role for the maintenance and variability of the climate system in the tropics (Nakazawa, 1988; Lau and Chang, 1985). However, little has been known about the structure of cloud systems over the tropical and subtropical land or land/ocean mixed areas under the Asian monsoon, where various scales of orographies and heterogeneous surface conditions may affect the regional scale divergent and rotational moisture field which in turn affects the organization of cloud systems. The different vertical as well as horizontal structure of the systems also seems to have a different role of energy exchange process in the atmosphere to those over the oceans.

The interaction of cloud systems between land and ocean also seems to be important. Some cloud systems in the monsoon area, e.g., those embedded in the Baiu (Meiyu) frontal rain band, have characteristic natures of both the tropics and the extratropics (Ninomiya and Yamazaki, 1979). This frontal system plays an essential role on the poleward moisture transport during the early boreal summer (Ninomiya, 1975), but has not adequately been resolved in the current models.

The cumulus ensemble over the heterogeneous surfaces of the continent should be affected by a completely different process interacted with the surface hydrological condition from those over the oceans. The interactive hydrological process that rainfall induced by moisture convergence and evaporation affect the soil moisture content and, in turn, feeds back to local rainfall may effectively occur over the semi-arid region of this area. It is plausible that this interactive process be responsible for vigorous convection over the Tibetan plateau, which produces the "plateau monsoon" circulation (Yanai et al., 1992).

Another essential aspect of cumulus convection in monsoon region is a remarkable diurnal cycle with the completely opposite phase in the day between the ocean and the continent (Murakami, 1983). This diurnal cycle is essential not only for evaluating the regional hydrological cycle in monsoon Asia, but also for understanding the characteristic structures of meso-scale cloud systems over there. The role of the outstanding diurnal cycle of the plateau monsoon circulation over and around the Tibetan plateau on the large-scale monsoon circulation also needs to be validated.

1-2-3. Role of land surface processes over Eurasia on the monsoon variability

The Eurasian continent, the largest continent on the earth, plays a predominant role on the seasonal cycle of the planetary-scale surface energy exchange and transport in the climate system. The diverse land surfaces and vegetations from the equatorial to the polar regions, from the humid tropics of the southeast Asia to the arid and semi-arid regions in the interior of the continent characterize the extremely large seasonal and spatial variation of surface sensible and latent energy fluxes over the continent.

The surface net radiation flux is a fundamental forcing of the sensible and latent energy fluxes. The estimation of these fluxes over the global surface was formerly done by Budyko (1956). This task should be updated by utilizing the satellite as well surface observations with higher quality and resolution over the whole of the continent, which is one of the major objectives of the GEWEX.

It has been pointed out that the tropical rainforest fed by abundant rainfall of various time scales act as a huge water reservoir with more constant evapotranspiration rate. The climate of humid tropics is plausibly maintained at least partly by this energy and water filtering process played by the rainforest itself. The seasonal heating over Borneo island, covered by tropical rainforest, is suggested to play an important role on the onset of the northern summer monsoon (Murakami, T. and J. Matsumoto, 1994). The recent deforestration of southeast Asia may have been changing this equilibrium in the energy process in the humid southeast Asia. However, no quantitative estimate of the energy fluxes representative of this region has yet been done.

On the other hand, the seasonal change of the active layer of permafrost and associated surface energy fluxes over the northern half of the continent seems to have some role in the seasonal march of the atmospheric circulation over the northern hemisphere and subsequently in the establishment of Asian summer monsoon. These diversities in land surface conditions over the Eurasia on the surface energy fluxes has to be validated not only as an equilibrium response to regional climate but also as an active component of large-scale boundary condition for the Asian monsoon circulation itself.

Some observational studies have suggested that the interannual variability of Asian summer monsoon is strongly influenced by the anomalous state of seasonal land-surface conditions, i.e., snow cover, soil moisture and possibly permafrost, of the Eurasian continent through the anomalous energy fluxes (Hahn and Shukla, 1976; Morinaga and Yasunari, 1994 etc.), as shown in Figure 1-4. These anomalous surface hydrological conditions are provided, through precipitation, chiefly by the anomalous mid-latitude westerly flow regime in the preceding winter and spring (Yasunari and Seki, 1992; Yasunari et al., 1994). It is of interest that these anomalies in the land-surface hydrological conditions influencing the monsoon variability are, at the same time, the anomalous state of hydrological cycle over the Eurasian continent. It should be pointed out, however, that neither observations nor modelling studies have substantiated the real physical processes responsible for these time-lag atmospheric responses to the anomalous land-surface hydrological conditions.

Some GCM studies have suggested, for example, the importance of the snow-hydrological effect, i.e., the effect of soil moisture anomaly in summer induced by melting the snow mass anomaly in the preceding winter and spring, rather than the albedo effect for the time-lag response to anomalous snow cover over the Eurasian continent (Yeh et al., 1983; Barnett et al., 1989; Yamazaki, 1989; Yasunari et al., 1991). This effect need to be validated by using the satellite as well as surface data of large-scale snow mass distribution on various surface conditions and seasons. The soil moisture has been considered to be a particularly important parameter which gives an initial as well as boundary conditions for the global as well as regional climates (Serafini, 1990; Fennesy et al., 1993) through the surface energy budget changes. The feedback process of soil moisture-evaporation-convection over land area should also be investigated further both by the observation and models under various land-surface and atmospheric conditions, since this process seems to be very essential for producing atmospheric diabatic heating anomaly.

The effect of atmospheric and surface heating over the Tibetan Plateau on the Asian summer monsoon has been noted since the MONEX during the GWE (Global Weather Experiment) at the end of 1970's (Nitta, 1983; Luo and Yanai, 1983; 1984, Yanai et., 1992). The quantitative evaluation of thermodynamical effect of the plateau, however, has not been fully realized, including the effect of boundary conditions (soil moisture, snow cover, and seasonal phase change of permafrost) on it.

The large diversity of vegetation over the continent, at the same time, provides us a good opportunity to validate and improve the conventional biosphere-atmosphere transfer schemes (e.g., SiB, BATS) and development of macro-scale hydrological models. Regional energy processes over some extreme land surface conditions from south to north (e.g., rainforest, paddy field in monsoon region, grassland in Mongolia,

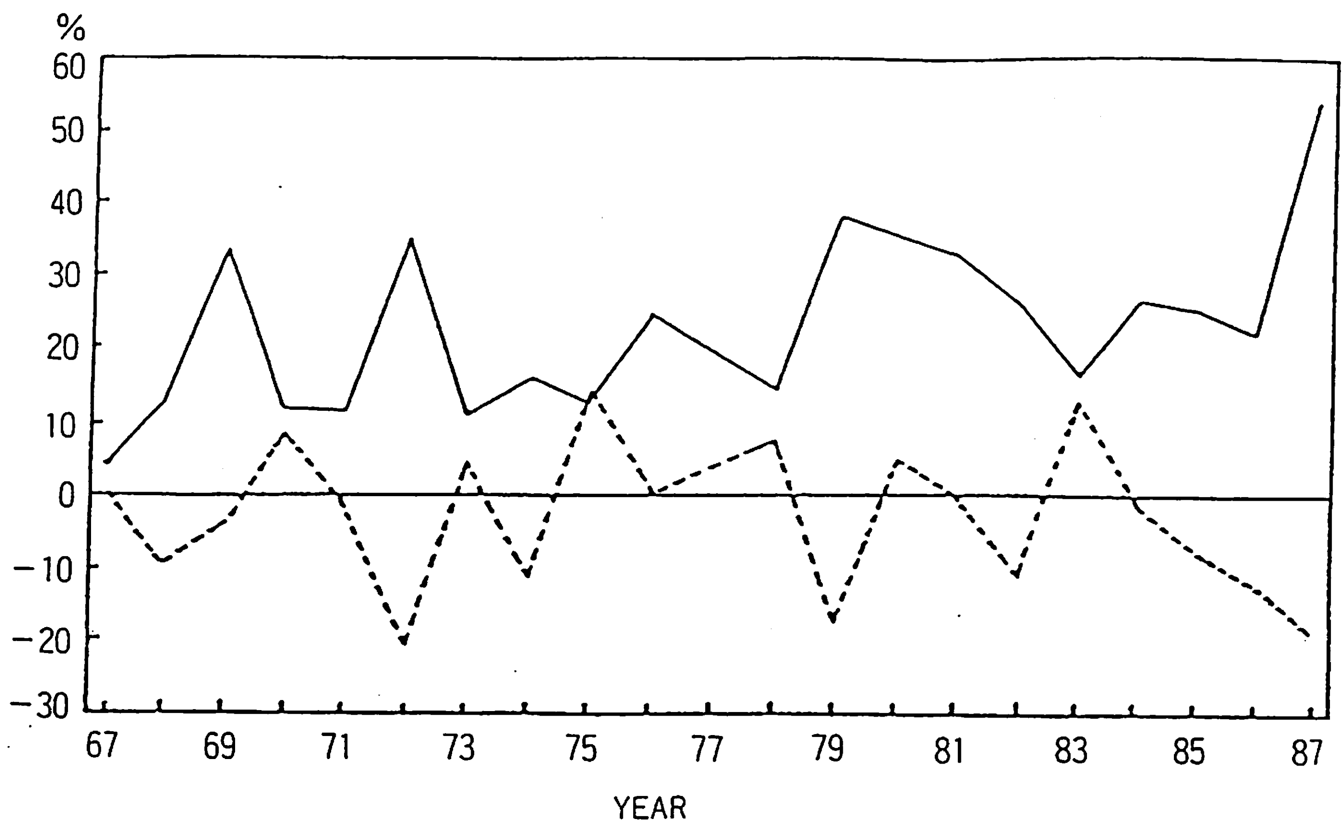


Figure 1-4: Interannual variation of All India monsoon rainfall(June to September) and snow cover extent over central Asia (April). (Morinaga and Yasunari, 1994)

permafrost in Tibet and Siberia etc.) would deserve to be studied for development of more universally-applicable macro-scale hydrological models.

1-3. Water balance in monsoon Asia and its implication

1-3-1. Water cycle cascades in monsoon Asia

The monsoon Asia, or more widely, the eastern half of the Eurasian continent is characterized as a broad area integrated by heterogeneous and complex terrains extended over the equatorial belt through the mid latitudes. A number of the major continental river basins on the earth are concentrated in this continent, each of which is located under a remarkably different climate. The fundamental parameters of the surface water balance, i.e., (P-E), water storage and discharge, of each river basin subsequently shows a quite different feature both in quantity and seasonal pattern. The characteristic time scale of response to precipitation forcing and associated water cycle should considerably differ from basin to basin, which is essential for evaluating the effect of land surface hydrology on the large-scale atmospheric condition. Seasonal change in various forms of surface water, i.e., snowcover, soil moisture, permafrost etc. would also affect this water cycle.

Another implication of the water balance of these river basins is the fresh water supply to the surrounding oceans. The huge amount of fresh water is supplied to the Arctic Sea from the three major rivers (Obi, Yenisey and Lena), which may in turn have considerable impact on the Arctic sea ice formation in the succeeding autumn. This suggests some linkage between the snow cover in winter and the sea ice in the succeeding year through the water balance of the river basins. The impact of fresh water supply from the rivers in the monsoon region to the surrounding warm tropical oceans on the atmosphere/ocean coupling also needs to be validated as a possible link in the climate system.

To validate these large-scale interactions between the surface hydrological processes and the other components of the climate system, however, development of macro-scale hydrological models is inevitably required.

1-3-2. Impact of monsoon variability on regional hydrological cycle

The planetary-scale Asian/Australian monsoon and its variability appears to be a different feature locally from region to region and from basin to basin scale, affected by local geographical and orographic conditions. Even though a large-scale atmospheric heating and monsoon circulation could be given as a result of prediction by the numerical models, the flood and/or drought conditions usually occur in more regional or local scales. In 1987, for example, the Indian subcontinent was prevailed by a drought condition, as a whole, associated with the typical El Ninõ event in the equatorial central Pacific, but large regional variety of drought/flood condition were also dominated (Krishnamurti et al., 1989). To exactly simulate and predict these regional-scale drought/flood conditions in the GCMs and forecasting models is an essential future requirement particularly for assessing and planning the water management and disaster prevention.

A key parameter may be precipitation resolved in the diurnal variation and spatial distribution in a basin-scale referenced. Evaporation and run-off characteristics closely related to vegetation, soil properties and regional/local orographic condition also need to be validated by developing macroscale hydrological models. The effort of this down-scaling, or disintegration of hydrological cycle and processes from the large-scale meteorological informations to regional or basin scale hydrological conditions is extremely important for the impact assessment of water resources and managements.

In addition, we have to pay more attention to the impact of long-term trend of monsoon climate and its variability. Currently, the plannings for water usage and disaster prevention are formulated on the assumption that the statistical characteristics of the prevailing climatic and hydrological processes never change. This concept has increasingly been being recognized as an unrealistic assumption, associated with the recent "global change" issue mentioned in the next section. It is absolutely necessary, in this context, that future plannings be redesigned and operated taking account of the more realistic assumption that the monsoon climate is not stationary.

1-4. The "global warming" issue and Asian monsoon

The recent climate model studies related to the "global warming" issue have commonly shown the increase of global surface air temperature due to the increase of the greenhouse gases (e.g., doubling of CO_2) particularly in the polar latitudes (IPCC, 1990; 1992). The results in these models have shown, however, that there are still large uncertainties in predicted anomalies in hydrological parameters. Particularly, the responses of the Asian monsoon rainfall and associated soil moisture over the Eurasian continent to the greenhouse gas increase have shown large discrepancies between the models as shown in Figure 1-5, though this issue is extremely important for the agriculture and economy in monsoon Asian countries.

The uncertainties in predicting the anomalous state of the monsoon in this issue seems to be chiefly attributed to those in hydrological feedback processes over the land surface. It has not been realized yet, for

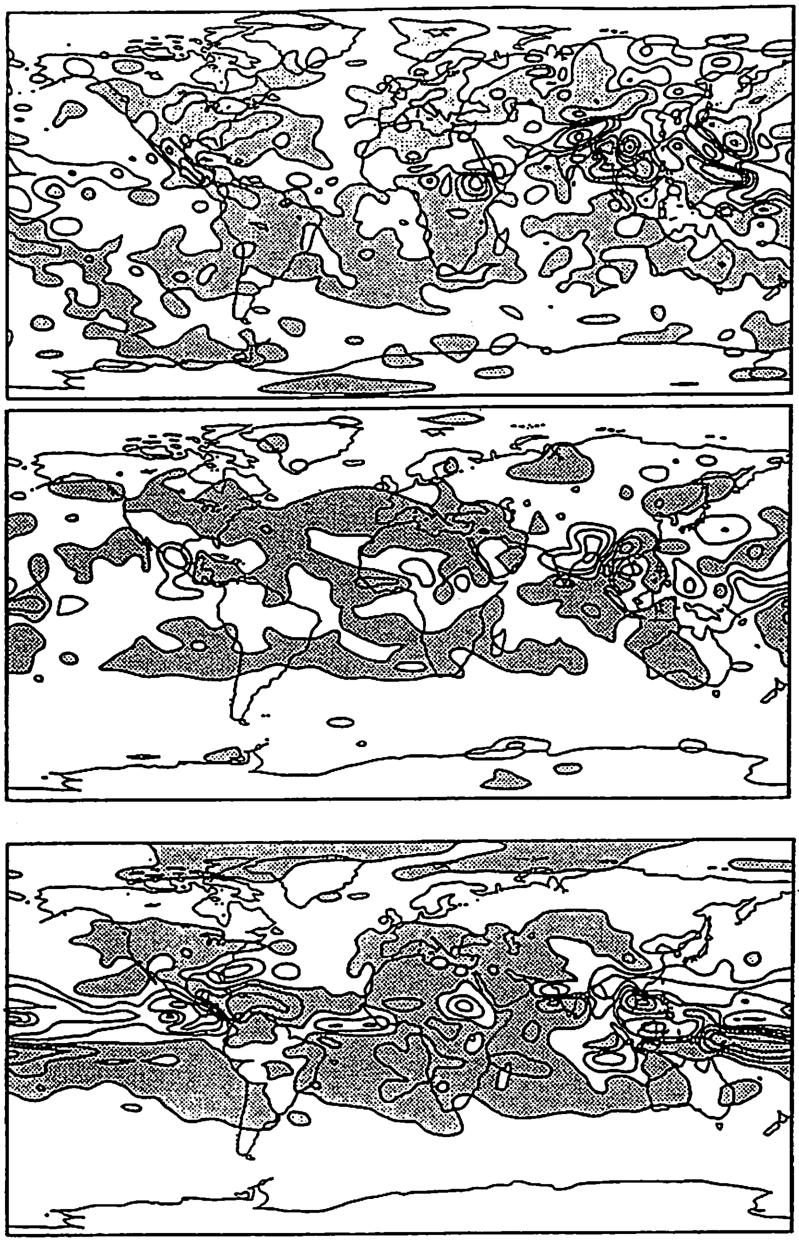


Figure 1-5: Change in precipitation due to doubling CO2, for months June-August, as simulated by three high resolution GCMs of (a)CCC, (b) GFHI, and (c) UKHI. (IPCC, 1990)

example, how the anomalous winter precipitation over the continent affects, through snow melting and evaporation in spring, the anomalous soil moisture and atmospheric heating in the following summer. In this process, the background soil moisture content in winter may play a key role in leading the anomalous surface condition in summer (Manabe and Wetherald, 1987).

It is noteworthy to state that in the real climate system a remarkable increase of surface air temperature in the northern hemisphere in the recent years particularly since 1970's is due mostly to that over the northern part of Siberia and central Asia. This warming over Eurasia may, at least partly, be related to the feedback in the land-surface process, e.g., partial melting of permafrost and snow cover etc. Partial, though not sufficient, evidence of decreasing trend of snow cover in recent years has been reported (IPCC, 1992), as shown in Figure 1-6. Further observations as well as process studies of these land surface parameters and their association to the Asian monsoon variability should further be investigated.

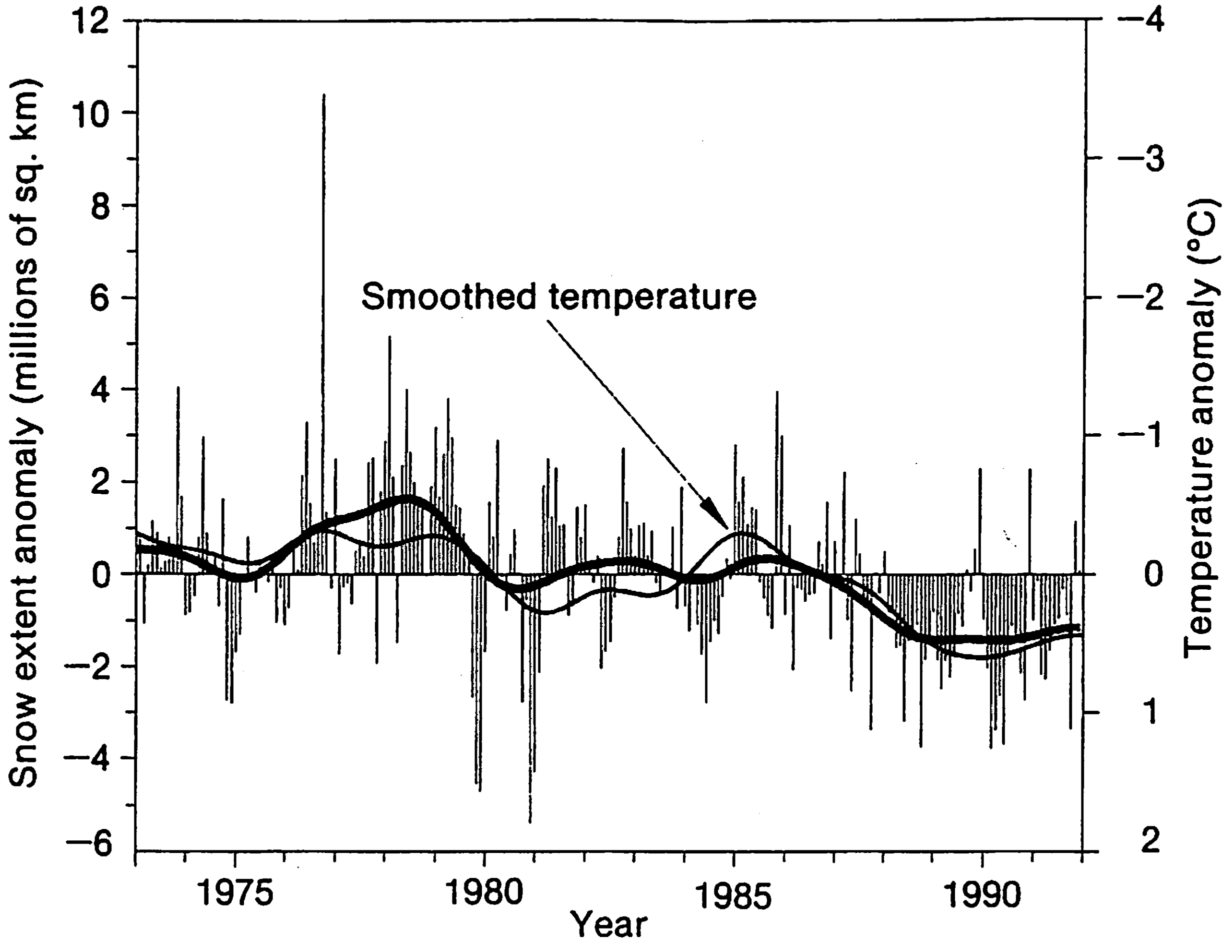


Figure 1-6: Northern hemisphere snow cover extent anomalies relative to 1973-1991 (NOAA) (vertical bars and thick line), and Jones (1988 updated) land air temperature anomalies relative to 1951-80 north of 30°N(thin line). Note the inverted temperature scale. (IPCC, 1992).

2. Scientific objectives of GAME

2-1. Main objectives

The scientific objectives of the GAME consists of the following four major parts:

A . To understand the role of Asian monsoon in the global energy and water cycle.

B. To improve the simulation and seasonal prediction of Asian monsoon by the global climate models and numerical forecasting models.

C. To understand multi-scale interactions in the energy and hydrological cycles in the Asian monsoon region

D. To assess the impact of monsoon variability on the regional hydrological cycle.

A will be based fundamentally upon global-scale satellite observation, analysis of four-dimensional assimilated data and GCM-based model studies. The data archive and compilation of global and continental-scale meteorological and hydrological data sets be included.

B will be proceeded by the atmospheric as well as the coupled atmosphere-ocean GCMs and the operational numerical simulation models. The development and improvement of cumulus cloud parameterization scheme and the land-atmosphere interface scheme should be incorporated to resolve all the processes with 50 km x 50 km grid scale with the aid of the GAME data archive from satellite observations and field-based process studies.

C will be based upon the field process studies carried out in some typical climatic regions in the Asian Monsoon area and the Eurasian continent which consist of the physical processes of the atmosphere-hydrosphere (and biosphere) interactions with horizontal-scale of 1 km to 1000 km and time-scale of diurnal cycle to seasonal variation. The essential task will be to develop the macro-scale hydrological models applicable to Asian monsoon regions, as well as to produce the main GAME field data sets.

D will be the application of GAME data archive and the macro-scale hydrological models to specific continental-scale and regional-scale river basins in monsoon Asia.

2-2. Strategy for GAME

Following the aforementioned scientific objectives of the GAME, the strategy for implementing the GAME program will be proposed as follows:

(1) Intensive regional experiments for multi-scale energy transfer and water cycle processes

The intensive regional process studies will be deployed based on three-dimensional field campaigns, which aim to integrate and disintegrate the energy transfer and water cycle processes in the heterogeneous surface condition of monsoon Asia. The four regions are selected for these studies to represent some extreme and typical land-surface and climatological conditions in monsoon Asia. In each region observations of cloud processes, planetary-boundary layer, meso-scale atmospheric circulations and surface hydrological processes will be intensively deployed to finally obtain 10 to 100 km grid sized parameters. The results obtained through these process studies are essential as basic data sets for modelling meso-scale atmospheric modelling and regional or macro-scale hydrological modelling and their coupling, described in item (5).

