GAME Publication No.37

GAME

(GEWEX Asian Monsoon Experiment)

Phase I

Summary Reports

GEWEX Asian Monsoon Experiment

March, 2003

edited by

T. Yasunari, K. Nakamura, A. Higuchi and J. Asanuma

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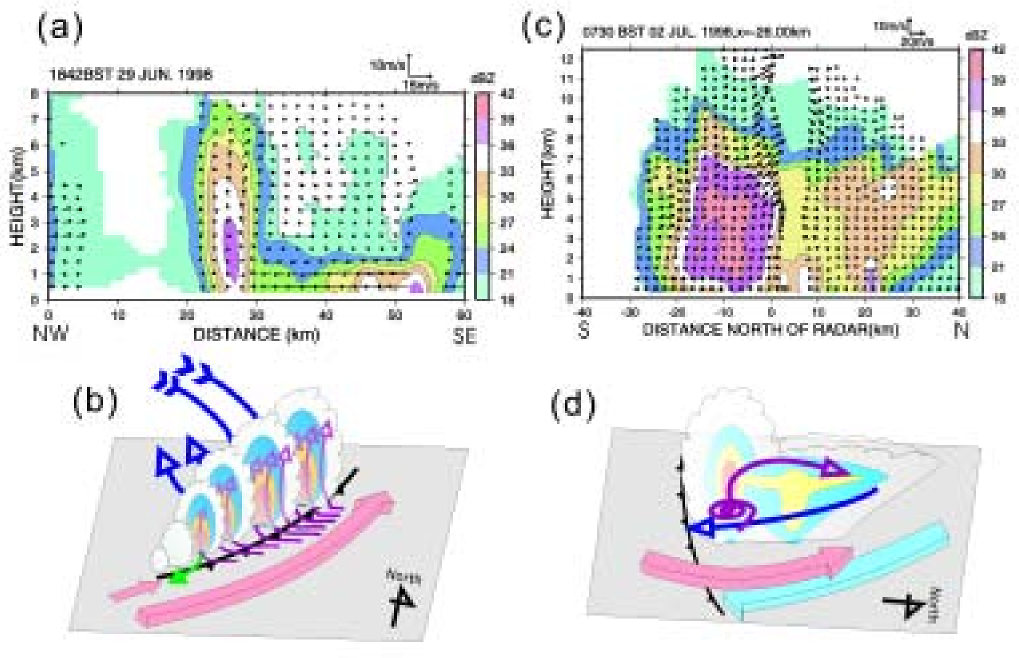


図１　GAME/HUBEX 1998 観測でドップラーレーダーサイト付近に降水をもたらした降水システム。a) 1998 年 6 月 29 日 1842BST に観測された降水システムのデュアルドップラーレーダー解析。b) (a)の降水システムの概念モデル。c)1998 年 7 月 2 日 0751BST に観測された降水システムのデュアルドップラーレーダー解析。d)(c)の降水システムの概念モデル。「亜熱帯・温帯エネルギー・水循環過程」班の成果から。

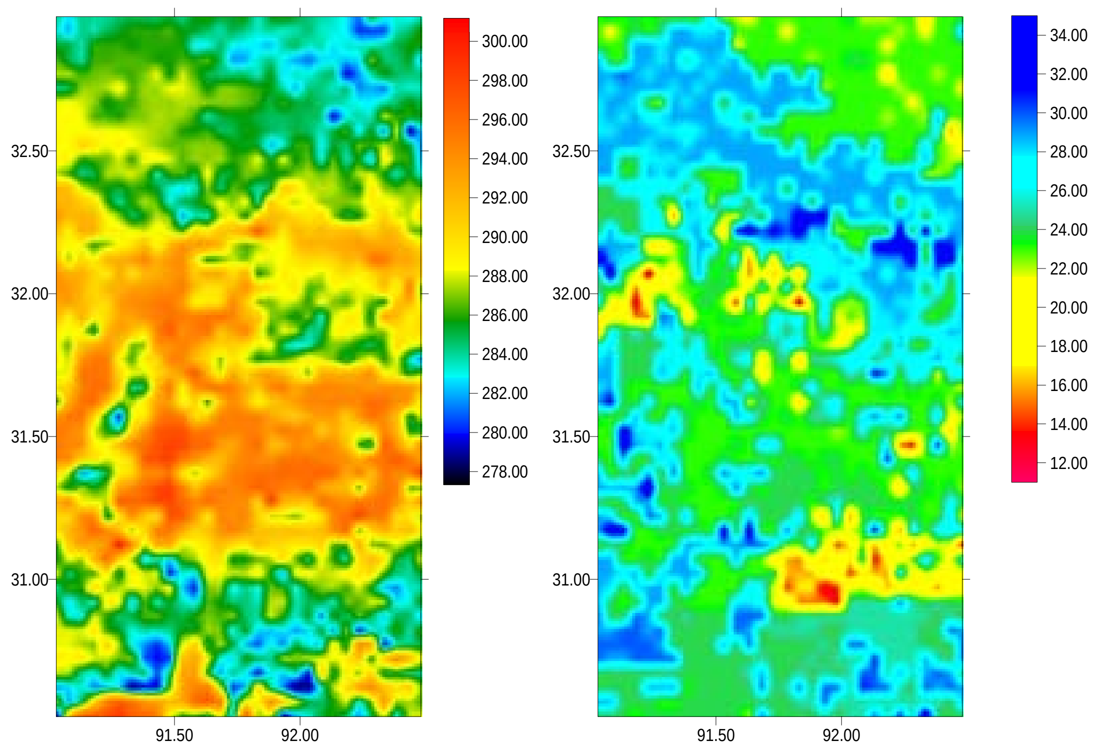


図２　陸面スキーム(PF/SiB2）とマイクロ波放射伝達モデルを組み合わせてた陸面データ同化システムを，TRMM/TMI データと「チベット高原陸面エネルギー・水循環過程」班のデータに適用して得られた表層土壌水分，地温マップ。

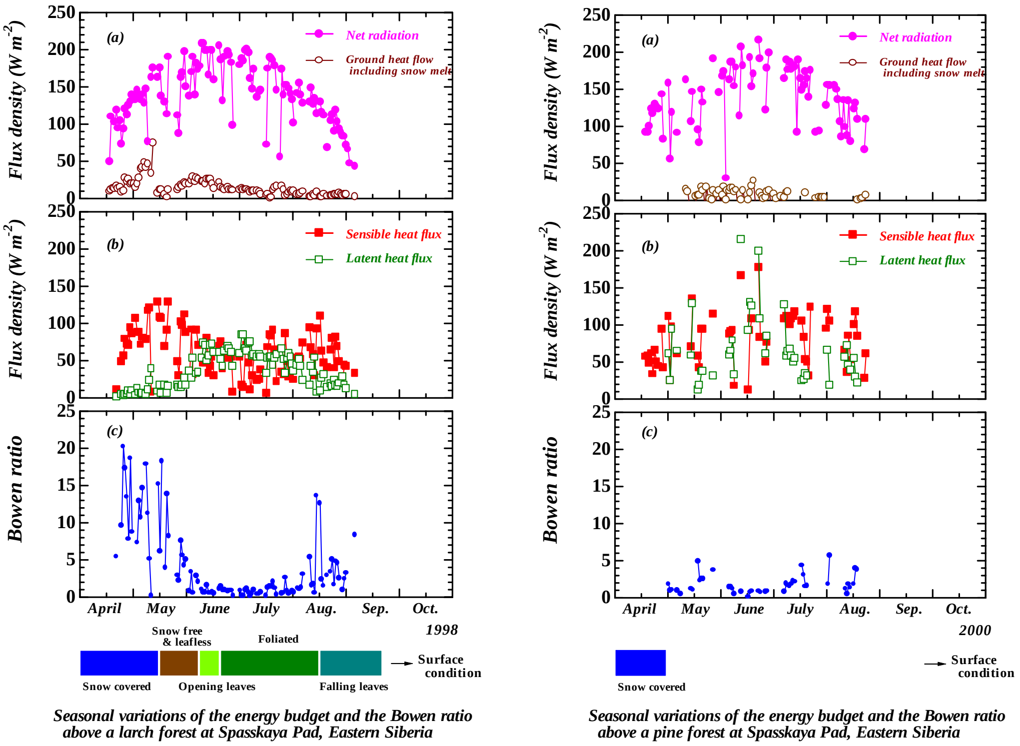


図３　1998 年、2000 年のヤクーツク、カラマツ林における生物季節進行と熱収支各要素の変化（「シベリア生物圏エネルギー・水循環過程」班の成果から）

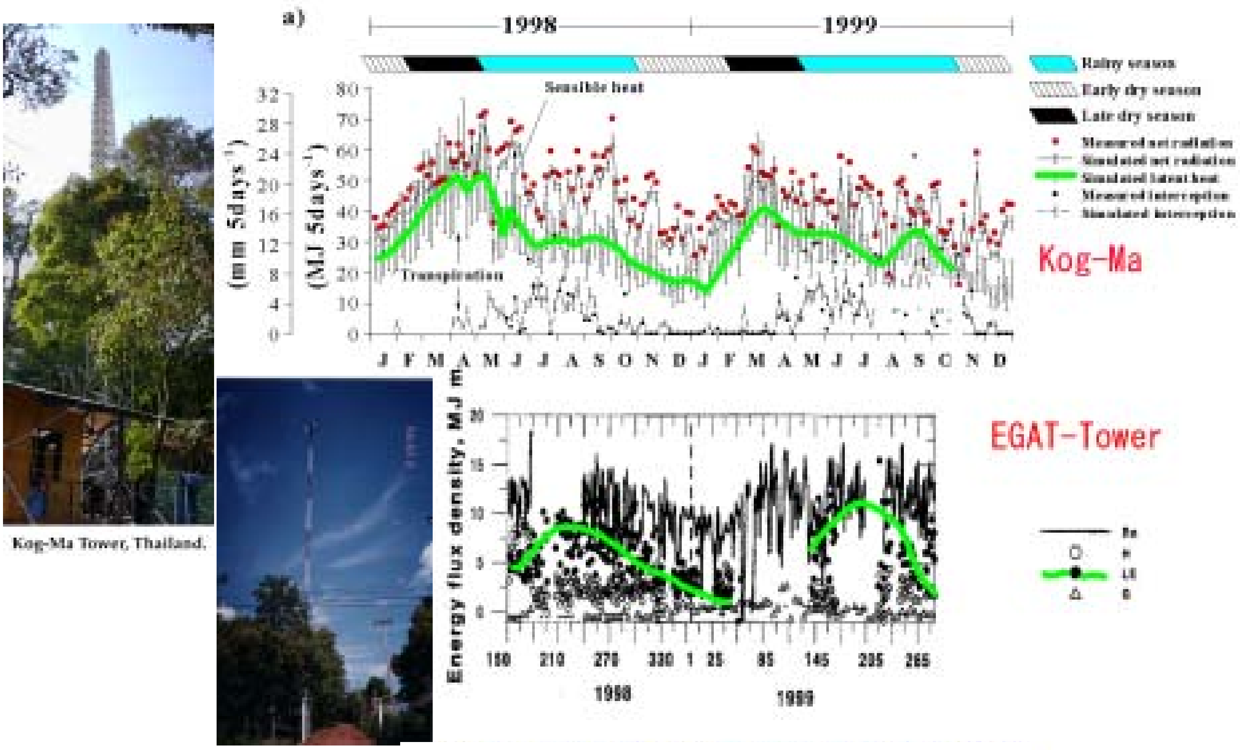


図４　「熱帯エネルギー・水循環過程」班のフラックスサイト(Kog-Ma,EGAT-Tower)での熱収支季節変化比較。

Preface

The Asian monsoon system is a huge circulation system in the global atmosphere and plays an important role in the energy and water cycle of the climate system. On the other hand, the seasonal prediction of regional or basin-wide water cycle affected by the monsoon system is an essential issue for the life, economy, agriculture in the countries in monsoon Asia.

To further understand and clarify uncertain and unsolved problems related to these issues, we proposed GEWEX Asian Monsoon Experiment (GAME) in 1994, as one of the Continental-Scale Experiments (CSEs) under the Global Energy and Water Cycle EXperiment (GEWEX). GEWEX is a major sub-program of the World Climate Research Programme (WCRP). In 1996, GAME formally started under the auspice of WCRP and GAME International Science Panel (GISP), and then GAME International Project Office (GIPO) were also established.

During the Intensive Observing Period (IOP) of 1998, the enhanced radiosonde observations were operated, in cooperation with the other international and national projects, and the collected data were utilized for the data assimilation to produce GAME Reanalysis Data. Intensive surface and atmospheric observations, including the Asian AWS Network activity and regional energy and water cycle experiments at the four target areas, i.e., Lena river basin in Siberia (GAME-Siberia), Huaihe river basin (GAME-Hubex) in China, Tibetan Plateau (GAME-Tibet) and Chao Praya river basin in Thailand (GAME-Tropics). were also conducted during the IOP. Further data collection effort continued for more than two or three years after the IOP, to obtain the data for studying seasonal and interannual variability of the processes. By utilizing these data, we have conducted many diagnostic analyses and modeling of energy and water cycle processes with various time and space scales. Nearly 200 scientific papers have already been published in many international journals for meteorology and hydrology.

This report summarizes the overall results of the GAME in 1996 through 2002. Further studies are still going on as GAME Phase-II, which has been planned for further integration of data analyses and modeling.

On the occasion of the successful ending of GAME Phase-I, we sincerely would like to thank all the collaborators and supporters of GAME, including the national meteorological and hydrological agencies and organizations in the Asian countries involved in GAME. We also would like to thank Prof. Pierre Morel, Prof. Hartmut Grassl, Dr. David Carson and Mr. Sam Benedict of WCRP, and Dr. Mous Chahine, Prof. Soroosh Sorooshian and Dr. Paul Try of GEWEX, for their continuous guidance and support to GAME.

Yours sincerely,
Tetsuzo Yasunari

Chairman,
GAME International Science Panel
and
Japan National Committee for GAME

Contents

Activity Review of GAME-T

K. Musiake, T. Oki, T. Nakaegawa, T. Satomura, S. Ogino, Y. Agata, and S. Kanae

1. Introduction

Among GAME research components, GAME-Tropics (GAME-T) bears a role to observe and investigate the energy and water cycle in the humid temperate region of the Asia Monsoon region, from the tropics to the sub-tropics, especially in the Indochina peninsula. The main target area for hydrological studies is the Chao Phraya river basin in Thailand. Other areas or larger regions (e.g. whole Indochina) can be the target for various research purposes. The areas are characterized by the small seasonal change of temperature and the predominant diurnal cycle of temperature and precipitation. The magnitude of seasonal evolution of surface soil wetness is quite large where dry season is observed, and interannual variability of precipitation is as predominant as diurnal cycle. The release of latent heat in the atmosphere is considerably large as the heat source of the global atmospheric circulation, and drives the Asian Monsoon system.

On the other hand, population density in this region is generally high, and the crop production supporting the large population is directly influenced by water resources. Therefore the prediction of precipitation and runoff is not only challenging scientifically but also contributing to societal issues through improving the accuracy of water resources prediction.

The goal of GAME-T is to accomplish its role well considering these characteristics of the target area as one of key sub-programs of GAME.

The objective of GAME-T is quantitative monitoring of vapor flux, precipitation, evapotranspiration, radiative flux and their seasonal, intra-seasonal and interannual variation at the target area of Southeast Asia. In paticular,

1) difference of water and energy fluxes at land surface among several representative land cover types, such as paddy field, grassland, forest and so on,
2) surface wetness which differs significantly in the dry and wet season, and
3) diurnal cycle of precipitation and other hydro-meteorological variables, have been focused on.

The better understanding of the role of such water and energy cycles in the Asian Monsoon climate system and improving the accuracy of seasonal hydro-meteorological prediction are vital issues of the research in GAME-T, as well.

In order to accomplish these objectives, various field observations,and data collections have been planned and implemented. The year of 1998 was set to be the Intensive Observation Period (IOP) of GAME and organized field observations and data collections were carried out.

The IOP of GAME-T is mainly divided into two periods. Phase I - Monsoon onset: middle of April to middle of June.Phase II - Mature stage of monsoon: middle of August to middle of September.

The observation in the transitional season from the wet to the dry season is also of interest and was implemented.

The schedule of each observation during IOP is summarized in Figure 1, and the locations of these observing stations are illustrated in Fig. 2. Subsequent or intermittent observations has been continuously carried out up to now, although major IOP activities were done during these two periods. The data was processed or under processing partly, and all the data will be available at:

http://hydro.iis.u-tokyo.ac.jp/GAME-T/GAIN-T

where GAIN stands for GAME Archive Information Netowrk, and GAIN-T is one of the distributed archive center of GAIN responsible for GAME-T related datasets. Detailed description on the individual dataset should be found either in associated document with the data on the Web or in scientific papers published by the principle investigators of each observation.

The research components of GAME-T can be divided into 5 sub-groups:

1) Land surface flux observation and modeling,
2) Investigation of diurnal cycle of precipitation using radar and numerical modeling,
3) Rawinsonde observation and analysis, and the description of climate in GAME-T,
4) Hydro-meteorological database for GAME-T (GAIN-T),
5) Hydrological modeling, regional atmospheric modeling and their coupling.

The summary of each sub component is shown in the following sections. The remained problems and the future perspective of GAME-T are described in the last section.

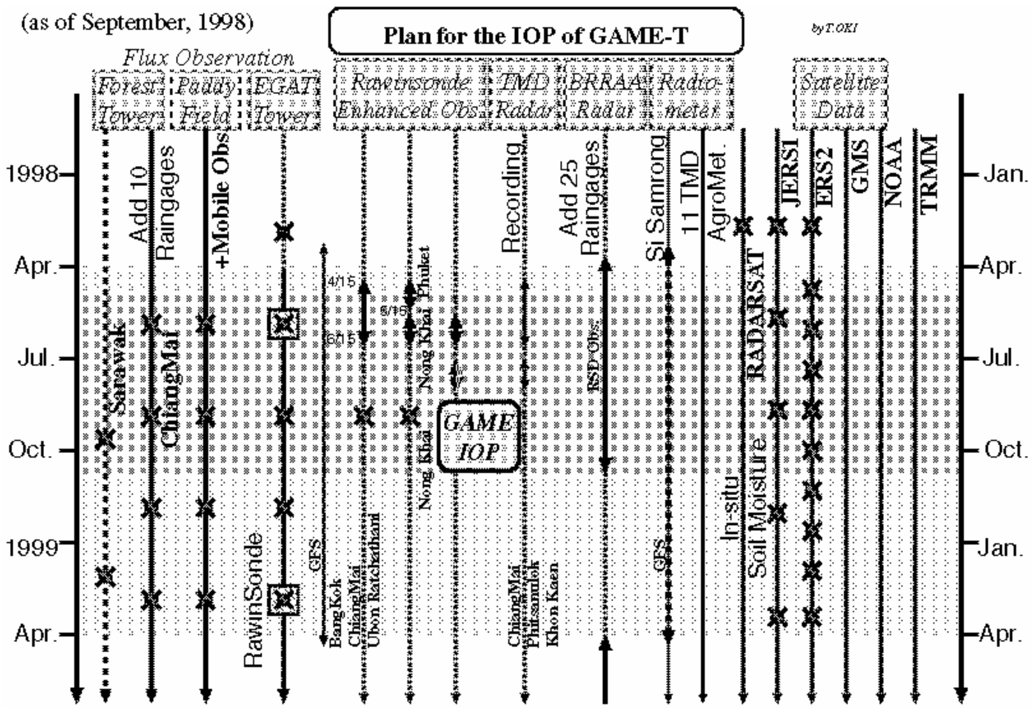


Fig. 1. The schedule of each observation during IOP

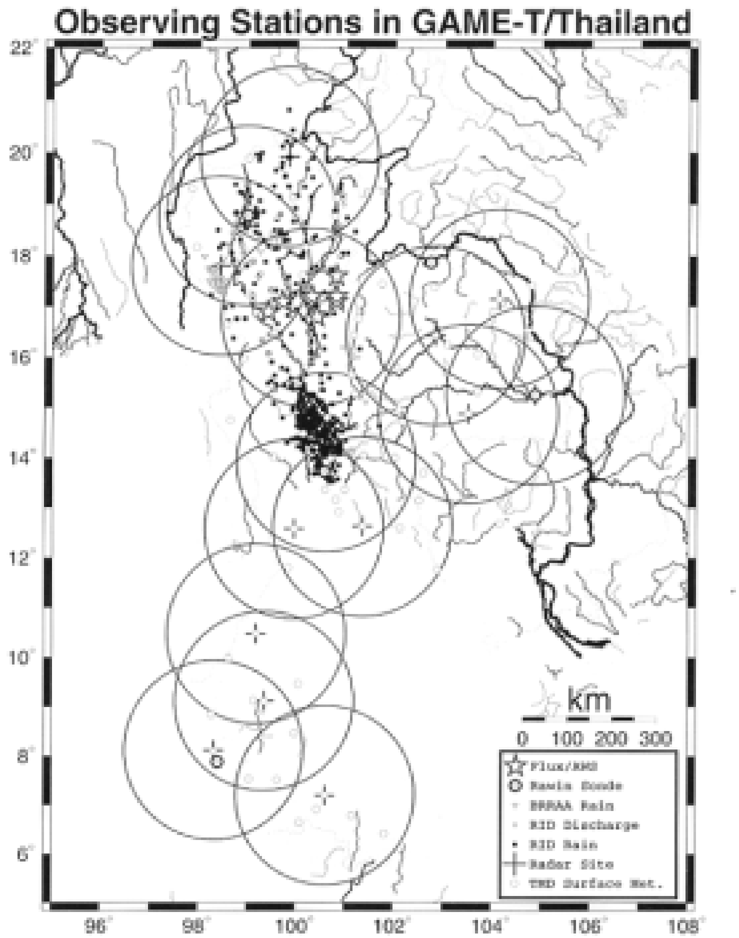


Fig. 2. The locations of the observing stations

2. Land surface flux observation and modeling

2-1. Land surface flux observation

The land surface flux observations by GAME-T members have been conducted mainly at three points of monsoon forest (Kog-Ma), paddy field (Sukhothai) and shrubbery forest with grassland (EGAT site in Tak) partly since 1996 and mainly since 1998. These three stations are located in the Chao Phraya river basin. They are also included in the GAME-AAN observation network. These activities aim to offer basic datasets for the construction and the improvement of one-dimensional land surface model to estimate energy and water flux from typical land surfaces of Southeast Asia. At the observation sites, net radiation and basic hydro-meteorological parameters have been continuously observed, and time series of energy and water fluxes have been estimated.

The statistics of land use classification in the northern region and the central plain of Thailand show that a half of the upper Chao Phraya river basin is covered by forests, 30 % is 'unclassified' and a half of cultivated area, namely 15% of total, is paddy field. The landscapes of the three flux observation sites correspond to these major land uses. However, Kog-Ma experimental site is located at higher altitude compared to whole forest region in the Chao Phraya river basin, and it may not represent the energy and water flux of forest region in the area. The shrubbery forest and mixed land-used site (EGAT) was set up assuming that most 'unclassified' area could correspond to such a landscape. The paddy field site (Sukhothai) is located in a typical non-irrigated (rain-fed) paddy field region. In addition to these flux observation sites, operationally observed hydro-meteorological data in Thailand is managed by TMD (Thai Meteorological Department), RID (Royal Irrigation Department), and RFD (Royal Forestry Department). These operational data can be used for flux estimation (e.g. Hirota, 2001). All the data including the observations at flux sites and the operational data are stored in the GAIN-T web page for the easy access from the entire world. Some basic datasets will be stored in a GAME cdrom which will be published in the fall of 2001.

Some new findings were obtained through the analysis of the land surface flux observations. The seasonal variations of heat fluxes were determined using the data during the Intensive Observation Period (1998) and the following seasons. For example, Figure 3 represents the seasonal patterns of heat budget observed at the EGAT site. The flux measurements at this site were substantially started on May in 1998 (DOY150). It is clearly found that dominant heat flux component was changed from sensible heat (H) to latent heat flux (LE) at around 180 in DOY of 1998 (the end of June), and then it was changed from latent heat to sensible heat at the end of 1998. This striking contrast in dominant heat component arose with the seasonal pattern of precipitation. In the dry season (from November to March or April), low soil moisture content and low vegetative activities caused low evapotranspiration from the terrestrial surface. Sensible heat flux consumed about 60% of total available energy (Rn-G). During the mature stage of the rainy season, latent heat flux used 50 to 80 % of total available energy. April to June is the transitional season. The dry-rainy seasonality was also clearly found in the observed data of the paddy field. This contrasting seasonality of heat budget can be said as a typical characteristic in the plain area of the Southeast Asian monsoon region. However, a different situation was found at the upland forest site (Kog-Ma). In the forest site, transpiration in the dry season is higher than in the wet season. It is mainly due to abundant solar radiation and atmospheric humidity deficit in the dry season. The shortage of soil moisture in the dry season does not have much effect on transpiration at this forest site. Soil moisture in the deep layer might be utilized for transpiration. Although such larger transpiration in the dry season was observed in an Amazonian experiment as well, we should investigate carefully whether this situation occurs just at this place or is possible over the whole forested region. Interannual variability should also be investigated.

These observed and estimated fluxes can be utilized for improving the land surface models, partly described below, in the next step of the GAME activities.

References:

Hirota, T., 2001: Estimation of seasonal and annual evaporation using agrometeorological data from the Thai Meteorological Department by the heat budget models, *J. Meteor. Soc. Japan*, 79 (1B), 365-371.

Toda, M., N. Ohte, M. Tani and K. Musiake: Observation of evergy flux and evapotranspiration over terrestrial complex land in the tropical monsoon region, *J. Meteor. Soc. Japan*, submitted.

2-2. Land surface modeling

These datasets obtained through the observations above are useful for calibrating, validating and developing land surface models, which can be used for describing hydrological and meteorological phenomena on terrestrial surface in general circulation models. The simple biosphere model 2 (SiB2) by Sellers et al. (1996) was adopted for the simulation of water and energy cycles at paddy field using the observed data at the paddy field site (Sukhothai) as inputs. This land cover type, paddy field, has the over-surface water of which heat capacity is comparatively large. Water budget and radiation flux of paddy field could be different from those of normal cropland owing to the water surface. Then, the SiB2 was revised into SiB2-paddy incorporating water surface over the land, and validated (Fig. 4).

The result of the original SiB2 simulation shows that net radiation (Rn) agrees with the observation. However, simulated latent heat flux (lE) had an early peak, and carbon assimilation rate (A), sensible heat flux (H), soil heat flux (G), surface soil temperature (Tg) and canopy temperature (Tc) are a little bit unrealistic. The SiB2-Paddy simulation improved the diurnal cycle of these parameters if compared with the observation. In terms of total energy and water budget for several days, Rn, lE, and A are not much different between the SiB2 and the SiB2-Paddy simulation. It is partly because H and G are too small compared to net radiation and lE, and the mean biases are not significant. It can be said that SiB2-Paddy is preferable for the realistic simulation of the diurnal cycle of lE and surface temperature, which, in turn, may affect the diurnal evolution of convective activity in the atmosphere.

These numerical simulations were carried out on a web-based interactive software system, named as “SiB2 on WWW.” It was developed as a part of a Ph. D research on computer science. This system can be used through the internet. It has a graphycal user-interface which can consider the user’s preferences, and it is based on massive database technology. Everyone can use it at
http://www.tkl.iis.u-tokyo.ac.jp:8080/DV/sib2/ .

Due to the delay of database construction and observed data processing, application of the land surface model to the forest and the shrubbery land is not carried out yet. It can be realized in the very near future.

References:

Kim, W., T. Arai, S. Kanae, T. Oki and K. Musiake, 2001: Application of the Simple Biosphere Model (SiB2) to a paddy field for a period of growing season in GAME-Tropics, *J. Meteor. Soc. Jpn.*, 79 (1B), 387-400.

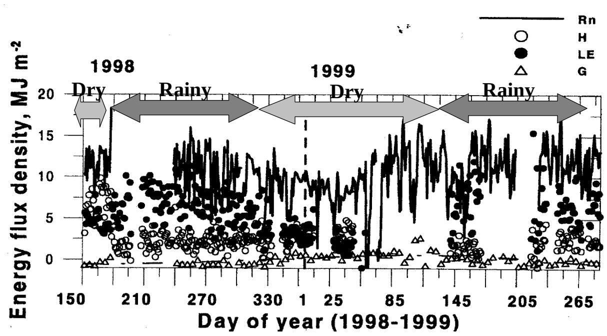
2-3. Rainfall observation in a mountainous area

For the accurate estimation of hydrological budget in a basin, the altitudinal increase in precipitation amount has a significant meaning. In order to determine the characteristics of altitudinal dependence in rainfall in mountainous area of the GAME-T hydrological targe area, 13 rain gauges were installed in a mountainous watershed of 3853 km^2 since 1998. The number of gauges has increased since then. After investigating carefully, it was found that the altitudinal increase in rainfall was obvious in the two wet seasons in 1998 and 1999. It means that the rainfall amount increases as the elevation gets higher. The altitudinal increase was also found in the dry season, however, the increment was smaller in the dry season. It was also found that not the rainfal intensity but the rain-falling hours can cause the altitudinal increase. More detailed analysis has being carried out (Kuraji et al., 2001). This altitudinal increase in rainfall and the observed evapotranspiration described above will be used for the real estimation of water budget of the target area.

References:

Kuraji, K., P. Kowit and M. Suzuki, 2001: Altitudinal increase in rainfall in the Mae Chaem watershed, Thailand, *J. Meteor. Soc. Japan*, 79 (1B), 353-363.

Observed Energy Budget at the EGAT site



[EGAT: mixed land use]

Fig. 3. Seasonal pattern of energy budget observed at the EGAT site

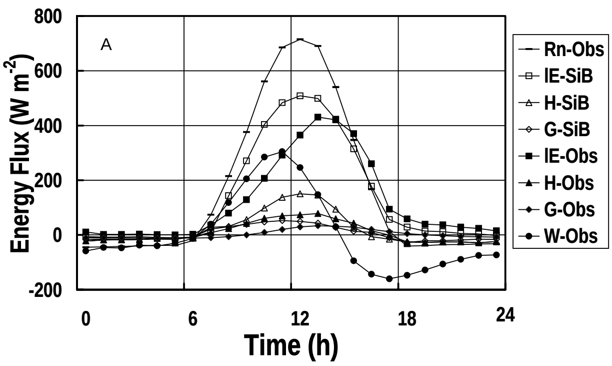


Fig. 4. Simulation of the diurnal evolution of surface energy components by the original SiB2 (upper) and the revised SiB2 with paddy scheme (lower). The simulated results are compared with observations.

3. Investigation of diurnal cycle of precipitation using radar and numerical modeling

The convective cloud systems in the tropics release huge amount of latent heat into the tropospheric atmosphere and play an important role in driving global circulation of whole atmosphere. The amount, location and time of precipitation are important factors in simulating the climate of the Earth. General circulation models (GCMs), however, fail to simulate maxima of diurnal variation of precipitation over the land; the analyses using Tbb revealed late afternoon or night maxima of precipitation over tropical land areas whereas GCMs produced early afternoon maxima. This difference of timing of the maximum precipitation between GCM simulations and observations certainly has climatic effects through the difference of radiational properties of clouds between day and night.

Radar observations and rain gage observations give more direct information on precipitation than Tbb observation from space. In GAME-Tropics, therefore, intensive radar observations and collection of rain gage data were done from 1998 to 2000. In 1998, radar data at 5 radar sites were archived. In 1999 and 2000, radar observation was done only at Chiang Mai. Routine observation data were archived once per hour and 24 hours over one day. Additional GAME-T radar observation, whose range is about half of operational one but has more sweeps in a volume scan, was performed only in daytime at Chiang Mai and Phitsanulok, and 24 hours at Khon Kaen and Phuket in 1998. In 1999 and 2000, GAME-T radar observation was performed once to twice per hour in 24 hours over one day. Because radar data at Chiang Mai had good quality and were collected several years, we analyzed those data most intensively. The results are as follows:

1) Echo area showed significant diurnal variation throughout the observation period. Averaged echo area at 3 km height reached its maximum at 15-16 LT at Chiang Mai. At Khon Kaen, and the maximum time was several hours later than that at Chiang Mai.
2) In most of observed days, each echo moved eastward at Chiang Mai. Line shaped echoes were also found in about half of these days (Fig. 5).
3) Monthly averaged echo data showed that an area of high echo probability appeared in late afternoon in south of Chiang Mai and shifted eastward with time. The same tendency was also noticed at Khon Kaen.
4) Inter-seasonal variation and inter-annual variation were evident. Precipitation mechanisms in August possibly differ from the mechanisms in earlier months in the same monsoon season.

In the extensive analysis of observed rainfall data (Ohsawa et al. 2001), evening to night maxima were also observed by rain gages. Rain gage data also showed that precipitation maxima later than the midnight were locally observed: the most northeastern part and the southeastern part of Thailand where the monsoon wind impinges mountain ranges nearly in a right angle.

Numerical simulation is a powerful tool to analyze and determine important factors for meteorological phenomena in detail. A set of numerical simulation targeting precipitation over Thailand was completed. Using a non-hydrostatic two-dimensional cloud ensemble numerical model initialized by June climate conditions, diurnal variation of precipitation was simulated successfully. The simulated results (e.g. Fig. 6) indicated a new mechanism producing diurnal variation of precipitation in Indo-China Peninsula (Satomura 2000):

a) Convective clouds were triggered at the lee-side foot of mountains in the late afternoon. They are organized to squall lines.
b) Those squall lines propagate eastward and produce night maxima of precipitation over

the inland areas far eastward from the mountain.

c) The timing and location of convection initiation are determined by the solar-synchronized intrusion of cold air from the windward side into the lee side and by the mountain wave.

The results 2) and 3) of radar data analysis agree with results (a) and (b) of numerical simulation. High resolution Tbb analysis also confirms the eastward shifts of cloud activity with time over Thailand. The connection between this section and the next section should be investigated in the next stage.

References:

Satomura, T., 2000: Diurnal variation of precipitation over the Indo-China Peninsula: Two dimensional numerical simulation, *J. Meteor. Soc. Jpn.*, 78, 461-475.

Ohsawa,T., H.Ueda, T.Hayashi, A.Watanabe and J.Matsumoto, 2001: Diurnal variations of convective activity and rainfall in tropical Asia, *J. Meteor. Soc. Japan*, 79 (1B), 333-352.

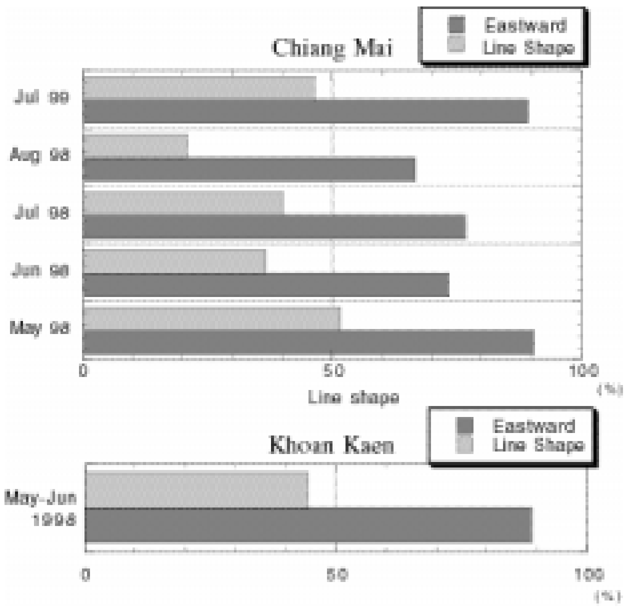


Fig. 5. Ratio of days when eastward-moving echoes and line-shaped echoes were observed to total days of observation in each month at Chiang Mai (upper) and Khon Kaen (lower).

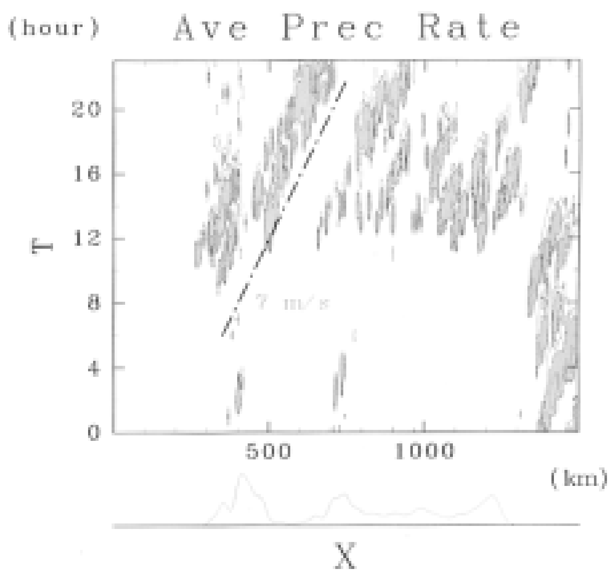


Fig. 6. Horizontal-time section diagram of precipitation rate averaged on the second and the third days. Contours of precipitation are 0.5, 1 and 10 mm/h. Shaded area indicates recipitation rate is greater than 1 mm/h. Dash-dotted line indicates moving speed of 7 m/s. The surface topography is depicted by the black shading at the bottom of the figure.

4. Rawinsonde observation and analysis, and climatological description

The heating and radiative effects due to convective clouds play an important role in the generation and maintainance of large-scale monsoon circulations. In order to understand the generation mechanism of diurnal, intraseasonal and seasonal variations of convective activity, as partly menioned in the previous section, it is important to clarify the background atmospheric conditions. Thus, the enhanced rawinsonde observations were conducted for 6 times during 1996 and 2000. The observed data are used for the atmospheric process analysis described below as well as it was transmitted through GTS in real time and contributed to objective analyses including GAME-4DDA by JMA. In addition to the rawinsonde observation, other atmospheric observations such as MPL (MicroPulse Lidar), wind profiler, GPS and sky radiometer observations have been carried out in the GAME-T area. A part of them will be described in the chapter of GAME-Radiation.

The seasonal change of Southeast Asian monsoon in a climatological sense was also studied by using the historically accumulated data by TMD (Thai Meteorological Department) and the ECMWF objetive analysis data.

4-1. Results of the enhanced rawinsonde observations

The GAME-T enhanced rawinsonde observations were conducted at the special station (Sukhothai or Nongkhai), and at the 3 operational TMD upper-air stations (Bangkok, UbonRatchatani, Chiang-Mai) in Thailand. The special stations were established and maintained by GAME-T members.

The enhanced observations were conducted 8 times from 1996 to 1999 in the wet season, the dry season and the transitional season. Each enhanced observation period continued approximately for two weeks. During each enhanced observation period, rawinsondes were launched 4 or 8 times a day at the special station. The prominent characteristic of these observations is the high frequency (3 or 6 hour interval) balloon launch. They revealed quite clear figures of diurnal and intraseasonal variations in wind and temperature.

Figure 7 shows a time-height section of diurnal component of equivalent potential temperature variations in the rainy season. It is found that the atmospheric structure is more unstable in the night time than in the day time. This fact is interesting because the stability variation may be closely related with the night time rainfall shown in the previous section. So, it is an important issue to understand the physical mechanism of the connection between the cloud activity and the atmospheric stability.

As for the diurnal variation, the opposite land-sea breeze (i.e., wind from land to sea in the day time and opposite wind in the night time) was observed with the boundary layer radar at Bangkok. This phenomenon is quite peculiar and is one of the puzzles the GAME-T researches. It is also the future subject to understand such an opposite circulation.

Figures 8 and 9 show time-height sections of equivalent potential temperature in the pre-monsoon period and in the mature monsoon period, respectively. Figure 8 is the composite of 1, 7, 9.3 and 14 day period component, and Fig. 9 is that of 1, 8.5, 11.3 and 17 day period component. It is found that about 2-week periodic variation dominates in the pre-monsoon period (Fig. 8). Downward phase progression with time is clearly seen in the middle and upper troposphere (above 5 km) and no phase difference in height is observed in the lower troposphere (below 5 km). On the other hand, in the mature monsoon period (Fig.

9), quasi 2-day variation has large amplitude. The similar features were found all over the Indochina peninsula during monsoon period.

The details are described in two publications "Enhanced rawinsonde observation in Thailand in 1996 and 1997" and "Enhanced rwainsonde observation for GAME-Tropics IOP in 1998" both available from GAME and GAME-T offices.

4-2. Climatological description of the Southeast Asian monsoon

It is generally believed that typical monsoon wind shift occurs between wintertime northeast monsoon and summer-time southwest monsoon in Southeast Asia including the Indochina Peninsula. This is true, of course, especially over the oceanic areas, for example, in the Bay of Bengal. In general, the winter monsoon corresponds to dry and fine condition, while the summer monsoon being wet and rainy situation in land areas except in east coast of the peninsula. However, it is shown by Matsumoto (1997), that the seasonal change process of wind and rainfall regime is not always simultaneous. The rainy season in inland part of the Indochina Peninsula starts earlier (in late April) than the seasonal wind shift to the summer-time monsoon circulation (in mid-May) characterized as lower westerly embedded with upper easterly flow. Furthermore, the lower tropospheric westerly is already established in early April in northern India and Indochina regions as a part of mid-latitude westerly wind system.

In order to show why such peculiar seasonal changes are generated in the Indochina Peninsula, large-scale conditions of wind, temperature and height fields at 850 hPa were analyzed using the ECMWF operational analyses. Due probably to dynamical reason, the center of the subtropical high is located in central (not northern) India in December. Then warming over northern India even from February induces the heat trough to be located in northern India and it gradually extends southward from December to April. In short, warming of the lower troposphere in mid-winter over south and southeast Asia is the main reason why southerly or westerly wind establishes in the midst of winter in northern Thailand then proceeds in central Thailand during the winter-spring seasonal transition. Further study is needed how warming in winter-spring season is related with the onset process of summer monsoon circulation.

For the purpose above, a lot of operational meteorological data of several countries in southeast Asia were collected extensively. The data are stored in the GAIN-T database and will contribute to various kinds of research in the future.

References:

Matsumoto, J., 1997: Seasonal transition of summer rainy season over Indochina and adjacent monsoon regions. *Advances in Atmospheric Sciences*, 14, 231-245.

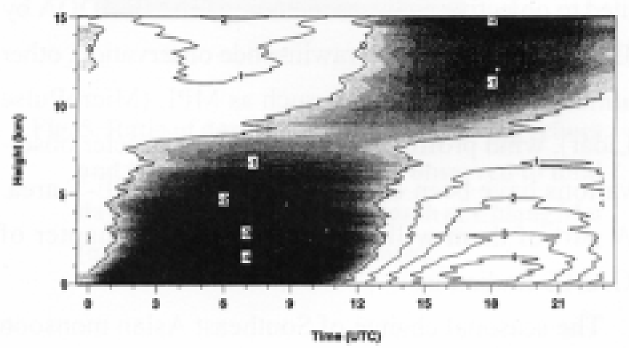


Fig. 7. A time-height section of diurnal component of equivalent potential temperature variations in the rainy season.

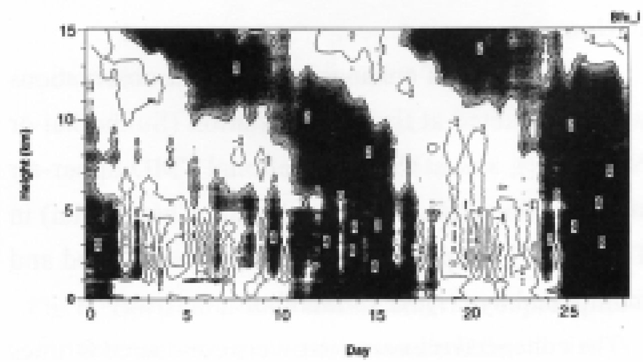


Fig. 8. A time-height section of equivalent potential temperature in the pre-monsoon period (composite of I, 7, 9.3 and 14 day period (composite of I, 7, 9.3 and 14 day period component).

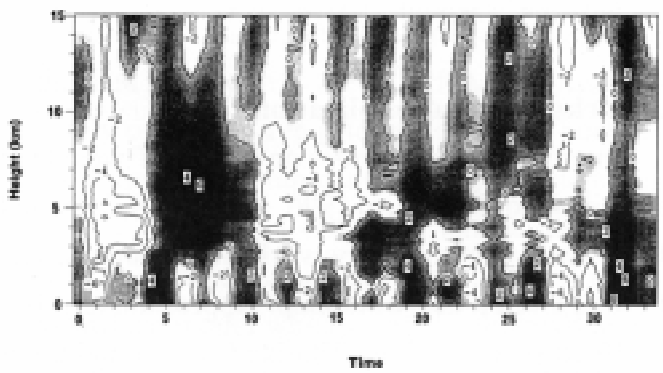


Fig. 9. A time-height section of equivalent potential temperature in the mature monsoon period (composite of 1, 8.5, 11.3 and 17 day period component).

5. Hydrometeorological database for GAME-T: GAIN-T

One of the main objectives of GAME-T is to collect hydro-meteorological data and to construct comprehensive hydro-meteorological dataset over tropical Asia. The GAME-T database team has carried out this mission for all period of GAME-T phase 1 and finally established the on-line dataset on the WWW network. The URL is:

http://hydro.iis.u-tokyo.ac.jp/GAME-T/GAIN-T/index.html

This dataset consists of three categories of sub datasets. First is long-term routine (operational) observation record mainly of Thailand as well as other some southeastern Asian countries. This category has some climatic values (rainfall, temperature, wind speed, sunshine duration, relative humidity, etc.) and hydrological values (soil moisture, river discharge, etc.). The duration of such data is mainly from early 1980's up to 1999 and temporal resolution is usually daily, with few exception of 3-hourly or hourly. This first category data were used in the hydrological simulations described in the following section.

Second categoly of dataset is that of intensive observation mainly in IOP (rainy season of 1998). Results of radiation and energy flux observation at three selected sites with high temporal resolution are included in this dataset, which allow us to validate land surface schemes by real field observation. Other datasets, such as that of rawinsonde observation records and densely distributed rain-gauge network will help us to understand 4-D structure of climate system over this area and to make grid-based climatic datasets for IOP.

Third category datasets are collection of values from some remote sensing techniques. This includes 3-D radar rainfall, MPL (micropulse lidar), wind profiler and satellite remote sensing.

Database management system has also been constructed, which gives future DB managers an easy way to maintain this DB. Currently, however, the user-interface that can help scientists to manipulate and analysis these datasets as they like has not been established adequately. This remains one of the important issues we have to make more effort.

6. Hydrological modeling, regional atmospheric modeling and their coupling

In order to investigate and forecast water resources in the target basin, the Chao Phraya, two kinds of hydrological model were developed. One is a fully distributed hydrological model on 10 km grid system which consists of 3D equations for surface, subsurface and ground water movement, and a river network solution (Jha et al., 1997, 1998). Another is a semi-distributed hydrological model incorporating a 2D hillslope submodel and a 1D river channel submodel based on the representation of the geomorphological structure of the basin (Yang et al., 2001). They were applied to the Nakhon Sawan catchment of the Chao Phraya basin, the largest catchment in the basin.

The simulations were conducted with the historical hydro-meteorological data in 1990's for several years, resulting good agreements with the observed discharge. Since they are a full- or semi-distributed hydrological models, the distribution of soil moisture as well as river discharge were investigated. An irrigation submodel was developed and is being incorporated into the semi-distributed model for water resources assessment.

A part of the full-distributed hydrological model was applied to an upstream basin for flood forecasting simulation for a few hours to a few days. In the beginning, it was just a research. However, it became of practical use. Actually, this flood forecasting system was installed in the hydrological center No.2 of RID in Chaing Mai city so as to forecast a flood in Chiang Mai city. To make this system more valid in the real situation, a telemetry system for this forecasting system is desirable.

As a starting point of coupling a regional atmospheric model and hydrological model for the application to this region, a three-dimensional regional atmospheric model simulation was carried out, showing that heavy and wide deforestation in the northeastern part of Thailand clearly reduced the amount of precipitation over the deforested area and increased the amount over the down-wind area (Kanae et al. 2001). This effect is evident in September and it coincides with observation.

However the general coupling of atmospheric model and hydrological model is still in the stage of trial and error.

References:

Jha, R. and Herath, S. and Musiake, K., 1997: Development of IIS distributed hydrological model and its application in Chao Phraya River basin, Thailand, Annual Journal of Hydraulic Engineering, *JSEC*, 41, 227-232.

Jha, R. and Herath, S. and Musiake, K., 1998: Application of IIS distributed hydrological model in Nakon Sawan catchment, Thailand, Annual Journal of Hydraulic Engineering, *JSCE*, 42, 145-150.

Yang, D., S. Herath, T. Oki and K. Musiake, 2001: Application of distributed hydrological model in Asian monsoon tropic region with a perspective of coupling with atmospheric models, *J. Meteor. Soc. Japan*, 79 (1B), 373-385.

Kanae, S., T. Oki and K. Musiake, 2001: Impact of Deforestation on regional precipitation over the Indochina Peninsula, *J. Hydrometeorology*, 2, 51-70.

7. Workshops and publications

International workshops on GAME-T were held in Thailand for 5 times, in 1996, 1998, 1999, 2000 and 2001. They were two-day workshops, and the last one was a three-day workshop. Approximately 100 to 150 participants from Thailand, Japan and other countries joined each workshop with enthusiastic discussion. In 2000 and 2001, the guests from neighboring nations (Vietnam, Cambodia, Malaysia and Myammar) were invited to the workshops for the future cooperative studies on hydrology and meteorlogy between Southeast Asian nations. Post proceedings of the workshops were published. In addition to the workshop proceedings, two publications on rawinsonde observation were also publised. These publications are listed below.

List of Publication

Proc.'96 Workshop on GAME-Tropics in Thailand
Proc.'98 Workshop on GAME-Tropics in Thailand
Proc.'99 Workshop on GAME-Tropics in Thailand
Proc.2000 Workshop on GAME-Tropics in Thailand
Proc.2001 Workshop on GAME-Tropics in Thailand
Enhanced Rawinsonde Observation in Thailand in 1996 and 1997
Enhanced Rwainsonde Observation for GAME-Tropics IOP in 1998

8. Future perspective

Two new synthetic research components have just begun. The first one is the integrated investigation on the monsoon onset and evolution over Southeast Asia. This synthetically includes the large-scale climatic study, the analysis of rawinsonde observation, the analysis of land surface flux observation, the land surface modeling study and the climate modeling study in GAME-T. Utilizing such many sub-components, we hope to clarify the interactive mechanism between land surface and atmosphere in the stage of the monsoon onset and evolution over Southeast Asia. Another is the estimation of water and energy budget at the land surface over the Indochina peninsula presumably on 0.1 degree grid system. This needs the interpolation and extrapolation of hydro-meteorological variables, just like 4DDA for land surface, using the observed data and satellite data. This also needs a land surface model which is well calibrated at each land type by the observed land surface flux data. The result of this study will become a primal illustration of energy and water budget over Indochina.

Except for the synthetic research components in the future as described above, the general future perspective of GAME-T is as follows.

Even though the scientific findings prevailed through GAME/GAME-T project are magnificent, there seem some research aspects that will not be accomplished within the time period of GAME-T. Major concern is the lacking or less application of scientific achievements for water resources management even though the importance of understanding and predicting the monsoon variability is highly emphasized in the GAME Science Plan published in 1994. It should be noted that in the GAME Implementation Plan, two scientific objectives are clearly focused at the biginning:

- To understand the role of Asian monsoon in the global energy and water cycle,
- To improve the simulation and seasonal prediction of Asian monsoon and regional water resources.

The first phase of GAME/GAME-T has been concentrated on building up the comprehensive observational network and data collections. Now, it should be the time for utilizing the obtained precious dataset for scientific and social issues. Integration among various observational facts, statistical data processing, and modeling approach should be required as partly described in the beginning of this section, and it will not be accomplished throughly within a year until March 2002.

Finally, the most relevant fruit of GAME-T could be the international research community organized under the project and firmly formed through the collaborative field experiments, joint data processing, and the exchange of various ideas at frequent meetings, workshops, and symposia. A lot of efforts will be required to build up such a smooth, constructive, and significant scientific community again. Therefore, even though current project funding of GAME-T will be finished March 2002, a follow up project should preferably inherit the research community and mechanism, and continue to promote the science and societal contribution initiated by GAME-T.

GAME/HUBEX research activity

T. Takeda, Bolin Zhao, Yihui Ding, and Y. Fujiyoshi

1. Main research topics

The energy and water cycle in the subtropical monsoon region of East Asia is characterized largely by the Baiu/Changma/Meiyu front in summer. It extends eastward from the eastern edge of the Tibetan Plateau and brings a huge amount of rainfall in East Asia in early summer. Its formation and maintenance processes are largely affected by the Southeast Asian summer monsoon (SEAM), the western North Pacific summer monsoon (WNPM), the mid-latitude westerly systems, and so on. It is interesting that the very humid and the dry climate regions are adjacent to each other just around the Meiyu front in China, affected by the Tibetan Plateau.

Various scale of cloud/ precipitation systems are formed in this frontal zone and play a major role in the energy and water cycle in the zone. The purpose of GAME/HUBEX is to make clear the role of mesoscale cloud systems in time variation of regional scale energy and water cycle, and to reveal their evolution and response to time variation of land surface conditions.

In 1998, HUBEX group performed meteorological observation during the period from May to August. During the intensive field observation, a record-breaking flood occurred in the Yangtze River region. A large amount of important data was obtained by the field observation. Following 1998, HUBEX group also performed meteorological observation in 1999: surface flux observations and the intensive field observation of meteorology and hydrology in June and July. Synoptic scale situation was largely different from the last Meiyu season. The long term monitoring of flux has been conducted since 1998.

2. Continental scale Asian monsoon variability

We analyzed the global precipitation data to study long-term variation of seasonal change of precipitation during the period from June to August in East Asia and the Western Pacific Ocean. Seasonal variations of precipitation can be classified into three patterns A, B and C (Fig. 1). The pattern A is that the intense precipitation area showed no northward shift and its amount decreased from June to August. The pattern B is characterized by a continuous northward shift of intense precipitation from 5 N to 15 N with increasing amount. The pattern C showed a shift from 15 N to 25 N with large amount of precipitation in June and August while less amount in July. These patterns are related to water vapor flux and have strong correlation with precipitation of Meiyu in China and Baiu in Japan.

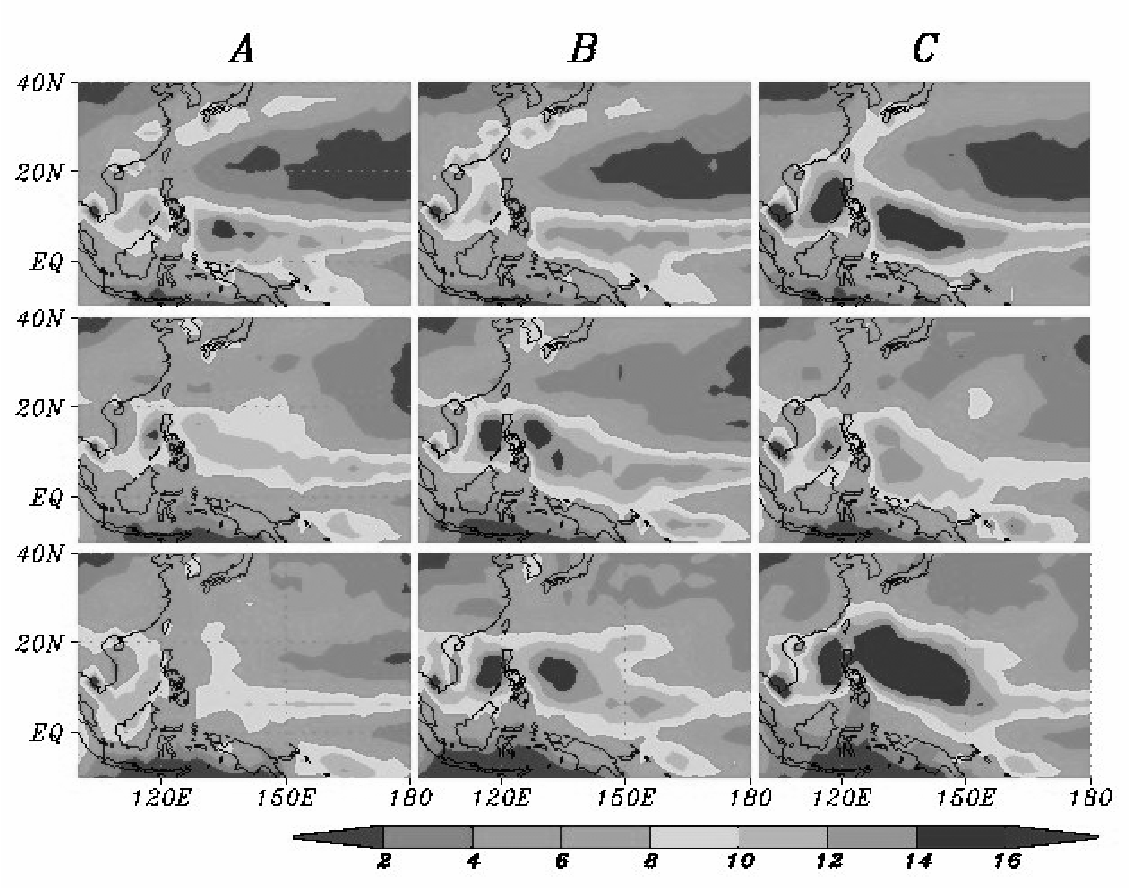


Fig. 1. Averaged monthly precipitation amount in the patterns A, B and C from June to August.

3. Regional scale energy and water cycles

Land-atmosphere interaction and its role in the formation of mesoscale precipitation systems are one of the most important research targets of GAME-HUBEX. We tested the JSM-SiBUC model using GAME reanalysis data as initial and boundary conditions. Figure 2 shows simulated and observed rainfall for the Huaihe River Basin (11 deg.× 5 deg.) from 27 to 30 June 1998. This model can predict the rainfall area rather well, but the predicted rainfall amount is larger than the observed one (especially on 27 June).