(2) Satellite-based observations of energy and water cycle in the Asian monsoon system

The variability of large-scale energy and hydrological processes of Asian monsoon system will be monitored from diurnal to interannual time scales at least for ten years, basically by utilizing the operational geo-stationary and polar-orbiting satellites (GMS, NOAA, DMSP, INSAT etc.), the special mission satellites (e.g., TRMM and its follow-on missions, ADEOS, EOS series, ENVISAT, METOP) and other satellites. Most of the parameters for the energy and hydrological processes (i.e., cloud, water vapor, precipitation, wind, snow cover, albedo, soil moisture, surface temperature etc.) will be able to measure directly or indirectly by these satellite informations. To develop the algorithms for obtaining these parameters from satellite informations will also be an essential task based on the data from the field observations described in (1) and (3).

(3) Long-term monitoring of the surface radiation and energy budgets in monsoon Asia

The monsoon is forced by differential heating between the continent and the oceans. The radiational forcing is, needless to say, a fundamental factor for this heating. The seasonal and interannual variabilities of this radiational forcing strongly depends upon the anomaly in clouds, aerosol distribution and surface hydrological conditions (snow cover, soil moisture, vegetation) particularly over the continent These variabilities in radiational forcing, in turn, produces those of surface and atmospheric energy balances, which directly affect the regional as well as large-scale monsoon circulation. The estimates of spatial and temporal distribution of radiation and surface energy budgets over the Asian monsoon region (eastern half of the Eurasian continent) is an essential part of GAME. This task will be done by integrating the surface-based monitoring of energy/radiation budgets with automatic weather station (AWS) network, in conjunction with the Baseline Surface Radiation Network (BSRN) and the satellite-based Surface Radiation Budget (SRB) projects.

(4) Four-dimensional data assimilation

Based upon the meteorological and hydrological data sets obtained through the observations and monitorings related to the GAME activity, the four-dimensional data assimilation will be performed by using the advanced forecasting model (T213L30 with horizontal resolution of about 50 km), and with the improved cloud and land-surface parameterization schemes. The satellite and field-based observations, in addition to the operational data network would be compiled as much and densely as possible, to conform to the resolution of the assimilation system. The Intensive Observing Period (IOP) with enhanced radiosonde observations would be required to obtain highly qualified analysis data sets for estimating the regional as well as global energy and water cycles. Finally, the re-analysis of the data sets obtained through the GAME implementation period will be operated to estimate the annual cycle and interannual variability of the global and regional energy and water budgets. The data set thus produced, will be a major product of the GAME.

(5) Modelling studies of meso-scale atmospheric processes and regional or macro-scale hydrological processes and their application to climate models

Based on the observational data sets obtained through the GAME, models for meso-scale atmospheric processes, macro-scale hydrological processes and their couplings will be developed to resolve the atmosphere hydrosphere interaction in the spatial scale of 10 to 100 km with diurnal cycle. To incorporate these models with atmospheric and coupled atmosphere/ ocean GCMs, and to simulate and predict the seasonal evolution of monsoon circulation and water cycle from regional scale to global scale would be a final goal of the modelling in the GAME frame work.

(6) Data archive and deployment of information network

The various kinds of data sets which will be obtained and collected through the observational components of GAME will serve us as a huge data archive, that should easily and promptly be accessed and utilized by the meteorological, hydrological and other related scientific and operational communities of the concerned countries. The data archive and utilization should systematically be implemented based on the state-of-the-art information network available for all over the world.

3. Process studies and regional experiments

3-1. Scientific objectives

To understand the physical processes and validate the models of multi-scale cloud processes and the atmosphere/hydrosphere interactions, and to obtain the surface or near-surface truth for the satellite measurements, several GCIP-like regional-scale field experiments in various land surface and climatological conditions should be made.

Main research subjects of process studies and regional experiments are as follows:

a. Understanding multi-scale physical processes associated with energy and water cycles by means of data collection and ground-based, air-borne and satellite observations
b. To provide data sets for development of atmosphere/land-surface schemes and for the verification of climate models
c. To develop of macro-scale hydrological models and their coupling to meso-scale atmospheric models
d. To develop and validate information retrieval scheme for satellite observations coupled with enhanced ground-based and aircraft observations
e. to assess the impact of large-scale climate and monsoon variability on regional hydrological cycles

3-2. Links with GCIP and other continental-scale budgets studies

The comprehensive and intensive field experiment of GCIP is scheduled for the period of 1994 through 1999 over the Mississippi River basin of North America. There are, however, wide range of varieties in the climatic and land-surface conditions on the earth. Not all of the atmospheric and hydrologic processes important to the goals of GEWEX occur within the Mississippi River basin. To study intensively these processes over the other continental areas with different climatic and ecological conditions, the four continental-scale budget studies have been approved as part of the GEWEX activities at the sixth session of the GEWEX SSG (Science Steering Group) meeting in February 1994. These are; BALTEX (BALTic sea EXperiment), LAMBADA (Land-Atmosphere Moisture Budget studies over the Amazon by the four-dimensional Data Assimilation), MAGS (MACkenzie river GEWEX Study), and GAME in monsoon Asia.

The Eurasian continent and the Asian monsoon region can provide major counterpart fields which are comparable with, and complementary to the fields of the GCIP and the other three budget studies. It is indispensable to validate and ensure the transferability of the results obtained for the Mississippi and the other continental areas to the key

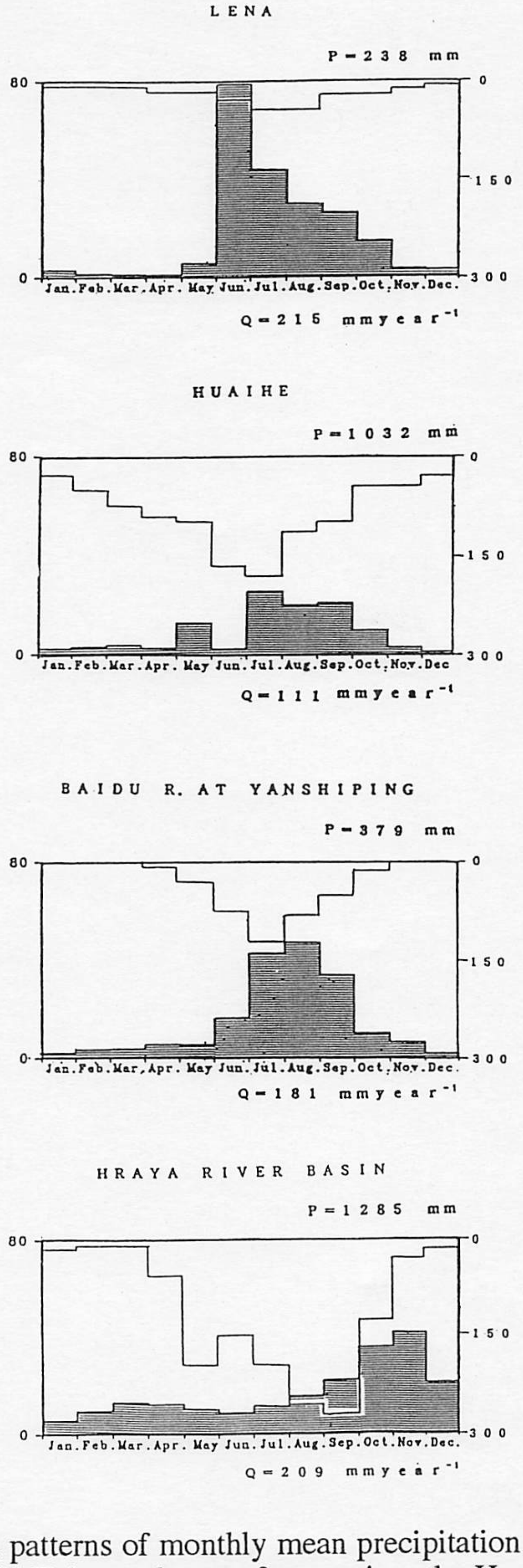


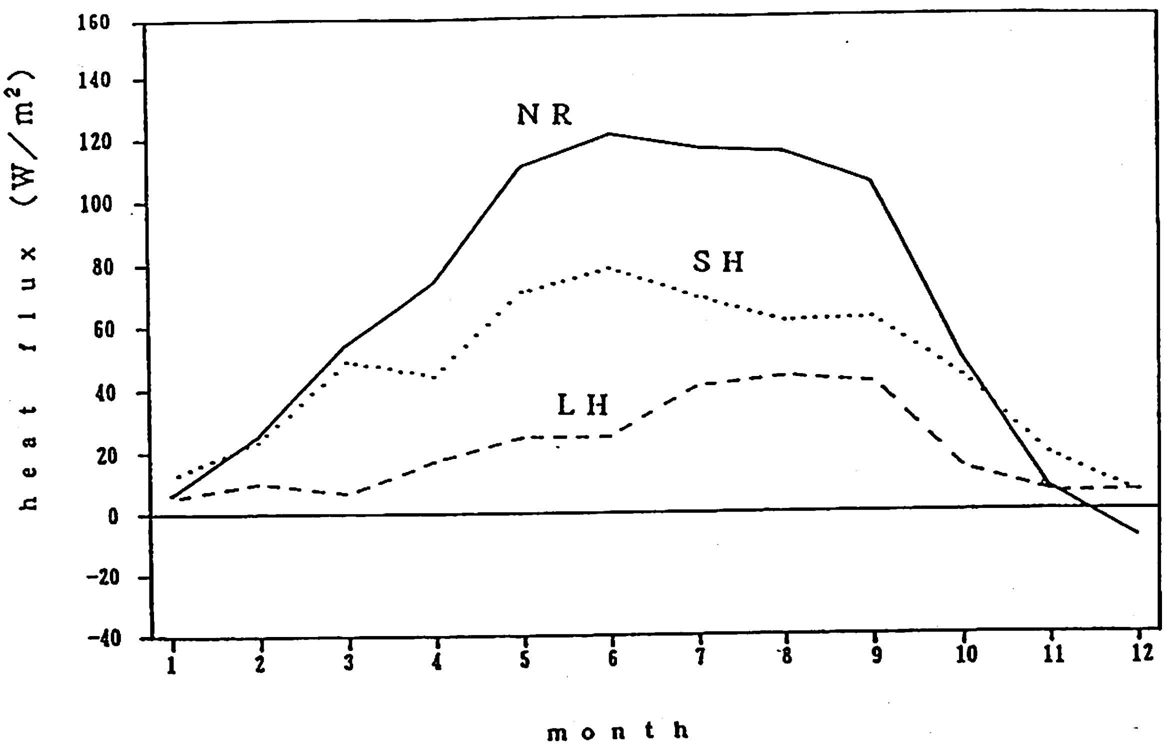
Figure 3-1: Seasonal patterns of monthly mean precipitation and runoff in the Lena River in Taiga and permafrost region, the Huai-He River in the sub-tropical front rain (Meiyu) zone in central China, the ChaoPhraya River in the tropical monsoon region of Thailand and the upper-most region of the Yangtze River on the Tibetan Plateau.

phenomena in the global energy and water cycles, for making the macro-scale hydrological models "universal". The term "universal" implies that the models include the applicability to the global domain by themselves. To meet these requirements, inter-comparisons between extremely different hydrological processes are essential as well as the process studies of each area, which will be sufficiently fulfilled by the concurrent four regional experiments covering from the polar to the tropical climate/vegetation zones within the monsoon Asia.

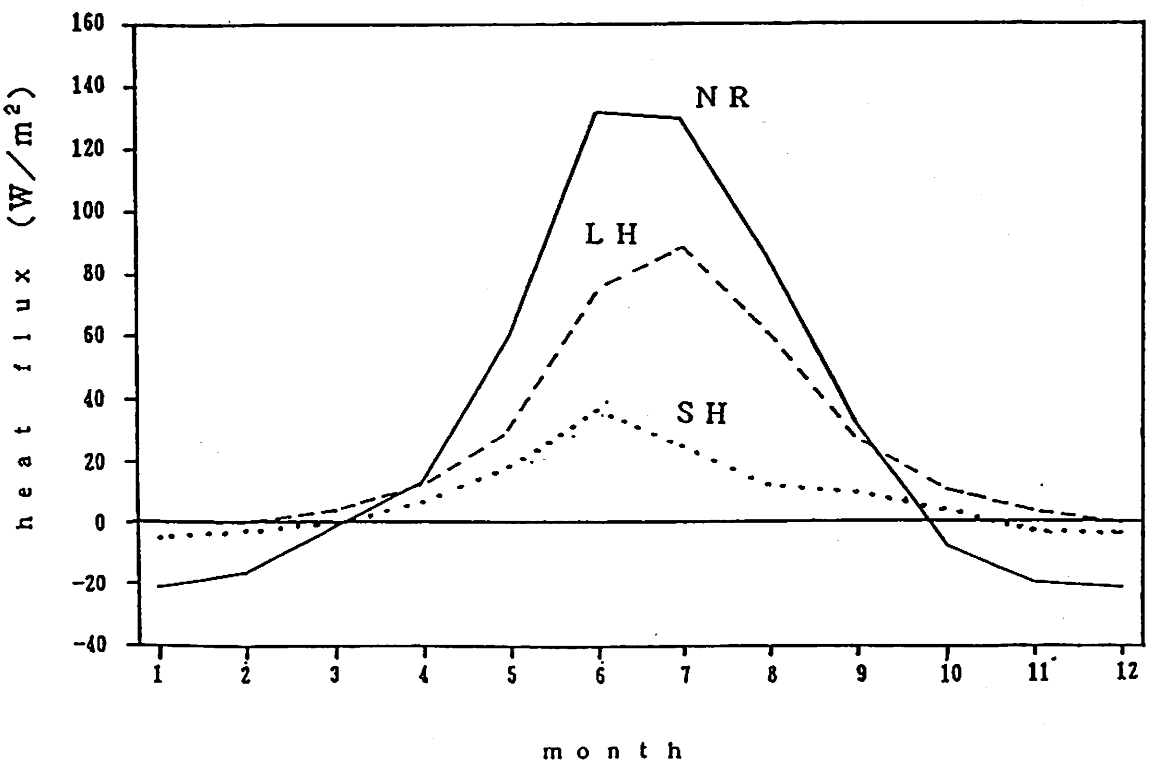
3-3. Selection of experimental fields

The eastern half of the Eurasian continent consists of heterogeneous and complex land-surfaces such as Taiga, permafrost in Siberia and Tibetan Plateau with seasonal snow cover, paddy field plains under monsoon and seasonal frontal rains, tropical rainforest, arid and semi-arid desert areas, etc. These land surface conditions ,combined with large diversity in climatic conditions, seem to characterize completely different surface hydrological cycles. Figure 3-1 shows the seasonal patterns of monthly mean precipitation and runoff in the Lena River in Taiga and permafrost region, the Huai-He River in the sub-tropical front rain (Meiyu) zone in central China, the Chao Phraya River in the tropical monsoon region of Thailand and the upper-most region of the Yangtze River on the Tibetan Plateau. The total values and monthly patterns of precipitation and discharge show a completely different feature from region to region. In the ChaoPhraya River basin, for example, more precipitation and less discharge, implying more evaporation, is noted during the monsoon season. In the Lena River basin, in contrast, extremely large discharge and very little precipitation is apparent, suggesting the time-filter effect of melting of snow (i.e., winter precipitation) in high latitude. Over the Tibetan Plateau, local difference is very large; the precipitation and runoff is most in the upper-most area with glaciers and continuous permafrost, while the precipitation and runoff is least in the middle area with partial permafrost and without glacier.

Figure 3-2 shows, for example, monthly surface heat fluxes over the permafrost in Siberia (Budyko, 1973) and on the Tibetan Plateau (Li et al., 1987), which clearly reflect the difference in geographic and climatological conditions. The relatively long (short) period of strong net radiation, e.g., over 100 W/m^2, on the Tibetan Plateau (in Siberia) is chiefly attributed to the incoming solar radiation in the lower (higher) latitude, while the larger (smaller) sensible heat flux and the smaller (larger) latent heat flux on Tibetan Plateau (in Siberia) may be closely associated with the dry (wet) surface soil condition particularly in summer.



Permafrost in Tibetan Plateau



Permafrost in Siberia

Figure 3-2: Monthly heat fluxes over the permafrost in Siberia and over the Tibetan Plateau. (Li et al., 1987; Budyko, 1973).

The different land-surfaces, in this manner, cause wide range of varieties in the hydrological and energy processes. Inter-comparison of these hydrological and energy processes between different land surface and climatic conditions would be a fundamental task for constructing the macro-scale hydrological model as well as improving schemes for atmosphere/land surface interactions in climate models.

Taking account of these scientific requirements, following several regions with typical climatological and hydrological conditions are selected for regional experiments to understand specific important processes of atmosphere, hydrosphere and biosphere interactions, which are proper to the Eurasian continent and monsoon Asia. The experimental field areas are shown in Figure 3-3.

1) Tropical monsoon region in southeast Asia

2) Subtropical and temperate monsoon region in east Asia

3) Tibetan Plateau and surrounding arid/semi-arid region

4) Permafrost region (Taiga and Tundra) in Siberia

The field experiments will be categorized elementally into two types as follows:

a) The three-dimensional experiment over the regional-scale river basin, with sufficient surface as well as radar, radiosonde observations and river runoff (stream flow) data, to estimate the full energy and water balance of the basin, in addition to the two-dimensional surface physical processes.

The experiments of the Huai-He river basin (China), the Chao Phraya river basin (Thailand) and Lake Biwa basin (Japan) will belong to this type.

b) The one or two dimensional experiment at limited points or small areas, to estimate the surface energy and water fluxes and one-dimensional surface physical processes representative for that particular region. To estimate the energy and water balance of the broader are or river basins, the satellite-retrieved data will be applied.

The experiments of the tropical rainforest in Sarawak (Malaysia), Tibetan Plateau and the permafrost (Taiga and Tundra) in Siberia will basically be those of this type.

Detailed experimental designs are described in the followings.

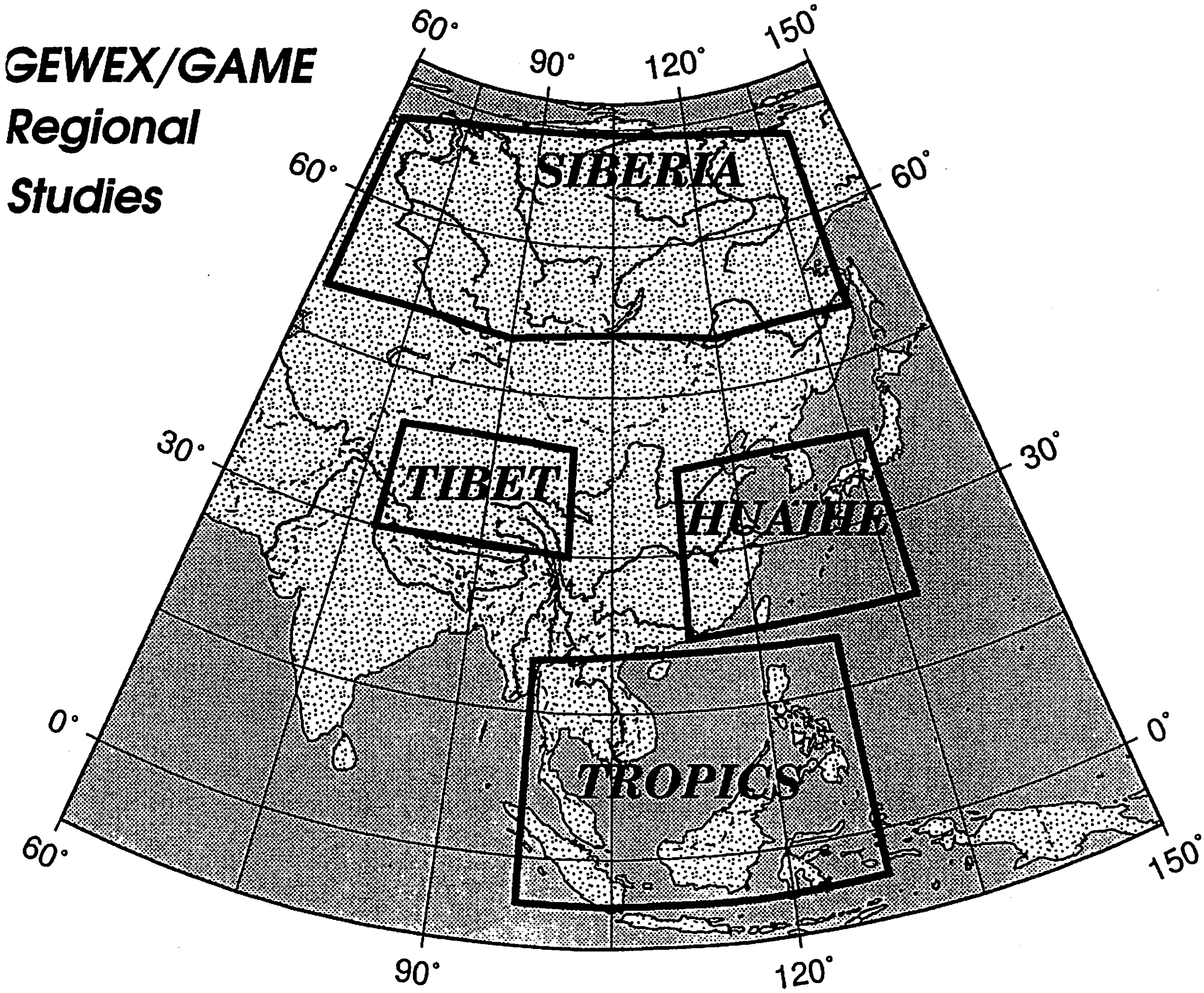


Figure 3-3: Domains of regional experiments.

3-4. Outlines of regional experiments

3-4-1. Tropical monsoon region in southeast Asia

This regional project consits of two parts: one is energy and water balance studies based on the conventional hydro-meteorological data network over southeast Asia (Thailand, Malaysia, Singapore etc.). The other is ad-hoc field-based experimental studies in the tropical rainforest areas and the Chao Praya river basin. The former studies aim to reveal the time-space characteristics of monsoon rainfall variability from intra-seasonal, seasonal to interannual time-sclaes, and their associations with the Asian monsoon activity. The different characteristics of rainfall patterns, water balances in different land cover and land use will be focused on. The surface-based validation of TRMM satellite data, which will be launched in 1977, is also an important part of these studies. The details of field-based experimental studies are described as follows:

(1) Tropical rainforest region in Sarawak and Malaysia

The tropical rainforest is a typical vegetation which characterizes the humid climate in the equatorial region. In monsoon Asia, this rainforest region roughly correspond to the maritime continent of the Indonesia archipelago and Malaysia. The role of this rainforest area has recently been noted as a source or sink in CO_2 cycle associated with deforestation in the tropics and the global warming issue.

In addition to the role in the CO_2 cycle, this rainforested region in southeast Asia, combined with the warm water pool region of the tropical western Pacific, would play, as well as that in the Amazon basin, an essential role as a heat and moisture source in the energy and water cycles of the global atmosphere. However, the quantitative as well as qualitative natures of this rainforest in terms of large-scale energy and hydrological processes are completely unknown, even compared to those for the Amazon basin. The intensive, though one-dimensional, observations of energy and water fluxes in the rainforest of the central Amazon basin have revealed some interesting characteristics of vertical fluxes in and over the forest canopy and a dominant role of latent heat flux over the canopy (Shuttleworth et al., 1984a, 1984b; Molion, 1987). Another striking feature may be a relatively important role of water recycling between in-situ rainfall and evapotranspiration compared to the advection process from the Atlantic Ocean (Salati, 1987). The role of rainforest of the Amazonia and its potential impact of deforestration on large-scale convection and atmospheric general circulation are comprehensively discussed by Paegle (1987).

Many of these features in the Amazon basin would commonly be apparent in the rainforest of southeast Asia. However, some remarkable contrast in physical and biological environments to the Amazon basin are also underlined. One of them may be larger amount of annual total rainfall over the most of the area under the humid maritime atmospheric condition. The vertical structure and variety of tree species of the forest are also likely to be considerably different depending upon the different climatic and geographic conditions, which characterize the different canopy structure of the forest. In addition to these micro-meteorological conditions, large-scale geographical and orographic conditions of the rainforested area are completely different from the Amazon basin. Most of the forest area is distributed in the Indonesian Archipelago and the Malaysian Peninsula. This situation suggests the active role of the forest area on local and regional scale orographic circulations and convections through the enormous supply of moist energy from the surrounding oceans, which should in turn affect the hydro-meteorological condition in the forest. The contrastive features of the diurnal cycle (M. Murakami, 1983) and even the intraseasonal variability of convection (Murakami et al., 1986) between land area and the surrounding ocean would, at least partly, be attributed to the different process of latent heat release between the forested land surface and warm sea surface. The role of these orographically-induced convection throughout the year on the large-scale diabatic heating field as shown in Fig. 1-2 should be assessed based upon moisture and energy flux distribution over the forested area as well as the oceans.