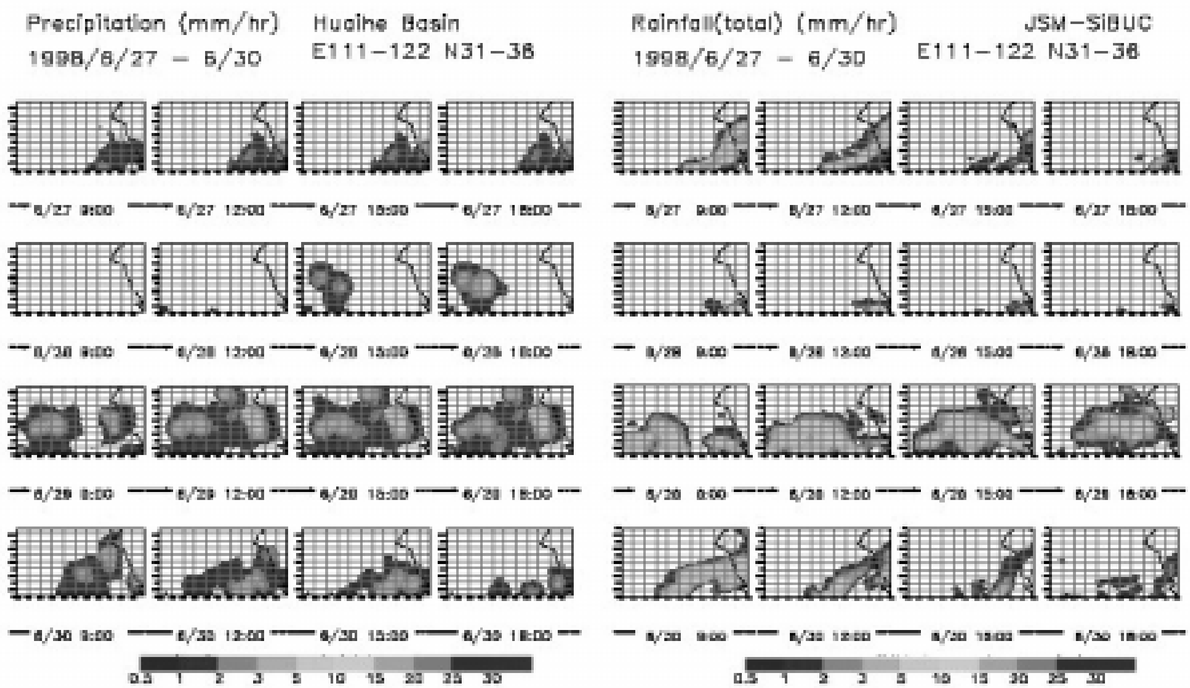


Fig. 2. Simulated and observed (surface station's data) precipitation in Huaihe River Basin (ll deg. × 5 deg.)

4. Frontal-scale characteristics of cloud systems

Frequent appearance of mesoscale convective cloud systems results in the persistent heavy rainfall area in the Meiyu frontal scale. It is interesting that such convective clouds are sometime associated with meso-scale circulation and interact with that circulation system strongly. As for the meso-scale lows, so-called the southwest vortices appear frequently around the Meiyu front in China, initiated around the eastern foot of the Tibetan Plateau.

It is noted that the Meiyu frontal rainfall area became organized into a meso-scale clouds, and a meso-scale low was generated after that. Distribution of the negative relative vorticity at 500 hPa level suggests that persistent generation of the instability associated with the strong low-level southerly wind around the shear line initiated and sustained the heavy rainfall area, resulting in the formation of the meso-low. It is interesting that the synoptic scale low-pressure area near the surface level extended to the northwest of the Meiyu frontal zone around the Huaihe River Basin. This low-pressure area seemed to be associated with the heating from the ground. In relation to this low-pressure area, the low-level southerly wind component reached to penetrate further northward around Fuyang (32.5 N/ 116 E), where cloudless area existed just to the north of the Meiyu cloud zone. Due to such change in the low-level wind field, the destabilization of stratification for deep moist convection was brought there through the differential advection of the equivalent potential temperature. The present study illustrates an example that the activation of the Meiyu frontal rainfall due to the synoptic scale system would result in the initiation of the meso-scale low.

Cloud clusters are important cloud activity of the Meiyu front over the China continent. Precipitation within cloud cluster over the continent is important for the water cycle in this region. A diurnal variation of cloud activity including cloud clusters was significant over the continent during HUBEX IOP. Most of cloud clusters began to develop at the late evening and attained maximum of the lowest cloud area at midnight (Fig. 3.). This is a significant diurnal variation of cloud clusters over the continent. We are trying to simulate the features of cloud clusters by using several mesoscale models (MRI-NHM, ARPS, RSM, etc.)

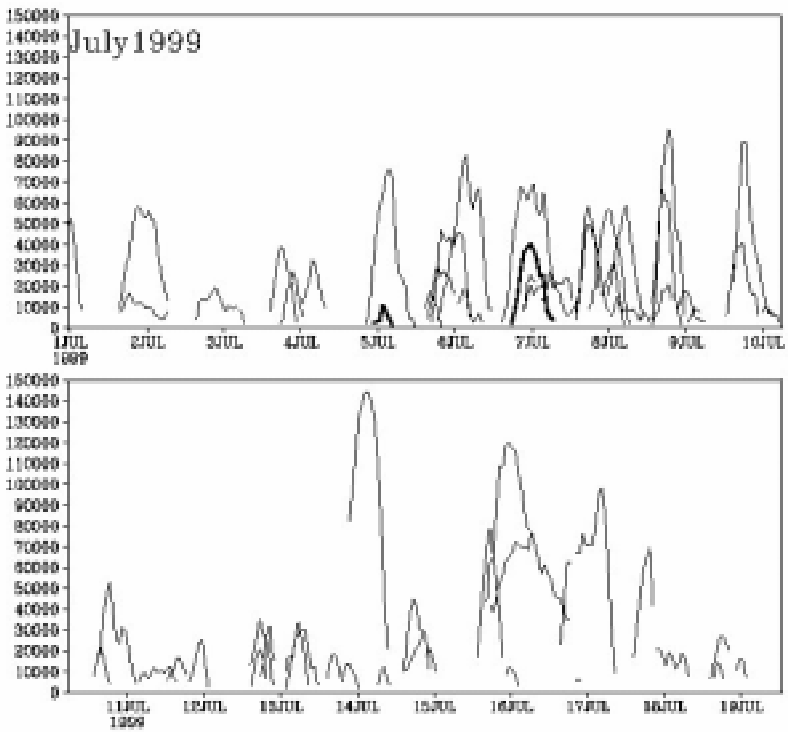


Fig. 3. Time variation of area of cloud clusters with Tbb lower than -60 C.

5. Mesoscale cloud systems

In the Doppler radar observation range, main precipitation systems were observed from 29 June to 3 July, 1998 (Uyeda et al., 1999). It is quite interesting that the Meiyu front moving to the north (south) showed a warm (cold) frontal-like structure as shown in Fig. 4. In addition, the front had three types of sub-structures, that is, warm frontal, cold frontal and meso-vortex types (Maesaka and Uyeda, 1999, 2000a). Warm frontal type of precipitation was in the morning of 29 June 1998 and cold frontal type in the afternoon of the day (Maesaka and Uyeda, 1999, 2000a) (Fig. 5.). Meso-γ scale vortices were observed in the precipitation systems on 2 July (Fig. 6.). Wind fields and divergence profile in and beside the precipitation systems are analyzed with VAD winds by Fujiyoshi et al. (1999, 2000). Evolution of meso-β scale precipitation systems was studied by using Fuyang radar (Xu and Xu, 1999) (Fig. 7.). Water budget in the Fuyang radar observation range (r = 250 km) was analyzed by using sounding data at 7 stations by Maesaka and Uyeda (2000a). Structure and development processes of the precipitation system of cold frontal type are analyzed from a different point of view (Kato et al., 1999; Geng et al., 2000; Maesaka and Uyeda, 2000b). In cold frontal type southwesterly inflow in the low altitude and condensation in the low altitude ahead of the precipitation area were prominent. In meso-vortex type, condensation above 3 km and ahead of the precipitation system, and evaporation behind it are analyzed.

After the main precipitation period, diurnal variation of convective clouds is recognized under the subtropical high from 11 to 15 July, 1998 (Uyeda *et al.*, 2000). On July 13 1998, a deeply developed and long-lived cumulonimbus cloud was observed by Doppler radars. It developed in the atmospheric situation of weak vertical wind shear and its primary updraft was situated in the rear portion relative to the storm motion. It seems that the presence of the broad downdraft observed around the region of low to mid-levels northeasterly inflow contributed to the development and maintenance of downdraft. It is interesting that, under the influence of low-level inflow from the northeast side, interaction between convective-cells occurred and long-lasting and very deeply cumulonimbus cloud was formed in the atmospheric condition of weak vertical wind shear. On 16 July a squall line passed over the Doppler radar sites (Tsuboki *et. al.*, 2000). An intense convection was located along the leading edge and decaying convection behind the edge. A parallel component of relative velocity was significant at every level of the squall line. Convective cells successively developed on the downshear side of this parallel component. As a result, a long line was formed.

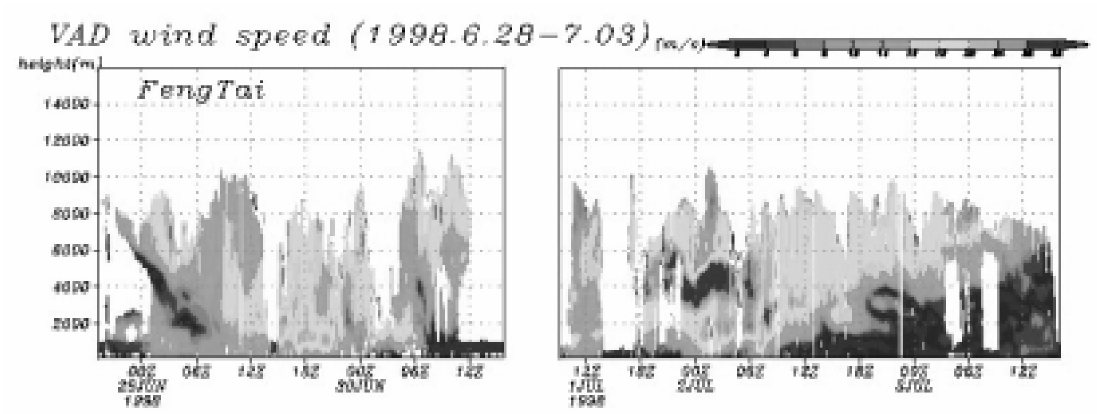


Fig. 4. Time-height cross section of wind speed measured by a Doppler radar at Feng Tai. The left panel (from 29 to 30 June) showed a warm frontal structure and the right panel (from 1 to 3 July) showed a cold frontal structure.

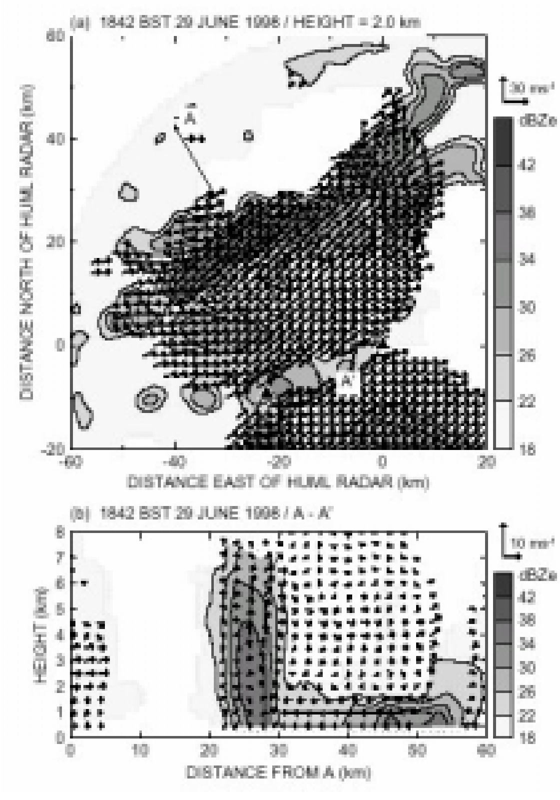


Fig. 5. Dual-Doppler radar analysis for 1842 BST on 29 June 1998. a) Horizontal plane at 2.0 km in height. b) Vertical cross-sections along A-A' lines in (a). The vector denotes the wind on the plane. Vectors of (b) are subtracted from the averaged wind. The shading denotes the radar reflectivity.

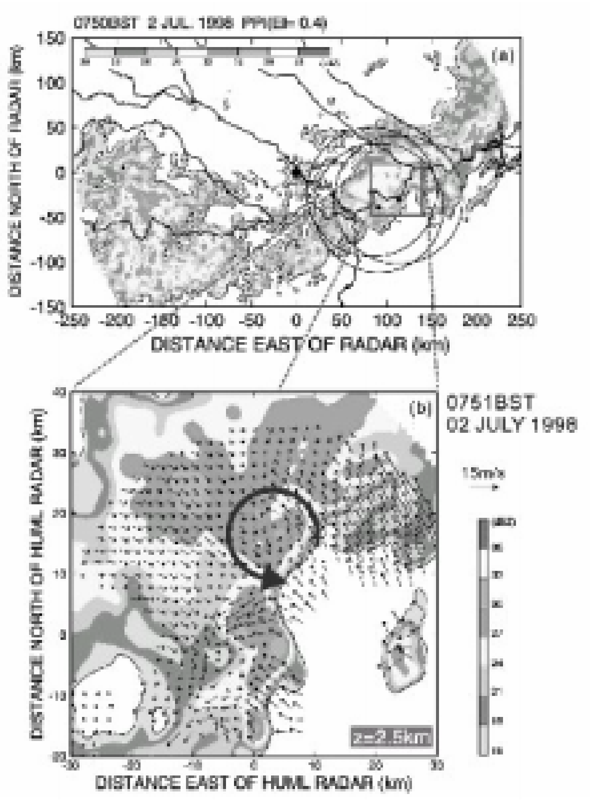


Fig. 6. The reflectivity(PPI, EI=0.4) of Fuyang radar at 0750 BST on 2 July 1998 (top panel). Horizontal plane of dual-Doppler radar analysis at 2.5 km in height (bottom panel). The round arrow indicates the vortex.

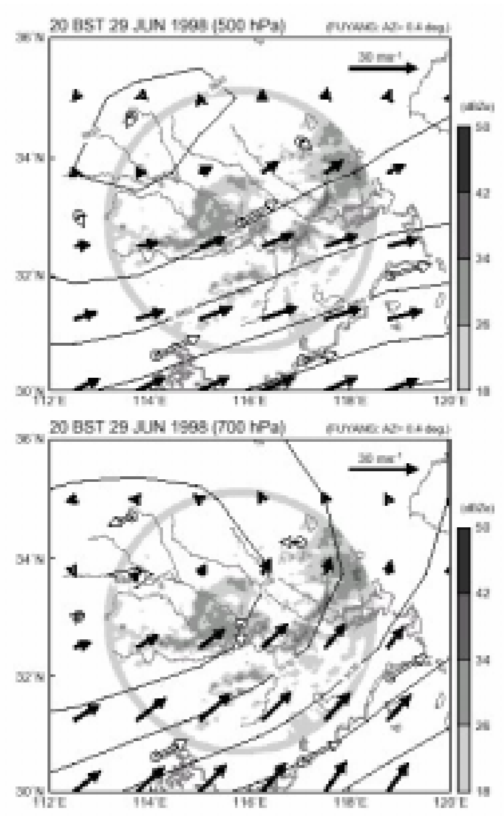


Fig. 7. GANAl wind (solid arrows) and geopotential height (contoured every 10 m) superimposed Fuyang radar reflectivity (0.4 PPI scan) at 700 hPa and 500 hPa (20 BST 29 June 1998). Open circle shows the sounding point and open arrows denote the wind by sounding at the level.

6. Study of land-surface hydrological processes

To predict floods, droughts and future water resources for a large river basin, a macro scale distributed hydrological model is an indispensable tool. For modeling water movement of a large river basin, modeling procedures such as basin partitioning, hydrological process modeling for a sub-basin, linking sub-basin models together to make a total runoff model require heavy tasks. Thereby, automatic procedures for processing hydrological modeling are necessary so that a model is transferable to various large catchments. In automatic modeling procedures, processing channel network linkages should also be included to incorporate a river flow routing model efficiently.

To satisfy such modeling requirements, a macro scale grid based distributed hydrological modeling system using OHyMoS, Object-oriented Hydrological Modeling System (Takasao et al.,1996, Ichikawa et al., 2000) is developed and applied to the Huaihe River basin in China. In the system, a watershed basin is subdivided into grid boxes according to a grid system of a meso-scale atmospheric model to incorporate atmospheric model outputs. By using the values of model parameters identified at the Shigan River basin (Fig. 8), the hydrological simulations for the Huaihe River basin were conducted.

A basic framework for building a macro scale distributed hydrological simulation system is as follows:

i) division of a river network into several sub-networks by rectangular grid boxes set by a numerical atmospheric model,
ii) modeling of hydrological processes in each grid box (runoff element modeling),
iii) modeling of channel flow routing in each grid box (flow routing element modeling),
iv) building a total simulation system by connecting subsystem models composed of the runoff element models and the flow routing element models.

To test the simulation model for working correctly, hypothetical precipitation was given to the system. This simulation shows that time lag of the peaks between two hydrographs is about three days. It is important to consider the effect of river flow routing.

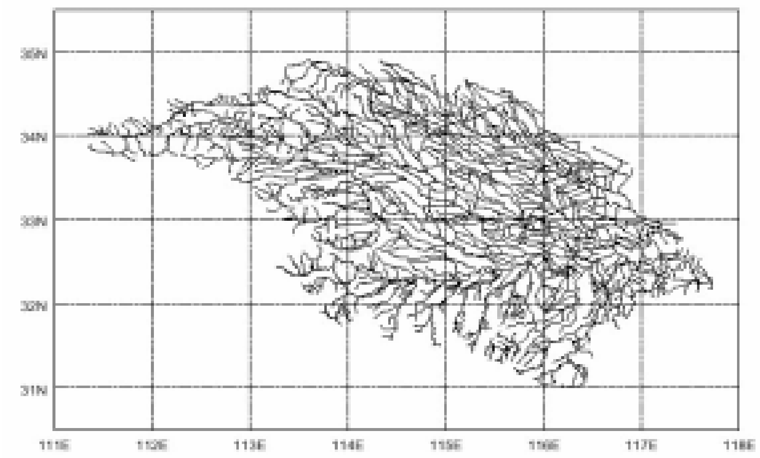


Fig. 8. Channel network for the Huaihe River above Bengbu

7. Concluding remarks

Many studies have been done on the structure and characteristics of precipitation systems during the intensive observation period of the GAME/HUBEX. Although a large number of reports were made on the structure of each precipitation system, the study of interaction between meso-α and meso-β scale systems is few. Combination of Doppler radar data, conventional weather radar data, sounding data, satellite data and surface data is expected. We should utilize objective analysis data and proceed to 4DDA. Only a few studies with numerical simulation are reported; for a squall line on 16 July by Tsuboki et al. (2000) and for an isolated convective cloud on 14 July by Shinoda et al. (2000). We are also encouraged to do numerical simulation for understanding the structure of precipitation systems and water circulation in and around the systems.

For HUBEX area, moisture budget analyses with objective analysis data as Peng and Song (1999) and moisture sink analyses with sounding data as Lin et al. (1999) would give information on the background of the precipitation systems. Doppler radar data are fully used for analyses of three dimensional wind fields in precipitation systems. However grid data of wind velocity available for statistical analyses are not ready. If we have time series of updraft field it will be very useful.

Reflectivity data of three Doppler radar need careful calibration and consideration of attenuation (Xu *et al.*, 1999). Reflectivity data of Fuyang radar is very useful for understanding the structure of precipitation systems (Xu and Xu, 1999; Geng *et al.*, 2000). Classification of precipitation types such as convective or stratiform are tried with Fuyang radar data (Zhang *et al.*, 1999). However Fuyang radar data had fluctuation of reflectivity and its value is compared with TRMM precipitation radar data and disdrometer (Uyeda *et al.*, 1999). Satellite data are very useful for the study of precipitation systems as follows. Estimation of precipitation amount using TRMM TMI is tested by Li *et al.* (1999). Further studies on the principle of satellite infrared rainfall estimation and passive microwave measurement, applied to the strong convective systems during the IOP by Zhang *et al.*, (1999) would be hopeful. Retrieval of water vapor above 500 hPa by using GMS-5 WV (water vapor) channel during the IOP by Osaki *et al.* (1999) would be useful for comparison with precipitation systems. Comparison with GMS IR data and hourly surface rainfall data, as shown by Zheng *et al.* (1999), is also necessary. Analyses with objective analysis data and GMS data as Tuboki and Monoe (2000) would be important.

As many studies on the structure of precipitation systems are made with Doppler radar data and Fuyang radar, we know what kind of precipitation systems we had during the IOP. However surface data is not used well and further use of satellite data should be encouraged for the study of large scale characteristics of Meiyu frontal precipitation systems at the same time with objective analysis data. 4DDA with observational data is expected for better understanding. Numerical experiments with synoptic model and cloud resolving model are also important. Combination of all of the analyses and investigation on the multi-scale structure and multi-processes of precipitation systems would be the most important target of the study.

For the comparison with precipitation systems in another areas, studies on the statistical feature of precipitation system are required; precipitation types, averaged vertical profile of reflectivity (rainfall intensity), updraft and non-adiabatic heating, and averaged precipitation efficiency. As basic data set for various studies are ready and provided, further processed data set such as grid rainfall amount and updraft distribution are expected.

It would be important for HUBEX researchers to reach to mutual understandings on a few focal points to study in a few years and present situation of studies. At the same time we have to provide better community data as soon as possible. Submission of each paper to scientific journals and publishing of special issue of HUBEX would be necessary. It would be important to continue collaboration in the study of the GAME/HUBEX for understanding precipitation systems during the IOP and Meiyu/Changma/Baiu frontal precipitation systems from China and Korea to Japan.

Most papers cited in this report are found in the following Proceedings.

- Proc. of Workshop on Meso-scale Systems in Meiyu/Baiu front and Hydrological Cycle. Xi'an, China (3-9 November, 1999) (GAME Publication No. 25)
- Proc. of International Conf. on Mesoscale Convective Systems and Heavy Rain in East Asia, Seoul, Korea (24-26 April, 2000)
- Proc. of 13th International Conf. on Clouds and Precipitation, Reno, Nevada, USA, (2000)
- Proc. International GAME/HUBEX Workshop, Sapporo, Japan (12-14 September, 2000) (GAME Publication No. 23)

Report on research progress of Siberia Regional Project

T. Ohata, T. Ohta, Y. Fukushima and A. Georgiadi

1. Background and general information

GAME (GEWEX Asian Monsoon Experiment) selected one of their field experiment sites in Siberia. Importance of this area was, first, that it is a northern region with widely covered snow cover/permafrost and possess typical surface such as taiga forest and tundra which occupies a large area on Eurasia Continent. Second is that there is abundant freshwater runoff to the Arctic Ocean which may strongly affect the ocean circulation. Thirdly, this region is one center of the recent intense warming and better understanding is needed on the response of the land surface and possible feedback to the climate system.

In order to advance the study, we set up the following objectives.

1) Clarify the physical processes of the land surface/atmosphere interacting system.
2) Clarify the characteristics and variability of regional energy/water cycle.
3) Obtain the climate trend and land surface change during the past 50 years and evaluate possible feedback processes.
4) Improve and develop models describing the energy/water exchange and atmosphere-land surface systems.
5) Collection and archive of regional ground based/satellite data.
6) Establishment of observational network for long-term study, and development of hardware.

Four main strategies for implementation were set. The first was to select one large drainage for study, which was Lena River, eastern most drainage among the three large Arctic flowing rivers. Enisei and Ob were candidates at the beginning, but they were omitted due to warmer climate and more anthropogenic influence than Lena. Second was to establish three local observation sites for intensive study from the criteria of land surface condition and climate in the drainage (Tundra area facing Arctic Ocean, flat taiga with little precipitation, mountain taiga with much precipitation). The location of these sites are shown in Fig. 1. Third was to hold an intensive study period for investigating the land surface/atmosphere interaction and spatial and temporal variability of water/energy fluxes in a regional scale (100 km scale), which was implemented in year 2000. The fourth is to involve researchers of various disciplines such as biology, soil science and others that can contribute to the understanding of the water/energy cycle in this region.

The study period was 1996-2001, and tight cooperation between Japanese and Russian institutions/scientists lead to a success. Table 1 shows the time sequence of the research progress for the group. The main results obtained in various study groups based on Japanese scientists will be presented were.

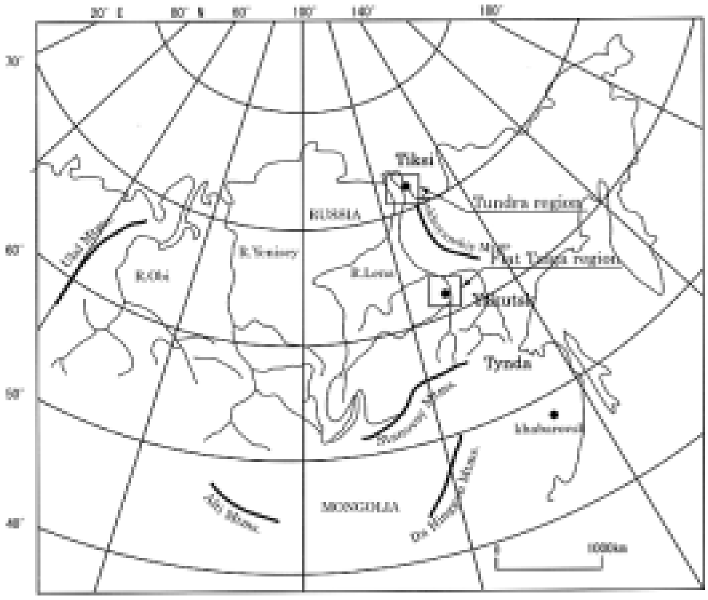


Fig. 1. The map of the study region and position of local observation sites.

Table 1. Yearly progress of the essential part of the Siberia Regional Project.

Year	1995		1996	1997	1998	1999	2000	2001
General Main meetings	GAME Conference (Pataya) GAME 1st Int. Workshop on Siberia (Nagoya)			GAME Conference (Cheju) 2nd Int. Workshop on Siberia (Moscow)		GEWEX/GAME Conference (Beijing) MAGS-GAME Meeting (Edmonton)		GAME Conference (Nagoya) planned 2nd MAGS-GAME Meeting (Sapporo) planned
Local patch drainage scale study	Tundra(tiksi) Patch Drainage		Construction of preliminary mast in the study area	Installment of the whole obs. system Start of runoff meas. and drainage study	Continued Upgraded the obs. system.	Continued Helicopter obs. started	Continued Continued	Continued Continued
	Taiga Forest (Spasskaya) Patch Areal		Aug.:Construction of 32m tower (larch) Setting of part of instrument and soil moisture/temp meas.	Setting of the whole obs. system	Continued	Continued Construction of 2nd 24m tower (pine)	Continued Continued	Continued Continued
	Taiga(Tynda) Patch Drainage				Started negociations with SHI	Negociation takes time	Construction of 24m tower and network within the drainage And start of obs.	Intensive obs. is being made
Regional intensive obs. study						Setting of tower, several masts and AWS at 7 sites in the right bank	April to June: Aircraft meas. were made. August: half of land obs. finish	
Variation, large scale analysis, Model studies			Made on personal basis	Made on personal basis	Made on personal basis	Made on personal basis	Made on personal basis	Made on personal basis

2. Tundra region

Tundra group stressed the following topics to be investigated.

(1) Seasonal and inter-annual variation of water balance of tundra watershed

(2) Seasonal variation of 1-dimensinal energy and water fluxes on tundra surface.

(3) Spatial distribution of surface and soil conditions

The following preliminary results have been obtained.

Figure 2 shows the map of the observation site. The observations for the patch scale energy and water exchange (theme 2) were carried out by ACOS (Automatic Climate Observation System) with a 10 m meteorological mast including the profiles of soil temperature and water contents for 4 years from 1997 to 2001. The result shows that, about 24 % of the net radiation reached at the ground during summer was spent as sensible heat fluxes back to atmosphere, 45-55 % as latent heat flux to the atmosphere, and 20-30 % as conductive heat flux into the ground. (Fig. 3.). Rather large amount of heat is used to melt the frozen ground where the melted depth is 50-100 cm at the most. Seasonal and inter-annual variations of summertime sensible and latent heat fluxes are relatively small. The dependence of these fluxes to the wind direction is seen as being reported by Yoshimura et al. (1999) for a coast site at Alaskan tundra. In case of southwest wind from interior with hot and dry air mass, sensible fluxes is small (sometimes changes its direction) and the latent heat fluxes large, while the northeasterly air masses is cold and damp, sensible heat flux is relatively large and the latent heat flux small.

Concerning the water balance (theme 1) of a watershed of 5.5 km^2, runoff, spatial distribution of snow cover and precipitation were studied. Inter-annual variation in annual precipitation was large (150-400 mm). About 80-150 mm of annual precipitation was as snow. The distribution of precipitation in the watershed was homogeneous at least from the study in 1998. Small vegetation height and strong wind enhance the redistribution of snow and form the snow drift, which acts as a natural snow dam during snowmelt season and becomes a source of summer discharge of the stream in the tundra watershed. The first day of snowmelt runoff was rather constant at the beginning of June for 4 years from 1997 to 2000. It is different from northern Alaska, where the first day of snowmelt runoff varies for more than one month. Most of initial snowmelt was refrozen inside the snow pack. The water level of a lake in the watershed changed seasonally with the ground water level. The change of water storage in ground could be estimated from the runoff curve. The evapo-transpiration was different by the vegetation, such moss, sedges, gravel. The water balance of tundra watershed was obtained for three years. (Table 2)

Seasonal variation of water cycle was simulated well by a one-dimensional model. The simulation of discharge by a nested hydrological model was improved by putting the place of snowdrift into account in the model.

Distribution of vegetation in the watershed was investigated and it was found that average LAI of moss was about 5. The distribution of thaw depth has auto-correlated patterns about every 7 m, which might be reflecting the hexagonal ground patterns. The thaw depth at the depression in the ground where soil water was relatively deep and different from general information in the past, which might be caused by the percolation of snowmelt water or rain.

The system of water and energy exchange and drainage runoff in this area seems to show different characteristics in certain aspects from the reports for the Alaskan sites.

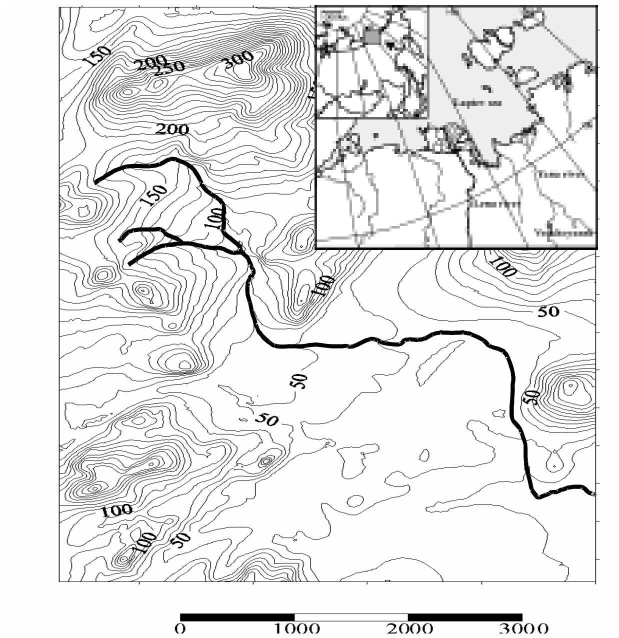


Fig. 2. Map of observational site at Tiksi (tundra)
1: hydrological station, 2: meteorological station

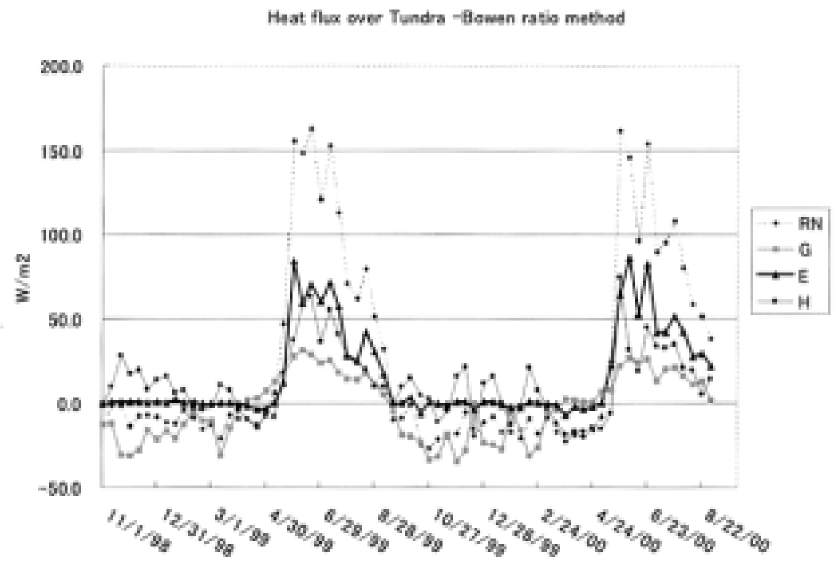


Fig. 3. Seasonal variation (10 days mean) of heat balance components at Tiksi from 1998 to 2000.

Table 2. Summer water balance at Tiksi watershed.
P: Precipitation, M: Snowmelt contribution, E: Evaporation,

Q: Runoff, dS: Change in ground storage.

Year	Period	P	M	E	Q	dS
1997	6/18-9/4	220*1	187*2	67*3	381*1	-41*4
1998	6/18-9/4	76*1	120*2	44*3	148*1	5*4
1999	6/13-9/8	99*1	65*5	55*6	110*1	-1*4
average		131	124	55	213	-13
Std.Dev.		77	61	11	146	24

*1 Observed, *2 Degree day Method, *3 Bulk Method
*4 Recession Analysis, *5 Residual, *6 Penman Method

3. Taiga forest

The predominant land surface condition in Siberia is the taiga forest, and this strongly influences the water and energy cycle in this region. Study was done at Spasskaya Pad near Yakutsk.

3.1 Meteorological conditions during the observation period 1997-2000

The meteorological data was obtained from 1997 to 2000. The amounts of precipitation from May to August were 81.5 mm, 235.7 mm and 131.7 mm in 1998, 1999, 2000, respectively and shows broad fluctuation year to year. The depth of active layer is 1 to 4 m in this area, deeper than Tiksi, the tundra site.

3.2 Seasonal and inter-annual variation of energy budget of larch forest

Figure 4 shows the seasonal variation of the sensible heat flux from 1998 to 2000. The sensible heat fluxes had maximal values at the end of May when it was just after a snow ablation, every year. The sensible heat fluxes decreased gradually ups to August, although the effective radiation increased until the end of June.

Figure 5 shows the time series of energy budget components above the larch forest in 1998. The energy incoming and outgoing were not balanced in this site, and the relationship between the avilable energy (Rn-G) and the sum of turbulent heat fluxes (H + lE) was presented as a following equation,

$$H + lE = 0.752\ (Rn\text{-}G)$$

where Rn is the net radiation, G the ground heat flux, H the sensible heat flux, and lE is the latent heat flux. The latent heat flux increased rapidly when larch stands begun to foliate. On the other hand, the sensible heat flux dropped at that time. According to these results, the latent heat flux might have the same as that in 1998. This result showed that the plant physiological activity affected the seasonal variation of energy budget strongly.

The canopy resistance in the Penman-Monteith formula varied widely and canopy resistance and evapo-transpiration efficiency were strongly controlled by the saturation deficit, and the efficiency decreased exponentially with the increase of the saturation deficit.

3.3 Differences of the energy balance characteristics between the larch forest and the pine forest.

The energy budget above a pine forest was observed in a warm season in 2000. The effective radiation and the sum of turbulent fluxes were almost balanced in this site. Figure 6 shows the time series of energy budget components above the pine forest. The latent heat flux indicated high values, 50 - 100 Wm^{-2} even at the beginning of May. Consequently, the seasonal variation of Bowen ratio did not show "U-shape" as that in the larch forest shown in Fig. 5 during the observation period.

Figure 7 shows the spatial and temporal distributions of soil temperature at the larch and pine forests. The thawing depth reached up to 60 - 80 cm depth at the beginning of May in the pine forest. On the other hand, the thawing depth was only 10 - 20 cm depth even at the beginning of June in the larch forest. Pine stands were evergreen and the thawing of permafrost begun early in the pine forest. Consequently, transpiration activity became high in a nearly spring in the pine forest.

3.4 Water flow and balance at the surface

Transpiration from the larch stands, not including evapo-transpiration from under-story vegetation, was estimated using a heat pulse method. The amount of transpiration was similar in two years, although there was a significant difference of precipitation. The result suggests that the soil moisture did not control transpiration and that transpiration was affected by atmospheric condition.

The percentages of stem flow to precipitation at the open site were less than 1 % in the larch and the pine forests. On the other hand, the percentages of through fall were around 15-25 % in the both forests, so under-story precipitation consisted of only through fall. The interception rate was around 15 % of the gross precipitation in the larch forest.

Snow adds complexity in the seasonal sequence of water flow at the surface. Maximum snow depth was 25 to 45 cm in this area. During the first half of thawing season, it was estimated that 40 % of the surface snow melt water percolated in to the frozen permafrost, although snow temperature was below the freezing point in almost layer. It was considered that the snow melt water flowed down through snow fingers formed in a snow pack.

Water balance in a at this larch forest for the warm season, including a snow-melting period, in1998 is as followed. Total water input was 211 mm. 105 mm of total input consisted of snowmelt water, and 106 mm was precipitation during the warm season. Evapo-transpiration from a whole ecosystem was 151 mm, and the under-story evapo-transpiration was equal to 35 % of total evapo-traspiration. The interception evaporation, 16 mm, was 15 % of the gross precipitation at the open site. The total evapo-transpiration exceeded the total precipitation, and snowmelt water compensated for this deficit.

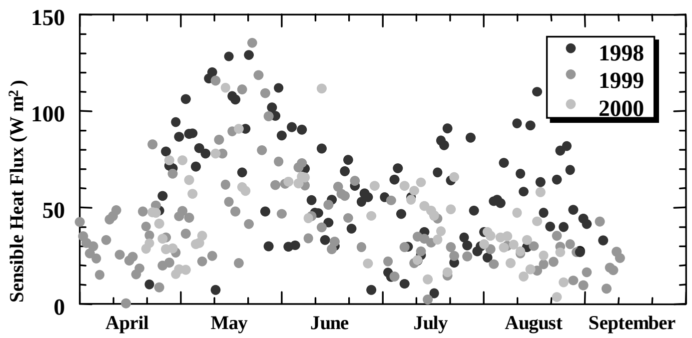


Fig. 4. Seasonal variation of sensible heat flux above the larch forest.

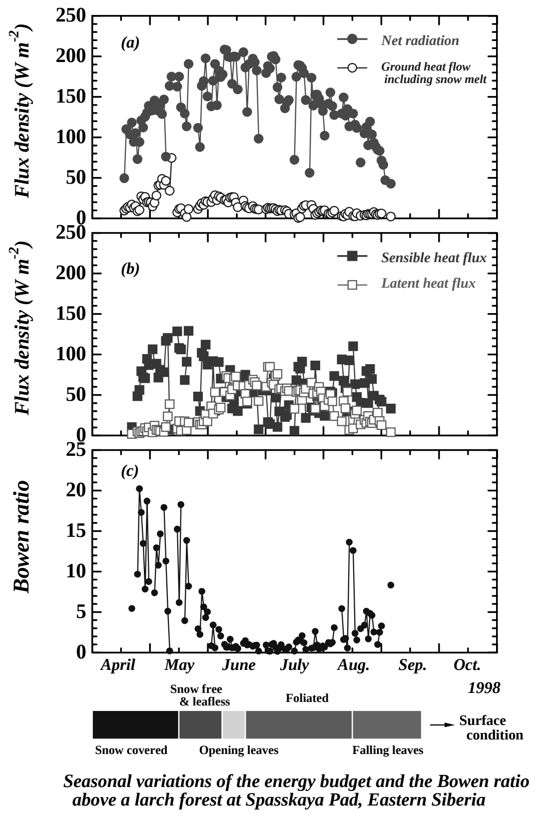


Fig. 5. Seasonal variation of each component of energy budget and Bowen ratio at above the larch forest in 1998. (Ohta *et al*., 2001)

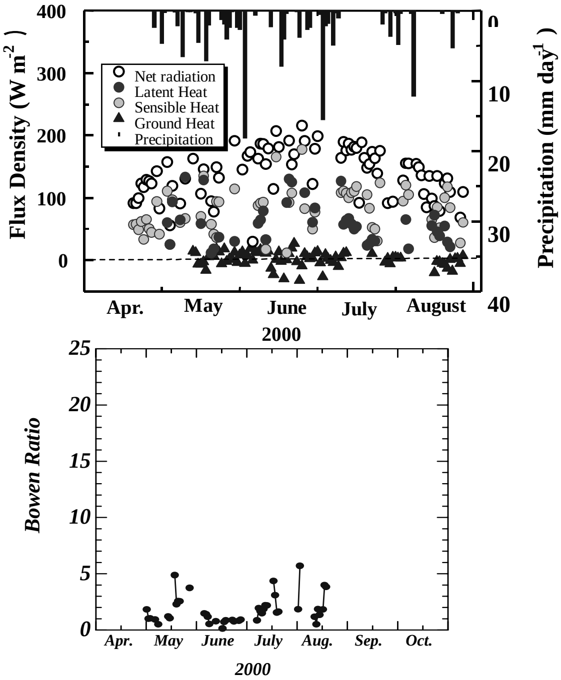


Fig. 6. The seasonal variations of energy budget components and Bowen ratio above the pine forest in 2000.

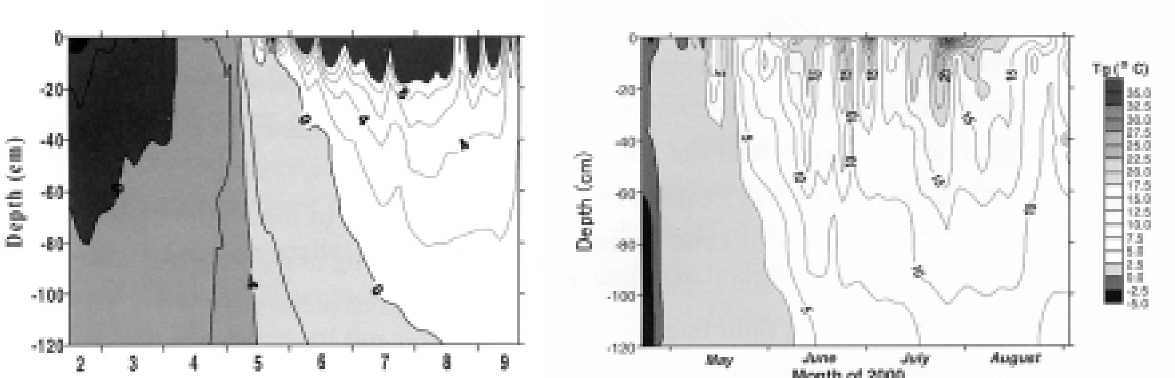


Fig. 7. Spatial and temporal distribution of soil temperature at the larch site in 1998 and at the pine site in 2000.

4. Intensive observation for spatial heat/water exchange in year 2000.

In year 2000, additional surface observation network was prepared in the Yakutsk area including a tower which was set in the taiga forest at the left bank of Lena River since 1997 (Sec. 2), to evaluate the heterogeneity of surface heat/exchange and spatial evaluation introducing the aircraft measurements. Observational network and flight courses are shown in Fig. 8.

4.1 Surface studies in right bank of Lena

4.1.1 Objectives for study and description of the area

There is a large number of sporadic grassland especially in the right bank of the Lena River inside the forest. These grasslands are called “alas”, occupying up to 20 % of this area. The alas is a concave landform that is formed after the forest has been cleared in an area where the ice content of permafrost was high. Usually the alas has a lake near the center of it. The field campaign of the year 2000 was carried out from April to September 2000, in an alas site near Tungulu village in the right bank of the Lena River.

The main objectives of this research are as follows:

(1) To characterize the one-dimensional water, energy, and CO_2 fluxes over the three typical land surfaces, that is, young larch forest, alas grassland, and alas lake.

(2) To clarify the difference in the surface energy balance between alas grassland and the forest floor, and to determine the moisture and thermal regime in the active layer at each site that reflect the surface energy condition.

(3) To learn how the water balance components affect the seasonal and inter-annual variation in water level/area of the alas lake.

The observation site in the right bank of the Lena River is called “Ulakhan Sykkhan”, and is a public alas, located 8 km west of the Tungulu village. It is oval-shaped, and is 1200 m long from west to east and 600 m long from north to south. It has an area of 0.64 km^2, including a 0.1 km^2 lake at the center. A 23 m high PBL tower in the young larch forest and a single mast system was set up at the center of alas grassland. Measurement on heat/water exchange was made at forest, grassland and lake.

These observations were made intensively between April and June 2000, in conjunction with the regional flux observations from the aircraft, then regularly from July to September.

4.1.2 Brief results

(1) Difference of seasonal change in energy flux among forest/grassland/lake surface (Fig. 9.)

- Net radiation: forest = grassland = lake
- Sensible heat: forest » grassland > 0, | lake | > grassland
- Latent heat: lake > forest > grassland > 0

(2) Difference in the surface energy balance between grassland and forest floor

- Solar radiation: floor/canopy = 0.4
- Soil heat flux: forest/grassland = 0.5 (Fig. 10.)

However, small soil heat flux value at the forest is also depending on the insulation effect of the litter layer on the forest floor.

(3) Unique water balance of the alas lake (Table 3)

Lateral groundwater inflow/outflow component during the summer seems to be very small.

It means that vertical components, precipitation and evaporation, are more important for the lake water balance. Because the lake water-level/area shows its maximum in just after the snowmelt period and decreases continuously after that, its inter-annual variation is mainly dependent on the snow storage volume in each year.

4.2 Spatial observation by aircraft

Aircraft observation in Yakutsk area (Eastern Siberia) was performed from April to June 2000. The object of investigations was ABL over Lena river and surrounding area and specially equipped Russian built ILYUSHIN-18 aircraft was used for observations. Main study topics were, spatial distribution of meteorological elements, sensible/latent heat and water vapor flux, atmospheric boundary layer structure, isotopic composition of water vapor at an altitude from 100 to 4000 m in the flight area shown in Fig. 8.

The aircraft was ILYUSHIN-18 operated by CAO, and it was equipped with the GPS, device for measuring dew-point temperature, system for measuring high response fluctuations of the horizontal/longitudinal wind respect to flight direction and vertical components of wind speed, high response temperature sensor, high response humidity sensor, high response closed-path CO_2/H_2O gas analyzer, infrared radiometer thermometer and video camera.

According to the schedule of observation days and the real weather conditions the experimental flights were made on April 24, May 1, 9, 12, 20, June 1, 5, 9 and 19, 2000. Each of these nine flights was made punctually according to the scheme.

Main results will be presented.

Large variability of meteorological and turbulent conditions in the studied area:

Surface underlying of regional legs (NW to SE) can be divided into 4 parts with different and relatively uniform (with respect to whole regional leg) structure. Each part of surface had the horizontal length about 20-22 km. Part #1 was located over pine and larch forest at the left bank of Lena River, Part #2 was chosen over Lena valley and Lena River. Part #3 of surface belonged to the right bank and consisted of mainly larch forest and grass fields and Part #4 (right bank) had complex profile with small hills covered with forests. The data obtained over these four parts of surface were taken into the analysis of the CBL models application.

Examples of obtained turbulent data (horizontal and vertical wind speed fluctuations, air humidity and air temperature fluctuations both with surface temperature and structure of underlying surface) and scheme of dividing the flight path are presented in Fig. 11.

Distribution of fluxes are variable in the area:

Flights over grid sampling area at the left and right bank sides of Lena River at a height of 100 m allowed to obtained horizontal distributions of turbulent sensible and latent heat fluxes and carbon dioxide fluxes. Examples of such horizontal distributions for flight made on May 1 are presented in Fig. 12 .

Data obtained during measurements on grid legs at a height of 100 m were the base for calculating square averaged turbulent fluxes. This gave possibility to estimate seasonal variations of sensible and latent heat fluxes and carbon dioxide fluxes. Results of aircraft observed and averaged fluxes are shown in Fig. 13. Seasonal variations of surface temperature and potential virtual temperature are also presented.

Observations made on regional flights allowed us to get spatial distributions of turbulent sensible and latent heat fluxes and carbon dioxide fluxes. These distributions for flight days of May 1, June 1 and 19, which we named as fine spatial structure of fluxes are presented in Fig. 14. These pictures also give image about seasonal variations of fluxes in Yakutsk region.

(1) Different characteristics of the ABL in the left and right bank:

Vertical sounding of ABL over left and right banks of Lena River showed:

ABL during all 9 days of observations can be treated as convective boundary layer (CBL)

During 5 flight days (on May 12 and 20, June 5, 9 and 19) development of thermal internal boundary sub-layers (TIBL) through the total depth of the CBL were observed. These also proved by fine spatial structure of potential virtual temperature, specific humidity, sensible heat and latent heat fluxes (see figs. 5 -7). On the others flight days (on April 24, May 1 and 9, June 1) there were no any internal sub-layers. Example of vertical sounding of CBL on two days without TIBL (May 1 and June 1) and with TIBL (June 9 and 19) is presented in Fig. 15

Spectra of coherence between vertical wind speed fluctuations and air temperature fluctuations also prove existing of TIBL developed in CBL through the total depth. These spectra obtained on May 1, June 1, 9 and 19 at the different height from 100 m up to 1500 m show clear differences between spectra of coherence at Part #2 for the days with and without TIBL. Threshold value of 0.15 for spectra of coherence was exceeded only on days without TIBL

Distributions of wavelet coefficients (or wavelet spectra) allow us to get not only existing of some events (heterogeneity zones of turbulent fluctuations), but also its locations in space (along the flight path) and scales (wave numbers). Wavelet spectra were the base for calculating distributions of wavelet variances or scalograms, which are the analogs of Fourier spectra.

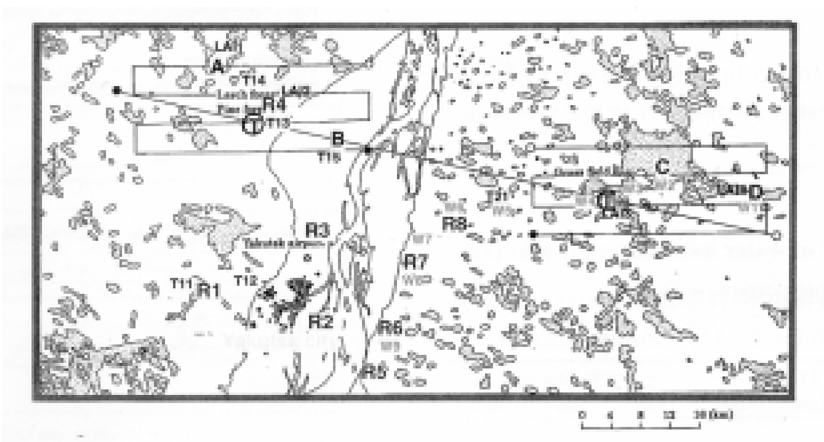


Fig. 8. The map showing the position of ground station during the intensive observation year 2000 and the flight course made from April to June. The shaded area in the map is the grasslands, and Lena River runs south-north at the center.

A-D: Radiation and precipitation and precipitation sampling

R1-R8: Precipitation and precipitation sampling **LAI**: Leaf Area Index

WO-9: Alas and lake water sampling

Tll-21: Surface soil moisture measurement with TDR (1*)

T: Observation tower at Spaskayapaid and alas station

(1*) Surface soil moisture was also observed at another sites for radiation and/or precipitation observation sites

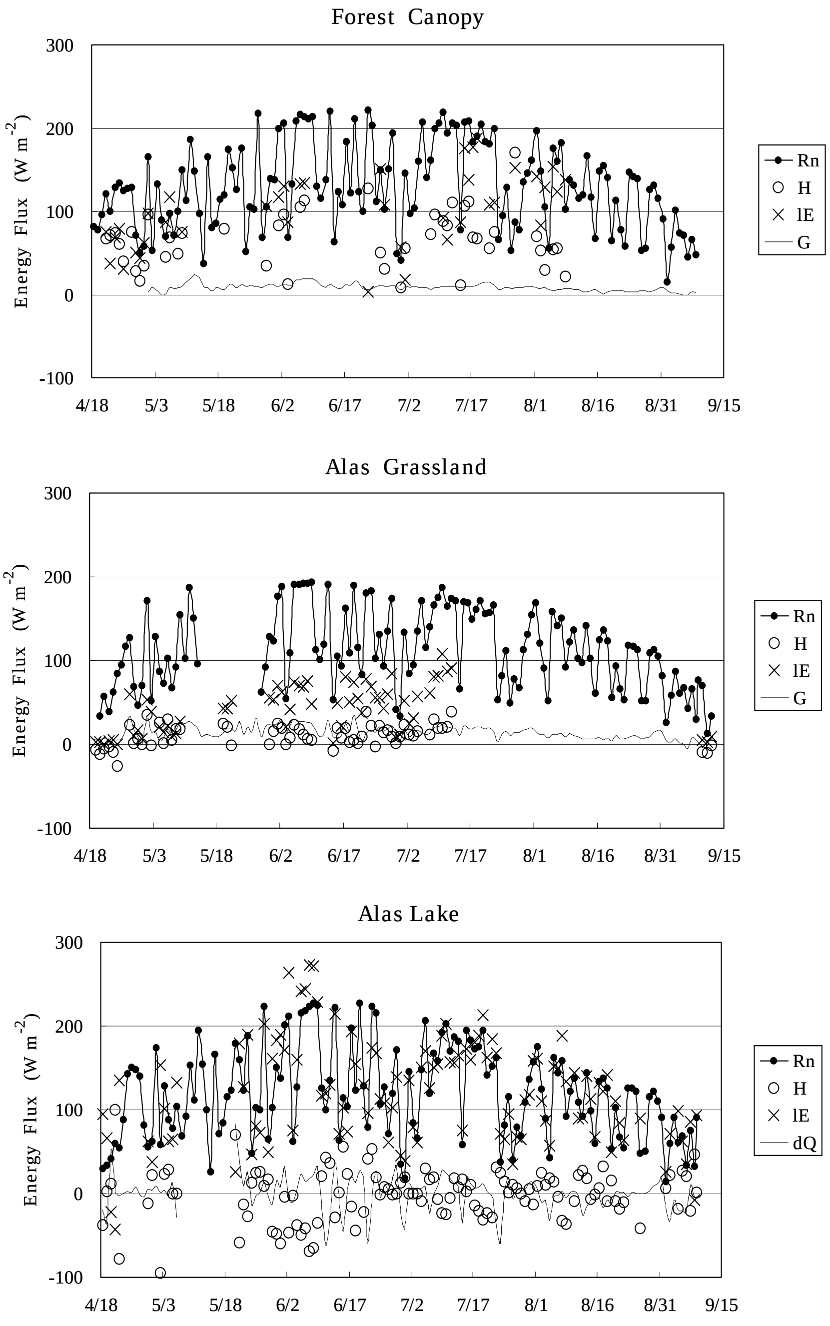


Fig. 9. Seasonal change in daily mean energy fluxes over the forest/grassland/lake in the Alas area.

Table 3. Result of water balance on the alas lake during the observation period.

Period	Δt days	Δh mm	P mm	E mm	Qi·Δt/A Mm
21 May – 9 Sept.	111	-288	129	451	34

Water balance equation on the closed lake is as follows:

$$A \cdot \Delta h = (P - E) \cdot A + Qi \cdot \Delta t$$

where, A : surface area of the lake, Δh : changes of water level, Δt : duration, P : precipitation, E : evaporation, and Qi : rate of surface/subsurface inflow.

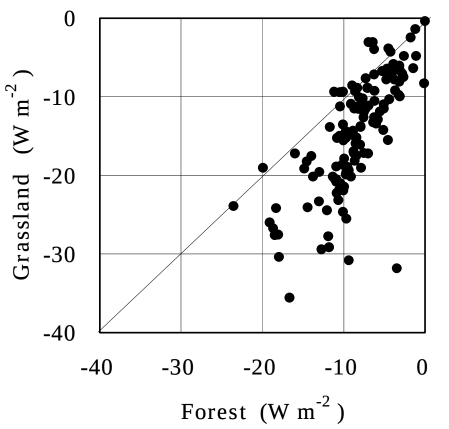


Fig. 10. Comparison of soil heat flux between forest and grassland at the Alas area in the summer season. Negative value show that heat is conducted into the ground from the surface

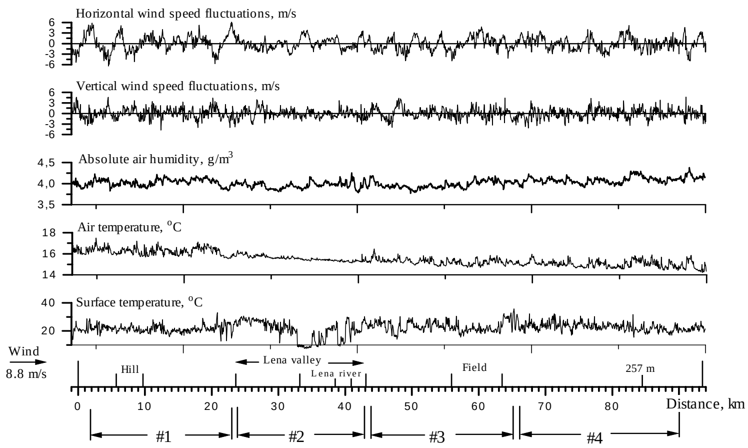


Fig. 11. The meteorological and turbulent elements at 100 m along the regionalleg (NW to SE) during the flight on May 1.

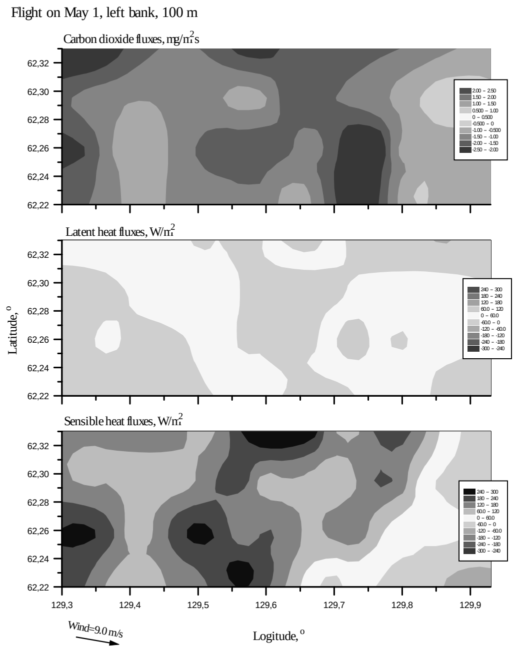


Fig. 12. Spatial distribution of CO2, sensible/latent heat on May 1 at the right bank.