The continuous observation of at least two or three years are desirable to examine large intraseasonal, seasonal and interannual variability in the water budget of this region (Whitmore, 1975). In addition, the atmospheric moisture budget study with the enhanced radiosonde observations (4 times/day) over the four of five coastal stations of Borneo island including Indonesian territory will facilitate us to estimate the island-scale evapotranspiration, provided that the data of TRMM-based rainfall rate over the island would be available.

Main specific subjects of this study will be as follows:

a. Energy and water transfer processes and balances in the tropical rainforest
   1. vertical structure of radiation, sensible and latent energy fluxes over and in the canopy layer
   2. water balance of the canopy layer
   3. hydro-meteorological properties of the ecological system

b. Validation of precipitation algorithms for TRMM and GMS satellites
   Areal average of precipitation amount will be estimated for the triangle area over and in the canopy of the forest to validate precipitation from TRMM and GMS geostationary satellite.

c. regional-scale atmospheric water budget over the rainforest

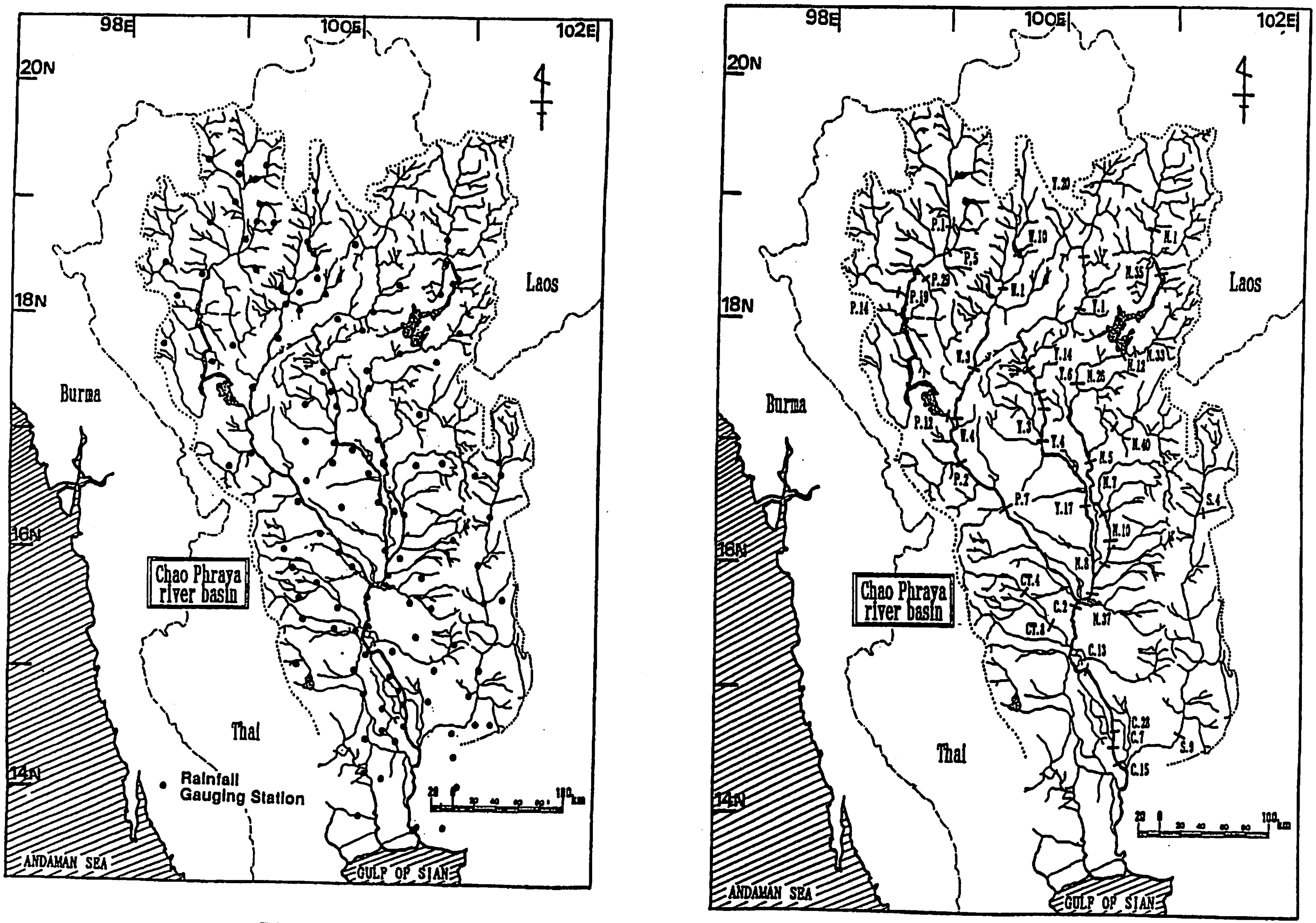


Figure 3-4: The map of ChaoPhraya river basin with raingauge and hydrological stations.

(2) Chao Phraya River basin in Thailand

The monsoon in south and southeast Asia is characterized as an annual cycle with distinct rainy and dry seasons. Most of the annual rainfall is concentrated in summer monsoon season. The interannual variability of monsoon rainfall is extremely large, which sometimes causes drought and flood condition in this area. The prediction of surface water balance of monsoon season is particularly important in this region, because the dominant agriculture here is paddy field cultivation of rice. In some particular areas the water deficit or surplus sways a single or double crops of rice for the year. The suppression effect of evapo-transpiration by the deficit of soil moisture may also be a proper but important hydrological issue of the typical monsoon region.

From the viewpoint of climate dynamics, the huge latent heating of monsoon rainfall and convection of this area manifest as an enhanced zonal asymmetry of diabatic heating in the global atmosphere and planetary-scale monsoon circulation as shown in Fig. 1-3. The energy and hydrological processes involved in this monsoon circulation, particularly of how the huge latent heating is generated and maintained over this region, is undoubtedly a central issue for the global energy and water cycle in the boreal summer.

Based upon these scientific backgrounds, the following field-based experimental study in Chao Phraya River basin is proposed as an international cooperative project.

The Chao Phraya River basin of Thailand, located in the central part of the Indo-China Peninsula, is a typical river basin with the area of about 200,000 km^2 in the tropical monsoon climate. The large variety of rainfall amount is noticeable between the relatively dry plain area and the surrounding mountainous area, with the large seasonal variation of soil moisture and relating hydrological processes. This sizable river basin with sufficient number of surface meteorological stations (of about 200) and hydrological stations (Figure 3-4) is suitable for investigating the surface hydrological cycle and its variability.

The cloud and precipitation process will be observed by the TRMM ground-truth radar after 1997, in addition to the operational meteorological radar. The Doppler-radar system may be introduced in the special observation period. The hydrological processes and their spatial-scale dependency will be compared with a river basin in the tropical rainforest of the neighboring Malay peninsula. The whole structure of the integrated observation-analysis-prediction system in the regional scale field experiment is schematically shown in Fig. 3-5.

The hydrological processes evaluated by this experimental study will be incorporated to construct a macro scale hydrological model. Research will be concentrated on the physical integration and scaling of hydrological processes. A final goal of this experiment is to construct a GCM-grid scale hydrological model in the tropical humid region. For

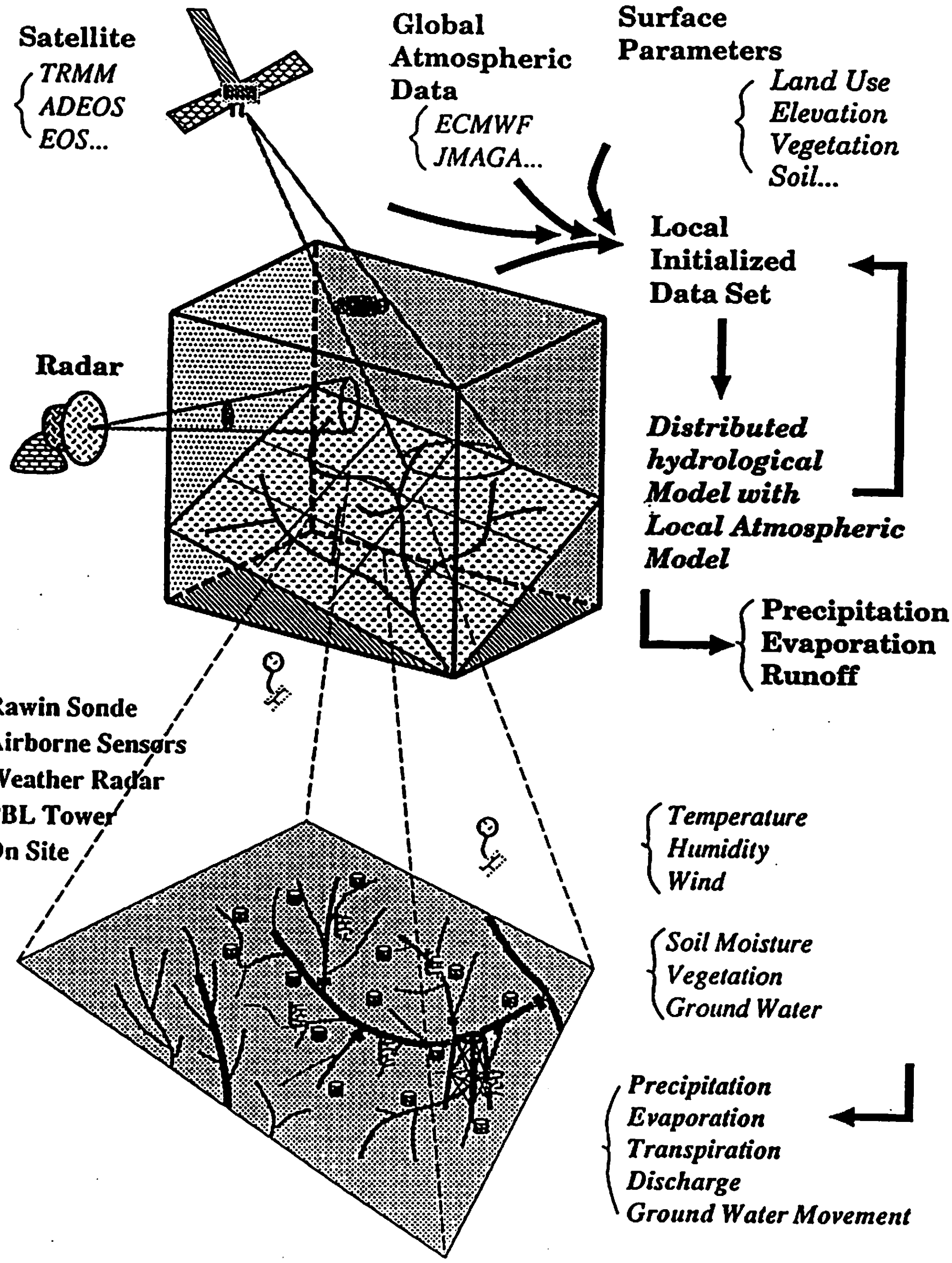


Figure 3-5:Schematic diagram of observing system of the regional experiment in the humid tropics of Thailand.

example, the comparison of the GCM grid-scale (2.5 x 2.5) atmospheric water vapor convergence over the girds of this river basin computed by the current ECMWF objective analysis data with the real discharge data of Chao Phraya river (Oki et al., 1991) only shows a qualitatively good agreement of the mean seasonal variation. To obtain far better result by the improvement of the model, which can resolve interannual variability of hydrological parameters with finer horizontal grid (of about 50 km or less), would be a basic requirement of this experiment.

The impact of human activities to hydrological processes, e.g., the impact of intake and drainage of water by irrigation facilities or the construction of dams and reservoirs to the river discharge, could also be evaluated quantitatively as an application of the deduced hydrological models.

Specific subjects of the field experiments are detailed as follows:

a. Seasonal variation of surface radiation and sensible and latent heat fluxes over the diverse land surfaces, i.e., paddy and other fields, bare soil surface, forest etc.
b. Seasonal variation of water balance of each sub-division of the river basin by ground-based and satellite observations. Intensive observations of actual evapotranspiration, soil moisture movement, water potential of vegetation, will be made at ad hoc observation sites.
c. Areally-averaged daily rainfall with 50 km mesh-scale will be estimated over the whole of the basin, by the algorithm deduced from the combination of raingauge data, radar data and TRMM and GMS satellite data. This would be a part of TRMM ground-truth project.
d. Method and algorithm for soil moisture measurement will be made by applying active/passive microwave measurement of satellites. Since there is a receiving ground station in Thailand, SAR data can be handled directly from a satellite without recorder. The seasonal change of surface soil moisture is significantly large related to the alternation of dry and rainy seasons, which will enable us to detect and validate the soil moisture change deduced from satellite informations.

3-4-2. Humid subtropical and temperate region in east Asia

Rainfall phenomena in east Asia (China, Korea, Japan) is closely associated with the subtropical front called the Baiu (or Meiyu in China, Changma in Korea) front during the early summer. The activity of this Baiu front is greatly influenced by the Asian monsoon circulation coupled with the subtropical high over the north Pacific. The subtropical high area sustains the rainfall activity in the frontal zone by huge moisture convergence and generation of convective activity (Ninomiya, 1984). Such moisture transport to the frontal zone basically depends upon the southwesterly monsoon flow from the Indian Ocean together with the southeasterly flow around the subtropical high over the Pacific, forming a huge "moisture conveyer belt" as shown in Figure 3-6.

The Baiu front is, on the other hand, characterized as part of the system in the mid-latitude westerly flow regime. Thus the frontal zone is an interactive system between the tropics and extratropics. The role of this frontal system on the energy and moisture transport to the polar regions in the northern summer is extremely large, though most of the current GCMs have not exactly resolved this frontal system.

This synoptic or planetary-scale frontal system embeds medium-scale and meso-scale cloud systems (Ninomiya and Akiyama, 1992; Akiyama, 1984) which affect regional or local hydrological processes in this area. Heavy rainfall associated with these meso-scale disturbances sometimes cause severe local flood in plain areas and mud flow in mountainous areas in Japan. The prediction of regional/local rainfall of this season, which should be based upon the understanding of physical processes of the meso-scale systems, has, therefore, been a big target not only for meteorologists but also for hydrologists in Japan.

The large-scale as well as the meso-scale characteristics of the Baiu (or Meiyu) front are rather different between the continent and the Japan Island side (Ding, 1992; Kato, 1985, 1987, 1989; Murakami and Huang, 1984; Ninomiya, 1989; Ninomiya and Akiyama, 1992; Ninomiya and Muraki, 1986 etc.). At the mature stage of the Baiu season in Central China and the Japan Islands (late June to early July), the low-level southerly wind component toward the front is stronger in the continent side than in the Japan Islands side and the moisture content in the subtropical high area to the south of the front is larger over the continent.

On the other hand, the meridional gradient of temperature in the lower layer across the front is nearly zero over the continent, while it is not so small around the Japan Islands. Furthermore, slow-moving upper-level cut-off cold low sometimes approaches to the Japan Islands and interacts with the Baiu frontal cloud systems. A part of meso-α scale systems on the front develop around the Japan islands in such situation. While the meso-α– or synoptic-scale disturbances which appear on the Baiu front in China are originated from the northeastern hem of the Tibetan Plateau or from the central part of the Plateau, which are called as SW (southwest) -vortices.

Thus not only large-scale features of the cloud distribution around the Baiu front but also multi-scale structure of the meso-scale cloud systems there are very different between the continent and the Japan Islands side (Akiyama, 1984; Ninomiya, 1989; Ninomiya and Akiyama, 1992; Ninomiya et al., 1981; Ninomiya et al., 1988). Cumulonimbus cloud clusters (Cb-clusters) frequently appear in the front in Central China (late June to early July) but they are not organized into meso-α scale pressure depressions. Around the Japan Islands where baroclinicity is not so small, the Cb-clusters tend to be organized into meso-α scale pressure depressions. In other words, dynamics of cloud systems around

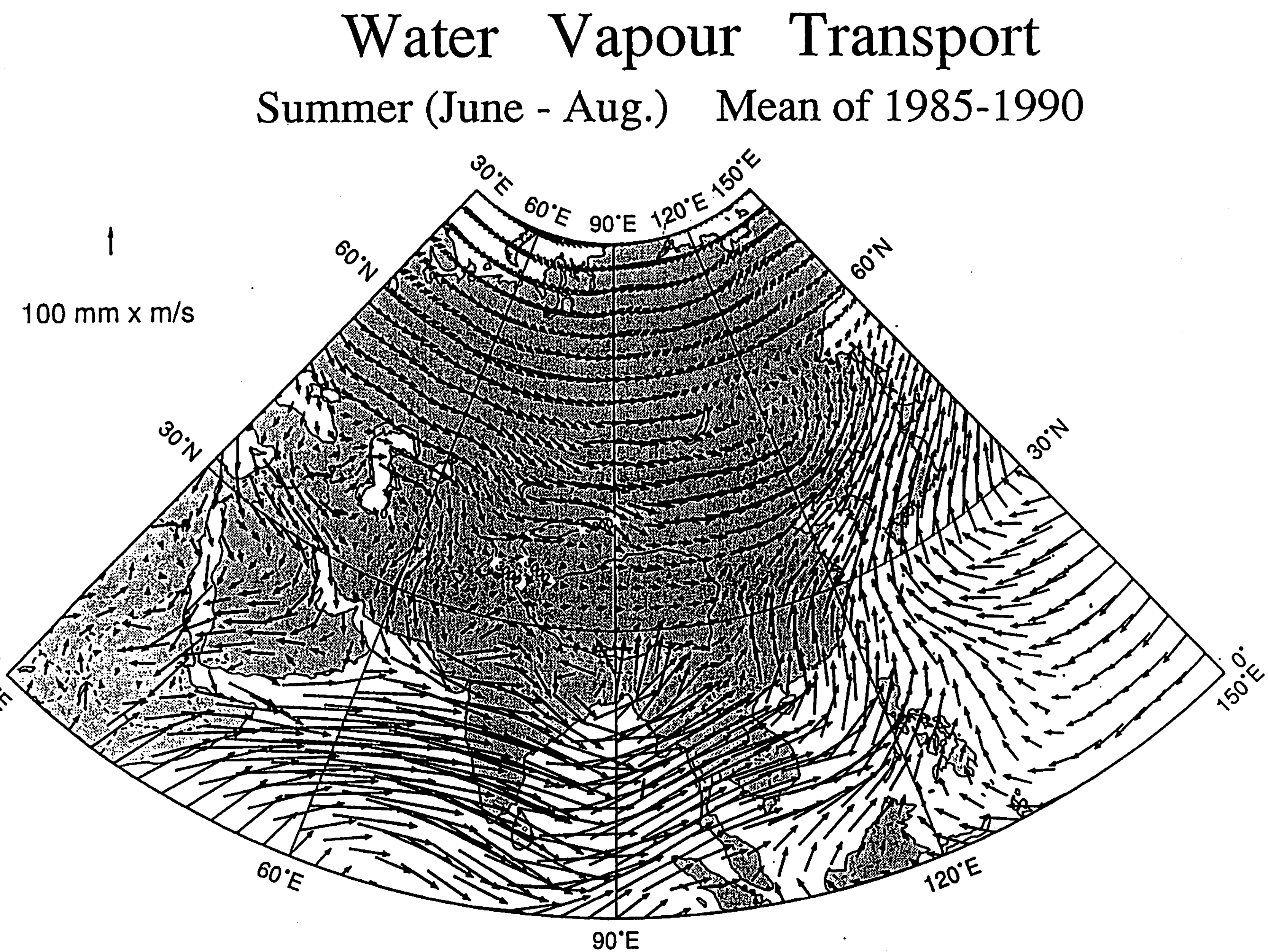


Figure 3-6: Vertically averaged water vapor flux (1000-700 hpa) for June - August 1981.

the Baiu front seems to be contrastively different between the two regions. Over and around the Japan Islands cloud organization of meso-α-scale depression with multi-scale structure is influenced both by huge amount of moisture supply and relatively strong baroclinicity, while over the continent cloud systems is organized under the condition without, or otherwise with very weak, baroclinicity.

However, the multi-scale dynamics of the cloud systems in the Baiu frontal zone in East Asia and their association with the global-scale Asian Monsoon, in China has not been sufficiently clarified yet.

In addition, the meso-scale cloud systems embedded in the front seems to be more interactive with the surface hydrological processes over the continent. The ground surface is strongly heated by insolation in warm season. Cb-clusters appears very frequently in day time in Central China associated with remarkable diurnal variation of surface condition (Kato et al., 1992). The soil moisture-evaporation-convection feedback suggested in the model experiment (Yasunari et al., 1991) may also be plausible.

(1) The Huai-He River basin experiment (HUBEX)

To understand energy and hydrological processes of multi-scale cloud systems, their interaction with the land surface hydrology as described above, the intensive field experimental study around the Yangtze River basin and the Huai-He (Huai river) River basin is proposed as a cooperative project of Japan, P. R. China and other countries. The special field observations will be made in the Huai-He River basin. This area is located between Yangtze River basin and the Yellow River basin, and is suitable for studying multi-scale energy and water cycles, because human activity has less effect in this basin and sufficient rainfall and hydrological data are available for this basin. The special network with radar systems, radiosonde systems, automatic station for fluxes and satellite data of TRMM, GMS and possibly Feng-Yung II expected for this experiment is schematically shown in Figure 3-7. In this project, routine rawinsonde (TEMP-B) and surface meteorological data over the Yangtze River and Huai-He River basins will be collected and 4-DDA analysis will be made. This project should be closely linked with the similar regional experiment over the Tibetan plateau (refer to 3-4-3), since the frontal system as well as some cloud clusters (SW vortex) to be targeted in this experiment is originated over the plateau region as mentioned above.