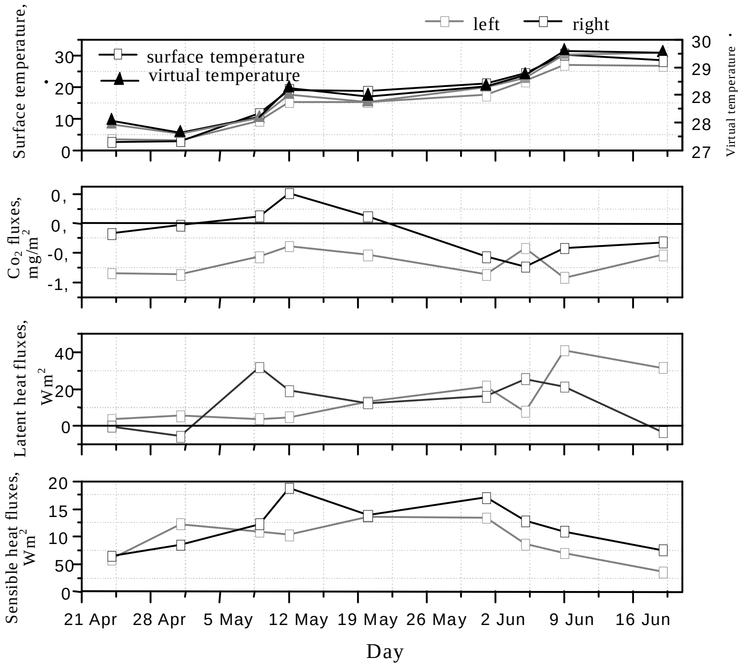


Fig. l3. Seasonal variation of meteorological elements and fluxes at the right and left bank. The values are areaverage.

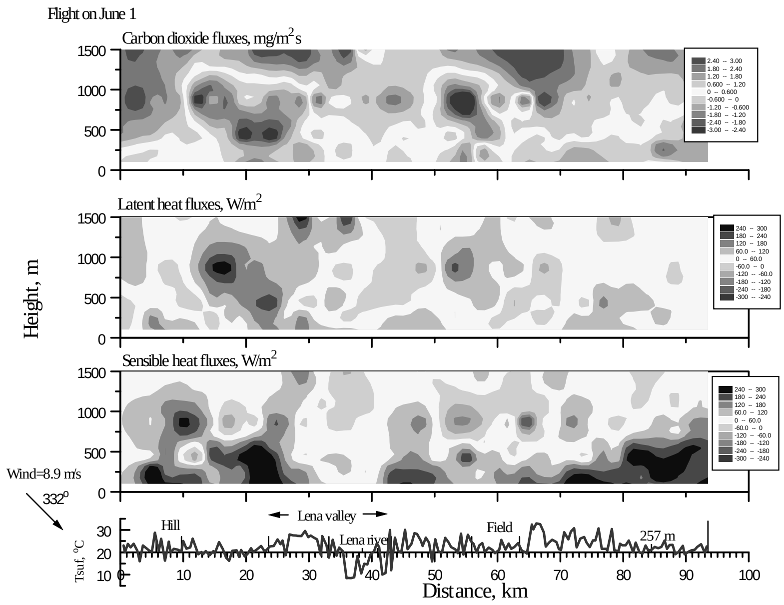


Fig. 14. The vertical distribution of fluxes along the regional leg flight on June 1.

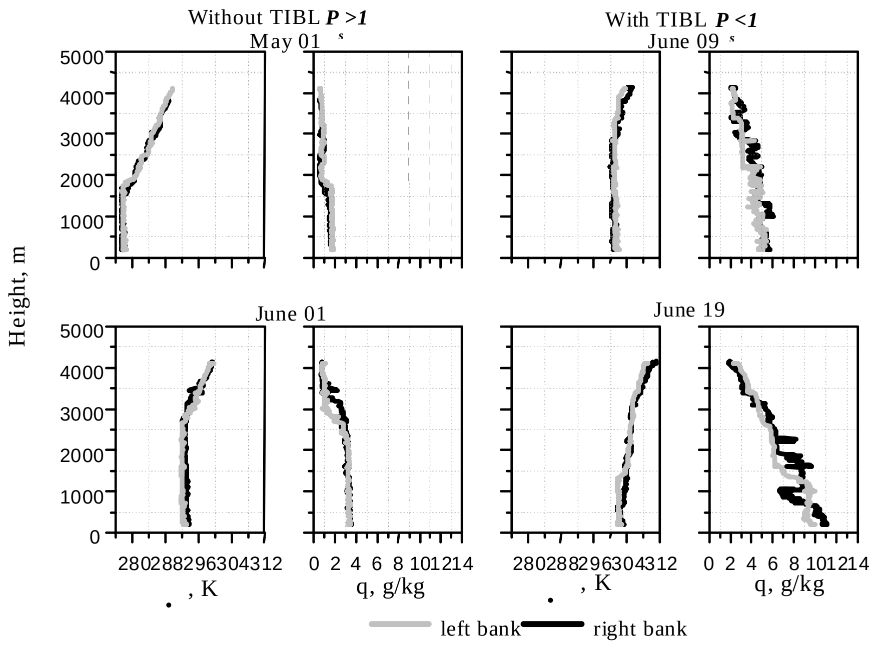


Fig.15. Vertical profile of potential temperature and specific humidity of CBL on two days without and with TIBL.

5. Large scale analysis using 4DDA and satellite data

5.1 Water circulation study of the atmosphere/land system.

Water budget study of the Lena River drainage was made using ECMWF and other global datasets. Results showed that there may be a lag in the precipitation and evaporation in these area for two years, evaporation proceeding the precipitation. The reason of this may be the influence of water storage and release system in the permafrost zone. However, there need to be more analysis to be made, since surface observation (patch scale such as the one at Spasskaya) of water fluxes shows rather small inter-annual variation.

5.2 NDVI analysis

Two analysis was mostly advanced with the use of satellite data. One was on vegetation using NDVI data and the other was snow cover estimation using microwave data.

The difference in the reflectance of chlorophyll pigment between the visible and near-infrared parts of the spectrum provides a means for monitoring the density and vigor of green vegetation. The Normalized Difference Vegetation Index (NDVI), a well-known vegetation index, is computed as NDVI =(Ch2-Ch1)/(Ch2+Ch1), where Ch1 and Ch2 are the surface reflectance from AVHRR Channels 1 and 2, respectively.

In summer, a zonal (west-east) high NDVI belt is found around 60N where a taiga forest flourishes in Siberia. By contrast, its southern and northern regions are characterized by a low NDVI due to arid climate and tundra climate, respectively. To examine these meridional changes, two meridional (south-north) transects were established, i.e., the arid-taiga transect (along 75E) and the taiga-tundra transect (along 110E) in Siberia (Suzuki et al., 2000). The meridional profile of annual mean NDVI, annual precipitation and warmth index (a cumulative temperature of monthly mean temperature above 0C) were compared. In arid-taiga transect, as indicated in Fig. 16, a strong positive correlation between NDVI and precipitation meridional changes, and a negative correlation between the NDVI and warmth index were found. From this result, it was suggested that aridity is the limiting factor for the vegetation amount in this transect.

In taiga-tundra transect, a strong correlation was found between the NDVI and warmth index meridional changes, suggesting that the limiting factor is temperature. Furthermore, it was revealed that the temperature spatial variation due to station’s elevation causes a NDVI variation. This fact suggests that the vegetation is quite sensitive to the temperature regionality.

Another study was done on vegetation regionality and its climatological implication over an extensive region of Siberia and surrounding areas, from a plant geographical stand point of view (Suzuki et al. , 2001a). By the cluster analysis, the NDVI seasonal cycles at 611 stations were classified into 10 classes (A, B, C, D1, D2, E1-E4, F) and it was suggested that each local region contains vegetation with a distinct phenological cycle. It was revealed that the high NDVI is zonally distributed mainly in the latitudinal lines from 50 to 60N, and this zone roughly coincides to the zone where the annual maximum monthly temperature is around 18C. From this result, it can be considered that the zone where the maximum temperature is around 18C has climatologically the greatest potential for the highest NDVI.

As for local area where intensive observation of 2000 were made, analysis for April 1992 to September 1993 was made (Suzuki and Ochi, 1999; Suzuki, 2000). It was revealed that the NDVI regionality should be partly characterized by the land cover type and topography. However, the NDVI indicates regional variations which do not correspond to both topography and land cover. Those unknown factors of the NDVI regionality should be focused by the future work, such as airborne field observation.

Photograph observation was carried out at a station Spasskaya Pad to record the forest/snow condition and phenological transition from August 25, 1997 up to October 15, 2000. In the winter season, the frequency was reduced. The time of major event of the forest was roughly revealed by the photographs.

5.3 Snow cover study

Snow cover distribution was studied using microwave signals of SSM/I for the north-east Eurasian part. The brightness temperature difference (ΔT) between 19 and 37 GHz were taken as index for snow depth. The seasonal change in ΔT was able to be classified into 9 types. There were areas where snow depth can be estimated by ΔT rather well throughout the winter, but some region had bad relation. Forest conditions, absolute value of snow depth and snow texture seemed to have influence on this relation.

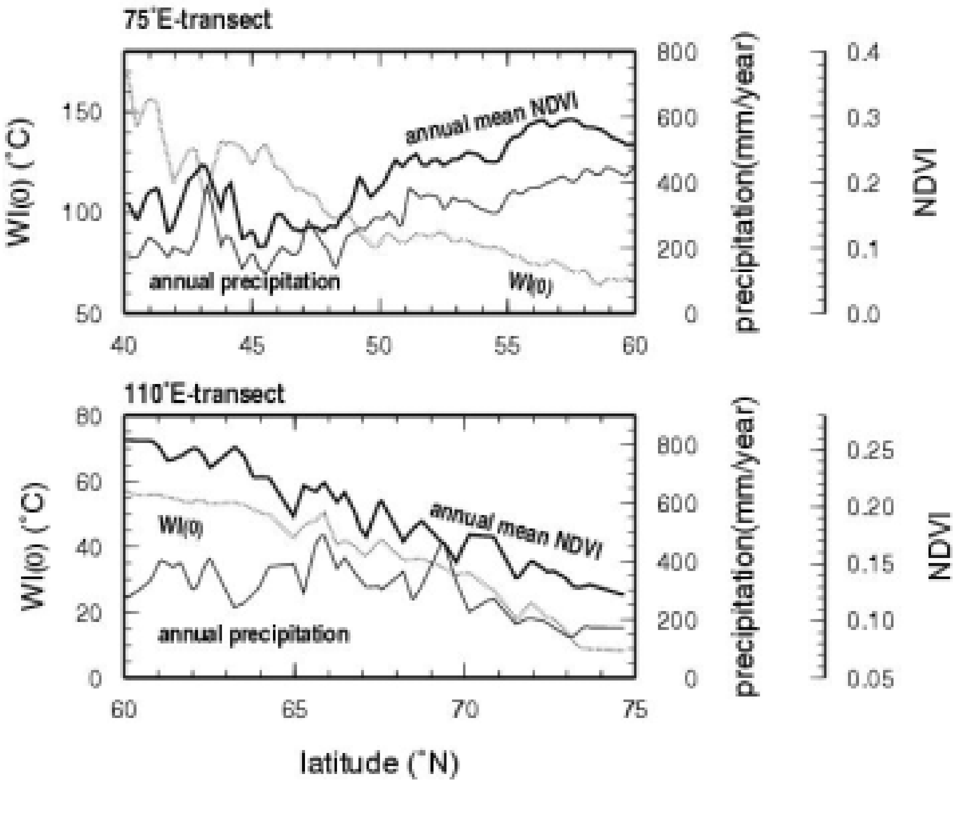


Fig. 16. Meridional profiles of the warmth index (WI(0)), annual precipitation, and the annual mean NDVl in 75 and 110E-transects

6. Modeling

6.1 One-dimensional models

Objectives of these models are estimating energy and water fluxes over various land surfaces, understanding of meteorological and hydrological processes and clarifying flux dependence on vegetation and terrain. A model, which was developed for intensively cold regions including vegetation, snow and soil layers, has been adapted to the plain taiga site. In 1998, diurnal and seasonal variations of fluxes are simulated reasonably, however, snowmelt is slightly earlier than observation. Another model, which was developed to couple with GCM or regional climate model, has been adapted to the tundra site (off-line simulation). In addition to these two simple models, two kinds of model have been developed to simulate CO_2 transfer and vertical fine structure of profiles. Remaining subjects are as follows: water flow in snow and soil, especially water channel in snow and water flow in frozen soil, and comparison with other site including right bank of Lena River.

6.2 Coupling one-dimensional models with atmospheric models

Preliminary results are obtained on simulation of a thunderstorm in 1998 near Yakutsk using a regional atmospheric model (RAMS). The followings are subjects in the near future: to estimate regional flux distribution and compare with aircraft observations, and to simulate precipitation events including cloud formation and comparison between left and right bank of Lena River.

6.3 Hydrological models

A macro-scale hydrological model combined with a simple SVAT model has been adapted to whole Lena River (Ma et al., 2000). When considering the effect of river freezing, seasonal change of runoff has been simulated reasonably. Remaining subject is long-term simulation to understand inter-annual variation. Two models joined the "Intercomparison of hydrological models" of PILPS-2e which is presently going on, and succeeded in getting good results.

7. Concluding remarks

The Siberia group had its main observation period in 2000, and the southern Taiga area only was able to implement its observation in 2001. Therefore, one or two more years are needed to elucidate major results.

7.1 Major scientific results

Although analysis is going on, there have been new findings up to now. The main ones are:

(1) Understanding advanced on the annual rhythm of the heat/water exchange at typical Siberian forest (larch and pine) using sophisticated observation systems. The amount and the timing of the heat/water fluxes especially from April to September were understood in more detail, comparing to the several observation done in the past (Pavlov, 1984). The absolute evaporation amount is smaller than previously estimated

and it can be said that the physiological characteristics of the vegetation determine the heat/water balance at patch scale and even at larger spatial scale.

(2) In tundra area, the amount of summer runoff seem to be regulated rather strongly on the distribution of winter snow cover, compared with Alaskan cases owing possibly to topography and wind climate. Also the difference of evaporation on low and high precipitation year does not differ much.

(3) Spatial distribution of regional sensible/latent heat (vapor) fluxes and ABL are complex due to influence of topography, land surface condition and dynamic response of atmosphere. The possibility that surface fluxes is partly regulated by atmospheric response was shown.

(4) The inter-annual variability of summer evaporation was obtained by a surface network and 4DDA analysis data, and they show rather contradicting results up to now.

(5) From NDVI analysis vegetation characteristics show latitudinal distribution implying zone of high vegetation activity. It will be interesting to know whether it is reflected in the heat/water exchange on land surface.

(6) Complexity of obtaining snow data from microwave information in Siberia region was shown.

(7) Through the application of various models to the observational and newly collected operational data, the models were improved, and in some cases, they were validated to be a good model.

7.2 Publication, international relations and contributions

The Siberia group has made following other progress.

(1) Our group has already published several project results, review monographs and papers listed at the end of this section.

(2) The Japanese research group has held approximately 15 domestic meetings since 1994 to discuss projects and its results.

(3) As part of interaction with foreign scientists and communities, we held two international workshop with Russian and scientists from other countries (Fukushima and Ohata, 1997; Ohata and Hiyama, 1998). Another direction was to hold scientific meeting with MAGS group, another continental experiment in clod region within the framework of GEWEX (MAGS and GAME, 2000) . The second of such meeting is planned in October, 2001.

(4) Members of the Siberia Group has attended SSGs of international project such as ACSYS/CLIC, IGBP-BAHC to have interference with them.

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A Summary Report of the GAME-Tibet Synthesis

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1. Introduction

The GAME-Tibet project is an international land-atmosphere interaction field experiment implemented in the Tibetan Plateau both at the plateau scale and a meso-scale under the framework of the World Climate Research Programme (WCRP) / Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME). The overall goal of GAME-Tibet is to clarify the interactions between the land surface and the atmosphere over the Tibetan Plateau in the context of the Asian Monsoon system. To achieve this goal, the scientific objectives of GAME-Tibet are to improve the quantitative understanding of land-atmosphere interactions over the Tibetan Plateau, to develop process models and methods for applying them over large spatial scales, and to develop and validate satellite-based retrieval methods. GAME-Tibet is an inter-disciplinary, coordinated effort by filed scientists, modelers and remote sensing scientists in meteorology and hydrology to address these objectives.

GAME-Tibet started in 1996 progressed rapidly through two experimental phases, the pre-phase observation period (POP) in 1997 and the intensive observation period (IOP) in 1998. It contributed to international research activities in the related science fields by providing the all obtained data through the GAME-Tibet Data Information System (DIS) in 2000. It has now moved on to the most rewarding part of project efforts for the analysis of results and the testing of new theories, models and algorithms.

This summary report is intended to introduce the reader to GAME-Tibet briefly and to summarize some of the significant findings of the science teams of GAME-Tibet, emphasize scientific gains in reference to the GAME-Tibet objectives, and outline some future research directions.

2. Experiment Design

The process-, modeling-, and satellite-based studies were carried out in cooperation with the Chinese national Tibetan Plateau Experiment (TIPEX) and the China-Japan Cooperative Study on Asian Monsoon Mechanisms (JEXAM) under the framework of the Joint Coordination Committee (JCC). Taking into account the importance of seasonal variations in key processes, the experiments at two different scales, the plateau-scale experiment and the meso-scale experiment, were implemented. To understand one-dimensional land surface-atmosphere interaction processes with spatial and seasonal variations, and to develop and validate sophisticated models, the plateau-scale experiment was carried out basically using the automatic weather station (AWS) and radiosonde networks. The meso-scale experiment was implemented in the central plateau, corresponding to the upper reaches of the Nujian basin, by using two- and three-dimensional intensive observing systems. The characteristics of frozen ground vary over a wide range, from continuous permafrost in the north to seasonal permafrost in the south. The details of the experiment design is provided in “GAME implementation Plan” (GAME International Science Panel, 1998).

GAME-Tibet covered the north to south transect observation of the plateau-scale experiment and the whole meso-scale one. The following measurements were done during the IOP by the efforts of GAME-Tibet:

1) Land surface-atmosphere interaction
- Boundary Layer measurements by using the AWSs at the 14 stations, the PBL tower at Amdo, and the turbulent flux measurement at Amdo and BJ site.
- Intensive radiosonde observation at Amdo on selected days to investigate diurnal variations of the PBL in June, July and August.
- Barometer network for local circulation measurement.

2) Precipitation and cloud studies
- 3-D Doppler radar observation about 10 km south of Naqu from the end of May to the middle of September.
- Ground-based precipitation measurement using the rain gauge network in the mesoscale area.
- A snow particle measurement system and a microwave radiometer for measurement of total water vapor and cloud liquid water content at Naqu.
- A GPS receiver for water vapor measurement at Amdo.

3) Land surface monitoring by satellite remote sensing.
- Ground truth data collection of spectral reflectance, soil moisture, surface temperature and surface roughness along the north-south transect and in the west part of the Tibet.

4) Cold region hydrology including permafrost study
- Soil moisture and temperature measurements along the north-south and east-west transects.
- River discharge and evaporation measurements in the meso-scale area.

5) Isotope study on precipitation and surface water
- Isotope sampling for study on the origin of precipitation and its recycling along the north-south and east-west transects.
- Isotope sampling for understanding formation processes of stable isotopic composition in the meso-scale experimental field.

67 scientists, including 37 Japanese, 25 Chinese and 3 Korean, organized the 5 expedition teams for the 5 months IOP from May to September in 1998. Each team covered one month observation by staying in Naqu or Amdo for 35 day including the 5 days overlapping with the next team. The AWSs in the west Tibet were maintained by JEXAM.

3. GAME-Tibet Data Information System (DIS)

According to the GAME-Tibet data policy, “final validated datasets obtained during the POP and IOP will be open to the international science community by June, 2000”, a data information system that could serve not only the GAME-Tibet investigators but also wider research communities was generated as a tool for archiving and distributing the complex datasets after the data collection efforts (Tamagawa *et al.*, 2001).

The level 2 data (quality checked and uniformly reformatted physical data associated with the detail information on site location, sensors, and observers) were transferred from the raw data obtained during the POP and IOP by the observers. All level 2 data were archived at the GAME-Tibet GIS and are opened through the user-friendly interface of WWW (http://monsoon.t.u-tokyo.ac.jp/tibet/index.html). Several pictures of the site and sensors and figures for the data quick view are also attached with the level 2 data at each site and its documentation for users' convenience.

4. Summary of Results

In this section, the results of the four science groups that were loosely arranged along disciplinary lines: atmospheric boundary layer, hydrology, modeling and remote sensing will be described.

4.1 Atmospheric Boundary Layer

The exchange of sensible and latent heat at the interface of atmosphere and the land surface was directly measured by eddy correlation method based on the measurement of atmospheric turbulence. Four flux sites, Amdo, MS3478, BJ (Naqu) and MS3637, were set up and the measurements were conducted during the IOP. In these sites the radiation budget, soil surface temperature, soil temperature profile, soil moisture profile and soil heat flux were also measured. These measured results serve as a consistent database to study land surface-atmosphere interaction.

With these results both diurnal and seasonal changes of the sensible and latent heat flux were clearly detected at Amdo where the longest and continuous data were obtained. Before the monsoon, the ground surface was very dry and the diurnal change of the surface temperature was as large as 50 degrees Celsius. The latent heat flux was very small and the sensible heat flux was dominant. As the ground surface became wet after the onset of monsoon, the latent heat flux increased and the sensible heat flux decreased. This change was in harmony with the decease of the ground surface temperature. Typical diurnal change of fluxes was also obtained for pre-monsoon, mid-monsoon and late-monsoon periods (Ishikawa *et al.*, 1999). Tsukamoto *et al.* (2001) compared the flux observation at four sites. They also showed that the sensible heat flux controls the development of the depth of mixing layer.

At these flux sites, Tanaka *et al.* (2001a, 2001c), Miyazaki *et al.* (2001), Wang (2001) and Kim *et al.* (2001) reported 'flux imbalance'. They suggest that many factors are responsible for the imbalance. They also stress the importance of mean vertical motion of air mass which may be induced by small scale organized disturbances. Tanaka *et al.* (2001c) gave a discussion on the measurement of soil heat flux. They roughly estimated the surface soil heat flux needed to melt the permafrost and to heat the soil layer from April to June using the soil moisture and temperature data. The required surface heat flux was about 30 W/m^2 on average, which was greater than that measured by soil heat plate. Tanaka *et al.* (2001b) examined the performance of a heat plate numerically and suggested that some correction is necessary to the soil heat flux. The surface imbalance problem has not yet been resolved. This severely limits the usefulness of the observed flux data.

The western Tibet is a region where the distribution of meteorological station is very sparse. Two automated meteorological stations were set up at Gaize and Shichuanhe and the continuous measurements of surface boundary layer and some soil variables have been conducted. Haginoya (2001) reported the surface meteorology and fluxes estimated by the

Bowen ratio method at these sites. Xu and Haginoya (2001) estimated the monthly averaged surface fluxes at fourteen Tibetan sites using conventional surface observation data. At Amdo site PBL tower observation has been continued after the IOP. Tanaka *et al.* (2001d) compute the bulk transfer coefficient for the sensible heat flux at the site by comparing the tower data with turbulent flux during IOP. The coefficient is obtained as a function of the bulk Richardson number. With this coefficient and the continued tower observation data they computed the sensible heat flux until July 2000. The data suggests the strong interannual variation, even the tower observation failed in Spring, when the sensible heat flux is largest in the year.

4.2 Hydrological Processes

The seasonal march in the Tibetan Plateau is characterized clearly by the rainy period and the dry one. During the rainy season, the active convection associated with a big amount of diabatic heat release plays an important role in the Asian summer Monsoon system. To understand and model the seasonal and interannual variability of the Asian summer Monsoon, it is important to address the hydrological processes, especially the origin and circulation of water vapor at large scale, the precipitation fields, and the land surface hydrological processes in the permafrost in the Tibetan Plateau.

4.2.1 Water vapor transport and water cycle in and around the plateau

Two approaches, the stable isotope study and the observation and modeling of the local circulation were introduced to understand the origin and transport of water vapor.The results of precipitation sample analysis for stable isotope study show the similar temporal variation of $\delta^{18}O$ in daily precipitation at the six sites in the meso-scale experiment field, the very low value of $\delta^{18}O$ in precipitation under the strong monsoon, and the higher $\delta^{18}O$ value associated with the convective precipitation (Tian *et al.,* 1999). The two characteristic feature of d-excess, which is often used for estimating the origin of the water, were found from the data obtained at Amdo (Numaguti *et al.,* 1999). One is an increasing trend of d-excess during continuous precipitation periods. The value is about 10 at the beginning phase of each precipitation event and over 20 in later stage. The other is an overall large value of d-excess, about 20, especially under a large-scale disturbance which embarked water vapor from south rather than from west. To explain this phenomena physically, a global isotope circulation model, which does not include fractionation process, was introduced. It suggests the importance of cloud process for high d-excess value.

Kuwagata *et al.* (2001) pointed out an important role of the mountain-valley circulation with the very typical diurnal variation in the water vapor transport in the Tibetan Plateau. Based on the radiosonde observation, the precipitable water decreased in the daytime at the valley area, while that increased during daytime over the mountain range. The magnitude of the diurnal variation ranged from 2 to 6 mm, which varied with time and space. The ECMWF 4DDA product also shows significant daytime decrease of precipitable water appeared in the valley regions around Naqu. Analysis of the GMS-5 water vapor channel image also indicated overall daytime increase of water vapor over the Plateau, but with some valley regions of daytime decrease. This diurnal variation of water vapor was also quantitatively simulated by a two-dimensional numerical model.

4.2.2 Precipitation fields

The intra-seasonal variation of the convective activity at the plateau-scale depends deeply on the variations of mid-latitude baroclinicity and the Tibetan anti-cyclone, while the spatial and diurnal variations of the convection are closely related with the mountain-valley topography in the plateau (Ueno, 1998; Kurosaki and Kimura, 2001). There are three types of meso-scale disturbances: the convective echo structure in daytime associated with vortex generation mechaaanisms, the stratified echo in nightime, and the combined system with frequent weak rainfall (Uyeda *et al.,* 2001; Shimizu *et al.,* 2001).

4.2.3 Land surface hydrological processes in the permafrost

The hydrological variability of permafrost was investigated both in the plateau- and meso- scales in the Tibetan Plateau. The plateau scale soil moisture distribution and its seasonal and interannual variations were observed by the space-based passive microwave remote sensing data. The thawing and freezing processes and their spatial and interannual variations were studied in the plateau scale by using the ground-based soil moisture and temperature profiles and atmospheric forcing data. The satellite synthetic aperture radar (SAR) data is used for detecting the surface soil moisture heterogeneity in the meso scale. A wide range of the meso-scale distribution of soil moisture in the permafrost region was examined by the observed data at several flat areas and on a slope (Koike *et al.,* 2001b).

The SSM/I surface soil moisture product shows the seasonal march of the soil moisture distribution in the Tibetan Plateau. The north-east and center parts of the plateau become wet in June while the other part is still dry. The wet area expands to north and west in July and to south in August. The center part keeps wet during the summer. Regarding to the spatial and temporal variation of soil moisture and temperature profiles along the Qinghai-Xizang highway, very clear spatial variability was identified, that is, the dryer and colder north and the wetter and warmer south, while any clear interannual variation between in 1997-1998 and 1998-1999 was not seen (Koike *et al.,* 2001b). The seasonal march of the soil moisture and temperature profile variation at the experimental slope suggested that the wide range of the soil moisture distribution along the slope, that is, wet valley and dry hilltop, was caused by the permafrost hydrological processes on the slope associated with the surface and sub-surface water flow along the slope and the surface energy budget differences due to the soil moisture distribution (Ishidaira *et al.,* 1999). In addition, the wide range of soil moisture distribution and its significant seasonal variation were also observed even at the flat areas. The wetter area appeared in the concaves, while the dryer in the convexes. Hirose *et al.* (2000) pointed out the importance of the interactive processes between the micro-topography and soil moisture in the permafrost region. The detention in the concaves keeps the active layer shallow due to the larger thermal capacity of soil and the larger amount of latent heat flux in the wetter area while the active layer grows more rapidly in the convexes due to the larger amount of soil heat flux.

Intensive observation of pressure head by using tensiometers in subsurface water and sampling of subsurface water at multiple depths were performed to investigate subsurface flow process in monsoon season, 1998. The pressure head of subsurface water ranged from -10 to -100 cmH_2O and zero flux plane was often observed above the depth of 30 cm. The groundwater recharge was very active during this period, thus the groundwater table rose up to the depth of 55 cm in the beginning of September. The δD and $\delta^{18}O$ of shallow subsurface water varied markedly with precipitation and evaporation, whereas those of groundwater were stable. The mean $\delta^{18}O$ of groundwater was 3.4 ‰ higher than the volume weighted mean $\delta^{18}O$ of precipitation. The difference of $\delta^{18}O$ between the groundwater and the precipitation would be caused by isotopic enrichment along with evaporation from the soil surface, and 27 % of precipitation might be lost by evaporation from the soil surface (Tsujimura *et al.*, 2001).

4.3 Modeling

Field observations under a wide range of meteorological and hydrological conditions motivated the development and testing of key process models describing soil moisture and temperature profiles, flux exchange at the surface-atmosphere interface, boundary layer flux profiles, radiative transfer, cloud formation and rainfall. In addition to one-dimensional modeling of land-atmosphere interaction, meso-scale and regional-scale modeling, and methods for scaling up land surface process were investigated.