This experiment is mainly composed of the following two studies:

A. Monitoring and process studies on regional- and meso-α-scale water cycle in relation to global-scale Asian Monsoon.
   a. Water budget around the Yangtze River and the Huai-He River basins in association with activity of the subtropical front in East Asia by using the high-quality data set including collection of

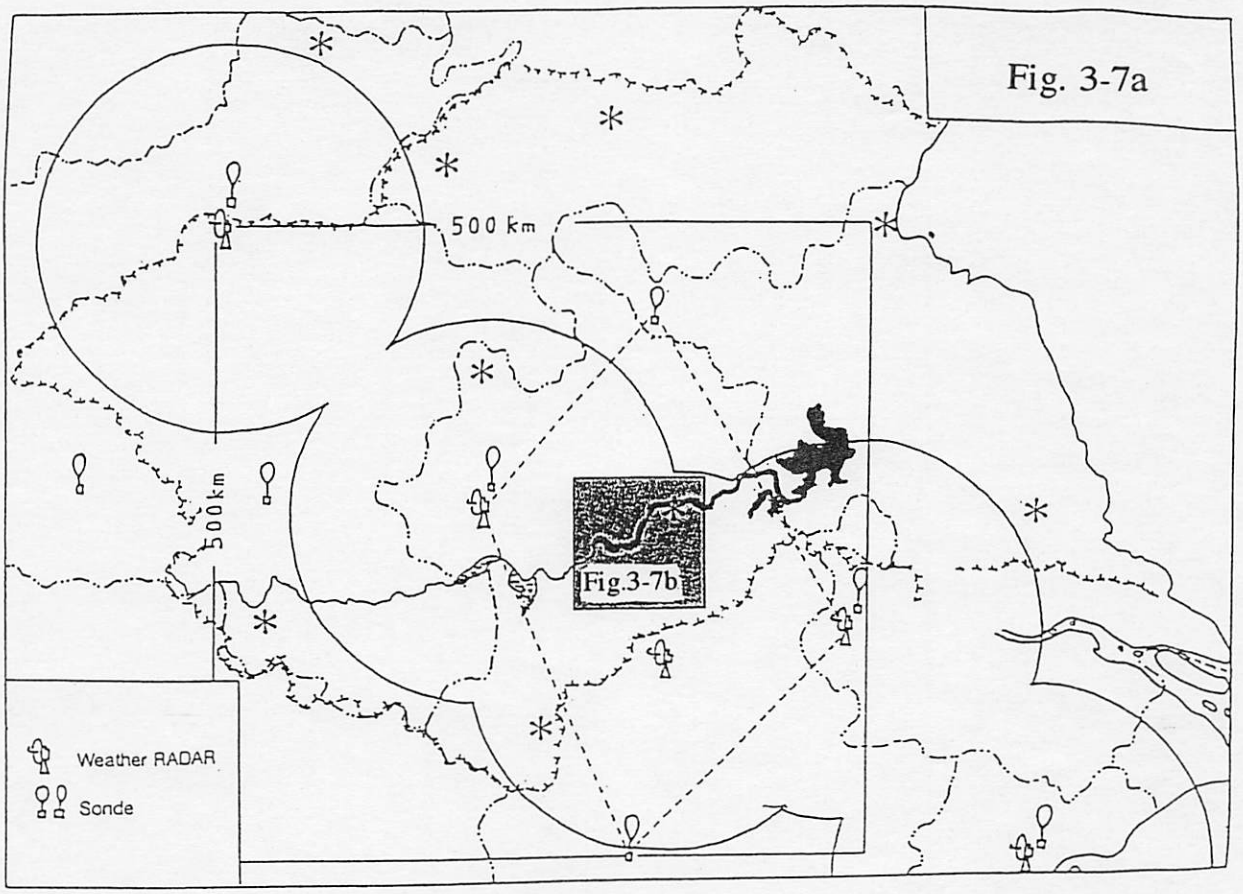


Fig. 3-7b

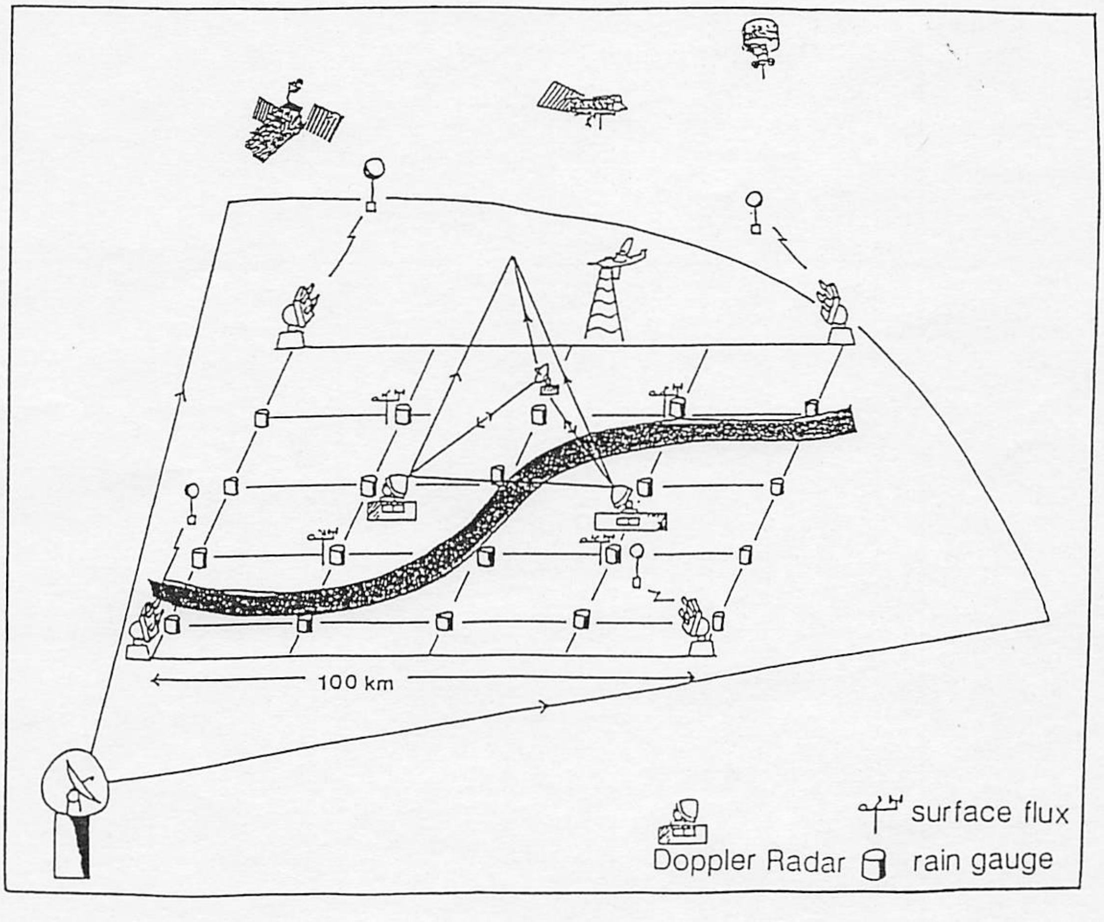


Figure 3-7: Schematic diagram of observing system of Huai-He river Basin regional Experiment (HUBEX).

routine surface and rawinsonde data in China, use of TRMM data, 4-DDA, etc.

b. Dynamics and climatology of meso-α-scale cloud systems.
   Intensive rawinsonde observation (at least 6 hourly) in whole this area are needed in cooperation with State Meteorological Administration in China.

c. Role of atmosphere-land surface processes and the global-scale Asian Monsoon in water cycle in this area.

B. Process studies on meso-β, γ-scale water cycle in the Huai-He River basin and their parameterizations. The main scientific objectives are:

   a. Dynamics of energy and water cycles in meso-scale cloud clusters.
      Special network of Doppler radars and aircraft are required.
   b. Time-space structure of energy and water balances during the Baiu period.
      TRMM data will be utilized after 1997 to the south of 35 N.
   c. Multi-scale atmosphere-land surface processes.
   d. Coupling of macro-hydrological model and meso-scale cloud model.
   e. Development of algorithm for converting satellite data to the estimation of rainfall, soil moisture and evapotranspiration.

(2) The Lake Biwa Basin experiment

Lake Biwa , the largest lake in Japan with 672 km^2, is located in the central-western part of Japan with a single outflow of the Yodo river. The water balance of this basin is influenced by Baiu-frontal rain in summer as well as large snowfall of winter monsoon. This basin, with sufficient meteorological and hydrological observing network with full cloud radar coverage, is suitable for intensive field study of meso/macro scale hydrological processes and atmosphere/land and water surface interaction. As part of the pre-GAME pilot experiment, preliminary field experiment has started since 1992.

The main objectives of this experiment is:

a. to understand the hydrological processes and land-atmosphere interactions in the typical east Asian monsoon climate. .
b to construct a macro-scale hydrological model with the horizontal resolution of 50 km x 50 km scale.
c. satellite algorithm study for hydrological parameters of land surface.

3-4-3. Tibetan Plateau and surrounding arid/semi-arid region

(1) Energy and water cycle and land surface processes over the plateau

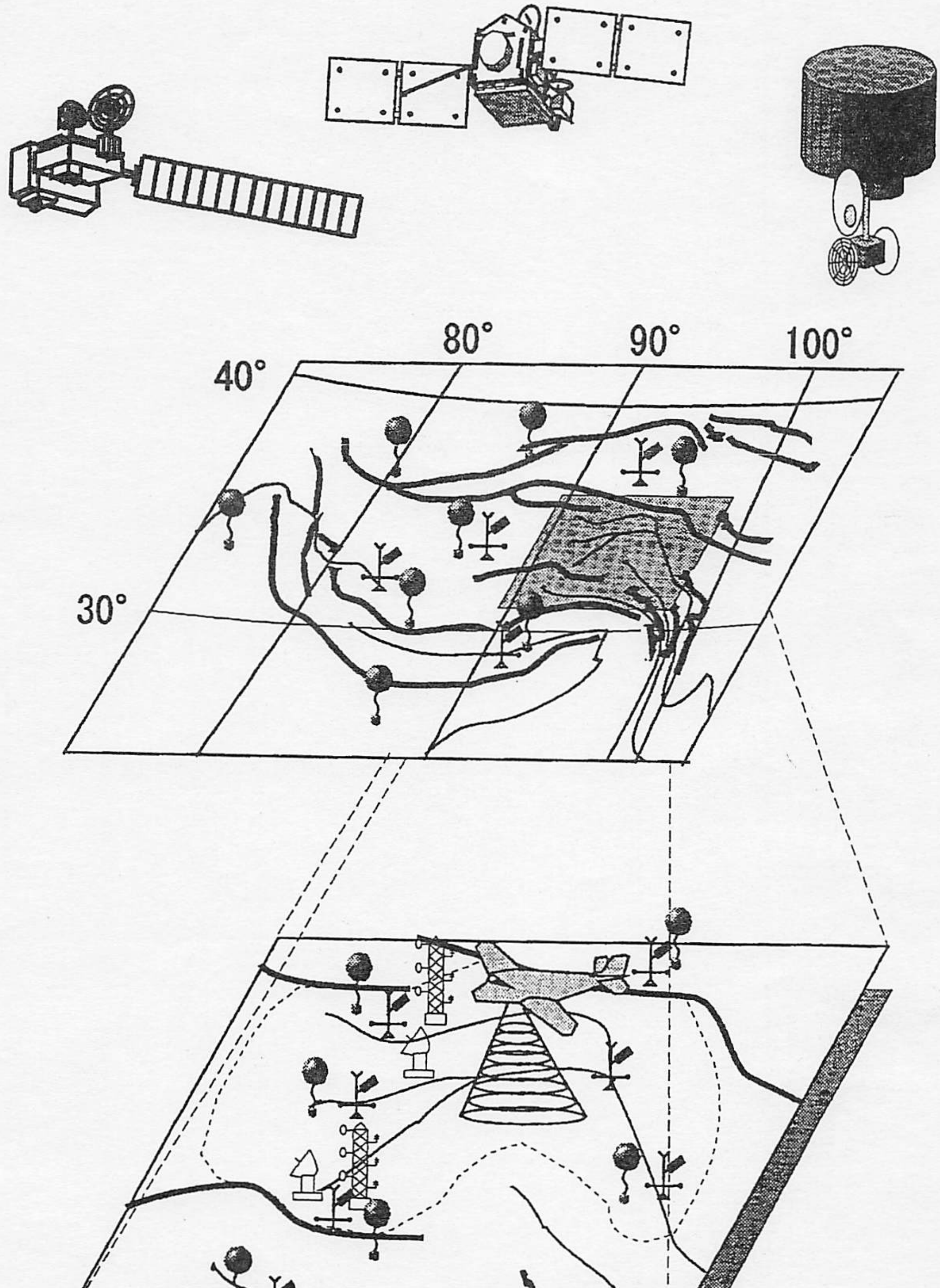


Figure 3-8: Network of observing system over the Tibetan Plateau. Intensive study area is shaded.

Atmospheric heating over the Tibetan Plateau has been suggested to play an essential role in the Asian Monsoon system, (Hahn and Manabe, 1975; Nitta, 1983; Yanai et al., 1992). This heating is strongly affected by sensible heating at the land surface as well as latent heating by convection over the plateau (Nitta, 1983; Chen et al., 1985; Luo and Yanai, 1989). The strong solar radiation over the surface due to thin optical thickness and relatively low latitude position of the plateau produces strong surface heating. The recent observational studies has noted the particular importance of extremely strong surface sensible heating at and near the surface level (Smith and Shi, 1992; Yanai et al., 1992; Yanai and Li, 1994). The plateau-scale mountain-valley wind system induced by strong heating produces a plateau-scale monsoon circulation system (Yanai et al., 1992), which also has a role of transporting moisture from the Indian Ocean side to the plateau.

On the other hand, the surface energy and hydrological processes over the plateau are also sensitively controlled by the characteristic natures of surface conditions, i.e., low vegetated dry or wet surface with permafrost, snow cover, lake water surface etc. These surface conditions would vary considerably depending upon changes in the atmospheric condition. A recent preliminary field observation has suggested, for example, the drastic seasonal change of surface heat fluxes associated with seasonal melting of permafrost and starting of precipitation spell in the early stage of the monsoon season (Ohata et al., 1991). However, these atmospheric/land surface interactive processes over the plateau have not fully been clarified yet due to seriously insufficient data of surface level and rawinsonde observations as well as limited knowledge on spatial and temporal variation of the land surface conditions. It is of particular interest that variation in the energy processes over the plateau seems to be closely linked to changes in water cycle processes at the surface and in the atmosphere over there.

The principal aim of the field-based study over the plateau will be to understand the seasonal and interannual variations of hydrological processes and related heat exchange processes over the Tibetan Plateau and their link to the large-scale monsoon circulation.

Following subjects and methods will be considered as part of the internationally-cooperated project. The design of the field experiments is shown in Figure 3-8.

a. Multi-scale water/heat exchange and transfer processes in the atmosphere/land surface system

Field measurement of seasonal variations of soil moisture, snow cover, permafrost, water/heat fluxes at the surface, cloud and precipitation characteristics with the assistance of aircraft and satellite remote sensing. Main drainage area will be the headwaters of Yangtze River of more than 105 km^2, and a smaller observing network with some towers for measuring the surface boundary layer structure and surface fluxes will be settled within this area.

b. Seasonal and interannual variation of water cycle over the plateau

Field measurement of seasonal and interannual variation of snow mass, soil moisture, atmospheric heating rate and precipitation based on automatic measurement systems and satellite, and use of hydro-meteorological data taken at permanent stations. Automatic stations will be set at regions above 3,000 m a.s.l. where permanent observation networks are scarce.

c. Meso-scale atmosphere/land surface water cycle model

A model developed for describing the runoff from the permafrost regions which is capable of evaluating the influence in change in the condition of permafrost.

d. Algorithm for using satellite data for estimation of snow cover, soil moisture, surface fluxes.

Comparison with the aircraft measurement and ground truth data taken in the main drainage area.

(2) Water cycle system between the plateau and the surrounding arid and semi-arid regions

The broad arid and semi-arid region with some large deserts expands in the interior of the continent, located mainly to the north and the west of Tibetan Plateau. This dry climate region is suggested to be formed by the orography of Tibetan Plateau by inducing upward motion to the southeast and downward motion to the northwest of the plateau (Broccoli and Manabe, 1992). The orography of the great Himalayan range also substantially reduces the moisture transport to this region.

Although the quantitative contribution of the water cycle over this region to the global domain may be minor, to understand the physical nature of water cycle and its variability of this region seems to be important for two reasons. One is that the arid and semi-arid region seems to provide some essential clue for understanding the sensitivity of atmosphere to land surface condition in the climate system (Charney, 1975; Shukla and Mintz, 1982). Recent model studies have suggested that this region tends to have larger persistence of climate anomaly than in the humid region (Liu et al., 1992; Broccoli and Manabe, 1992). The other reason may be that this region seems to provide a good experimental field for the fast water cycling with a large amount of precipitation (snowfall) in the mountain region and active evaporation in the arid river and lake basin. The human impact on this water cycle is, undoubtedly, an important and serious problem for application.

The arid and semi-arid region of central Asia is bounded by the mountain ranges on its eastern and southern edge (the Tian Shan and the Hindu Kush) and contains two huge lakes, the Aral Sea and the Caspian Sea. The region forms one interior basin of about 3 million km2 without outlet rivers. The water level of the Aral Sea has been decreasing remarkably since 1970 and the surface area of the lake in 1985 has diminished to two third of that in 1965. This drying up of the lake has become a serious problem in the former USSR, though it has been pointed out that its main cause may be the over-irrigation for agricultural use around the lake. This basin, however, seems to be suitable for evaluating on the typical water cycle and recycle of the semi-arid zone, including the processes of snowfall and snow and glacier-ice melting in the Pamir and Tien-Shan mountains, run-off, evaporation and groundwater in the large-scale river basin of Amudar'ya and Syrdar'ya Rivers, and evaporation from the lake.

In addition, the large-scale spring snowcover anomaly of this region has shown a significant correlation to the circulation anomaly of the following summer monsoon (Kodera and Chiba, 1989; Morinaga and Yasunari, 1994). The validation of snow-hydrological effect, involving the soil moisture anomaly of melted snow, would be most plausible in the semi-arid region.

Satellite-borne passive microwave sensors and the advanced 4-DDA data sets, combined with surface-based run off and hydrometeorological data, will provide basic information for seasonal and interannual variability of large-scale hydrological processes and water cycle of this area.

(3) Hydrological processes over the Indian sub-continent and the Himalayas and their interactions with the Asian monsoon system

In the interior of the continent, water vapor, originally evaporated from the surrounding oceans and transported by the monsoon or the mid-latitude westerly flow, is fallen as rain or snow drops, but again is evaporated or transpirated from the land or vegetation surface to form cloud and rain drop, and these processes will further continue. This recycling transport process of water vapor is likely to be dominated toward the interior of the Indian sub-continent and the Himalayan region, during the summer monsoon season. This process is important not only for understanding the transport process of water vapor and cloud formation in the interior of the continent, but also for assessing the hydrological processes including the soil moisture-evaporation-precipitation feedback, which control the seasonal and intra-seasonal variability of the Indian monsoon rainfall (Webster and Chou, 1983).

The problems may be, how much water vapor can effectively be transported to the interior of the continent and the Himalayas? To what extent does water recycle in the continent? How will the land surface change affect the water vapor supply for the interior of the continent? Where is the origin of water vapor for snow in the highland Himalayas? The geochemical analysis of stable isotope (deuterium and oxygen-18) contents of rain water, snow, river and ground water collected over and in the Indian sub-continent and the Himalayan region will support to unravel these problems.

Main study subjects will be proposed as follows:

a. Large-scale atmosphere-land surface processes, particularly the time-lag effect of snowcover and soil moisture to the surface heat and water balance over the Tibetan plateau and the Indian sub-continent.

b. The impact of the monsoon variability on the regional water cycles of the regional mountain river basins, including the mass balance of glaciers, of the Tibetan plateau and the Himalayas.

c. Transport and recycling processes of water vapor based on the stable isotope hydrology.

3-4-4. Permafrost region (Tundra and Taiga) in Siberia

(1) The cryosphere/atmosphere interaction

Siberia, the northern half of the eastern Eurasian continent, is covered with continuous permafrost zone. This area also overlaps with the major part of the snowcovered area over the continent. The cryosphere/atmosphere interaction would have a massive role on the seasonal march and its interannual variability of climate over and around the continent. The continental-scale snowcover acts as a heat sink and moisture source to the atmosphere during melting season, whereas the permafrost would do the same work through warm seasons after snow melting. In fact, a combined effect of these two processes in the cryosphere may have a more essential role in the seasonal evolution of the climate system, as suggested from the preliminary field observation over the Tibetan plateau (Ohata et al., 1992). The physical processes involved in the significant observational evidences of Eurasian snow cover vs. Indian monsoon relation (Hahn and Shukla, 1976; Morinaga and Yasunari, 1994) have not been clear yet.

The two typical surface conditions are dominated in Siberia; Tundra and Taiga. Tundra area is located approximately to the north of 70 N with poor vegetation. The major part to the south of 70 N in this region is called Taiga with boreal conifer forests. The energy and water

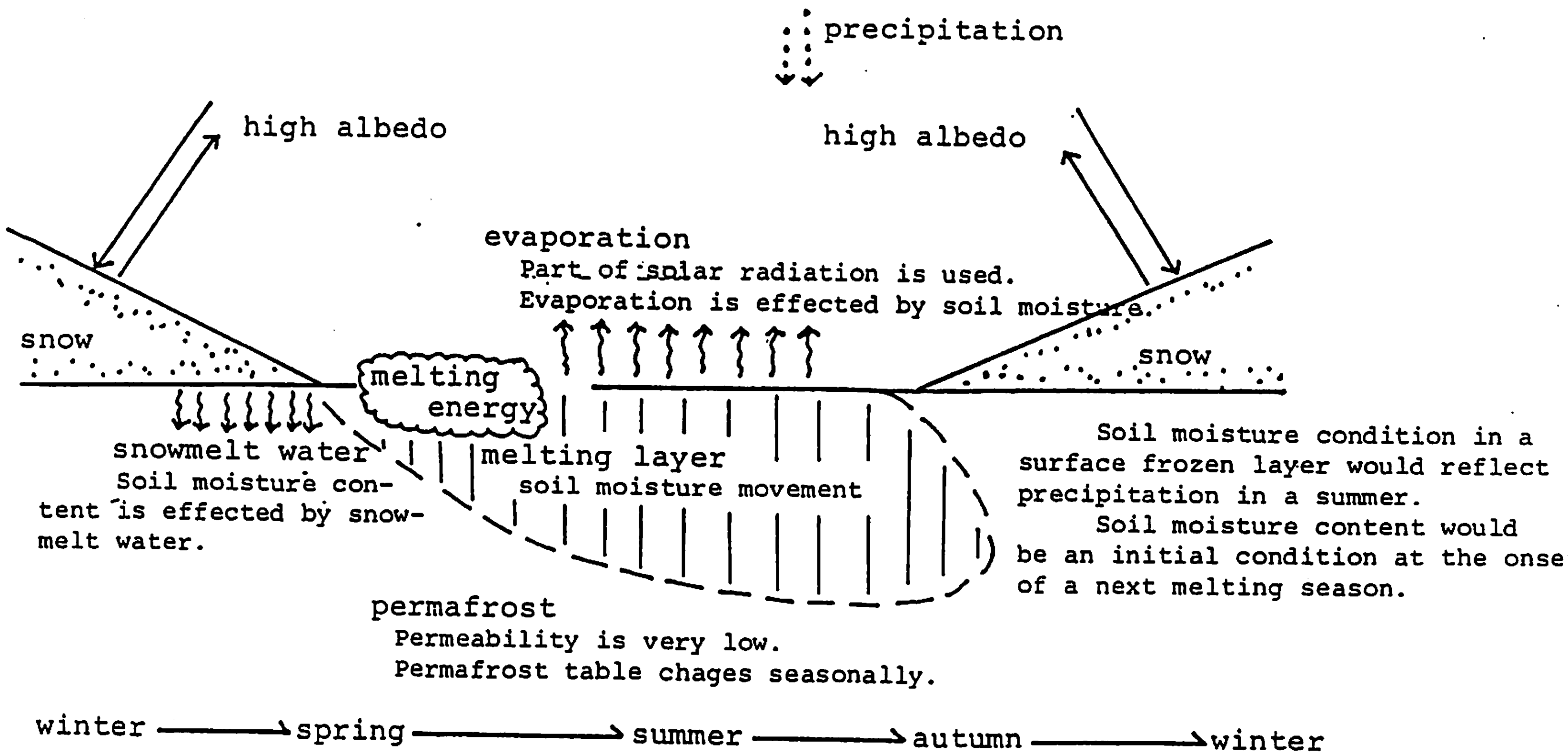


Figure 3-9: Schematic diagram for seasonal change of land surface condition with snowcover and permafrost in the tundra in Siberia (and in the Tibetan Plateau).