4.3.1 One-dimensional modeling of land-atmosphere interactions

A new frozen soil parameterization in the land surface scheme was developed by incorporated a modified approximation Stefan solution in the framework of the land surface model - SiB2 to calculate the frost/thaw depth over time, and to estimate the soil moisture and temperature profiles during the freeze-thaw cycle. The structure of the soil model in SiB2 is kept but the governing equations of water balance and surface heat balance are modified to account for soil freezing/thawing. The model was calibrated and validated using the GAME-Tibet observations (Li and Koike, 2001). The new model estimates the frost depth more precisely, predicts the soil temperature reasonably and phase transition time more realistically than original SiB2.

An one-dimensional heat and water flow model was developed to simulate soil moisture and temperature profiles and surface fluxes in detail (Ishidaira *et al.*, 1998). Regarding to heat flow, thermal diffusion in soil is calculated with fine vertical resolution by introducing the thermal conductivity and the heat capacity which are considered as the function of volumetric water content. The ground surface temperature is calculated by surface heat balance and is used as the upper boundary condition. The water transport is expressed by a 5-layer soil model, in which the water budget is calculated by using the change of liquid water in the layer, the amount of water transport between layers, the change of liquid water content associated with thawing and freezing of permafrost and the deifference of the hydraulic conductivity and in the soil matrix potential.

To consider the soil moisture – micro-topography interaction, a detention storage component, which affects on the surface energy budget, was added into the one-dimensional model (Hirose *et al.,* 2000). The performance check of the soil moisture-microtopography interaction component was done, and indicated the variability of surface soil moisture that is consistent to the observed one.

4.3.2 Two- and three- dimensional meso- and regional- scale modeling

To simulate the seasonal variation of the diurnal cycle of the cloud activities over and around the plateau derived by GMS, Regional Atmospheric Modeling System (RAMS) developed at Colorado States University (CSU-RAMS) was applied in two dimensions domain with north-south direction (17N-42N, 90E) (Kurosaki and Kimura, 2001). The characteristic diurnal cycles of cloud, less or no cloud in the morning of the pre-monsoon period and low-level cloud in the morning of the monsoon over the Tibetan Plateau, and frequent low-level cloud over the southern slope of Himalayas, were simulated well.

Yoshikane *et al.* (2001) conducted numerical experiments to investigate the mechanism of the Baiu front by using CSU-RAMS. The location of the Baiu front is speculated to be quite sensitive to the zonal mean flow. The Baiu front accompanied by the low level jet was also represented by numerical experiments without topography, which suggests that the Baiu front could be reproduced by two factors alone, the zonal mean field and the land/sea contrast. The orography, including the Tibetan Plateau, intensifies the precipitation of the Baiu front, especially when the upper-level jet is weak and located northword.

4.3.3 Development of methods for scaling up land surface process models

Due to the non-linear relationship between evaporation and soil moisture, calculated evaporation by using spatially averaged soil moisture is smaller than actual one under dry condition and larger under wet condition. The effects of the wide range of the soil moisture distribution due to the presence of detention storage in the Tibetan Plateau is expressed by a linear function of the standard deviation of soil moisture (Hirose *et al.,* 2000). This result suggests a method for scaling up heterogeneous land surface processes.

4.4 Remote Sensing

Due to the dynamics and constantly changing behavior of the parameters inherent to energy and water cycle processes, and because of the relatively few ground observation stations over the Tibetan Plateau, efficient monitoring and continuity in space and time sampling over the complete plateau are only possible by satellite remote sensing. In turn, the field observations and process studies help to serve as sources of ground-truth information for satellite-based retrieval algorithms. To meet the objectives of the process and modeling studies reported above, GAME-Tibet focused on the development and validation of satellite algorithms for precipitation, radiation budget, surface fluxes, soil moisture and snow.

4.4.1 Precipitation

Quantitative estimation of spatial distribution of precipitation in the Tibetan Plateau is one of the important aspects for understanding the function of water cycle processes and estimation of water resources. Ueno *et al.* (2001) developed an SSM/I algorithm for rainfall by introducing a new scattering index into the existing scattering algorithm detect the weak intensity of precipitation in the plateau. The accumulated monsoon precipitation distribution in 1998 obtained by the new algorithm shows better agreement with the GMS estimated precipitation in the plateau area without screening of the surface condition.

A new algorithm for precipitation over land by deriving the optical thickness from the brightness temperature of the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) (Fujii and Koike, 2001). The effect of land surface controlled by soil moisture emissivity on radiation transfer is taken into account in this algorithm. This means that soil moisture can be estimated at the same time in addition to precipitation. Based on a microwave radiative transfer equation, two indices, *Index of Soil Wetness* (ISW) and *Polarization Index* (PI), which remove the effect of land surface physical temperature, are introduced into the algorithm. Surface roughness effects on land surface emissivity are included by using the polarization mixing ratio and the surface roughness. As the results of the algorithm application to the GAME-Tibet meso-scale experimental field, the estimated optical thickness and soil moisture are in good agreement with the patterns of precipitation observed by the 3D Doppler radar, and the observed soil moisture at 4 cm in depth, respectively. A unique relationship between the optical thickness and the observed precipitation by rain gauges can not be seen due to the emission from precipitation layer, the temporal sampling of TMI observation, and the profiles of hydrometeors. A reasonable relationship between the estimated optical thickness, and observed precipitation by rain gauges is obtained after 10 days of longer temporal averaging.

We can produce the diurnal cycle of rainfall because the TRMM satellite has a non-sun-synchronous orbit. Area-averaged rain rate, averaged storm height, proportion of convective rain to all rain in the rectangular area, and the rain area to the rectangular area were calculated from the TRMM Precipitation Radar (PR) data. This rectangular area almost covers the overlapping area of the Naqu hydrological basin and Doppler radar coverage. Totally 87 snapshots of rainfall events were obtained by TRMM PR during the IOP. The results indicate that precipitation with a high storm height developed in the afternoon while the rain area was not large. In contrast, large startiform precipitation developed in the evening and night and the largest amount of rainfall appeared in the night (Shimizu *et al.,* 2001).

4.4.2 Radiation budget and surface fluxes

Estimation of the energy exchange distribution between the land and atmosphere is one of key issues of the GAME-Tibet project. The fluxes of radiation, soil heat, sensible heat and latent heat were estimated by combining the in-situ data, NOAA14 Advanced Very High Resolution Radiometer (AVHRR) data and the radiation transfer model, MORTRAN (Ma *et al.,* 2001). The results show that 1) the very wide range of fluxes due to the complex surface conditions, 2) the estimated components of energy budget are in good agreement with the observed ones except the latent heat flux at one site, 3) the large value of the net radiation due to the high elevation and the land cover condition.

4.4.3 Soil moisture

A new algorithm based on microwave radiative transfer theory was developed for soil moisture using passive microwave sensors (Koike *et al.,* 2001a). It was applied to the data from the TMI and evaluated by using the field data obtained during the IOP (Koike *et al.,* 2001b). The estimated soil moisture corresponds reasonably to the soil moisture observed by the TDR sensor at 4 cm in depth. Just after the heavy rainfall, the satellite derived soil moisture is greater than the ground observations because the TMI only detects the surface moisture, which is much wetter than the observations at 4 cm depth. Conversely, during dryer periods the algorithm underestimates because the soil surface dries more rapidly. The monthly averaged diurnal cycle of the land surface physical temperature calculated by the proposed algorithm shows the same pattern as the ground observations, however with several K bias. The estimated water content of the vegetation also corresponds well to the observations, with an accuracy of 10% or less.

A time series data from the Japanese Earth Resources Satetlite-1 (JERS-1) Synthetic Aperture Radar (SAR) at L-band was used an algorithm for surface soil wetness at fine spatial resolution by using surface roughness measurements during the POP and a microwave backscattering model (Tadono *et al.,* 2000). A surface roughness map was generated by the JERS-1 SAR winter data by applying the scattering model and the relationship between two surface parameters under the perfectly dry condition. A soil moisture distribution in summer was estimated by applying the scattering model and the surface roughness map to a summer SAR data. The estimated distributions of soil moisture in the Tibetan plateau qualitatively correspond to those obtained by field measurement.

4.4.4 Snow

An algorithm for snow was developed by a relationship between the land surface radiation and snow properties derived from the radiative-transfer theory on a scattering dielectric layer over a homogeneous half-space. The total land surface brightness temperature is the sum of the direct component and diffuse component, which corresponds to the reflected sky radiation and the thermal radio emission from the snowpack and soil, and the radiation scattered from the direct and diffuse fields, respectively. By assuming snow grain size, snow density, and radiation from the soil-snow interface, brightness temperatures at two different frequencies, 19 and 37 GHz, were calculated by inputting snow depth and physical temperature. This algorithm was applied to the data from the

TMI and evaluated by using the field data obtained in the winter of 1997-1998 (Koike *et al.,* 2001a).The estimated snow physical temperature is in good agreement with ground observations made with infrared thermometers. Snow depth was not validated because of the lack of adequate ground observations.

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AAN Report

M. Sugita,T. Nakajima and S. Miyazaki

[Heat budget group]

1. Background and General Information

The Eurasian continent 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 vegetation 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. Despite its importance, available basic data have been quite limited to study these issues. To remedy this situation, at least partially if not completely an automatic weather station (AWS) which has a capability to measure not only the regular meteorological and hydrologic variables but also surface fluxes of momentum, heat, water vapor and radiation as well as soil moisture status, have been installed over the Asian countries since 1996 as a part of GAME activities. Currently 15 stations are in operation (see Fig. 1) and valuable data have been accumulated and analyzed in the framework of GAME-AAN project. Currently, the project is in the beginning of its Phase II (Monitoring phase) which has started in the year 2000, and this will be the period for a long term monitoring to determine mean, seasonal and annual variations of surface variables. Phase I (Installation phase) had been for the development of the AWS system and initial study period.

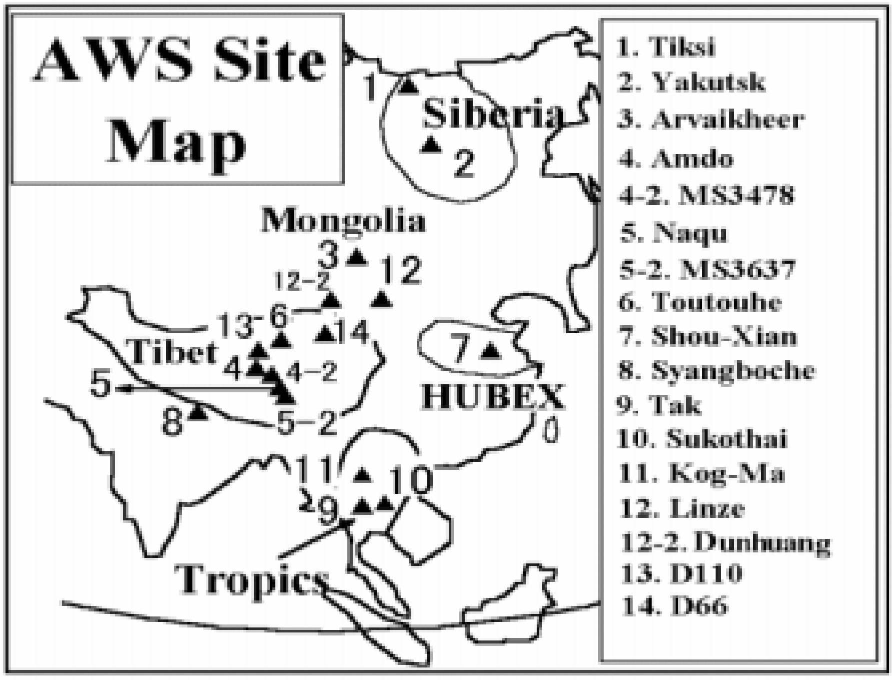

Fig. 1. A map showing the location of GAME-AAN flux stations currently in operation. Triangles indicate those stations expected to operate through phase II of GAME-AAN, while circles represent those that will operate only during phase I.

2. Phase I activity summary

- AWS test and operation

As mentioned, Phase I has just been completed. In general, initial plan of the test and installing AWSs in GAME areas achieved as planned. However, there were problems, both expected and unexpected, that interrupted field measurements and resulted in unavailability of relevant data during the intensive observation periods of GAME in some areas. Problems came from probably two separate reasons. First one is that in AWS systems, particularly PAM III station developed and produced by National Center for Atmospheric Research in the U.S. are very sophisticated and require a careful maintenance and operation, although they have strong capability to produce very accurate measurements with a modest cost when compared with other AWS systems. Although we could get a long term data of turbulent fluxes through direct measurements with the PAMIII when it works well, unfortunately we had more missing data than the other AWSs (see Fig. 2 and Fig. 3). Most of the missing data was caused by the unstable and incomplete system of data acquisition system of PAMIII, while most of sensors were working properly. Some other reason for such trouble is that in GAME scientists and local counterpart personnel to operate AWS systems did not have adequate time to get accustomed to the system due to the quite complicated systems. Thus when a technical problem occured in some remote area, it took a long time to solve it. These problems, however, have occurred gradually less frequently and continuous measurements become more common at some stations, after we modified the system of PAMIII based on the discussions between NCAR and GAME scientists in the workshop held at Boulder, U.S. in July, 1999 (see detail in our

website: http://www.suiri.tsukuba.
ac.jp/Project/aan/meeting-ws/ws-PAM99.html). Both GAME scientists and counterparts have got a better knowledge of the system and an additional backup data acquisition system was installed in 2000-2001 for a reliable long-term measurements.

- The AAN data

The data have been, and will be, checked and processed as they are provided from each station for archiving at the AAN data center at Terrestrial Environment Research Center of the University of Tsukuba. Each station has four types of dataset within the data archives. They consist of (i) the station documentation, (ii) the dataset documentation, (iii) the data inventory and (iv) actual dataset. To produce these datasets and to provide them in AAN data center have the responsibility by PIs of each station. At the moment, for most stations (i)-(iii) are available (see Fig. 4-6 as examples), through the AAN website (http://www.suiri.tsukuba.ac.jp/Project/aan/aan.html). The actual data (iv) are now being distributed within the GAME community for the 1998 data sets, and will soon be open to a wider scientific communities based on GAME data policy. However, there are some stations which lack an adequate description of the data sets or the station. There are also some station which has not produced complete data sets from the original measurements. These variables often include the latent and sensible heat fluxes which require a careful quality check of the data and processing of the measured values before they can be used with confidence.

- Scientific Issues

To summarize and wrap-up the Phase I activities and to address future needs of AAN activities, the International Workshop on GAME-AAN/Radiation was held at Phuket in Thailand on March 7-9, 2001 with about 100 participants and 40 oral presentations. Some of presentations were already published to scientific journals (e.g., Aoki *et al.,* 1998; Ohta *et al.,* 1999, 2001; Toda *et al.,* 2001). Below some important topics discussed in this workshop are summarized as follow:

One of the issues that has emerged in the process of deploying AWSs and the data analysis is the so-called energy imbalance problem. Theoretically, the sum of latent and sensible heat fluxes should be balanced with net radiation and soil heat flux. However, in many AAN sites this turned out not to be the case, although some sites reported close to perfect balance (see Fig. 7). Current consensus appears that the closure problem is site specific and that up to 20-30% of the net radiation may not be able to accounted for from measurements. Possible reasons have been identified as a problem of turbulence measurements technique, sampling error of the soil heat flux and the net radiation measurements, and a mismatch of foot print of equipments used to measure energy balance components. Intensive discussions at scientific meetings, both at the international workshop and other related meetings, took place, and as a result, an additional field observation initiative has started in which 5-10 eddy flux measurement systems were installed side by side at a well maintained and controlled site, and their difference, and possible causes for the imbalance problems are being investigated.

Although Phase I is for the test and deployment of AWS systems, some initial results of a long term measurements are being reported. Figs. 8-9 which indicates that three geographically very different locations showed difference in variations of surface energy partition regime, both in time and in magnitude (Miyazaki *et al.,* 2001).

Additionally, some interesting and encouraging results were reported with the Phase I AAN data set. Figs. 10 and 11 illustrate such two examples. Figs.10 and 11 give comparisons of the surface fluxes obtained from one AAN surface station and from GAME and ECMWF reanalysis data (Yatagai *et al.,* 2001). For the reanalysis data, flux values of the nearest grid were used. The comparison indicates reanalysis very good agreement of the measurements and model derived values. This tends to indicate, in the viewpoint of the surface station, that a point measurement of the station represents somehow a region surrounding the station. This is encouraging for the use of the AAN data and actually may not be too surprising given the fact that each station site was selected so as not to be too local and not to be too different from its surrounding areas. Fig. 12 illustrates one example of the use of AAN data for the model validation (Sugita *et al.,* 2001, Sugita, 2001). Because AAN sites cover a wide range of geographical areas and climates, a comparison of any variables produced from a model or from a satellite against the AAN data sets should give opportunity for a thorough validation of these data (and, in turn, the model or the satellite measurements themselves).

3. Future Plan

Curretly 9 stations are planed to keep operation through Phase II of the AAN to obtain a long-term trend of surface variables. At the moment, proposals to get adequate funding and resources for the operation are under consideration.

In addition to the continuation of the measurements, an urgent task to be made is to update and complete the AAN data sets. This should include strong efforts of the AAN data center to obtain the data and the derived values by each PIs for distribution among the scientific communities. Also, for those scientists who do not have easy access to the Internet, data distribution by some medias (e.g., CD-ROMs) are also being considered.

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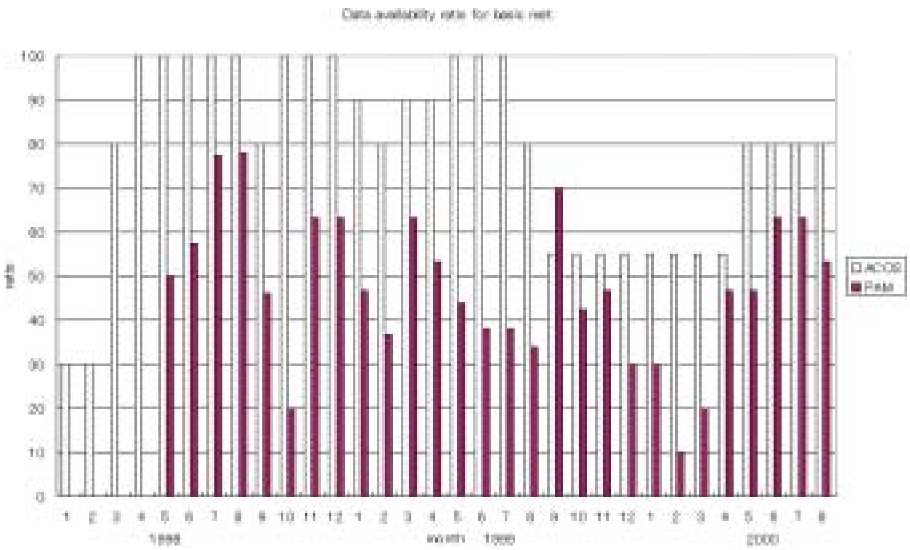

Fig. 2. Time series of the data availability for basic meteorological elements (e.g., air temp., precipitation, wind speed) obtained by ACOS (Automated Climate Observing system) and PAMIII. These values were calculated by using raw data for ACOS but processed data for PAMIII.

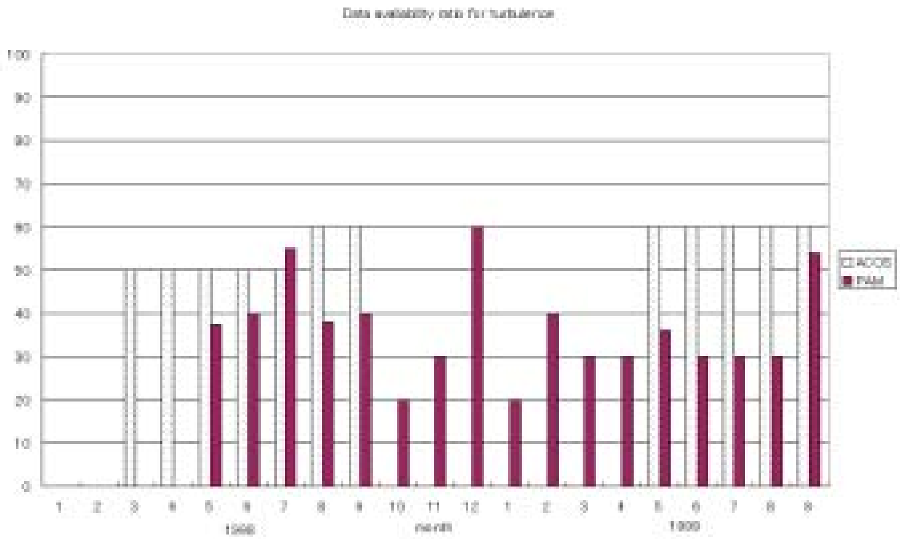

Fig. 3. Same as Fig. 2 but for surface fluxes (sensible heat flux, latent heat flux, momentum flux).

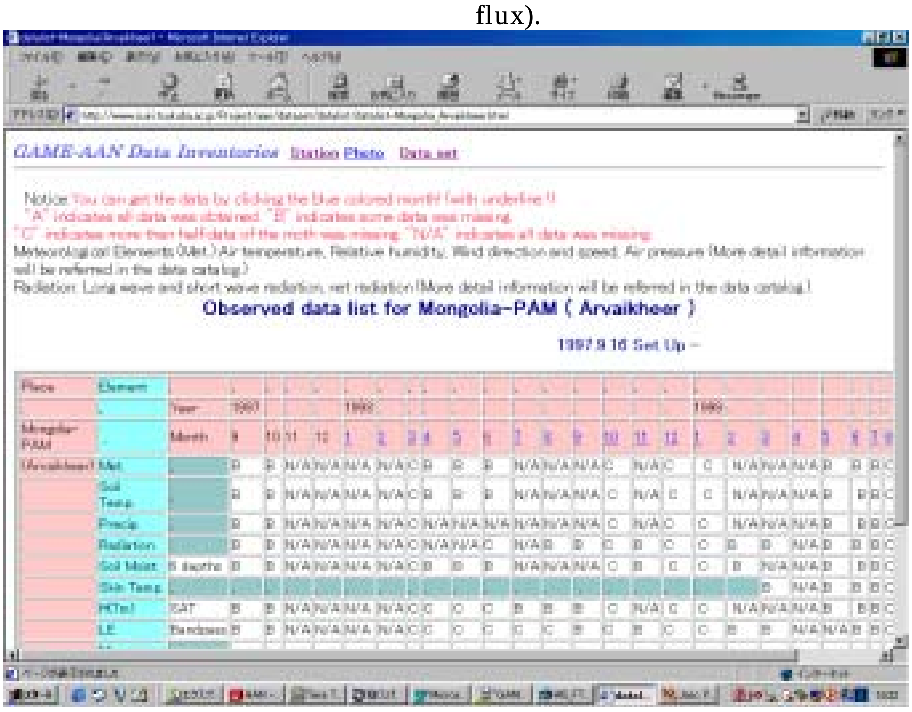

Fig. 4. An example of the GAME-AAN data inventory list as seen on the AAN web site.

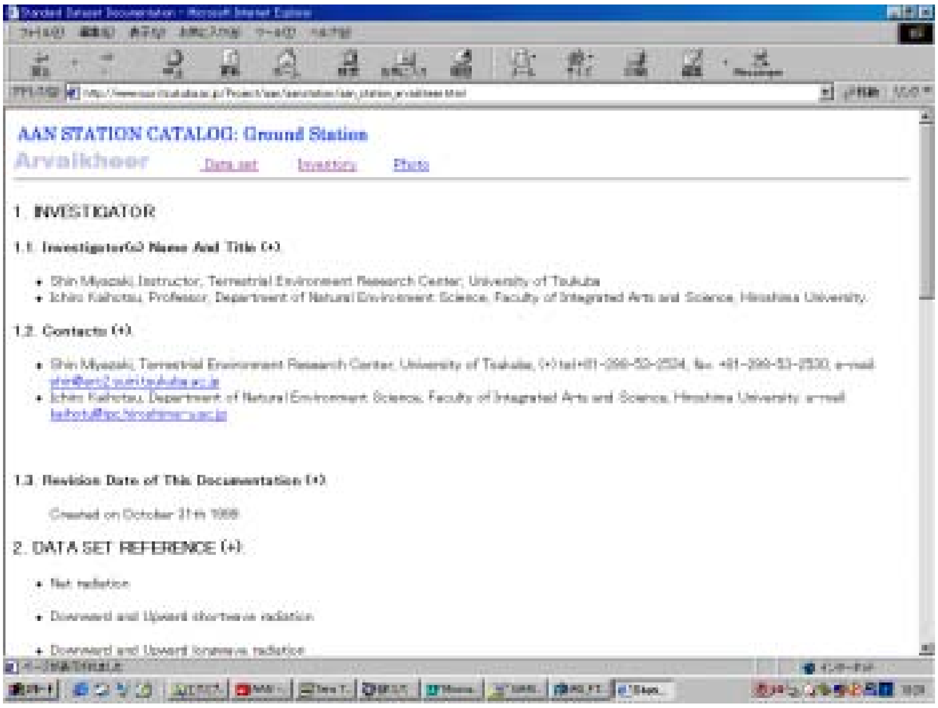

Fig. 5. Same as Fig.4 but for dataset documentation.

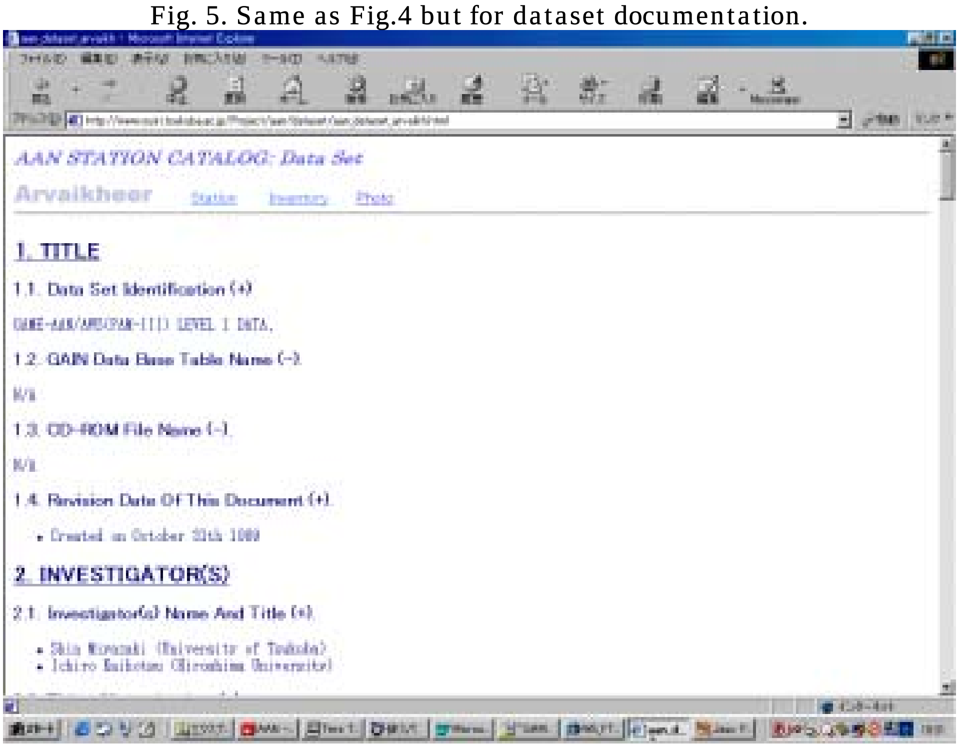

Fig. 6. Same ad Fig.4 but for station documentation.

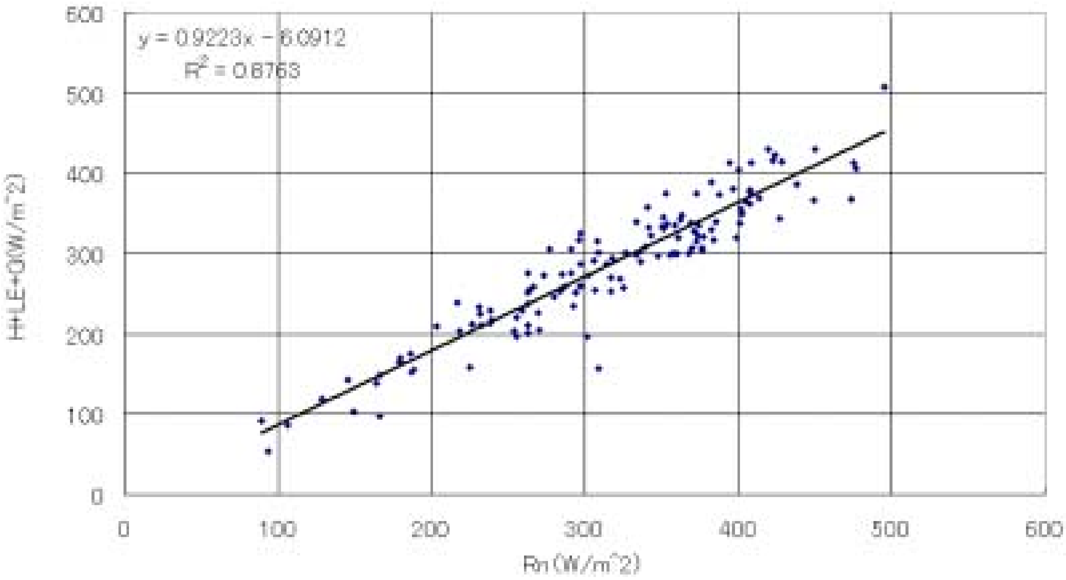

Fig. 7. An example of energy balance closure as reported from an AAN station located in Mongolia.

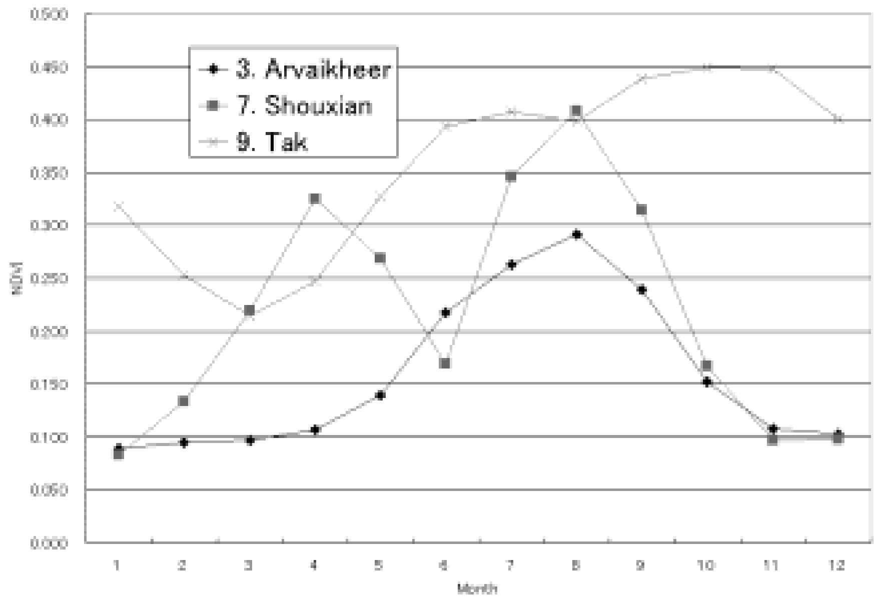

Fig. 8. Seasonal variation of NDVI at three AWS locations as given with 20-year means.
(see Fig. 1 for the exact location)

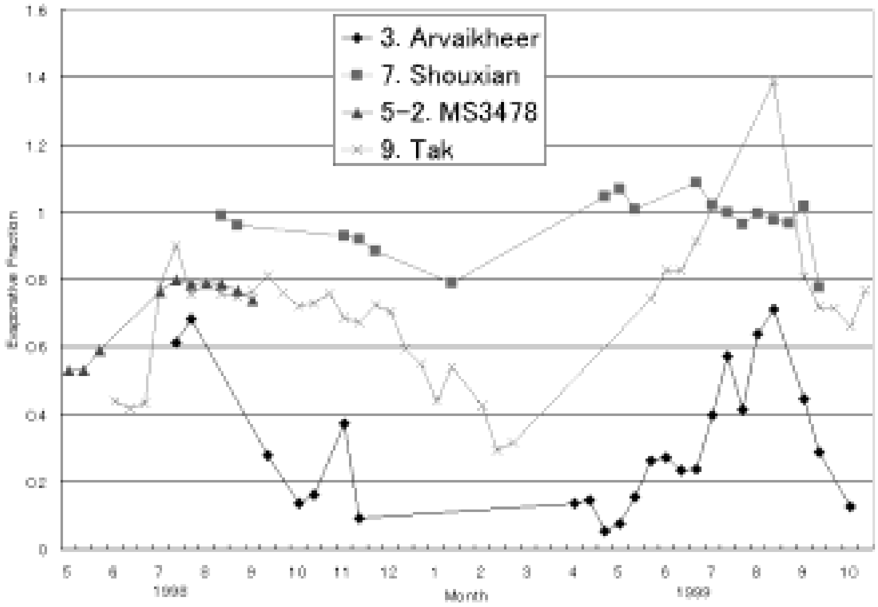

Fig. 9. Seasonal march of evaporative fraction
[=LE/(Rn-G), the ratio of latent heat flux and available energy]

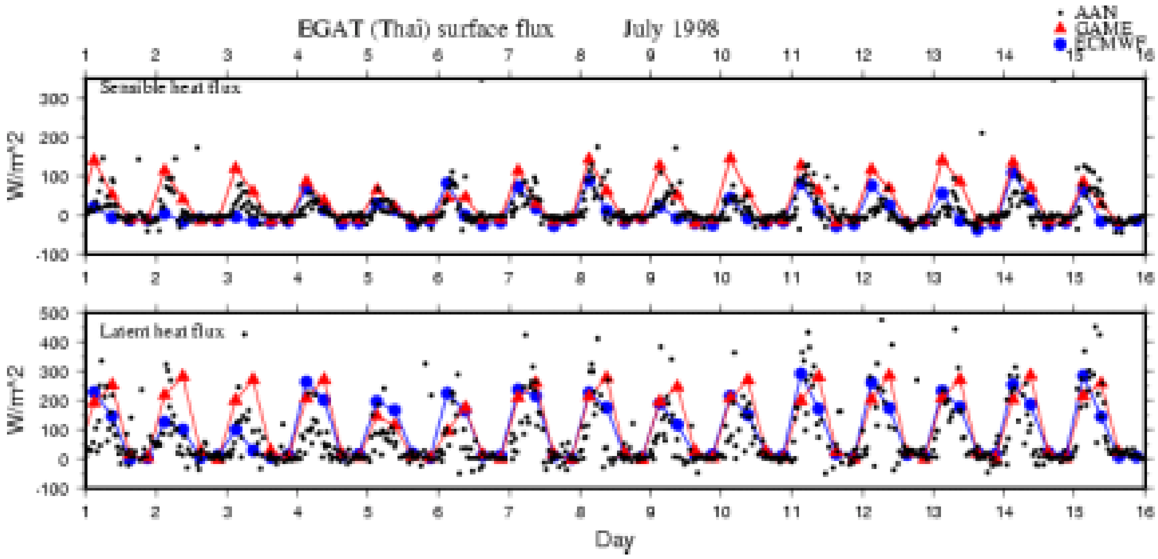

Fig. 10. Comparison of sensible heat flux (upper panel) and latent heat flux (lower panel) between GAME reanalysis Ver. 1.1, ECMWF operational dataset and AAN observation (EGAT tower at Tak in Thailand). Small dots indicate AAN observation (every 30 minutes); triangles, GAME reanalysis; and circles, ECMWF operational dataset.

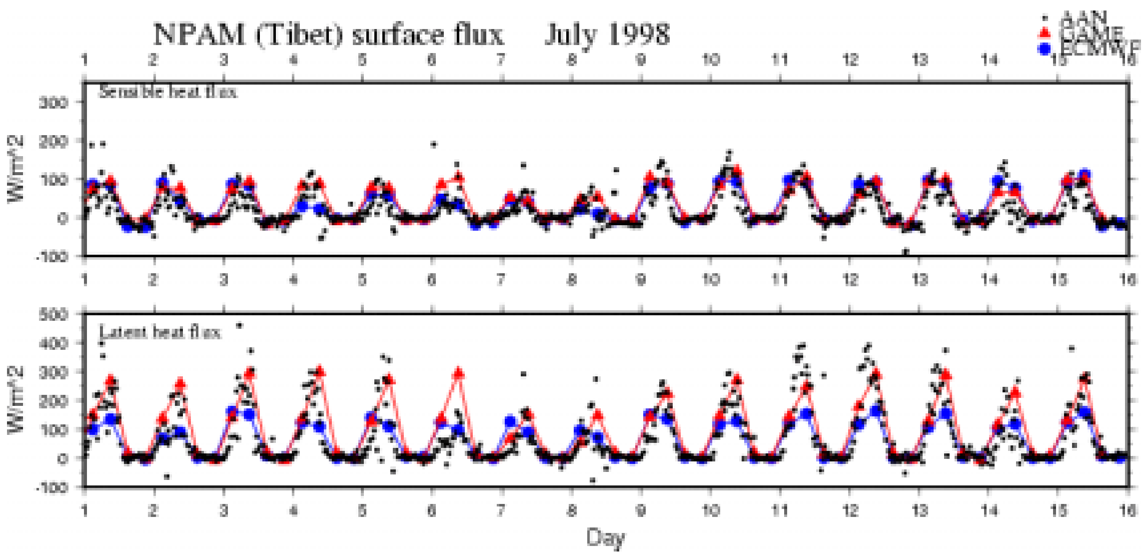

Fig. 11. Same as Fig. 10 but for the site of AAN observation (north PAMIII on Tibetan Plateau).

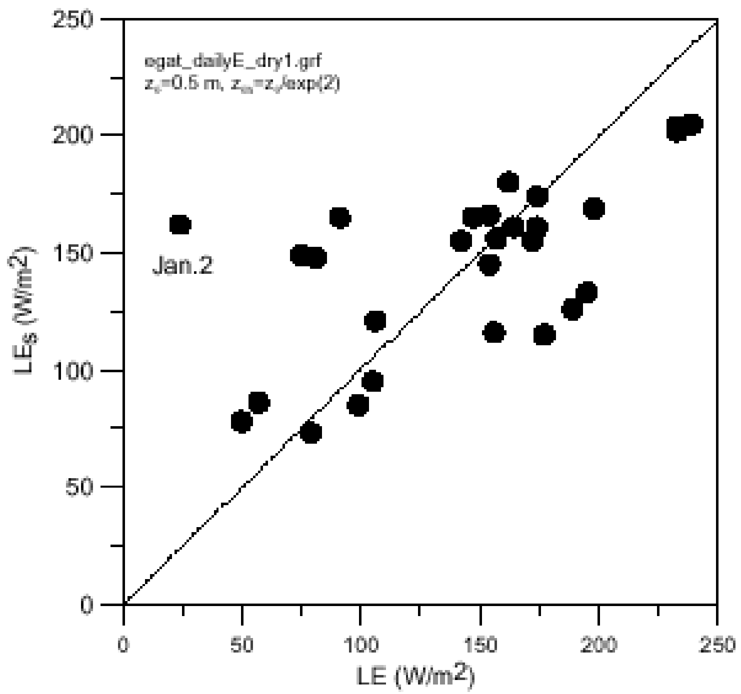

Fig. 12. Comparison of model derived latent heat flux (LEs) and AAN measurements at Tak in Thailand during dry season (Sugita *et al.*, 2001).

[Radiation group]

1. Objectives of the GAME Radiation Study

Investigation of the earth's radiation budget is important for understanding the energy and water circulation processes in the GAME region. It is also important to study the impact of large scale air pollution in the Asian region to understand the impact of anthropogenic aerosols to the global warming phenomenon through investigation of the radiative properties of aerosols and clouds (Emori *et al.,* 1999). In this program, the following tasks are considered to attain these researches:

1) Developing an accurate method to estimate the surface radiation budget from satellite data. The wide area distribution of solar insolation flux at surface is desirable to obtain from the GMS satellite data.
2) Establishing an accurate radiation budget monitoring at several sites in the GAME

area for validation of the radiation budget derived from satellites. In this activity, BSRN (WMO Baseline Surface Radiation Network) type instrumentation is introduced for accurate measurements of the surface radiation budget. A microwave radiometer and a sky radiometer instrumentation to retrieve the cloud and aerosol radiative properties which are indispensable for theoretical simulation of the radiation budget. The data are being archived to provide surface shortwave and longwave radiation budget at these sites.

3) Investigation of the effect of cloud and aerosol radiative forcing. Direct and indirect climate effects of anthropogenic aerosols have become recent important topics for improving the global warming simulation. Data from the sky radiometer network called SKYNET which includes GAME radiation sites and satellite radiance data of AVHRR, SeaWiFS and MODIS have been analyzed to derive the radiative properties of aerosols and clouds useful to depict the aerosol climate effects.

The final goal of the radiation activity is to reduce uncertainties involved in the estimation of the earth and surface radiation budget, especially due to clouds and aerosols in the Asian region. The uncertainty of the radiation budget coming from cloud and aerosol is said to be 20 to 30 W/m^2, which is 6 to 8 % of the total incoming solar radiation.

2. Activities of the GAME Radiation Group

In order to pursue the previously mentioned three objectives, the following activities have been performed.

- SKYNET and GAME high precision radiation Sites

The SKYNET is a network of a sky radiometer, which is similar to the NASA AERONET sun/sky photometer network (Holben *et al.,* 1998), to measure the sky radiance distribution as well as the direct solar irradiances at several wavelengths from 360 nm to 1020 nm, from which aerosol size distribution and optical thickness are retrieved. A pynanometer is also required at the sites for measuring the downward solar radiative flux. SKYNET sites are shown in Fig. 1. Sri Samrong (Thailand, 16.9N, 99.8E, since July 1997), Shou-Xian(China, 32.6N, 115.8E until March 1999) /Hefei (China, 31.9N, 116.9E, from April 1999) are the GAME-AAN High Precision Radiation sites, where full instrumentation of the surface radiation budget and cloud/aerosol measurements have been installed. A lidar, and a microwave radiometer were installed at Sri Samrong. Takayabu *et al.* (1999) studied the radiation budget in Tsukuba with data from similar instrumentation as shown above.

- Solar flux distribution from GMS satellite

The surface solar radiation was estimated from GMS visible and infrared radiance data (Fig. 2) and compared with the values observed at the GAME High Precision Radiation sites and SKYNET sites (Fig. 3). Monthly mean values of the surface radiation flux in 1997, 1998, and 1999 are basically in good agreement with the observation. Detailed comparison shows, however, a minor difference which is considered to relate to the aerosol optical thickness and the diffused light intensity. When the aerosol optical thickness is large the surface radiation flux is correctly estimated, but the satellite value underestimates the surface-measured value when the aerosol layer is thin. This suggests that an adequate introduction of aerosol loading is important for accurate estimation of the surface solar radiative flux from satellite radiances.

- Lidar measurements

From the lidar monitoring, the cloud base height statistics was obtained. The results show that the cloud base height is dominant at around 1.5 km altitude and the cloud is detected in 90 % cases in rainy season (July and August), whereas clouds tends to be double layered with peak altitude at 1.5km and at an altitude higher than 6 km in dry season (Fig. 4).

-Aerosol characterization by surface measurements

From the model simulation, it is known that each aerosol has a different effect to the earth radiation budget. Light absorbing aerosols such as black carbon and soil dust aerosols have a warming effect, but other aerosols such as sea salt and sulfate aerosols show a cooling effect (Fig. 5). It is important to obtain a large scale distribution of the aerosol optical radiative properties, especially the single scattering albedo, to attain an accurate estimation of the radiative forcing of the direct effect of the anthropogenic aerosols. In February, dry season in Thailand, the effect of biomass burning was outstanding. The size distribution from the sky radiometer, showed a large optical thickness and smaller size distribution with smaller single scattering albedo than those in rainy season (Fig. 6). Chemical analysis of sampled aerosols gave a large black carbon (BC) concentration in the dry season, which is considered to be due to biomass burning. The large absorption by black carbon is reflected in the single scattering albedo as low as 0.75 in the beginning of the period, whereas the single scattering albedo started reaching 0.9 when the optical thickness becomes small in the latter period.

The radiative properties of aerosols were also monitored in the West Pacific region in a cruise of the research vessel Mirai. The latitudinal dependence of the aerosol size distribution shows that fine particles (larger Angstrom exponent) are dominant in the region to the north of 20N due to industrial sources located in the middle and high latitudes. This is also reflected in the single scattering albedo value observed by the Mirai cruise (Fig. 7). The northern area has a single scattering albedo as low as 0.8, whereas the subtropical and tropical area has a value close to the unity, indicating the effect of the black carbon is significant in the large area of the northern hemisphere.

- Satellite remote sensing of aerosols and clouds

An algorithm of retrieving the aerosol optical thickness and Angstrom exponent were developed (Higurashi and Nakajima, 1999) and applied to channel 1 and 2 radiance data of AVHRR (Nakajima and Higurashi, 1998; Nakajima *et al.,* 1999b; Higurashi *et al.,* 2000). It is found that the resulted characteristic distribution of small-size and large-size aerosols are consistent with model results from the aerosol transport model of Takemura *et al.* (2001) although the satellite-derived aerosol optical thickness somewhat overestimate the model values due to cloud screening problem. The model results, on the other hand, may have an error due to an uncertainty in the emission source assumption. The radiative properties of biomass burning aerosols were investigated for the Indonesian forest fire event in 1997 (Nakajima *et al.,* 1999a). The single scattering albedo shows a value around 0.9 in this Indonesian case, which is slightly larger to the Thailand biomass burning case shown in the previous subsection. This may be explained that Indonesian aerosols included sulfate particles generated from the peat bog burning.

Cloud microphysical parameters were also retrieved in this study with the solar reflection method (Kuji *et al.,* 2000; Kawamoto e*t al.,* 2001). The radiative forcing of the indirect effect of anthropogenic aerosols was further estimated by Nakajima *et al.* (2001) using the correlation between aerosol and low cloud microphysical parameters derived from AVHRR remote sensing. It is found, for example, the columnar aerosol number density has a correlation with that of low clouds as $\Delta \log 10\ Nc \approx 0.5\ \Delta \log 10\ Na$. These correlations thus obtained give an estimate of the indirect forcing of anthropogenic aerosols as RF= -0.7 to -1.7 W/m^2 over ocean.

3. Future Prospect

More comparison between surface radiative flux observed at the radiation sites and satellites is required in order to reduce the uncertainty in the surface radiation budget. Model calculations of the surface radiation budget with the radiative properties of aerosols and clouds retrieved from surface and satellite measurements are also important to understand the role of clouds and aerosols to determine the radiation budget. The vertical structure of aerosol and cloud stratification observed by lidar data should be incorporated with such analysis and model calculation of the surface radiation budget, especially for the longwave radiation. From a logistic view point, we need more stable instrumentation at the existing radiation sites to generate long-term and complete data sets from all the instruments. We may need 2 to 3 more stations to cover the GAME region for the radiation studies. Development of aerosol remote sensing over land is one of high priority issues to pursue. In this regard it should be pointed out that the recent TERRA/MODIS aerosol product over land will be useful to be combined with the GMS retrieval algorithm of the surface radiation budget, because it is found that a suitable aerosol loading should be introduced in the retrieval algorithm. Data from the coming satellites, ENVISAT, AQUA, and ADEOS-II, will increase our ability for retrieving the earth and surface radiation budget as well as the global distribution of aerosol and cloud parameters (T.Y. Nakajima, 1998; King *et al.,* 2000; Kuji and Nakajima, 2001).

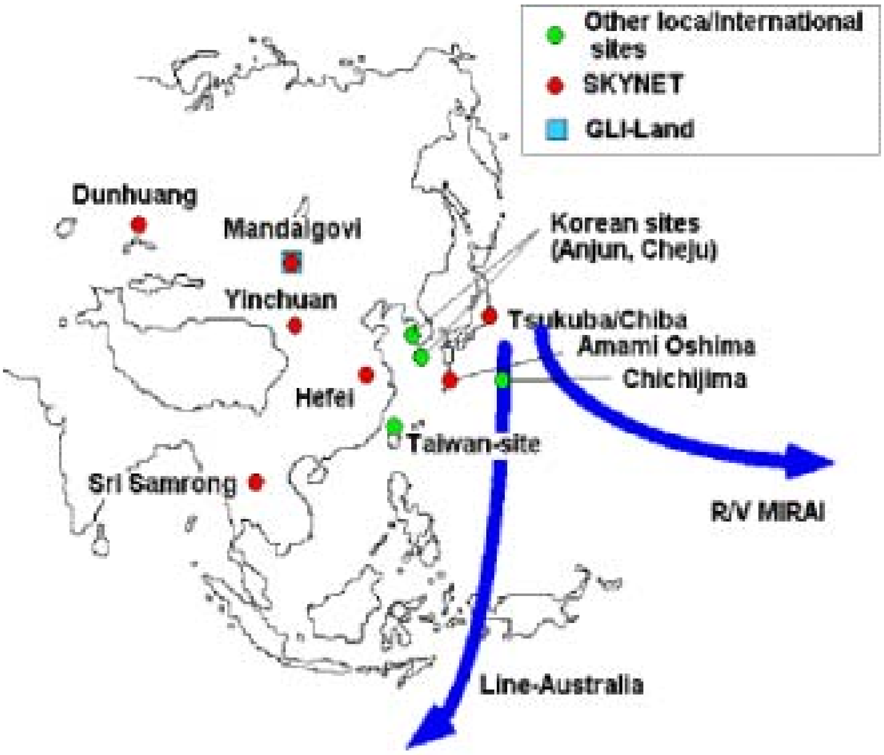

Fig. 1. Radiation observation sites.

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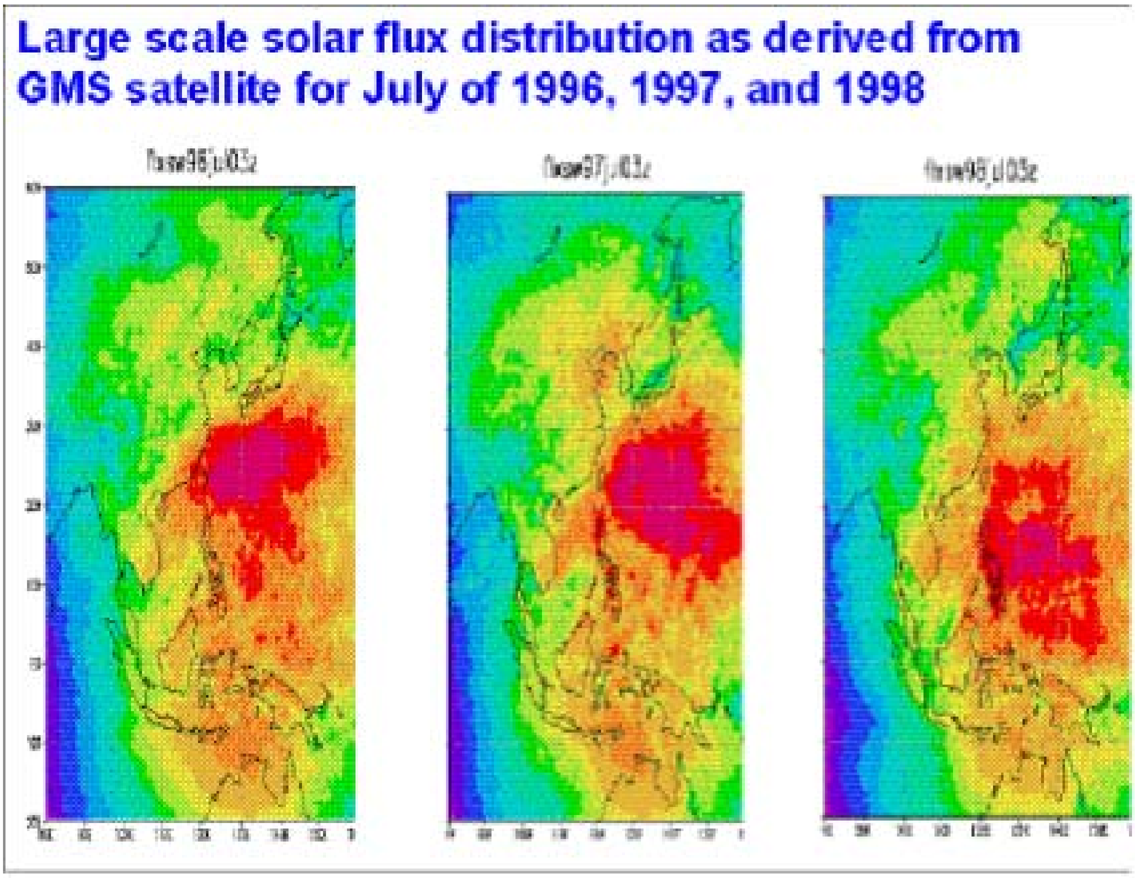

Fig. 2. Surface solar radiation was estimated from GMS data.

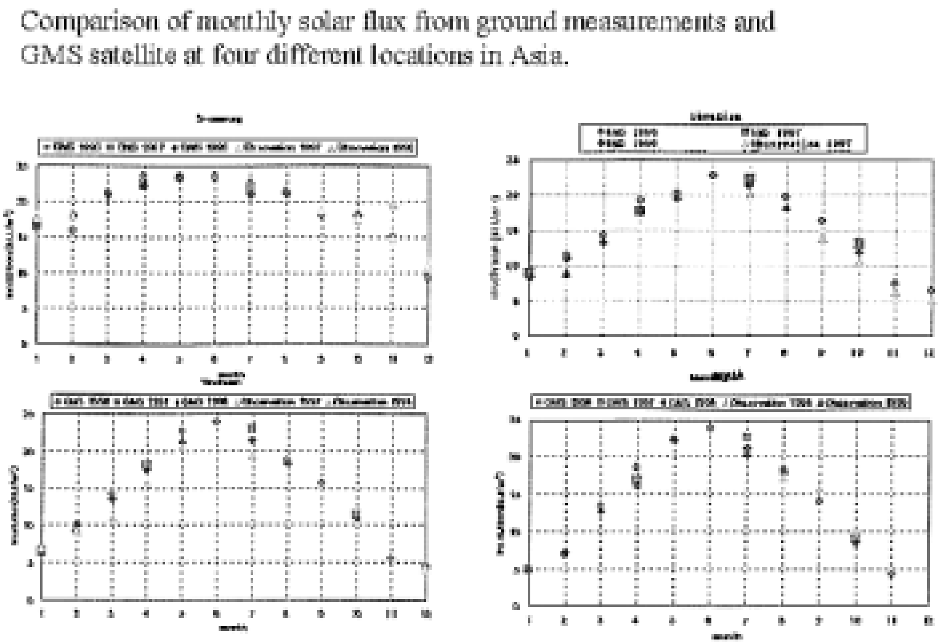

Fig. 3. Comparison of monthly solar radiation flux from the ground measurement and GMS data.

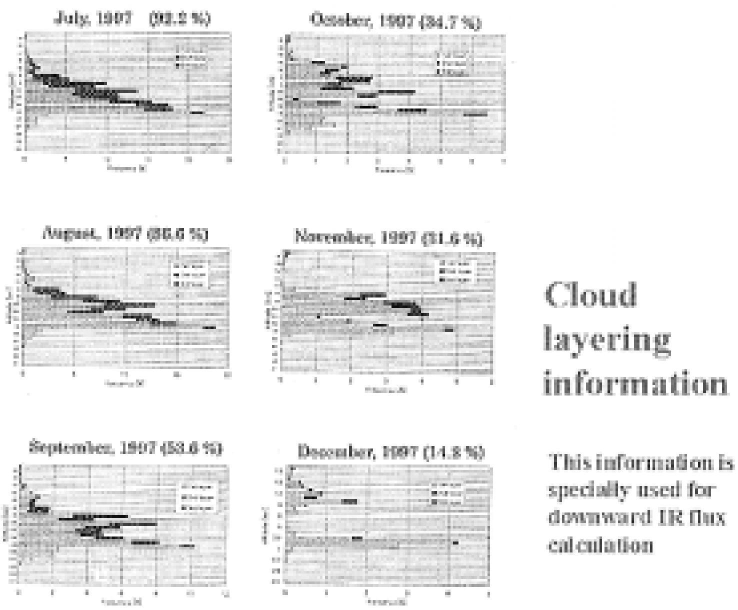

Fig. 4. Histogram of cloud height observed by lidar.

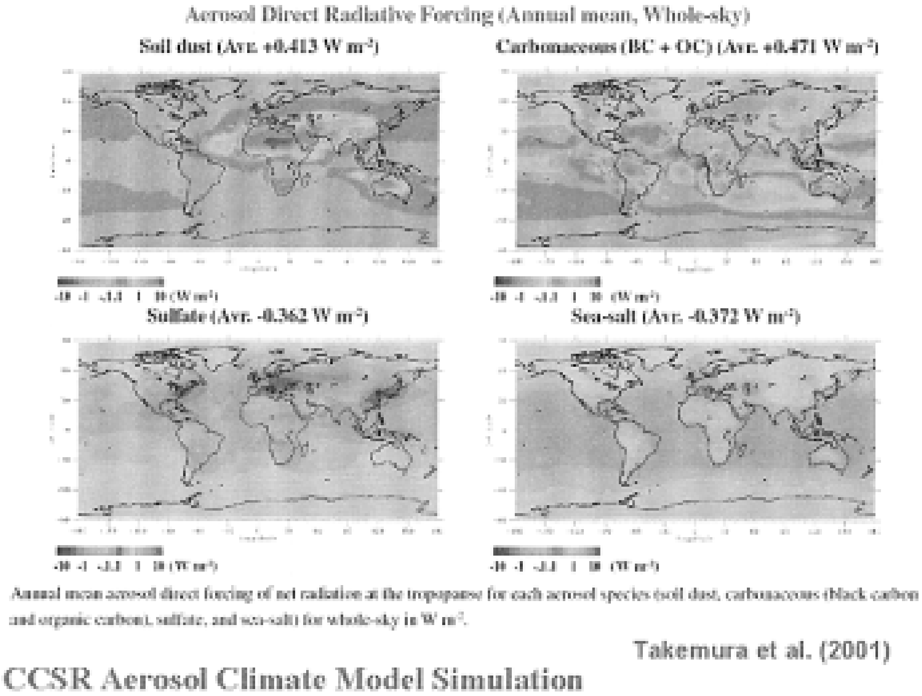

Fig. 5. Aerosol direct radiative forcing(annual mean).