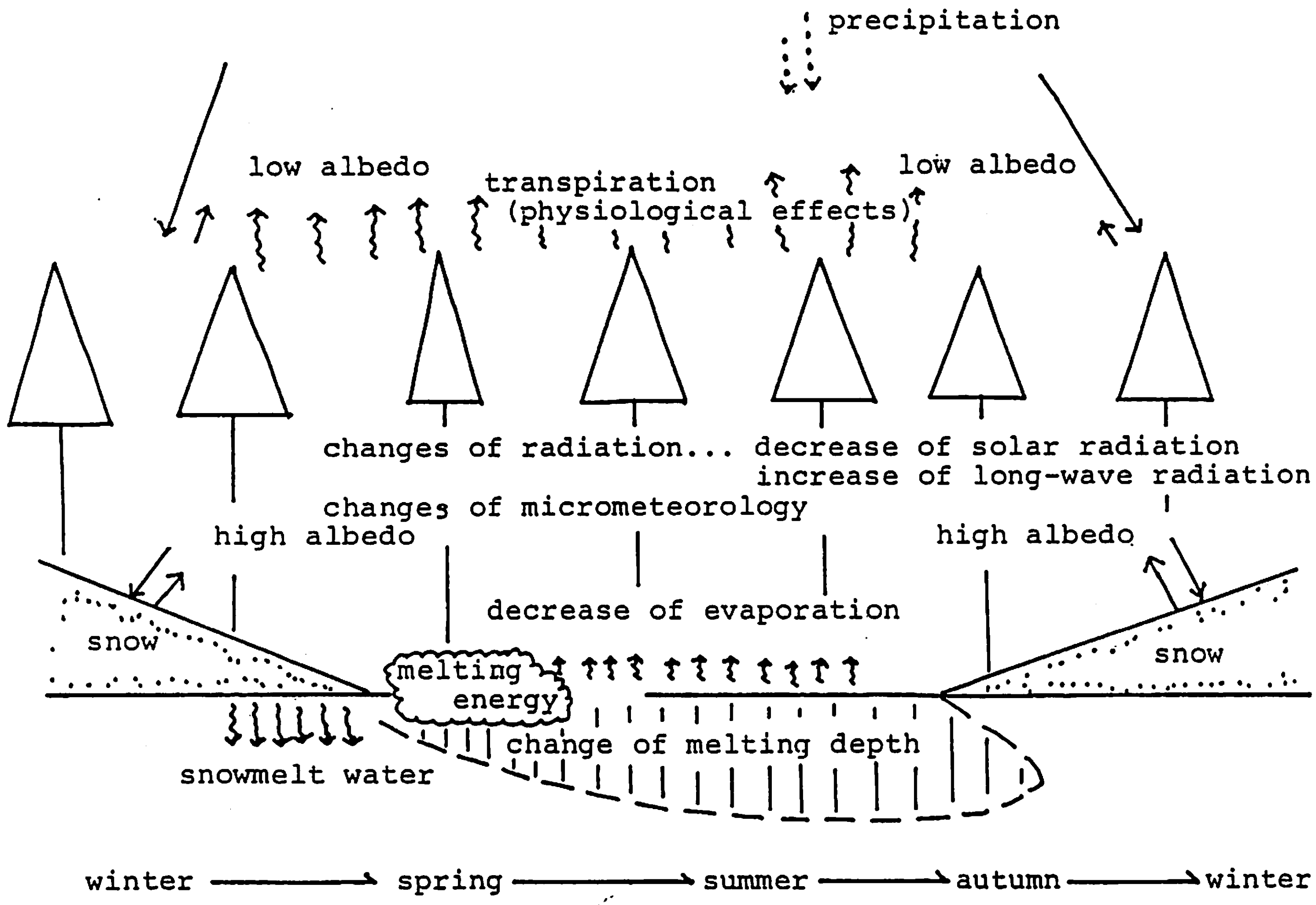


Figure 3-10: Same as Fig. 3-9 but for the Taiga region in Siberia.

cycle processes are considered to show considerably different features between the two types of land surfaces.

In Tundra, wetland condition seems to be prevailed in mid summer, where not a few amount of melting and evaporation may occur (Ohmura, 1982). The seasonal cycle of the surface energy and hydrological processes is schematically shown in Figure 3-9. In Taiga trees and forest would affect the energy and hydrological processes in the canopy with the surface of permafrost and snow cover. The forest affects the surface radiation and energy balance of the snow surface, which in turn affect snow melting (Ohta et al., 1992; Yamazaki and Kondo, 1992). Similar intensive studies have to be pursued at the permafrost/snow cover surface of Taiga (Figure 3-10), which will also enable us to compare the effect of forests on the surface heat and water balance in high latitude region to that in temperate mid-latitudes and humid tropics.

Recently, the permafrost zone of this area has been noted as a source of atmospheric methane and CO_2 induced by the increase of surface melting of the permafrost, which contains a lot of organic matters and gases as a clathrate compounds, associated with the recent hemispheric warming trend (IPCC, 1990). To fully understand these problems, however, the seasonal and interannual variations of surface energy and water exchanges must be quantitatively evaluated over the permafrost zone. The special attention must be paid to the role of snowcover on seasonal melting of the permafrost. The difference in the response of permafrost between Tundra and Taiga region to climate changes, e.g., the recent hemispheric warming, should also be examined through a comparison of energy and water balance studies of these two regions.

(2) Role of river runoff on the Arctic climate system

The impact of the energy and hydrological processes mentioned above on the seasonal evolution of water cycles in the major continental river basins (i.e., Obi, Yenisei and Lena Rivers) is another essential and interesting issue for climate system study. The annual total discharge of these three rivers occupies more than 60 percent of fresh water supply to the Arctic sea, which may possibly be an important factor controlling the seasonal formation of the Arctic sea ice (WMO, 1991). The seasonal energy and water processes of permafrost and snowcover as well as summer precipitation over these river basins may, in this manner, have some effect on the climate anomaly of the northern high latitudes in the succeeding cold seasons.

(3) Design of field campaign and data analysis

The main subjects of the field campaign and related data analyses are as follows:

a. Observations of one dimensional heat and water balances over the active layer of permafrost
b. Comparative field observations on the cryosphere, vegetation and atmosphere interactions over Tundra and Taiga region
c. Observations and modelling of hydrological processes in the permafrost zone
d. Seasonal and interannual variability of the hydrological cycles in the continental-scale river basins
e. Characteristics of the heat and water balance of the permafrost area in the high latitude in comparison with Tibetan Plateau.

The heat and water balances for the medium scale(100 km) and the small scale(1-10 km) will be evaluated by the field experiment of one dimensional heat and water balances and be expanded by satellite data sets available. The seasonal and interannual variations of the water cycle in major watersheds (i.e., Obi and Yenisei) will be evaluated based on conventional and ad-hoc observation data. Figure 3-11 shows the outline of the observations. The field campaigns of the three spatial scales are tentatively planned in the Obi and/or Yenisei River basins as follows:

1) Small scale (1 - 10 km)

The observations are based upon the one dimensional heat and water fluxes in Tundra and Taiga area with soil moisture flux, depth of active layer and moisture movement in trees. A pixel-size comparison and retrieval of satellite informations will be made.

2) Medium scale (100 km)

The observations are carried out in watersheds selected in Tundra and Taiga regions, to estimate spatially-averaged heat and water balances and discharge from the watershed(s).

3) Continental scale (1000-10,000 km)

The seasonal and interannual variability of the large-scale hydrological cycle in the high latitude of the continent are estimated. The continental-scale snow mass, surface melting of permafrost and summer precipitation and runoff are basic and essential components of water balance of this scale.

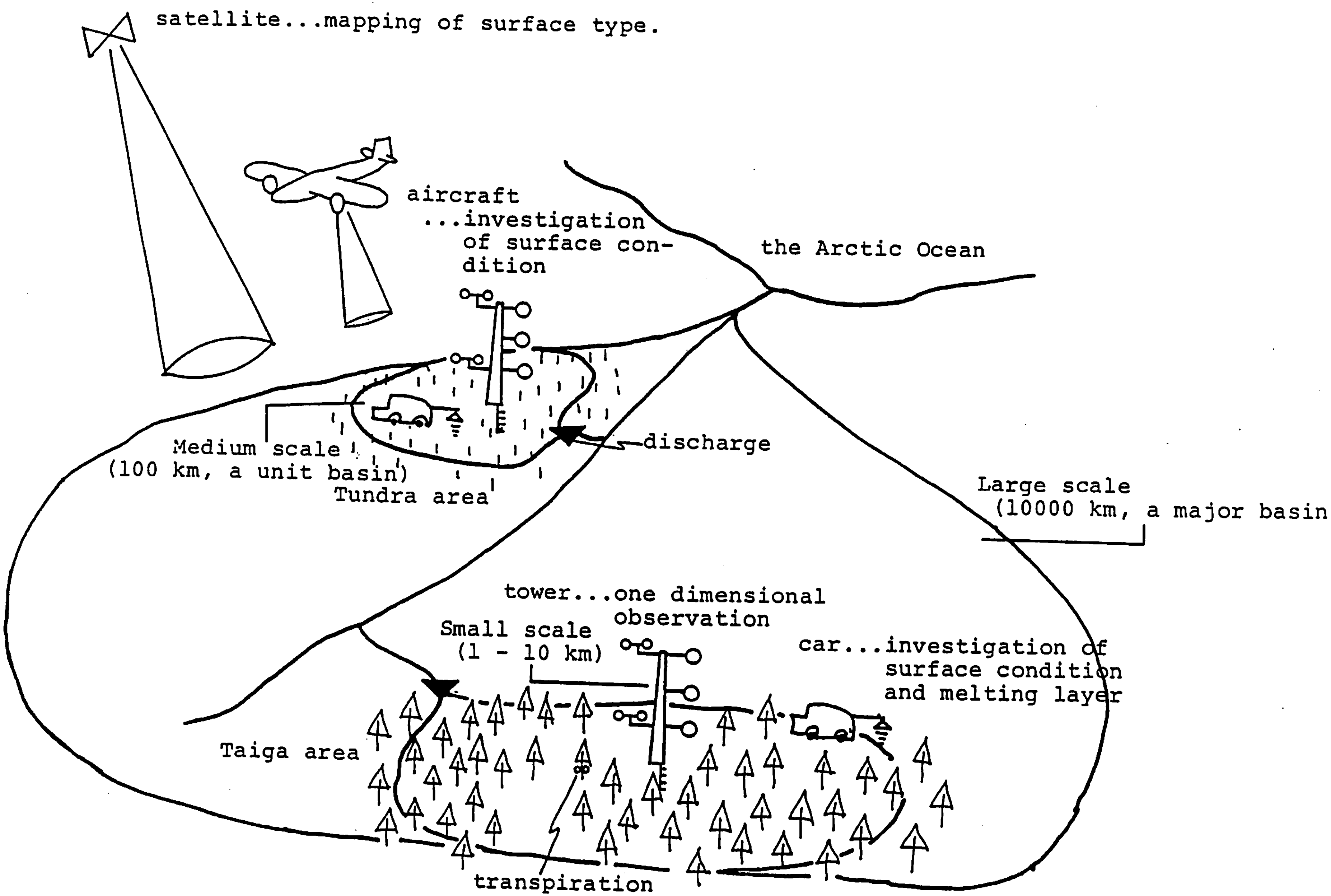


Figure 3-11: Schematic view of regional experiment in Siberia.

4. Continental-scale monitoring and observing systems

4-1. Satellite observations

4-1-1. Satellite requirement for GEWEX and GAME

Since the GAME covers a broad complex and heterogeneous land area over the Eurasian continent through the tropical Indian and the Pacific oceans, this project cannot be executed without the satellite observing network. In addition, since the Asian monsoon system is a major component of the global climate system, the global coverage by the satellite observing network is essential for extending and applying the products of the GAME to the analysis of the global domain. The field observations and process studies related to the GAME would function, at the same time, as a ground-truth and algorithm study for the satellite observations.

4-1-2. Pre-GEWEX status

The operational satellites, such as GMS, NOAA and DMSP series have already been providing us homogeneous and continuous informations on the fundamental properties of the atmosphere and the hydrosphere, such as cloud cover, SST, OLR, vegetation, snowcover and surface wetness in the global domain.

During the pre-GEWEX period, the halfly-operational and halfly-experimental satellites, such as TOPEX/POSEIDON, E-ERS-1/2, J-ERS-1, RADARSAT have, or will have, advanced sensors and try to obtain more specific but higher-order informations on the atmosphere and the earth surface conditions. ADEOS, which will be launched by Japanese H-II rocket, will be equipped with a microwave scatterometer which will measure the sea surface wind vector which is essential for estimating the surface monsoon flow as well as surface drag force of ocean currents.

4-1-3. Satellite missions and sensors dedicated to GEWEX and GAME

Table 4.1 shows sensors which will be supplied by space agencies during the GEWEX. The conditions of atmosphere such as three dimensional distribution of air temperature and water vapor and column cloud liquid water content will be well observed using microwave sounder and microwave radiometer, respectively. The SAR of ERS-2, RADARSAT, ENVISAT and ALOS, and the advance microwave radiometer of ADEOS-2, EOS-PM and METOP have potential to

Table 4-1. Global Observations of land/atmosphere by satellites

Year	Name of Satellite	Nation·Agency	Sensors					
			VIS/IR	IR	MicroW. R.	MicroW. S.	SAR	PR
1994 1996 1997 1999 2000	NOAA—K, L, M, N	NOAA	○		○	○		
1995	RADAR SAT	Canada					○	
1995	ERS-2	ESA	○				○	
1996	ADEOS	NASDA	○					
1997	TRMM	NASDA·NASA	○		○			○
1998	EOS AM-1	NASA	○					
1998	ENVISAT-1	ESA	○				○	
1999	ADEOS-2	NASDA	○		○			
2000	EOS PM-1	NASA	○	○	○	○		
2000	METOP-1	ESA	○	○	○	○		
2000	TRMM-2	NASDA·NOAA	○		○			○
2000	HIROS-1	NASDA	○				○	

measure soil moisture, vegetation, snow accumulation. The laser altimeter may be used to estimate the snow accumulation. In addition to the geostationary satellites of GMS, INSAT series and possibly Chinese Feng-Yung II, diurnal cycles of hydrological and meteorological parameters over Asian monsoon region will be observed by TRMM and TRMM follow-on missions. The information of diurnal change of land-surface conditions, e.g., surface temperature and albedo, would also be obtained from the observations of EOS-AM and PM missions. These satellites are also expected to contribute to the estimation of evaporation in high accuracy.

4-1-4. TRMM as a basic satellite mission

The most important satellites for GAME and GEWEX may be TRMM and, possibly, TRMM follow on missions, which will provide us informations on seasonal and interannual variations of energy and hydrological processes in the atmosphere. TRMM is non sun-synchronous satellite and very unique mission dedicated to measure the tropical and subtropical rainfall. A rain radar will be aboard the TRMM and the radar will be the first space-borne rain radar. TRMM also have microwave and visible/infrared radiometer which are upgraded from those already in space. The microwave radiometer is upgraded from SSM/I and the visible/infrared radiometer is upgraded from AVHRR. The radar will not only measure the rainfall intensity, but also observe the three-dimensional structure of the rain drop distribution. Though the swath is limited due to the hardware limitation, the radar data will be unique and it will also be used to validate or calibrate the radiometer data which have much wider swath. The TRMM data are also expected to refresh the vastly accumulated satellite-borne radiometer data. Monthly averaged rainfall and wind velocity over the precipitated area are expected to be obtained by using retrieval method.

4-1-5. Prospect of TRMM follow-on mission

The planned launch year of TRMM will be 1997 and its life time will be only three years. The life time is too short for completely monitoring the seasonal and interannual variations of tropical rainfall distribution, since the tropical climate typically shows a time-scale of 2 to 6 years, associated with the ENSO cycle. The TRMM follow-on mission is, henceforth, very crucial for the GEWEX and the GAME. The continuous rainfall data set of al least 5 years for the GAME could only be obtained by the successive operations of TRMM and TRMM follow-on satellites.

The TRMM follow-on mission is recommended to have higher orbit inclination (of about 55 degree) than that of TRMM (i.e., 35 degree), to cover the most part of the Eurasian continent and the north

Pacific. The larger orbit inclination would enable us to measure summer rainfall with meso-scale clouds in the interior of the continent, which would be important for the atmosphere/land surface interaction between rainfall, soil moisture and evaporation over the continental land surface. The elevation should be higher than that of TRMM for the longer life of the mission. It is also indispensable for highly-accurate measurement of snowfall as well as rainfall that the higher-frequency radar (24 GHz, 35 GHz etc.) be added to the upgraded PR on TRMM. Furthermore, microwave sounder combined with the upgraded TRMM sensors are desirable for estimation of evaporation from the surface with high accuracy. The non-sunsynchronous sampling of surface parameters by these sensors will enable us to estimate patterns of diurnal cycle of evaporation in various climatic regions.

The whole concept of the TRMM follow-on mission is still under discussion. The "Wet Atmosphere Research Mission (WARM)" has been proposed by the Japanese scientists as a TRMM follow-on mission. The main objective of WARM is to provide date sets of precipitation, water vapor amount and energy and water vapor fluxes in wider area coverage than that of TRMM. The continuous observation by TRMM through WARM will provide us the date set of several to ten years, covering at least one whole ENSO cycle in the tropics, which will contribute a lot to GEWEX/GAME and CLIVAR.

The space program needs a lot of resource and time of typically 7-8 years before launching. The initiative of the international collaboration for the TRMM follow-on mission would be urgently required, as has been successfully done between the U.S.A. and Japan for TRMM, and between the U.S.A. and France for TOPEX/POSEIDON.

4-1-6. Missions for land surface hydrology

The recent observational studies and GCM studies (refer to 1-1 and 1-2) have strongly pointed out that snow cover and soil moisture in winter and spring affect the anomalous state of succeeding Asian summer monsoon and climate in the northern hemisphere. Currently, only dry snow is measurable using passive microwave sensors. Some preliminary surveys by Nimbus-7 SMMR microwave data have shown that the continental-scale snow (water equivalent) mass and its seasonal variation can be estimated provided that dry snow condition is assumed (Chang et al., 1987; Yasunari et al., 1991). Passive microwave radiometer would become more effective if it would have reasonably high spatial resolution in the lower frequency bands.

Active microwave sensors are more desirable to observe snow water equivalent and soil moisture. The E/ERS-1 and J/ERS verification project is now under way in Japan, involving more than fifty scientists, which will reveal the availability of these passive microwave data sets for detecting snow mass and soil moisture. The field experiment of snow, as part of this project, by using the ground-based scatterometer have shown the validity of the multi-polarization measurement for wet snow (Fukami et al., 1992). We can not find, for example, any meaningful relationship between back scattering coefficients and snow water equivalent in the case of like-polarization as shown in Figure 4-1a. The depolarization factor, on the other hand, has proved to be an effective index for the estimation of snow water equivalent, as shown in Figure 4-1b.

It is thus recommended that for monitoring of land surface hydrological parameters, i.e., snow water equivalent, soil moisture, in addition to the high resolution multi-channel passive microwave sensors (e.g., AMSR) and the multi-polarization SAR be on board the bus of satellites. The sun-synchronous polar-orbit missions of ADEOS-2, EOS, ENVISAT and METOP and the non-sunsynchronous missions of TRMM and TRMM follow-on currently planned to be launched in the latter half of 1990's would be essential for these requirements for GAME and GEWEX.

4-2 Asian Automated Weather Station (AWS) Network (AAN)

4-2-1. Network of surface radiation and energy budgets

The Eurasian continent, the largest continent on the earth, plays a predominant role on the seasonal cycle of the planetary-scale surface energy exchange and transport in the climate system. The diverse land surfaces and vegetations, however, characterize the extremely large seasonal and spatial variation of surface sensible and latent energy fluxes over the continent, which in turn may produce the regionality and asymmetries in the seasonal cycle over the continent.

The surface net radiation flux is a fundamental forcing of the sensible and latent energy fluxes. The estimation of these fluxes over the global surface was formerly carried out by Budyko (1956). This task should be updated by utilizing the satellite as well surface observations with higher quality and resolution over the whole of the continent, which is one of the major tasks of the GEWEX. The surface energy budgets are fundamental forcing of the seasonal march of the climate system. These elements are particularly important over the eastern half of the Eurasian continent, to unravel the role of the land/ocean heating contrast on the Asian winter and summer monsoon systems.

There has been, so far, a considerably dense routine observation network of surface meteorological station in the eastern half of this continent, maintained by the operational meteorological agencies of each country. However, these station data are providing only indirect measures for estimating the surface radiation and energy budgets over the broad area of the continent, based mainly upon the bulk method. In addition, the diverse and heterogeneous land surfaces of the continent

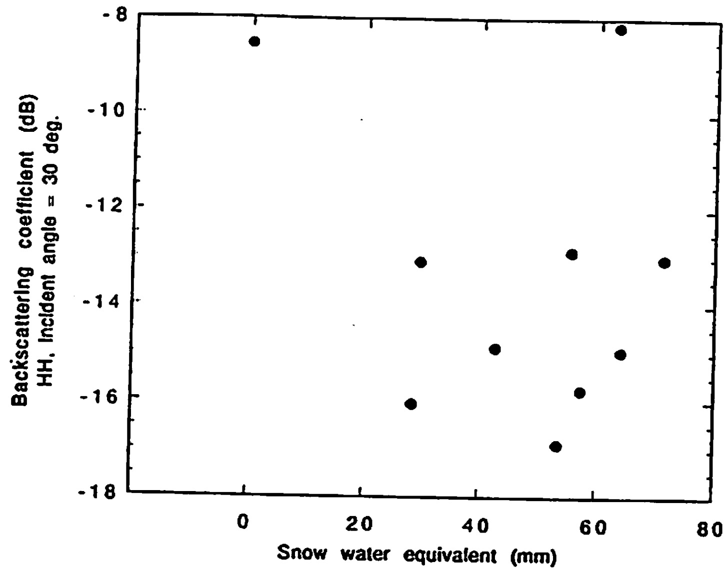


Fig. 4-1a Relationship between backscattering coefficient and snow water equivalent (mm) HH, incident angle = 30 deg. at Nagaoka, 1992/2/3~3/2

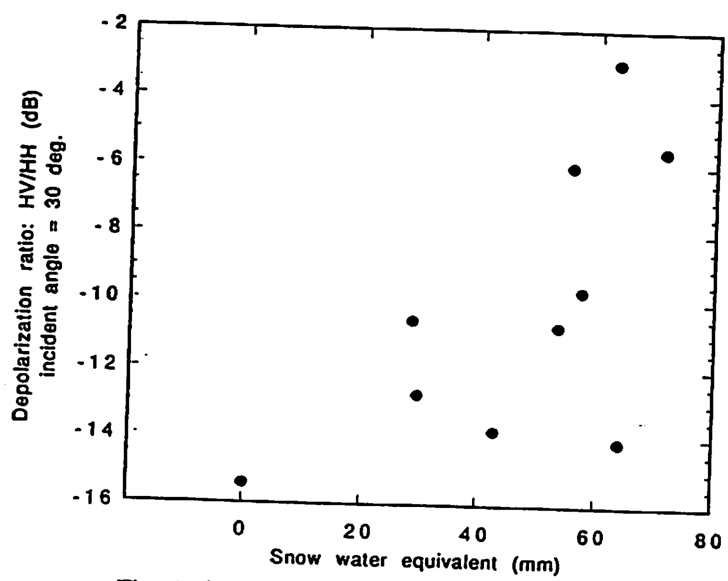


Fig. 4-1b Relationship between depolarization ratio and snow water equivalent incident angle = 30 deg. at Nagaoka, 1992/2/3~3/2

Figure 4-1: Scatter diagrams for snow water equivalent versus backscatter coefficients for (a) like-polarization and (b) depolarization factor (Fukami et al., 1992).

make it more difficult to estimate the appropriate bulk transfer coefficients for the momentum, heat and moisture fluxes of each station.

The satellite-based SRB (Surface Radiation Budget), combined with the surface-based BSRN (Baseline Surface Radiation Network), has been continuously providing us with data sets of surface radiation elements with continental-scale coverage. The long-term monitoring of directly-measured energy fluxes, however, has not been undertaken except at very few micro-hydrometeorological stations (e.g., ERC, Univ. of Tsukuba, refer to Kotoda(1986)). The continental-scale monitoring system of surface energy fluxes and surface conditions (albedo, soil moisture, vegetation etc.), combined with the radiation network mentioned above, will provide us with key information for unraveling the physical processes of the recent climate change (e.g., rapid warming over Siberia and Mongolia) of the continental-scale.

This network would also contribute greatly to the validation of surface energy conditions derived from satellites, and to the advanced 4-DDA (refer to 4-3) as part of the essential data input from the surface.

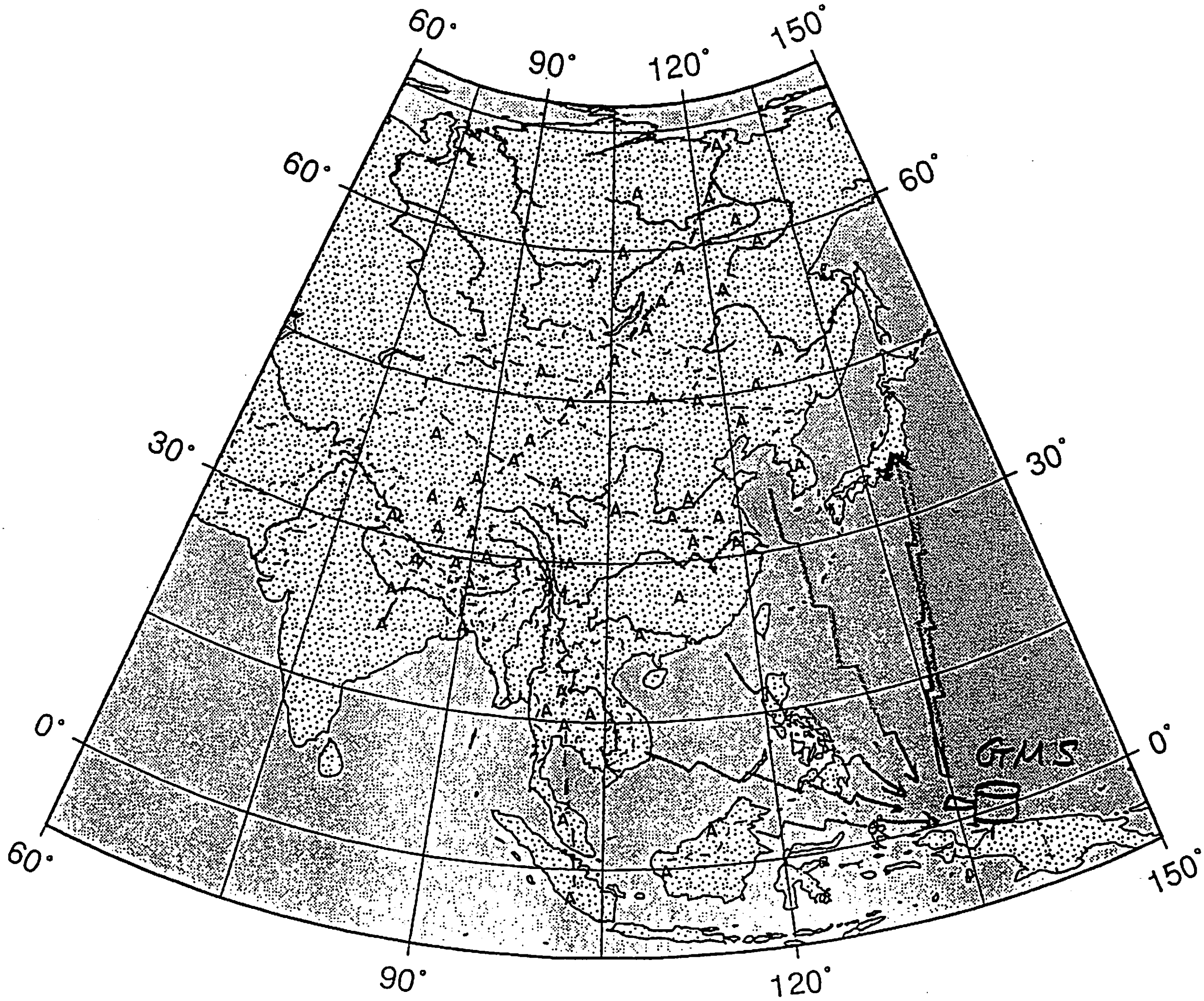
4-2-2. A proposed system of AWS

An important function of the AWS (Automated Weather Station) system is to measure the radiation and energy flux components, with the surface parameters (soil moisture, snow cover etc.). Currently, AWS systems to fully satisfy this purpose are not available. One possible candidate system may be PAM (Portable Atmospheric Mesonet) III system, which is currently under development at NCAR (National Center for Atmospheric Research) of USA. This system contains a one-dimensional sonic thermometer-anemometer for measuring sensible heat flux, full energy supply from solar battery board and a data transmission unit for geostationary meteorological satellite (GOES, GMS etc.).

The automated continuous monitoring of soil moisture has long been desired as mentioned above. The microwave soundings from satellites are expected to provide useful information on soil wetness or moisture, though the retrieval technique for this requires comprehensive validations by the surface truth soil moisture data. On this basis, it would be desirable that the AWS system designed in the AAN would include a unit for measuring soil moisture continuously. Though the method of continuous measurement of soil moisture without disturbance of soil structure and properties has not been available yet, a recently-developed technique of TDR (Time Domain Reflectometry) would be one of the candidates to be introduced to the AWS system.

4-2-3. A master plan of the network

The network of AWS for measuring the surface radiation, energy fluxes and surface conditions is expected to cover the whole of monsoon



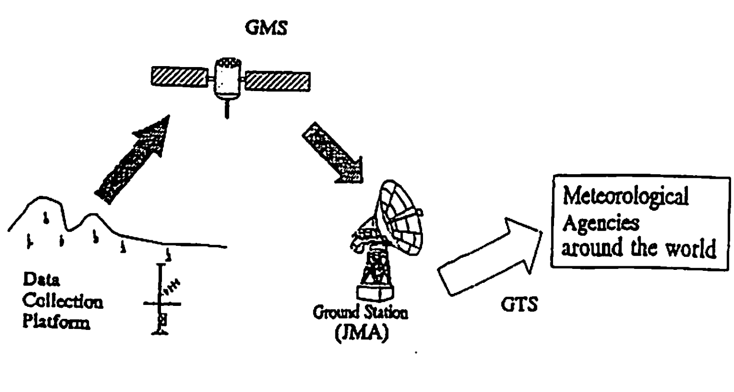


Figure 4-2: Tentative distribution of AWS for AAN.

Asia, or the eastern half of the Eurasian continent. This area should be within the coverage area of GMS with a transmission beam of sufficient elevation (of 3 degree or more) for the on-line monitoring from each station. The AWSs should be arrayed fundamentally along the meridional and zonal section lines crossing over this area, which represent large gradients of climatic conditions and vegetation. A tentative idea of the arrangement of AWS is shown in Figure 4-2. One major meridional section crosses over the Tundra, Taiga of central Siberia, Mongolia, Gobi desert, Tibetan plateau, the Himalayan range and the Indian sub-continent, representing the temperature gradient from the polar region to the tropical monsoon region. Another zonally-oriented section lies over the humid subtropics in central China to the arid zone in the interior of the continent, representing basically the gradient of moisture and continentality. Several sub-networks with relatively high density of stations will also be considered, related to the intensive regional experiments (refer to 4-1). The total number of AWS over the whole of this area is expected be around 50-60.

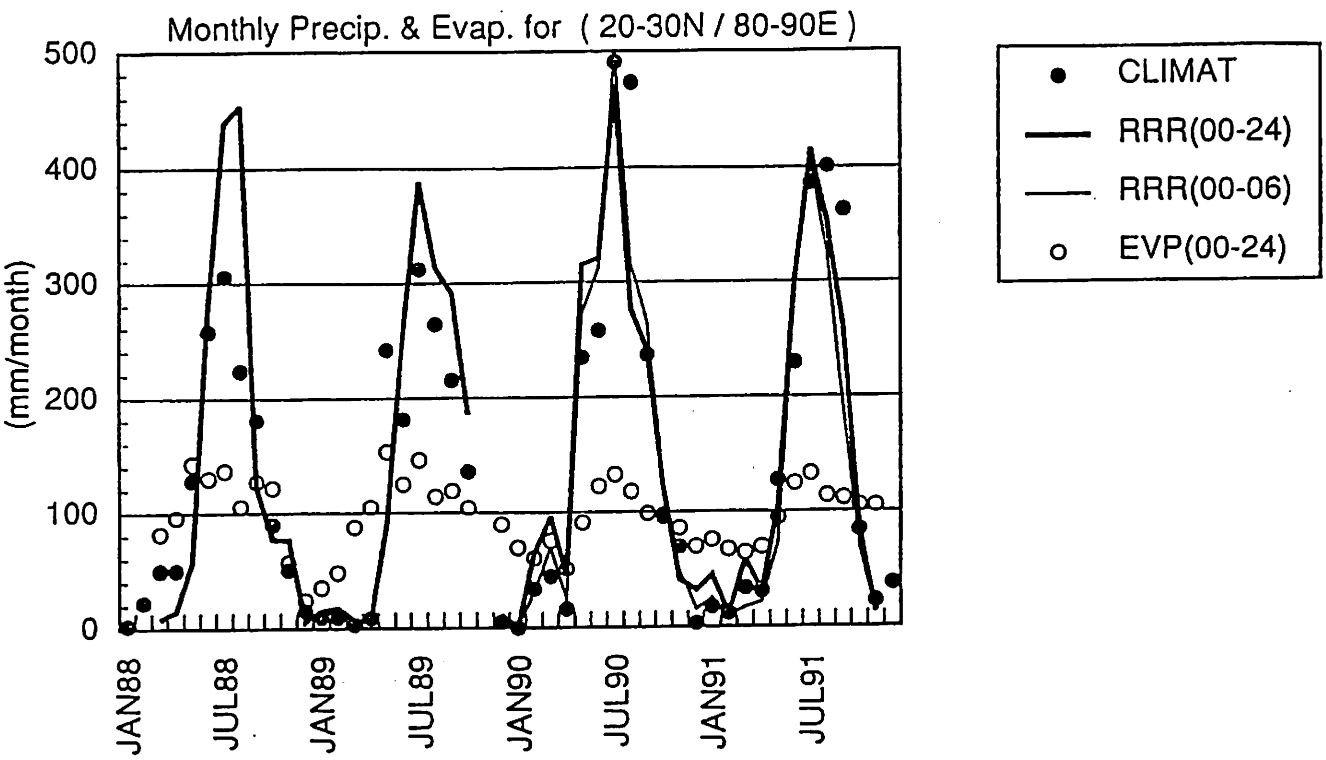
4-3 Four-Dimensional Data Assimilation (4-DDA)

4-3-1. Development of GDAS at JMA

To integrate satellite data, operational observation data and ad-hoc field observation data to get more homogeneous and qualified data set, the four-dimensional data assimilation (4-DDA) by GCM with the sophisticated land-surface scheme are essential and inevitable for GAME.

JMA started atmospheric Global Data Assimilation System (GDAS) in March 1984, by utilizing T42L12 global model combined with a multi-variate optimal interpolation scheme for analysis. Currently, the global model upgraded to T106L21 since November 1989 is operated. This model includes the implementation of hybrid vertical coordinate and the Simple Biosphere (SiB) model as a land surface hydrology parameterization.

Diagnostic quantities of the complete physical processes in our assimilation and forecast have been archived since march 1988. These are surface fluxes (latent heat, stress, precipitation etc.) and three dimensional heating fields by condensation and radiation. This archive serves two purposes. One is the investigation of the cause of systematic errors and the improvement of physical parameterizations. The other is the diagnosis of short-term climate variability. The prognostic fields such as wind, temperature and moisture have been useful as a basic climate data in the past decade and they will continue to be so. In addition to this, the improvement of the analysis and prediction model in recent years has opened the possibility for us to directly investigate the physical processes which generate climate variability.



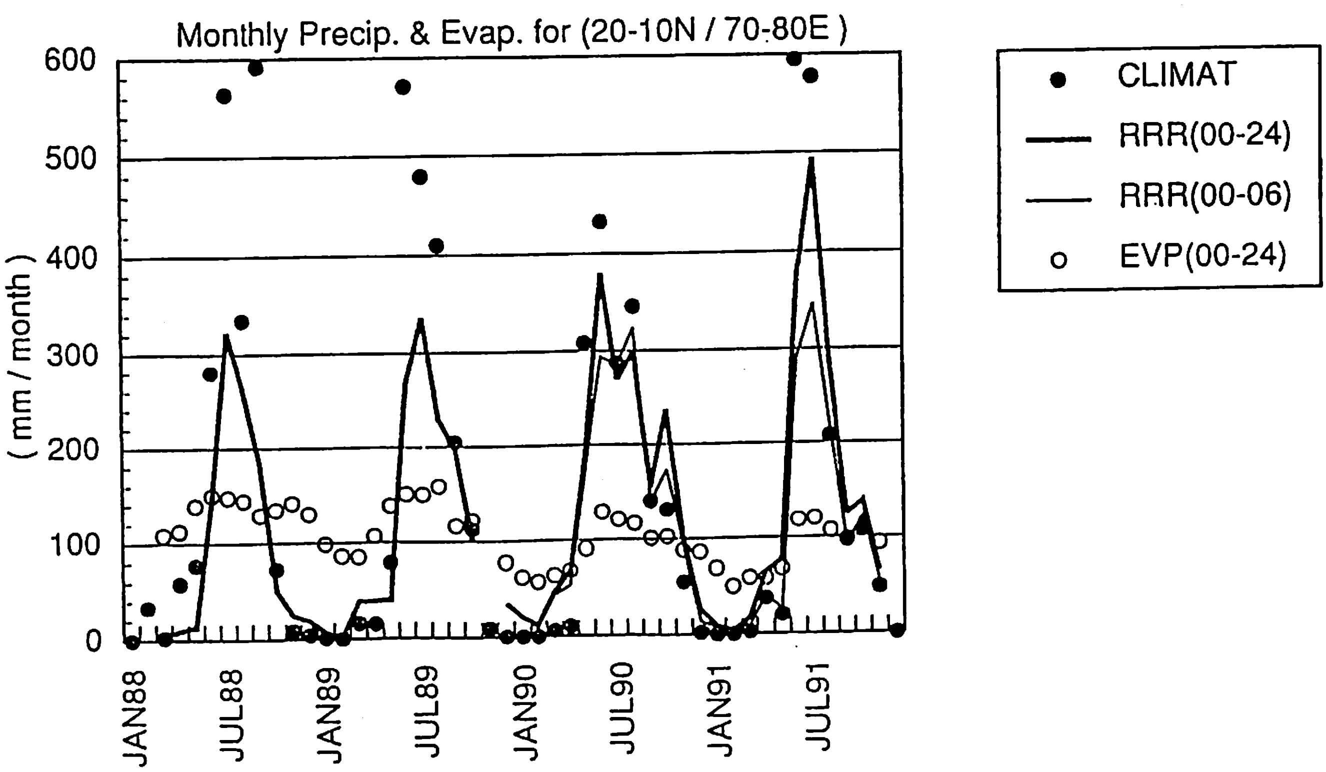
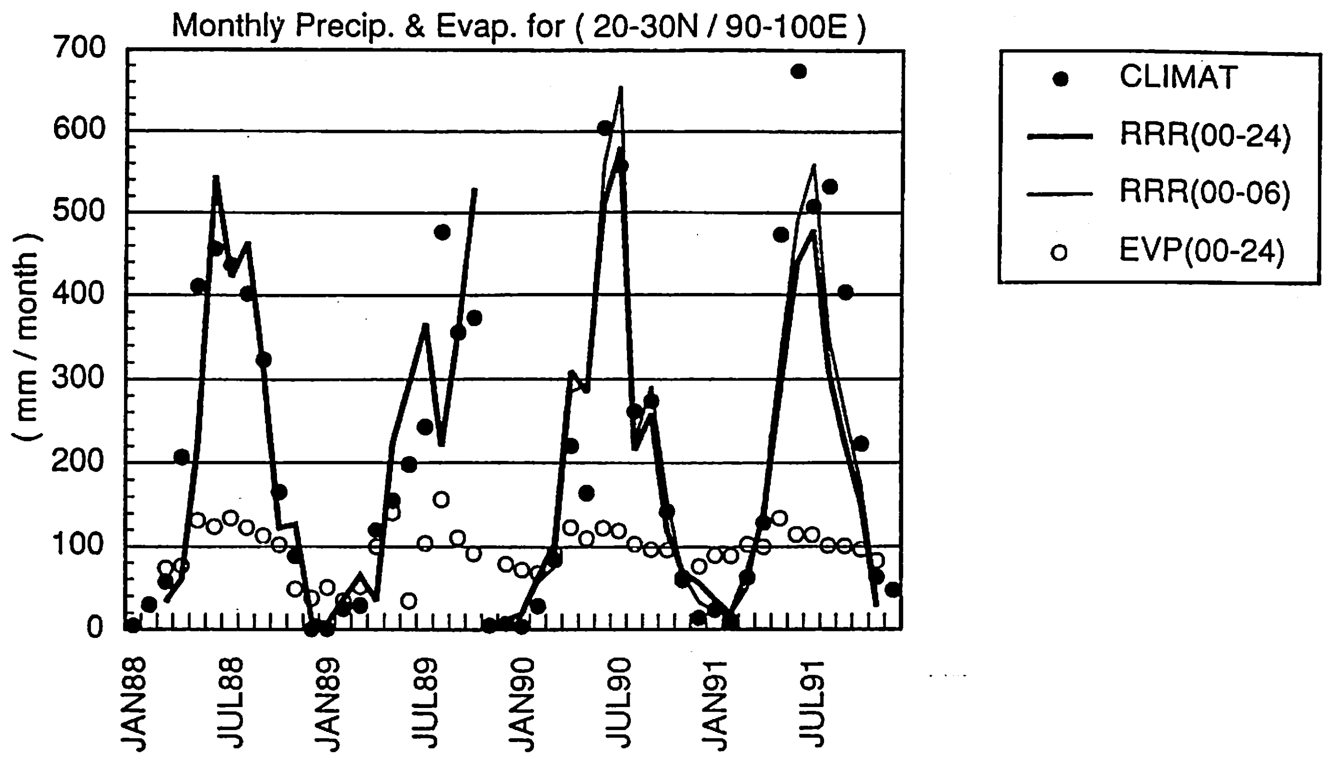


Figure 4-3:The 6-hour and day-1 assimilated precipitation and evaporation in south and southeast Asia compared with the CLIMAT data. (Sato, 1992)



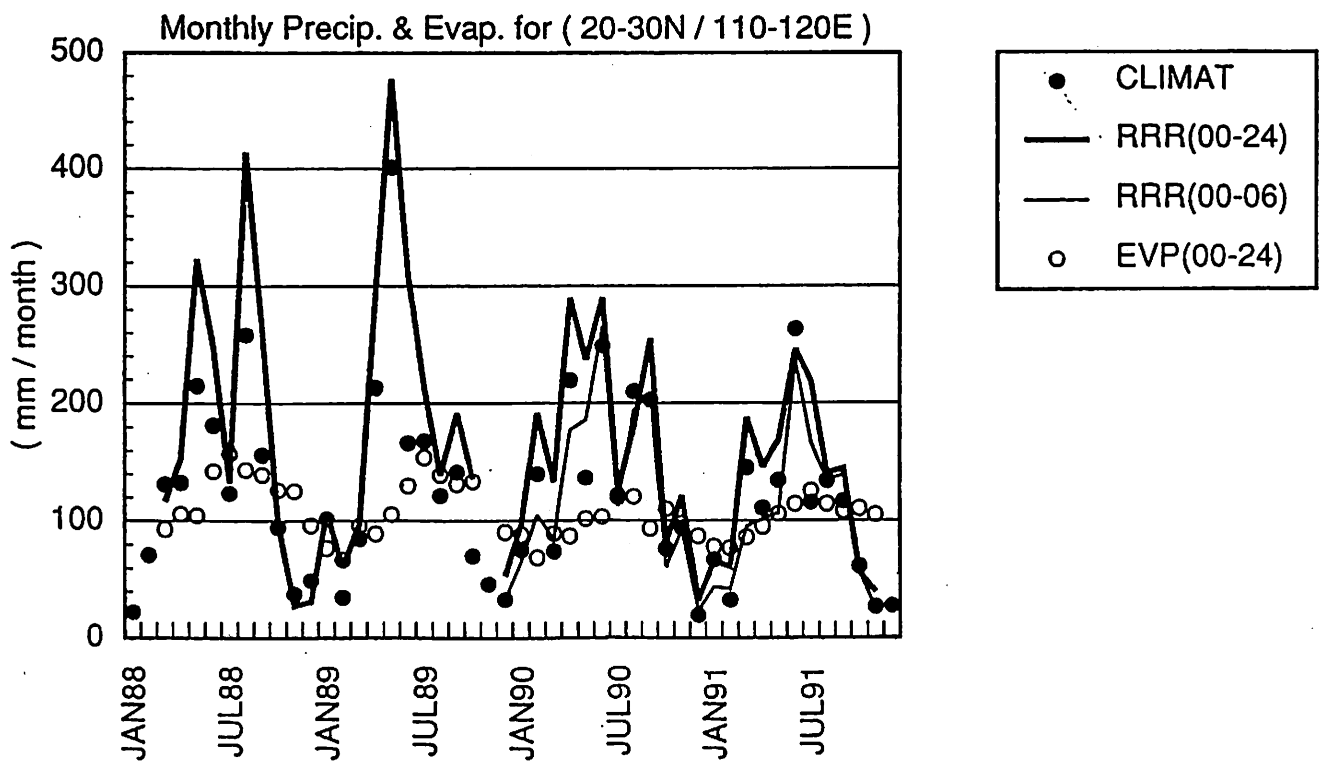


Figure 4-3(continue)

4-3-2. Hydrological processes revealed from 4-DDA data

The preliminary test for regional hydrological processes by using the output data from the currently available assimilation scheme (Sato, 1992) has proved the validity of this method for large-scale hydrological process provided that the input observational data are sufficiently and adequately given.

The 6-hour and day-1 assimilated precipitation and evaporation in south and southeast Asia, for example, are compared with the CLIMAT data as shown in Figure 4-3, which shows fairly well simulation of monthly precipitation except the ocean area.

The direct measurement of large-scale evapotranspiration is very difficult, which hampers us to validate and improve the parameterization of land surface hydrology. This could be done by data assimilation. The mean runoff computed as the difference of simulated 6-hour and day-1 precipitation and evaporation for the two years December 1989 - November 1991 was compared with the climatological runoff (Global Runoff Data Center and UNESCO) for major river basins over the globe., as shown in Figure 4-4. We find that for some river basins the model runoff is less than zero (i.e. dried-up river beds). This means that the model evapotranspiration is too much for the river basins in the northern hemisphere where model precipitation is quantitatively well simulated. For other basins in the world, we cannot tell whether evaporation is too much or too less, because the simulated precipitation itself is doubtful due to lack of input observations. This result by GDAS suggests somewhat better resolution of the run off than that by the ECMWF analysis data (Oki et al., 1992).

It is not at all surprising that model runoff becomes negative in some basins, because the initial soil moisture has nothing to do with the model precipitation. It is interpolated in time from monthly climatological soil moisture. One solution to this problem is to adopt predicted soil moisture for the initial soil moisture. Another possible cause of negative runoff is too much net surface radiation. Continental-scale soil moisture observation is absolutely required.

4-3-3. Advanced 4-DDA in GAME

Currently, the model precipitation was assessed on monthly basis in 10 x 10 degree boxes. The dependence of the model performance on temporal and spatial resolution should be investigated further. The good correspondence between simulation and observation reflects the fact that seasonal change is very well simulated by the model. The capability of the model to simulate interannual variability is not sufficiently assessed. Ocean precipitation can be verified against satellite data if qualitatively. The diurnal variation and the association of precipitation with the

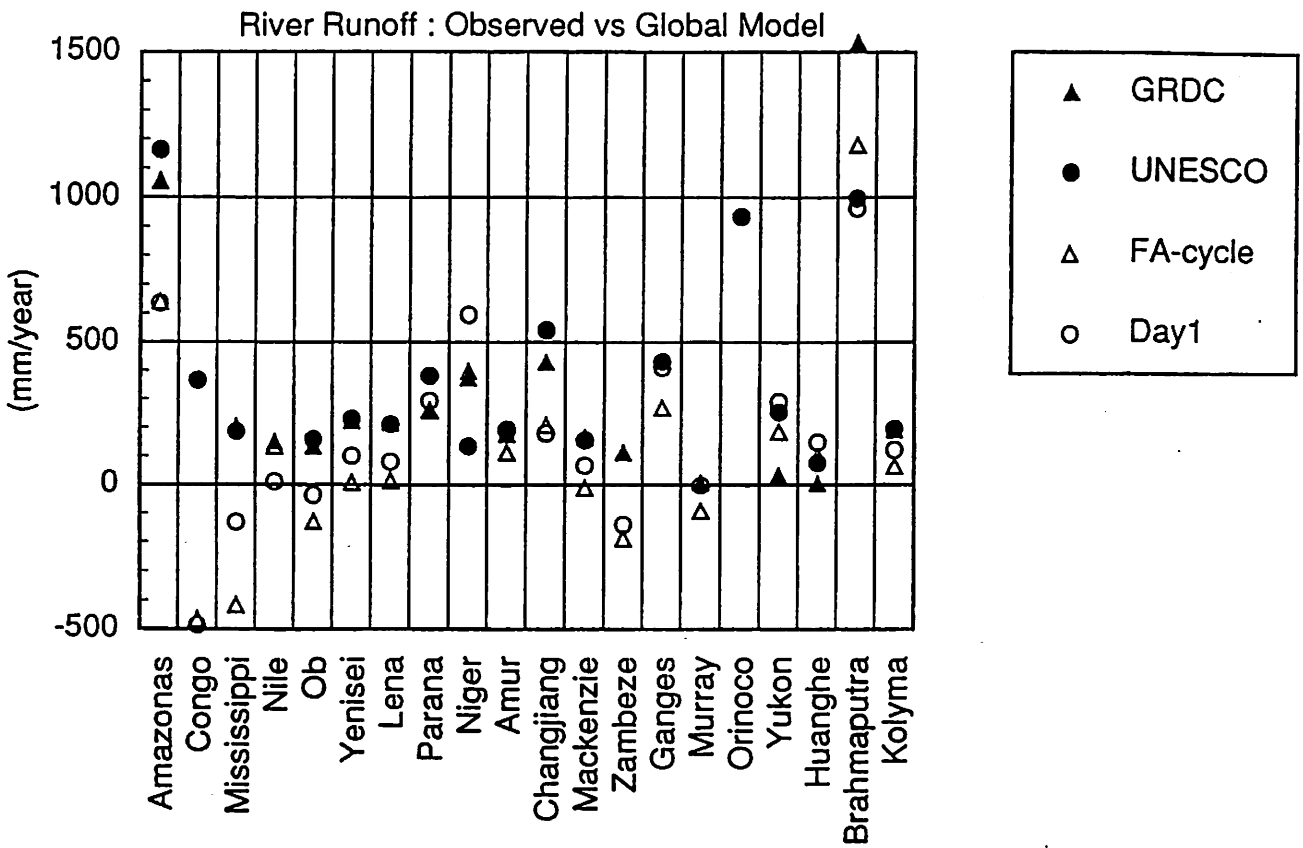


Figure 4-4: The mean runoff computed as the difference of simulated 6 hour and day-1 precipitation and evaporation for the two years (December 1989 - November 1991), compared with the climatological runoff (World Runoff Data Center and UNESCO) for the major river basins in the globe (Sato, 1992).

dynamics of the atmosphere (ex. intra-seasonal oscillation) are also essential targets for the assimilation in GAME.

The incorporation of the satellite derived precipitation and moisture information to the GDAS will undoubtedly promote much progress in simulating large-scale precipitation. Recently, for example, the high resolution TOVS data was assimilated, which improved to some extent the forecast in the southern hemisphere and the tropics (Kashiwagi, personal communication). This improvement was evident in the wind the pressure fields. The simulation of precipitation may have been improved as well. The JMA GDAS also uses cloud top temperature data as a proxy data in moisture analysis in the region covered by GMS. This moisture analysis significantly contributes to the better forecast performance of tropical motions.

The assimilation with surface wind data from ADEOS, with precipitation from TRMM (and possibly TRMM follow-on series) and land surface hydrological parameters from ADEOS-2, EOS series along with the ad-hoc ground-based data from AAN will enable us to the highly resolved energy and hydrological processes with 50 km x 50 km mesh size in the tropics and monsoon region. The assimilation will be implemented fundamentally as operational basis, but the re-analysis will also be implemented for the intensive observing periods.

In addition, the nested regional assimilation with even higher resolution (with about 20 km x 20 km size) would possibly be implemented, as part of some regional field experimental studies, to assess and diagnose the regional basin-scale water cycle and energy processes. This project will, however, be possible only under the cooperation between the research center of the regional experiment and JMA.

5. Model studies

5-1. Simulation and prediction of Asian monsoon by GCM

5-1-1. Issues for modelling of Asian monsoon

The modelling effort of simulating and predicting the seasonal state of year-to-year variation of the Asian summer monsoon has already been started as part of the TOGA program in the TOGA-MONEG (Monsoon Numerical Experiment Group). The very recent studies related to the MONEG activity (Palmer et al., 1992; Mo, 1992; Kitoh et al., 1992; WCRP, 1992) have pointed out and summarized the problems on simulating the seasonal mean state of the Asian summer monsoon as follows:

1) The systematic errors in simulating the seasonal monsoon circulations were found to be sensitive to four physical processes, i.e., convection, surface heat fluxes in the warm water pool region, land surface processes and the representation of subgrid-scale orography. The sensitivity was also noted to the space resolution change (e.g., from T21 to T42).
2) The gross features of the interannual difference in monsoon circulation could qualitatively correctly be simulated provided that the observed SST distribution over the tropical Oceans, particularly over the Pacific, were prescribed. This implies the importance of the oceanic component of the boundary condition for the monsoon system, though this component seems, in reality, to be completely interactive with the monsoon circulation itself (Meehl, 1987, 1993; Yasunari, 1990; Yasunari and Seki, 1992; Webster and Yang, 1992).
3) More detailed and quantitative features, e.g., regional rainfall amounts and patterns, showed large discrepancies between the observation and any model result, as well as among the model results. In addition, these regional features, e.g., Indian and southeast Asian monsoon rainfall, were extremely sensitive to initial state.

5-1-2. Land/ocean surface processes and cumulus convection

These results suggest the relative importance of land/ocean surface processes and cumulus convection (and possibly, their interactions) in producing large systematic errors. and discrepancies between the models. In fact, all the models adopt considerably or delicately different parameterization schemes for these processes, either of which are not fully validated by the observations. The change of these processes, or the integration of slightly different processes would result, non-linearly, in a great change in the distribution of latent heat transport and convergence in the monsoon region, which in turn is easily fed back to the distribution of diabatic heating and monsoon circulations.

For example, the recent numerical experiment with ECMWF model (Miller et a., 1992) has proved that the change of evaporation scheme at the surface with more realistic formulation of lower limit value under the weak wind speed condition (of less than 5 ms-1) drastically improves the overall feature of the Asian monsoon circulation. The improvement is mostly due to the drastic increase of evaporation over the warm water pool region of the tropical western Pacific and the Indian Ocean. This new formulation of evaporation is based upon the incorporation of the effect of subgrid-scale wind induced by convection, though it is not sufficiently warranted and verified by the observation.

Similar sensitivity on large-scale as well as regional-scale changes in monsoon circulation and rainfall are very plausible to changes in the formulation of land surface processes, particularly the soil moisture/ evaporation/ precipitation feedback process. The model comparison of response of CO_2 doubling experiment (IPCC, 1990) showed, for example, large discrepancies between the models of soil moisture and precipitation anomaly over land area, particularly over the monsoon regions, which urges us to improve and validate this process based upon the observational data. Furthermore, it is suggested that this process is also sensitive to the initial soil moisture condition (Manabe and Wetherald, 1987). Some diagnostic studies (e.g., Yasunari and Seki, 1992; Webster and Yang, 1992) also suggested that the summer monsoon state is sensitive to the land surface condition in spring and pre-monsoon season. Fennessy et al. (1993) noted that the simulation of the summer climate condition over north America (i.e., 1988 drought) was significantly improved when their integration was initialized by the observed soil moisture.

In view of these, to obtain a better simulation of the seasonal cycle with accurate initial as well as boundary conditions may be particularly important for the prediction of the monsoon. To finally meet this requirement, the further development of the physical processes in the coupled atmosphere-ocean-land GCM is essential, which should be pursued in collaboration with CLIVAR program. In other words, an essential point for simulating and predicting the seasonal monsoon state may be that both seasonally renewed initial conditions and boundary conditions of land and ocean surface be evaluated correctly.

5-1-3. Main subjects

On these bases, main subjects to be taken up may be as follows:

a. Improvement of cumulus cloud parameterization applicable to both land and ocean surfaces, by utilizing TRMM satellite and intensive surface observation and by combining the meso-scale atmospheric models (refer to 5-2 in detail).

b. Validation of subgrid-scale surface hydrological process and boundary layer process with the one-dimensional physical process model, based on the ad-hoc intensive field experiments (also refer to 5-3).

c. Production of homogeneous data of large-scale land surface parameters by the 4-dimensional data assimilation of GCM with the improved scheme of surface hydrological processes, which will be used as initial values of numerical forecasting (also refer to 4-3).

d. Prediction of monsoon circulation and meteorological parameters with time scale of a week to seasonal mean state by utilizing the initial values and boundary conditions described above.

5-2. Modelling of meso-scale cloud systems

The Asian monsoon system is characterized by large variety and diversity of cloud systems both in size and structure, as is aforementioned. The objective of cloud system modelling in the concept of GAME is to understand the physical process of each cloud system, particularly meso-scale systems, and to apply the results to improve the cloud parameterization in the climate model.

To develop the cloud-resolving model is particularly important, because of the difficulty in observing the detailed structures of cloud system. The interaction of meso-scale clouds with the large-scale circulations is also essential, since diabatic heating which forces and maintains planetary-scale monsoon circulation is produced fundamentally by cumulus convection systems of various scales from 1 km to 1,000 km.

Emphasis should be made on the development of meso-scale cloud model resolving 50 km x 50 km size, taking account of the forthcoming GCM girds introduced presumably during the middle of GEWEX. Because the large-scale environment and boundary condition of cloud systems are so diverse in the monsoon region from the ocean to the continent, from the equator to the sub-tropics and mid-latitudes, universally-applicable cloud parameterization is really required.

In addition, modelling of radiational processes in cirrus and stratus clouds in the planetary boundary layer is also important for parameterizing the cloud-radiation feedback. To meet this requirement, basic studies on water vapor and cloud water transport by cloud systems, statistical treatment of cloud types and amounts and micro-physical properties of clouds will be necessary based upon satellite (e.g., TRMM follow-on mission) and ad-hoc field observations.

(Numerical models)

	horizontal grid size	domain size	understanding of
climate model GCM	300-50km	global	global and regional water and energy cycle
↑ mesoscale organized convection			
mesoscale model	50-5km	1,000-5,000km	regional water and energy cycle; interaction between cloud systems and larger-scale motions
↑ cumulus convection			
cloud resolving model	1km	100-1,000km	cloud systems and their interactions with larger-scale motions
↑ microscale motions cloud microphysical processes			
fine resolution cloud model with explicit cloud microphysical processes	1km-100m	50-100km	cloud microstructure

arrow: parameterization of physical processes to be improved

(models related to improvement of cloud models)

radiation model ...... parameterization of radiative processes used for cloud models

boundary layer model .. parameterization of turbulent processes (fluxes of sensible and latent heat and momentum)

Figure 5-1: Structure of cloud-system modelling for GAME.

The structure of the modelling studies related to the cloud systems are shown in Figure 5-1. The main subjects are as follows:

a. To develop cloud-resolving models and its application to meso-scale cloud models

b. To develop meso-scale cloud models and its application to cumulus parameterization in the GCMs

c. Process study of micro-structure and micro-physics of clouds

d. To validate the role of cloud systems in the energy and hydrological cycle in the climate models

5-3. Modelling of hydrological processes

The monsoon Asia, or more widely, the eastern half of the Eurasian continent is characterized as a broad area integrated by heterogeneous and complex terrains extended over the equatorial belt through the mid latitudes. The fundamental properties to be obtained both for meteorological and hydrological purposes may be the surface water balance (P-E), water storage and discharge.

To assess these values over various extreme geographical and land surface conditions, macroscale hydrological models should be developed by addressing some of the key issues as follows; 1)the relative influences of soil structure and composition, slope parameter, vegetation and rainfall distribution in determining hydrologic response, 2)the spatial and temporal complexity in the grid, and 3)the space-time scale at which statistical treatments of processes governing the basin hydrology yield accurate water balance.

The issues presented here share common scientific objectives to GCIP, which is planned to be systematically and comprehensively implemented in and over the Mississippi river basin. It is expected that some or many aspects of land-surface/atmospheric processes and hydrological modelling will be able to be transferred or applied to those over the Asian monsoon region. To apply the results obtained from the GCIP Mississippi and other regional experiments to the global domain of the energy and water cycle, it is necessary to achieve a universally-applicable macroscale hydrological model, which includes applicability to the global domain itself, coupled with the meso-scale atmospheric models, as schematically shown in Figure 5-2. To meet these necessities, the inter-comparison and integration of hydrological processes and the tunable parameters of macroscale. Models are absolutely required over some other major climatic domains on the earth, e.g., the monsoon Asia and/or the Eurasian continent, where various extreme climatological and

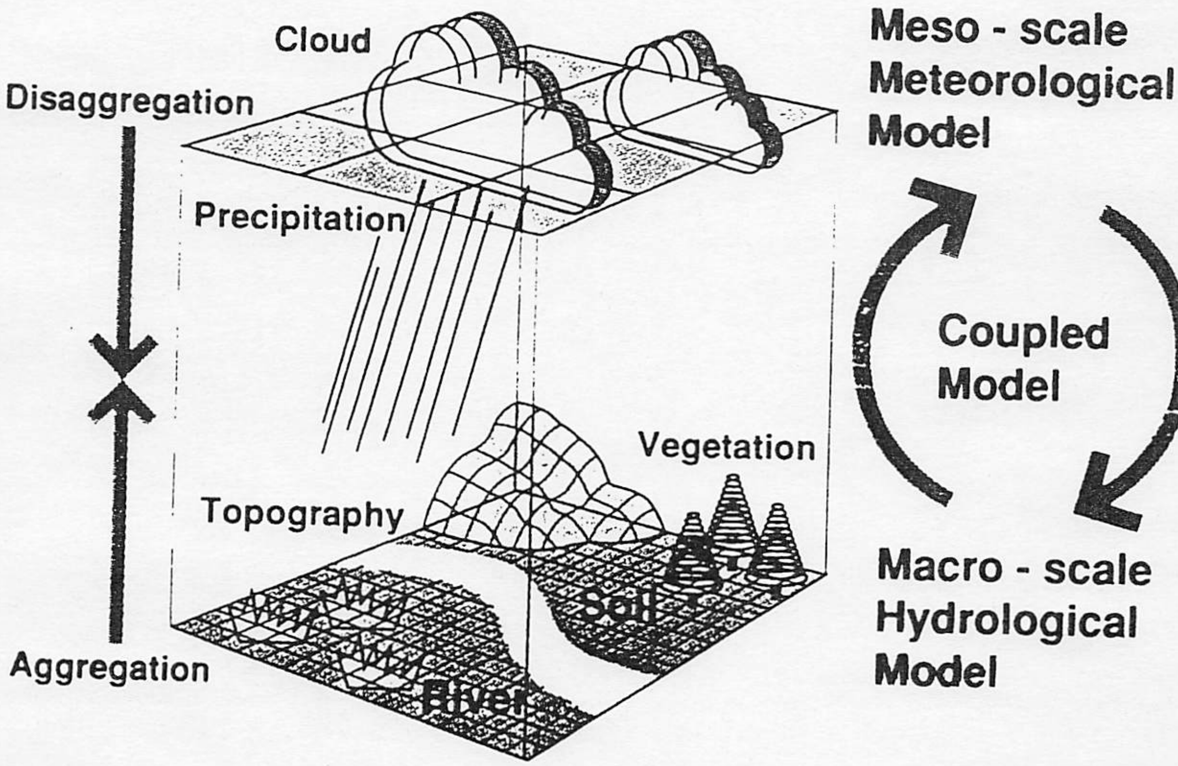


Figure 5-2: Schematic diagram for coupling of macro-scale hydrological model with meso-scale atmospheric model.

hydrological conditions are dominated. The development and validation of a universally-applicable macroscale model is one of the key objectives of GAME.

The following subjects are focused in this study:

a. To develop and validate universal macro-scale hydrological models;
   (1)Determination of heat and water fluxes on the land-surface and hydrological cycles.
   (2)Methodology for scale-up of the local energy and water cycle.
   (3)Mixed pixel problem
   (4)Development and validation of coupled macro-scale hydrological /meso-scale cloud models

b. To develop the evaluation of impact of monsoon variability on regional water resources and water management
   (1)Methodology for scale-down of the global energy and water cycle
   (2)Evaluation of variability of water resources and its impact

c. To develop and validate information retrieval schemes incorporating currently operating and future satellite observations, coupled with enhanced ground-based and aircraft observations

6. Data archive and management

6-1. Collection of ground-based data

Although satellite observation data are useful in monitoring broad land areas, it is needed to be validated by ground based observation data. Also the results of numerical models should be verified by land observations. Furthermore, ground based data have long history over 30 years in many cases, and in some cases over 100 years. These long term data will be valuable to study decadal scale variability of the monsoon system, which is rather difficult by using merely satellite data.

In real time basis, the GTS (Global Telecommunication System) data can be obtained. However, precipitation data is often inaccurate or missing in GTS data. Moreover, some important data elements, such as snow depth or ground temperature, are not reported through GTS lines. The observation and data management in most of countries over Asian and Australian monsoon region is fairly good. Although it is often difficult to use these data from foreign countries, it is strongly recommended to create a new data set based on conventional meteorological as well as hydrological observations. In using such data, collaboration with foreign meteorological and hydrological organizations are indispensable. By utilizing these station based data, the average condition of the special observation fields will also be verified.

In terms of daily precipitation data, for example, FGGE level II-c data set was archived by the National Climatic Data Center (NCDC, USA) from 149 countries during the FGGE year (Williams et al, 1985). This data set contains the most dense station data ever achieved. For example, 751 station data are collected over China (Matsumoto et al, 1992, Figure 6-1), though the data quality is not very good with many missing data.

Considering scales of time and space particularly for the requirement of the data assimilation for the GAME, it is desirable to structurize three levels of data set. The station density / observation frequency / areal cover / data period of each level are as follows;

Level 1: 1 station per 50 x 50 km / hourly or several times a day / special area related to the field observation / since 1995

Level 2: 1 station per 200 x 200 km / hourly or daily / whole monsoon region / since 1961

Level 3: 1 station per 200 x 200 km / monthly / whole monsoon region / since 1901 (as long as possible)

The data element will be precipitation, air and ground temperature, duration of sunshine, snow depth, runoff.

6-2. Collection of satellite data

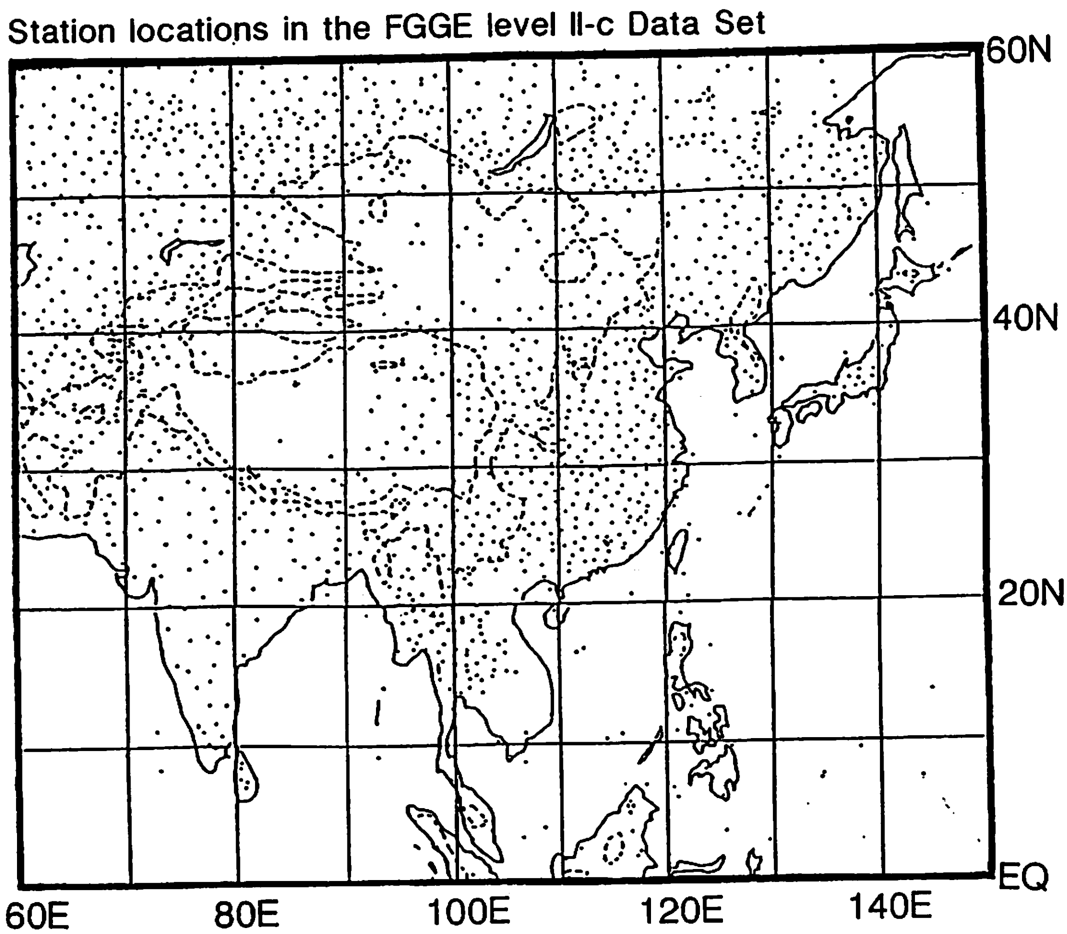


Figure 6-1: Distribution of daily precipitation in monsoon Asia available from FGGE level II-c data set archived by the National Climatic Data Center (NCDC, USA).

The satellite data archive related to GEWEX and GAME would be huge. In addition to the operational meteorological satellite data (GMS, NOAA, DMSP) including SSM/I, the data from TRMM, ADEOS series, EOS series will become available one by one after 1996. To collect and archive these data sets to be provided for scientific and operational users ought to be pursued by multiple number of data analysis centers, which are to be established, or partly has already been established. One of the leading centers expected to function as a host data collection and analysis center, at least for the data of J-ERS, TRMM, ADEOS series, would be the Earth Observing System Data Analysis Center (EOSDAC) of NASDA, which is going to be established in 1994. Other data analysis centers are also to be established at some universities and institutes, for handling the data sets from some specific satellite missions. It should be emphasized here that these multiple centers be coordinated with the information network for the maximal use of data sets, which should be a part of GAIN in the next section (6-3).

6-3. GAME Archive Information Network (GAIN)

6-3-1. Structure of GAIN

Many field observations, numerical experiments, data analysis and satellite data processing are planned in GAME. They will have their own research purposes, but the results will be precious information and those will have to be widely shared among researchers throughout the world.

Ad-hoc data will be acquisited by field campaign observations but period and location will be limited. On the other hand, each country has long-term records through routine observations. The directory of these data archive will help researchers to access various data sets, and the data distributing system will make it possible to pursue the complicated analysis of enormous data, which would be very difficult without the system of data collection.

The GAME Archive Information Network (GAIN) is proposed as one of the core sub-project of GAME to unify these information in GEWEX and GAME. The final object of GAIN is to estimate large scale circulation, distribution and balance of water and energy in Asian monsoon region, by compiling data sets of field-campaigns, AAN, routine observations, satellites and 4-DDA.

There are three main activities in GAIN as follows:

(i) data collection
(ii) data management and compilation

(iii) data analysis

The activities of GAIN is schematically shown in Figure 6-2.

For data collection of existing data, official contract with governmental organization of each country should be pursued. Offering of observational instruments and the request of data acquisition to local institution will be inevitable for some special observations.

Data from campaign field observation will be accumulated in real time. It will support the observation by row-level data processing, illustration of figures, and backup of observed data. The prompt sharing of the data will enhance the efficiency of observations.

In terms of data management, quality check and scientific visualization of data are planned.

The construction of `Global Geographical Information System' is also planned to compile all collecting data. Data distribution will be done by both network and CD-ROM or other digital media of large capacity.

GAIN will also analyze large scale water balance and annual variation of it using accumulated data sets and information.

In order to secure rapid data exchange, computer network should be prepared among all related research institutes and countries. Also it is very important to establish the GAME data analysis center, where original data from various countries related to the GAME will be collected and compiled by most reliable and fastest method and the processed and assimilated data will be re-distributed to those countries.

6-3-2. Data classification

Data levels are roughly classified into 4 categories in GAIN .

	row data	processed data
point data	P0	P1
image data	I0	I1

Image data here means spatially distributed data, which includes one dimensional horizontal data by airborne observations. They can be also divided as routine data or not, and some data may be vector data such as geographical information.

P0 :Observation data at a point, including vertical profile of the atmosphere and soil layers. They will be precipitation by raingauges, temperature, humidity, wind speed and direction, radiative values, albedo, surface pressure, discharge and water level of rivers, ground water level, evaporation rate, snow depth etc. In special observations, sensible and latent heat flux, vertical profile of temperature, wind, and humidity, rain drop size distribution and micro-physical values, quality and density of snow cross section,

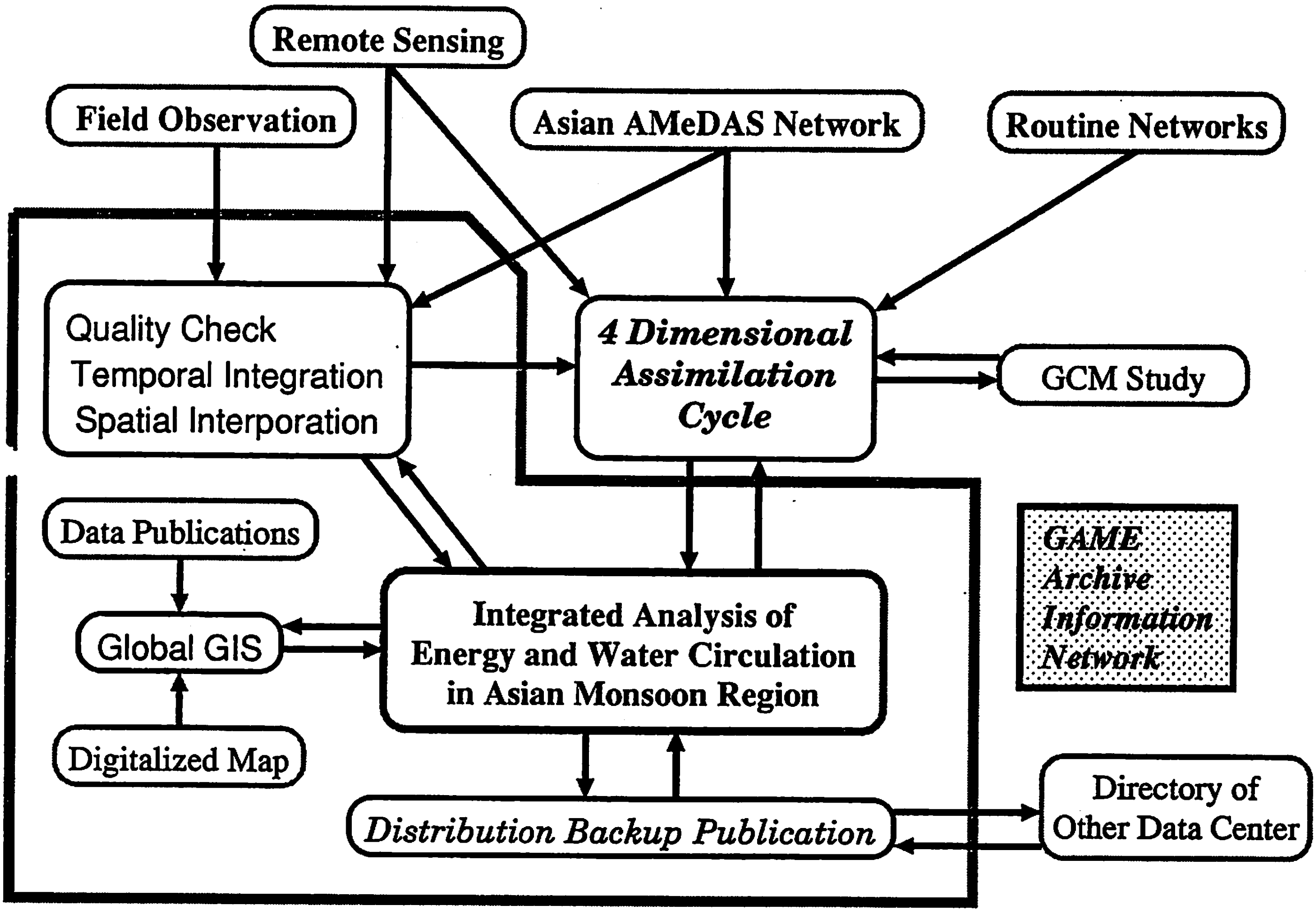


Figure 6-2: Activity of GAME Archive Information Network.

potential of soil layer and vegetation, liquid velocity in vegetation, the depth of permafrost, and the radiative characteristics of ground surface will be added for the information.

P1: Physical values estimated from point data and also satellite data by numerical analysis belong to this category. They are energy and water balance of the surface, sensible and latent flux, rainfall intensity, snow depth, and radiative balance etc.

I0 : Remote sensing data by satellite belong to this category. It is not practical to store all row satellite data, and therefore quick look and archive directory will be supplied by GAIN.

I1 : Standard products which can be shared among researchers in GEWEX/GAME belong this category. They may classified by their origins.

i) Image data in published CD-ROM
ii) digitized data from existing maps
iii) Spatially interpolated image of point data
iv) 4-dimensional assimilation data of the atmosphere
v) Results of numerical simulation such as GCM outputs

The contents are topography, vegetation, soil properties, atmospheric variables, precipitation, evapotranspiration, sensible heat flux, sea surface and land surface temperature, and 3 dimensional circulation of energy and water. Standard spatial and temporal scale will be decided, and the data will be accumulated and distributed for research purposes.

6-3-3. Policy for data management

Data management is an essential and final task for GAME. Fundamentally, all the data sets collected and archived as part of GAME activities should be open and available for all the researchers involved in GAME. Though some hydrological and meteorological data are currently not available in some countries, it is expected that those data would become available for constructing the final GAME data sets. It should contain more homogeneous and highly-qualified data, e.g., the assimilated data of 50 km X 50 km, for the numerical weather prediction and for the control of the water resource and management of each country and regions. Details of the policy for data management should be finalized by mutual agreement of the attendant agencies and institutes.

7. Implementation plan

7-1. Outline of (tentative) implementation plan

The GAME implementation program has four primary phases: preparation phase, build-up phase, main observing phase and data archive and long-term monitoring phase. The main observing phase will be divided into two sub phases; phase I before 2000, and phase II will be after 20000. Phase II is still under consideration, which may depend partly upon the result of Phase I as well as other conditions. A Intensive Observing Period (IOP) is included in the main observing phase I. The each component is defined as follows:

a) Preparation phase (1994-1995)

1. Planning and feasibility study of each field campaign
2. Establishment of GAME International Science Panel
3. Establishment of GAME International Project Office
4. International and domestic coordination
   <2nd International Study Conference ('95.3 Thailand)>
5. Development and field test of AWS for AAN

b) Build-up phase (1995-1996)

1. Preparation and pilot experiment for each field campaign
2. Development and test for data processing and retrieval algorithm satellite observations
3. Initial phase of deployment of AAN
4. Launching of ADEOS (1996)
5. Initiation of Advanced 4-DDA at JMA (1996-)

c) Main observation phase I (1997-2000)

1. Implementation of field campaigns
2. Initiation of full processing of satellite data
3. Implementation of **IOP** (summer of 1998)
4. validation and continuous development of models
5. Full processing of 4-DDA

d) Data archive and long-term monitoring phase (1998-)

1. Establishment of GAIN
2. Continuous monitoring of AAN (at least to 2005)
3. Implementation of high-resolution nested 4-DDA for the regional experiments

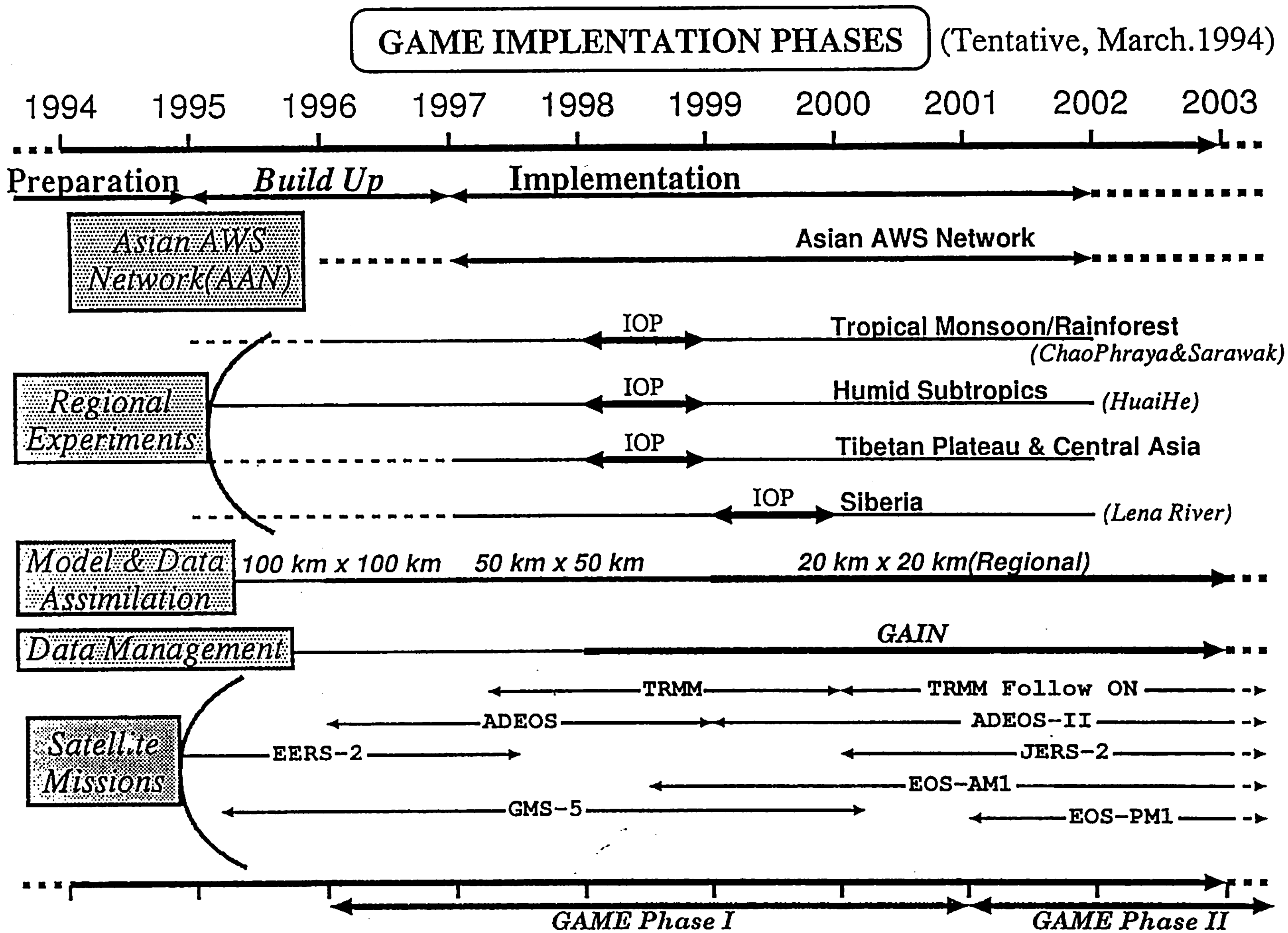


Figure 7-1: Outline and tentative time table of the whole program of GAME, with the (scheduled) operation period of related satellite missions .

e) Main observing phase II (after 2000)

(Details have not been decided yet. Monitorings of surface fluxes by AAN and satellite observing system will further be continued and developed. The second IOP, including land/atmosphere/ocean interactions over the Indonesian maritime continent and/or the tropical Indian Ocean region, will be desirable.)

The outline and tentative time table of the whole program, including the operation period (presumed) of related satellite missions is shown in Figure 7-1. The IOP is placed taking account of availability of TRMM and its follow-on mission. The International Study Conference or Workshop would possibly be held once per year.

7-2. Strategy for IOP

The objective of IOP is to produce the data set for understanding the full energy transfer and water cycle processes both in the regional and continental scales, associated with the full seasonal march of the Asian summer monsoon, i.e., from the pre-monsoon stage, the onset stage, the mature stage and the withdrawal stage. In the tropics and subtropics, the diurnal cycle of cumulus convection is to be resolved in the continental-scale analysis of 4-DDA, and the cloud clusters of meso-α scale is to be resolved in the nested regional 4-DDA analysis. The land surface hydrological processes are to be observed intensively to provide sufficient data for developing sub-grid scale hydrological models.

To attain this objective, all the regional experiments for GAME (refer to 3-3 and 3-4) will be conducted during the IOP with the full ad hoc observing systems available (radar, Doppler radar systems), combined with the enhanced operational and ad-hoc radiosonde observations (4 times/day in the tropics and subtropics). The full operation of TRMM satellite, providing rainfall rate over this area, is one of the basic conditions of IOP.

Considering the necessary conditions mentioned above, and some other logistic conditions, we tentatively have set up a period of 4 or 5 months in 1998 (from May to August, or September) as the most suitable period for IOP.

8. Links to other programmes and projects

8-1. GCIP and other continental-scale projects under GEWEX

Some of the objectives of this program is compatible and complementary to GCIP, as is aforementioned in 3-2. The field experimental studies of GAME (refer to 3-3 and 3-4) can also be compared to other GEWEX related field-based experiments (i.e., MAGS, LAMBADA, BALTEX) in the sense that these experiments aim commonly to understand the energy and surface hydrological processes and their modellings. A somewhat different characteristics of GAME from GCIP and the other experiments may be to focus on the extremely large heterogeneity and diversity of the land surface and climatic conditions over a broad area of the Eurasian continent.

Another remarkable aspect of GAME is that it is more directly aimed to one of the main objective of the GEWEX, focusing on the role of the Asian monsoon in the global energy and water cycle itself.

8-2. ISLSCP and GPCP

GAME will provide elementary data sets for land surface hydrological parameters and vegetation data through the four major regional experiments and AAN, in addition to the satellite land surface informations by J-ERS, ADEOS and ADEOS-2 series, which will greatly contribute to ISLSCP data archive. TRMM and hopefully TRMM follow-on satellite will absolutely provide the most basic data for global precipitation climatology in the tropics and sub-tropics, which will be a major contribution to GPCP. Furthermore, GAME will strongly support the Global Soil Wetness Project (GSWP), which has recently been initiated jointely by ISLSCP and GEWEX Modelling Panel, since the soil moisture and snowcover over the Eurasian continent are key ingredients for predicting the Asian monsoon and assessing the human impacts on the climate variability in monsoon Asia.

8-3. TOGA, CLIVAR and GOALS

To accomplish one of the main objectives of GAME, i.e., to understand the energy and water cycle of the Asian monsoon system itself, it is also essential and crucial to assess the role of Oceans around the continents. The atmosphere/ocean interaction over the equatorial Pacific related to the ENSO has been a main topic for TOGA. The Asian monsoon - ENSO relationship is , in fact, becoming one of the major targets of TOGA follow-on CLIVAR program. This oceanic component of the Asian monsoon, particularly focusing on the mechanism of the interannual variability should be a major topic for CLIVAR phase I. The meteorological and oceanographical community in the United States of America is also planning the GOALS (Global Ocean-Atmosphere-Land interaction System) program as a compatible program of CLIVAR in USA. GAME will focus more on the role of continental land surface conditions on the seasonal cycle and the interannual variability of Asian monsoon system, which is, however, also indispensable for understanding the physical basis for understanding the monsoon/ENSO interaction. In ths second phase (after 2,000), GAME may include some oceanic component as part of the energy and water cycle in the land, atmosphere, ocean interactions. GAME will, in this manner, play a complementary role with CLIVAR and US-GOALS program.

8-4. ACSYS

The role of the cryosphere (snowcover and permafrost) over the Eurasian continent on the seasonal evolution of the Asian summer monsoon seems to be very large as described in 1-3-2. Associated with this issue, the energy and water balance over the continental-scale river basins in Russia will be studied as part of the regional experiment of the permafrost region in Siberia (refer to 3-4-4), which concurrently provides the detailed information of fresh water supply from those rivers to the Arctic Sea basin. In fact, the refined assimilation data, which should be a major product of GAME, will provide more accurate estimate of water balance and its variability, which is one of the main topics of ACSYS (Arctic Climate SYtem Study), one of the regional sub-programs of WCRP (WCRP, 1991). In this context, GAME will contribute to some essential aspects of ACSYS.

8-5. SCSMEX and other monsoon-related projects

The South China Sea Monsoon Experiment (SCSMEX) is currently under planning maily by Chinese and US scientists as a multi-lateral joint project, focusing on the mechanisms of the summer monsoon onset and the role of disturbances over the South China Sea (Lau, 1994). The energy and water cycle processes over the oceans surrounding the Eurasian continent should, in fact, be a part of GAME tasks. In this sense, this regional experiment will complement fully with GAME, particularly with some regional experiments adjascent to SCSMEX region (i.e., Chao Praya/Borneo, Huai-He, and Tibetan plateau experiments), if the cooperation for the observing period as well as for some observing systems such as radiosonde network would be implemented between the two. In the same sense, the Ocean Climate Observing Study over the tropical Indian Ocean (OCOS) now being planned by the Australian scientists (Godfrey, 1994) would be expected to provide invaluable data for GAME.

8-6. START and IGBP-related projects

START (SysTem for Analysis, Research and Training for global change study) is an international initiative of network for regional studies on global changes, recently renewed as a joint program between IGBP, WCRP and HDP (Human Dimension Progarm). START consists of regional committees covering the whole globe, each of which has a role to promote and recommend regionally-oriented global change researches to the societies and countries. Very recently, TEACOM, the START regional committee forTemperate East Asia has agreed that GAME will be an essential part of the monsoon system study, which is one of the key study topics of TEACOM.

The objectives of GAME are closely related to those of some core projects of IGBP, e.g., BAHC (Biological Aspects of Hydrological Cycle), since the heterogeneity and diversity of land surface in the Eurasian continent correspond, at the same time, to those of vegetation. Some part of GAME activities, particularly the AAN and the regional experiments in the boreal Taiga in Siberia would also be expected to collaborate with the IGBP Siberian transect study, supported by another core project of IGBP, i.e., GCTE (Global Change and Terrestrial Ecosystem).

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APPENDIX

A-1. Organization of national committees in Japan

Japan National Committee for WCRP

Prof. Taroh Matsuno (DPGC, Hokkaido University), **chairperson**
Prof. Kimio Hanawa (IEPS,Tohoku University)
Prof. Akimasa Sumi (CCSR, University of Tokyo)
Dr. Tatsushi Tokioka (Japan Meteorological Agency)
Prof. Tetsuzo Yasunari (IG, University of Tsukuba)

National Planning Committee for GAME

Prof. Tetsuzo Yasunari (IG, University of Tsukuba), **chairperson**
Prof. Tosio Koike (Nagaoka University of Technology), **vice-chairperson**
Prof. Yoshihiro Fukushima (IHAS, Nagoya University)
Dr. Yasushi Fujiyoshi (IHAS, Nagoya University)
Prof. Shuichi Ikebuchi (DPRI, Kyoto University)
Dr. Toshiki Iwasaki (JMA: Japan Meteorological Agency)
Prof. Taroh Matsuno (DPGC, Hokkaido University)
Dr. Masato Murakami (Meteorological Research Institute)
Prof. Katumi Musiake (IIS, University of Tokyo)
Prof. Teruyuki Nakajima (CCSR, University of Tokyo)
Prof. Kenji Nakamura (IHAS, Nagoya University)
Dr. Kazuo Nakane (NIED, Science and Technology Agency)
Dr. Tetsuo Ohata (IHAS, Nagoya University)
Prof. Akimasa Sumi (CCSR, University of Tokyo)
Prof. Masakazu Suzuki (DF, University of Tokyo)
Dr. Makoto Tani (Forestry Research Institute)
Dr. Akira Terakawa (Public Works Research Institute)
Prof. Masaki Yamasaki (IEPS, University of Tokyo)

Secretariats:
Dr. Ken'ichi Ueno (IG, University of Tsukuba)
Dr. Taikan Oki (IIS, University of Tokyo)

DPGC: Docotr Prgram for Global Change studies
CCSR: Center for Climate System Research
IEPS: Institute of Earth and Planetary Sciences
IG: Institute of Geoscience
IHAS: Institute for Hydrospheric-Atmospheric Sciences
DPRI: Disaster Prevention Research Institute
IIS: Institute of Industrial Sciences
NIED:National Research Institute for Earth science and Disaster Prevention
DF: Department of Forestry

Working Groups under the GAME Planning Committee

Tropical monsoon Regional Study (Chao Praya and Sarawak)
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HUBEX (Huai-he river Experiment)
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Tibetan Plateau Experiment
chair: Prof. T. Yasunari(IG, University of Tsukuba, Ibaraki 305,
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Siberia Regional Study (Lena river basin)
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Satellite Remote Sensing
chair: Prof. K. Nakamura (IHAS, Nagoya University, Nagoya 464-01,
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Asian AWS Network
chair: Prof. T. Yasunari(IG, University of Tsukuba, Ibaraki 305,
FAX: +81-298-51-9764, TEL: +81-298-53-4399)

4DDA
chair:Dr. T. Iwasaki (Numerical Weather Prediction Center, JMA, Tokyo 100,
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Atmospheric and hydrologic modelling
chair:Prof. A. Sumi (CCSR, University of Tokyo, Tokyo 153,
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Global Soil Wetness Project and ISLSCP
chair: Prof. T. Koike (Nagaoka University of Technology, Nagaoka 940-21,
FAX: +81-258-47-0019, TEL: +81-258-46-6000 ext.6124)

GAIN (data archive and information)
chair: Dr. M. Murakami (MRI, Tsukuba, Ibaraki 305,
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A-2. LIST OF ACRONYMS

AAN	Asian AWS Network
ACSYS	Arctiic Climate SYstem Study
ADEOS	Advanced Earth-Observation Satellite
AIRS	Atmospheric Infrared Sounder
ALOS	Advanced Land Observation Satellite (of NASDA)
AMSR	Advanced Microwave Scanning Radiometer
AWS	Automated Weather Station
BAHC	Biological Aspects of Hydrological Cycle
BALTEX	Baltic sea Experiment
BATS	Biosphere-Atmosphere Transfer Scheme
BSRN	Baseline Surface Radiation Network
CLIVAR	Climate Variability and Prediction
DMSP	Defense Meteorological Satellite Program
DPR	Dual-frequency Precipitation Radar
ERS	European Remote Sensing Satellite
ECMWF	European Centre for Medium-range Weather Forecasts
ENSO	El Ninõ/Southern Oscillation
ENVISAT	ESA Environmental Satellite Series
EOS	Earth Observing System
EOSDAC	Earth Observing System Data Analysis Center
4-DDA	Four-Dimensional Data Assimilation
FGGE	First GARP Global Experiment
GAIN	GAME Archive Information Network
GAME	GEWEX Asian Monsoon Experiment
GCIP	GEWEX Continental-Scale International Project
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystem
GDAS	Global Data Archive System
GEWEX	Global Energy and Water Cycle Experiment
GEWEX SSG	GEWEX Science Steering Group
GMS	Geostationary Meteorological Satellite
GOALS	Global Ocean-Atmosphere-Land System?
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
GSWP	Global Soil Wetness Project
GTS	Global Telecommunication System
GWE	Global Weather Experiment
HDP	Human Dimension Program
HUBEX	Huai-he river Basin Experiment
IGBP	International Geosphere-Biosphere Programme
INSAT	Indian National Satellite System
IOP	Intensive Observing Period
IPCC	Intergovernmental Panel for Climate Change

ISLSCP	International Satellite Land Surface Climatology Project
J-ERS-1	Japanese Earth Resources Satellite-1
JMA	Japan Meteorological Agency
LAMBADA	Land-Atmosphere Moisture Budget studies over the Amazon by the four-dimensional Data Assimilation
MAGS	Mackenzie river GEWEX Study
METOP	ESA Operational Meteorological Satellite Series
MONEG	Monsoon Numerical Experimentation Group
MONEX	Monsoon Experiment
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center (of NOAA)
NOAA	National Oceanographic and Atmospheric Administration
OCOS	Ocean Climate Observing Study
OLR	Outgoing Longwave Radiation
PAM	Portable Atmospheric Mesonet (of NCAR)
PR	Precipitation Radar
RADARSAT	Radar Satellite
SAR	Synthetic Aperture Radar
SCSMEX	South China Sea Monsoon Experiment
SiB	Simple Biosphere Model
SMMR	Scanning Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave/Imager
SRB	Surface Radiation Budget
SST	Sea Surface Temperature
START	SysTem for Analysis, Research and Training
TDR	Time Domain Reflectometry
TEACOM	Temperate East Asia Commiittee for START
TOGA	Tropical Ocean-Global Atmosphere (Program)
TOPEX/POSEIDON	Ocean Topography Experiment/POSEIDON
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measurement Mission
UNESCO	UNited nations Education, Scientific, and Cultural Organization
WARM	Wet Atmosphere Research Mission
WCRP	World Climate Research Programme
WMO	World Meteorological Organization