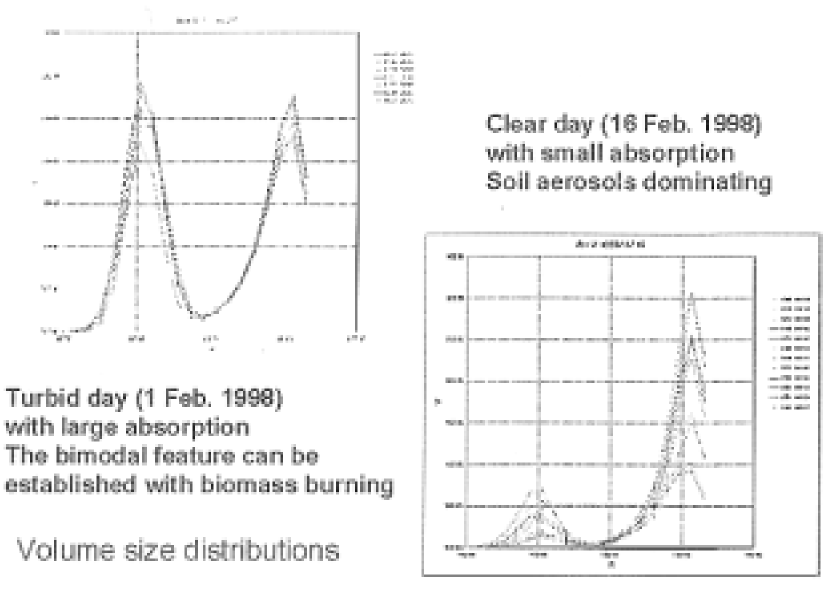

Fig. 6. Aerosol size distribution.

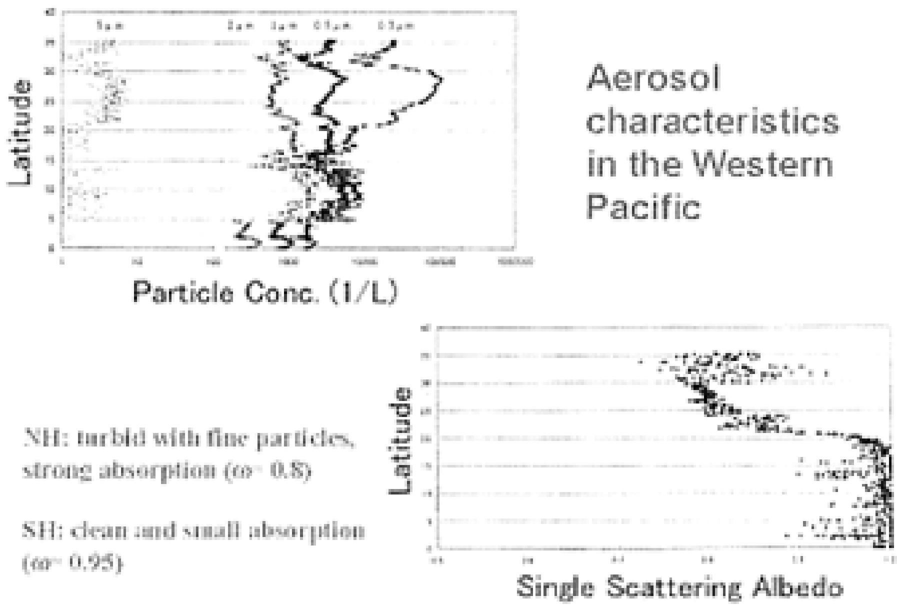

Fig. 7. Aerosol characteristics in the Western Pacific.

Summary of GAME modelling activities

A. Sumi and F. Kimura

1. Introduction

When the GAME was started, the objectives of the modelling component was defined as follows;

1) By conducting the flux observations in the various regions over the Asian Monsoon area, we can develop/improve a land-atmosphere interaction scheme, which is now used in GCM.
2) By applying the improved parametarization scheme, we can improve the prediction skill of the atmospheric flow and precipitation in the Asian Monsoon region.
3) Based on the improved models described above, we can contribute to the improvement of seasonal prediction and water-resource management, and present the detailed information about the change of water cycle in the Global Warming situation

In order to achieve these objectives, the research activities were organized in the three components;

4) One dimensional study: the land-atmosphere interaction is investigated by comparing the observations conducted in the GAME IOP and the various models such as SiB2 and the bucket model.
5) Two-dimension study: the land-atmosphere interaction is investigated by using the non-hydrostatic meso-scale model such as the RAMS and the NHM developed at the NMI/JMA. Emphasis is placed on the interaction between detailed orography and convection.
6) Three-dimensional study: the land-atmosphere interaction is investigated by using the CCSR AGCM and the CCSR/NIES Climate model.

It should be noted that research relating to study 4) and 5) is conducted in the regional studies of the GAME activities and many results are described in the other sections. Here, we will briefly summarize the achievement of the modelling component.

2. One dimensional study

- Evaluation of SiB2

Takayabu(MRI/JMA) are collecting observational data from the regional experiments and making a standard data set for comparising and evaluating the one dimensional flux schemes. He compared the observed data in the Tibet by the SiB2 result.

3. Two dimensional study

- Relation between orography and convection by two-dimensional RAMS

Sataomura (2000) investigated the diurnal variation over the Indo-China Peninsula using the two-dimensional RAMS, which is a nonhydrostatic cloud-resolving numerical model. He found out that solar-synchronized life cycle of the squall lines and their eastward movement cause the nighttime maximum of the precipitation over the inland area of the Peninsula, which has been actually observed.

Kurosaki and Kimura (2001) carried out some two-dimensional numerical experiment over a cross-section over Himaraya and Tibetan Plateau (Fig. 1). The model shows the clear diurnal variation of convective clouds over some dominant mountain ranges in the Plateau, which agree well with the satellite observations.

4. Three dimensional study

GCM study has been conducted by using the CCSR/NIES GCM. As you may expect, it is impossible that the new scheme is proposed immediately after the IOP was over. Then, emphasis is placed on the understanding of the atmosphere-land interaction by using the present CCSR/NIES GCM. Regional and mesoscale modeling are also conducted using RAMS and other numerical models.

- 1997 and 1998 Asian Monsoon Study

1997 and 1998 was the El-Nino year and the influence of the El/Nino to the Indian Monsoon was investigated by Xhen and Kimoto (1999). Besides that, it was the abnormal year when the heavy rainfall occurred in the Yantzen River. This topic was investigated by using the 1998 SST. It is concluded that SST in the Indian Ocean has a strong effect on the anomouraous precipitation over the Asian region (Kimoto *et al.,* 2000).

- Sensitivity study to the horizontal resolution for the atmosphere-land interaction

Atmosphere - land Interaction Sensitivity to the horizontal resolution is now being conducted by using T42 and T106 CCSR/NIES AGCM . The simulation was stared from the April 1, 1998 and integrated until the end of August. Sensible and latent fluxes and precipitation in the two models were compared over the different regions, such as the Tibetan lateau (80-100E, 27.5-35N), Thai (100-106E, 15-20N) and China (115-120E, 30-35N). Over the Tibetan region, difference are about 20 W/m^2 in the monthly mean. The large differences are noted in May, which are due to the differenece of the large scale flow. In China, a large difference of precipitation is noted in June. However, difference of fluxes are about 20 W/m^2 in these areas. In order to estimate the differenecs due to the internal fluctuation of model simulation, the ensemble experiment will be conducted.

- Sensitivity study to the land scheme for the Asian Monsoon Flow

As it takes some time for the new scheme to appear, we decided to use the other scheme developed at other place. We has chosen the MATSHIRO, which is now being developed by the researchers in Japan. Now the MATSHIRO model is being implemented and tested. After that, simulation study will be conducted.

- Baiu/Meiyu Front and heat contrast between Asian continent and Ocean

Yoshikane *et al.* (2000) clarified one of the formation mechanism of the Baiu Front. By a regional climate model, they showed that one of the most important mechanism of the Baiu Front is the heating contrast between land and ocean. The Baiu Front can be formed only by the interaction between global scale zonal mean flow and the contrast between them. Surface moisture of the Asian continent may affect the position and intensity of the Baiu Front.

- Hydrological and Atmospheric Modeling Studies in HUBEX

The modeling study of HUBEX (the Huaihe River Basin Experiment) includes hydrological and meteorological modelings. In particular, their coupling and water cycle modeling experiment using a coupled model are most important objectives of HUBEX. In the hydrological modeling, SiBUC (the Simple Biosphere Model including Urban Canopy) has been progressed in Kyoto University. A coupling experiment of SiBUC with a mesoscale atmospheric model was performed. To simulate movement of ground water, a runoff model also has developed. Simulation experiment of water discharge using the runoff model showed good an agreement between simulated and observed runoffs.

In the meteorological modeling study, a mesoscale simulation using JSM (the Japan Spectral Model) which was developed by the Japan Meteorological Agency has been performed to study a regional water cycle and precipitation.

Cloud and precipitation studies are the most important objectives in HUBEX. In order to study dynamics and evolution of convective clouds over the China continent, we now develop the Cloud Resolving Storm Simulator (CReSS). We performed the simulation experiment of the observed squall line using CReSS with very high resolution in a large three-dimensional domain. The inhomogeneous initial field was given by the dual Doppler radar observation and the sounding. The experimental design is as follows. The horizontal and vertical grid sizes were 300 m and 300 m, respectively with a domain of 170 km × 120 km. Cloud microphysics was the cold rain type. The boundary condition was the wave-radiating type. The result of the simulation experiment shows that CReSS successfully simulated the development and movement of the squall line (Fig. 2). The convective reading edge was maintained by the replacement of new convective cells and the simulated squall line moved to the northeast which is similar to the behavior of the observed squall line. Convective cells reached to a height of about 14 km with large production of graupel above the melting layer. The rear inflow was significant as the observation. A stratiform region extended with time behind the leading edge. Cloud extended to the southwest to form a cloud cluster.

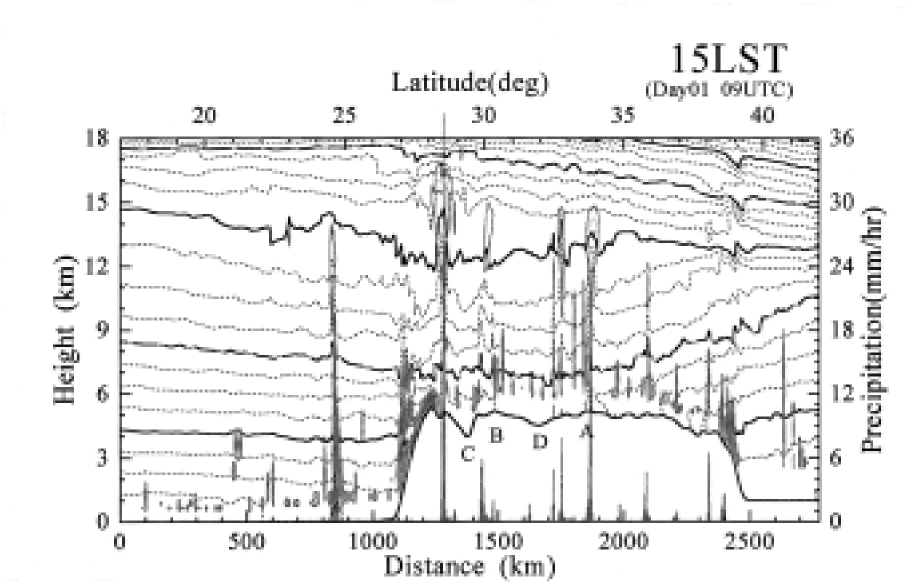

Fig. 1. Vertical cross-section of potential temperatur (broken lines), liquid/ice water content (thin lines) and precipitation (bars) at 1500 LST over Himaraya and Tibetan Plateau, simulated by the two-dimensional RAMS. Grid interval is 2 km.

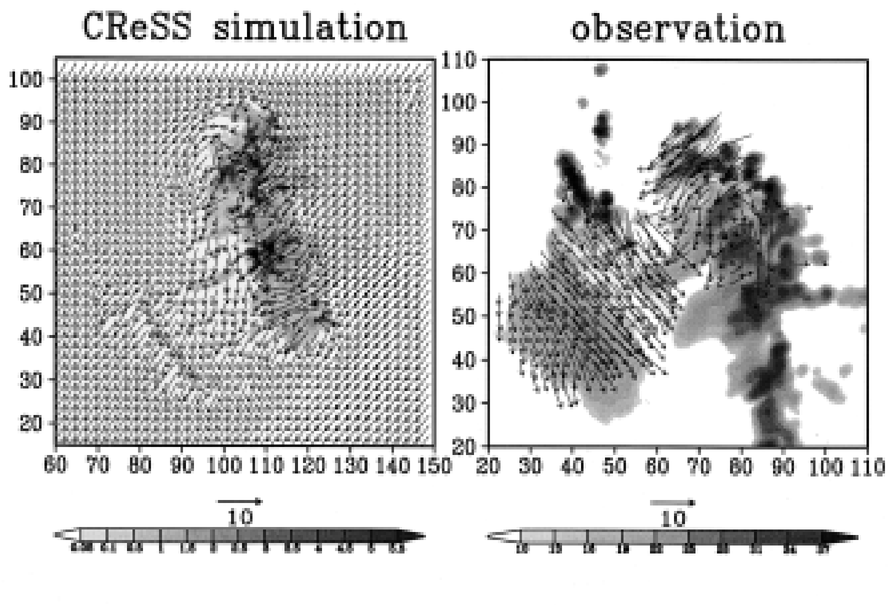

Fig. 2. Horizontal displays of the simulated squall line (left panel) and the observed squall line (right panel) at 1204UTC, 16 July 1998. Gray levels indicate total mixing ratio (g/kg) of rain, snow and graupel in the left and radar reflectivity (dBZ) in the right. Arrows are horizontal velocity.

Report on the GAME Reanalysis

Nobuo Yamazaki and Kiyotoshi Takahashi
(Meteorological Research Institute/JMA)
Akiyo Yatagai(Research Institute for Humanity and Naturey

1. Introduction

GAME reanalysis project in Japan started in 1999 with a joint effort of the Meteorological Research Institute, Numerical Prediction Division/Japan Meteorological Agency (JMA), and the Earth Observation Research Center. The Object of the GAME reanalysis is to collect off-line data during the GAME IOP period and to obtain reanalysis (Yamazaki et al., 2000, Yatagai et. al. 2000) of higher quality using the most updated assimilation system and the off-line data as well as on-line data through the GTS. The target period is from April to October, 1998. Most of collected off-line data are located between 25 N and 40 N in China. The assimilation system used is almost the same as the current operational JMA system: 3 dimensional optimum interpolation scheme and forecast model with 0.5625 degree horizontal resolution, 30 vertical layers and prognostic Arakawa-Schubert convective scheme.

The GAME reanalysis version 1.1 and 1.5 were released in September 2000 and June 2002 respectively. Anyone can access and use these reanalysis data for scientific purpose. Please refer to the web page http://gain-hub.mri-jma.go.jp/GAME_reanal.html for more detailed information and data access.

The difference between ver.1.1 and 1.5 is shown in Table 1. The main differences are:

1) SCSMEX Sonde observation data are incorporated.
2) Input data of snow depth are retrieved from SSM/I and input data of soil temperature are taken from result of the six hour forecast. Both of them were climatological values in ver.1.1.
3) Total precipitable water information over sea estimated from SSM/I and OLR is incorporated.
4) Forecast time to obtain some reanalysis output as precipitation is now 12 to 18 hour forecast. It varied 18 to 24 hours or 12 to 18 hours in ver.1.1.

2. Validation

Purpose of this paper is to validate the GAME reanalysis data using independent observation data, GPCP, TRMM, station(sonde, flux) and to compare with other reanalysis. Table 2 shows data used and methods to validate.

(1) Wind validation

The Tibetan Plateau is believed to play an important role in evolution of the Asian monsoon, few sonde stations are operational, e.g., no operational rawin sonde station in west Tibet. GAME IOP(Intensive Observational Period) sonde network is specially focused in the Tibetan Pleateau. Fig. 1 shows comparison of mean square wind vector difference from sonde obsevation at Amdo, east Tibet in 1998 summer season. Reanalysis data is interpolated from 2.5 degree data. No Amdo data happen to be used at any analysis products. The difference of the GAME reanalysis ver1.5 is comparable to ECMWF and shows good performance.

Comparison with Shiquanhe data in west Tibet is shown in Fig.2. Only GAME reanalysis uses this station data. As expected, GAME reanalysis ver.1.5 is the closest to the observation.

(2) Validation of surface energy fluxes

Surface energy fluxese are the important driving forces to control the seasonal evolution of the asian monsoon. Comparison of latent, sensible heat fluxes at Tak, Thailand for July 1998 (Fig. 3) indicates the GAME reanalyses are the closest to the observation in diurnal variation as well as in absolute magnitude.

(3) Validation of precipitation

In the Asian monsoon regions better precipitation estimate in data assimilation is essential to analyze better circulation fields associated with the monsoon because condensation heating due to precipitation is dominant to determine the circulation pattern.

Truth data for precipitation is TRMM combined 3G68 hourly precipitation. To validate precipitation and compare with other reanalyses, we first interpolate all data into 2.5 by 2.5 gridded data and calculate monthly root mean square at each grid and every 6 hourly if TRMM data are available. It is defined as

$$\text{Monthly RMSQ} = \Sigma\ \Sigma (R(reanl) - R(obs))^2$$

$$= \Sigma [(\langle Rreanl \rangle - \langle Robs \rangle)^2 + 2\, Sreanl\, Sobs\, (1-CR) + (Sreanl - Sobs)^2],$$

where <Robs> is TRMM monthly precipitation and <Rreanl> is that from reanalyses, Sanal and Sobsare corresponding monthly standard deviation, and CR is temporal correlation coefficient between TRMM and reanalysis precipitation. Summation for average runs over tropical belts or over entire TRMM observation area (37.5S to 37.5N).

Fig.4 shows comparison of validation with other analyses. The two left (right) hand figures are the monthly RMSQ and correlation coeffients, respectively. The first and the third figures (the second and the fourth) from the left are those averaged over the glove

Table 1 Main difference between Game Reanalysis ver.1.1 and 1.5

Version	Ver.1.1	Ver.1.5
Release	September 2000	June 2002
Model	T213L30	
Sonde data	+GTS(GAME-T) +TIPEX & JEXAM +HUBEX	+SCSMEX +North INDIA:Wind
Assimilation	3D-Optimal Interpolation	
Snow	Climatological	Retrieved from SSM/I
Soil temperature	Climatological	6 hour forecast
Water Vapor bogus	Not used	Derived from SSM/I TPW and OLR only over the ocean
Physical monitor	18 & 24 hour forecast at 00 & 12UTC initial	18 hour forecast at 00,06,12,18UT

and over the Asian Pacific regions, respectively. Irrespective of the averaging regions, the GAME reanalysis precipitation shows the least RMSQ and large correlation with TRMM precipitation.

3. Summary

We made validation of the GAME reanalysis output with observation. The key variables as wind field and surface energy fluxes over the Asian Continents and precipitation over the entire tropical regions are validated and compared with other reanalysis output.

1) Wind fields in the GAME reanalysis have better quality than others in the vicinity of GAME intensive observation regions. The GAME IOP sonde observations, which were not reported to operational numerical prediction centers via GTS, contribute to improvement of the GAME reanalyses products.
2) Precipitation from the GAME reanalysis shows better agreement with observation than others. The version 1.5 is better than the version 1.1. This due to inclusion of the moisture data over sea retrieved from
3) We also made validation of geopotential height and surface energy flux over the Tibetan Plateau, precipitable water over sea. These results also show good correspondence of the GAME reanalysis output with observation.

Yatagai et. al.(2001, 2002,2003) extensively comapred surface fluxes from the GAME reanalysis and AAN observations. These studies also shows the GAME reanalysis are reasonably close to the AAN observational.

We believe the GAME reanalysis product is comprehensive and usefull data to study water and energy budget over the Asian monsoon region and hope many people use these

Table 2 Data used and methods

Analysis products	Analysis	Physical monitor	
			Precipitation
GAME reanalysis Ver.1.1	2.5 deg.	2.5 deg.	0-6h
GAME reanalysis Ver.1.5	2.5 deg.	2.5 deg.	0-6h,12-18h
JMA routine analysis (GANAL)	1.25 deg.	2.5 deg.	0-6h
NCEP1 reanalysis	2.5 deg.	1.875 deg.	0-6h
ECMWF routine analysis	2.5 deg.	2.5 deg.	Not used

Global precipitation	TRMM 3G68	GPCP 1x1 daily

Interpolated into 2.5 deg. for precipitation analysis

Station data	location
Sonde	Amdo,TIPEX
Flux (LE,H)	EGAT(Tak)

All data were compared with values estimated by interpolation at the location of the station.

data for their study.

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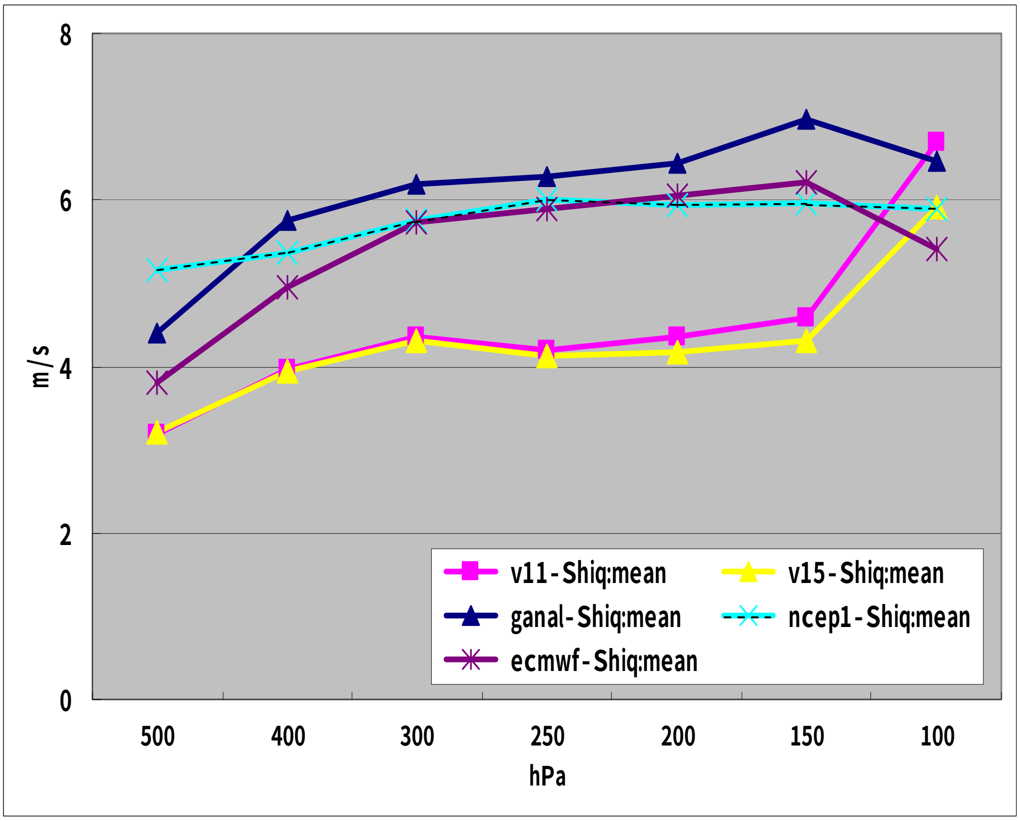

Fig. 1 Mean wind vector difference at Amdo

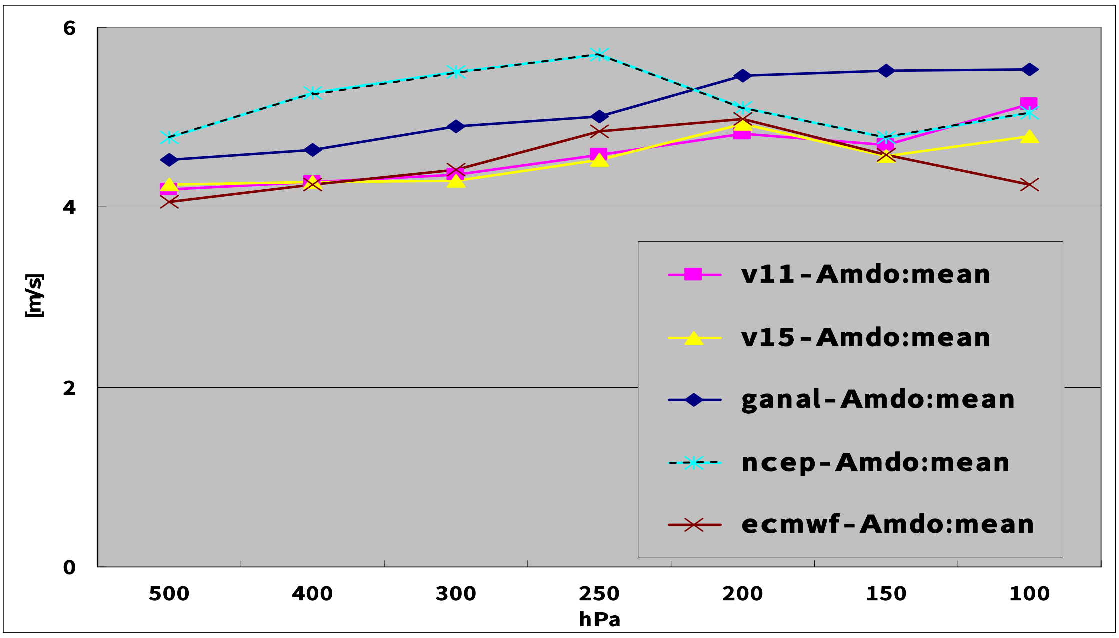

Fig. 2 Mean wind vector difference at Shiquanhe

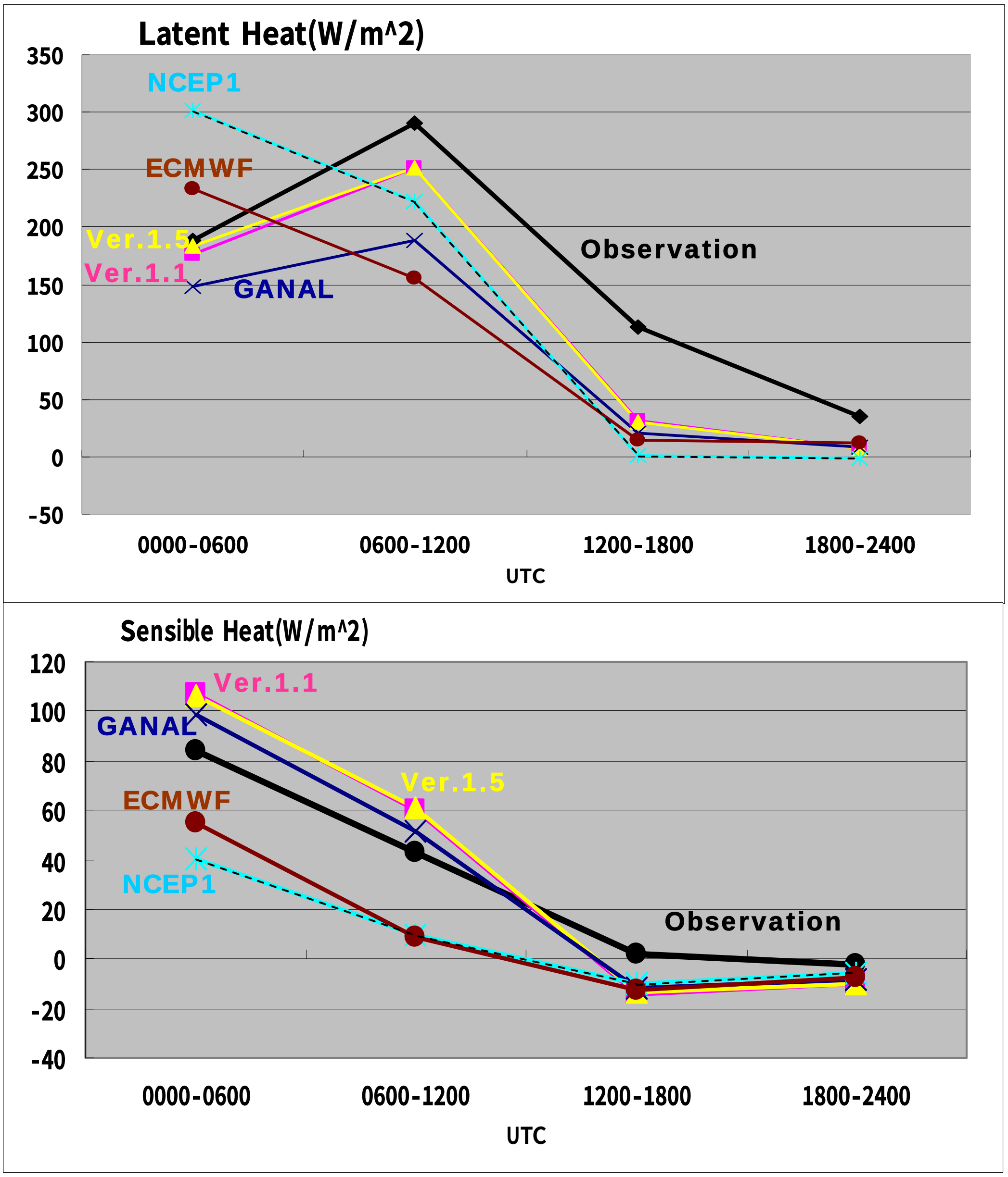

Fig. 3 Comparison of latent, sensible heat flux at Tak for July 1998

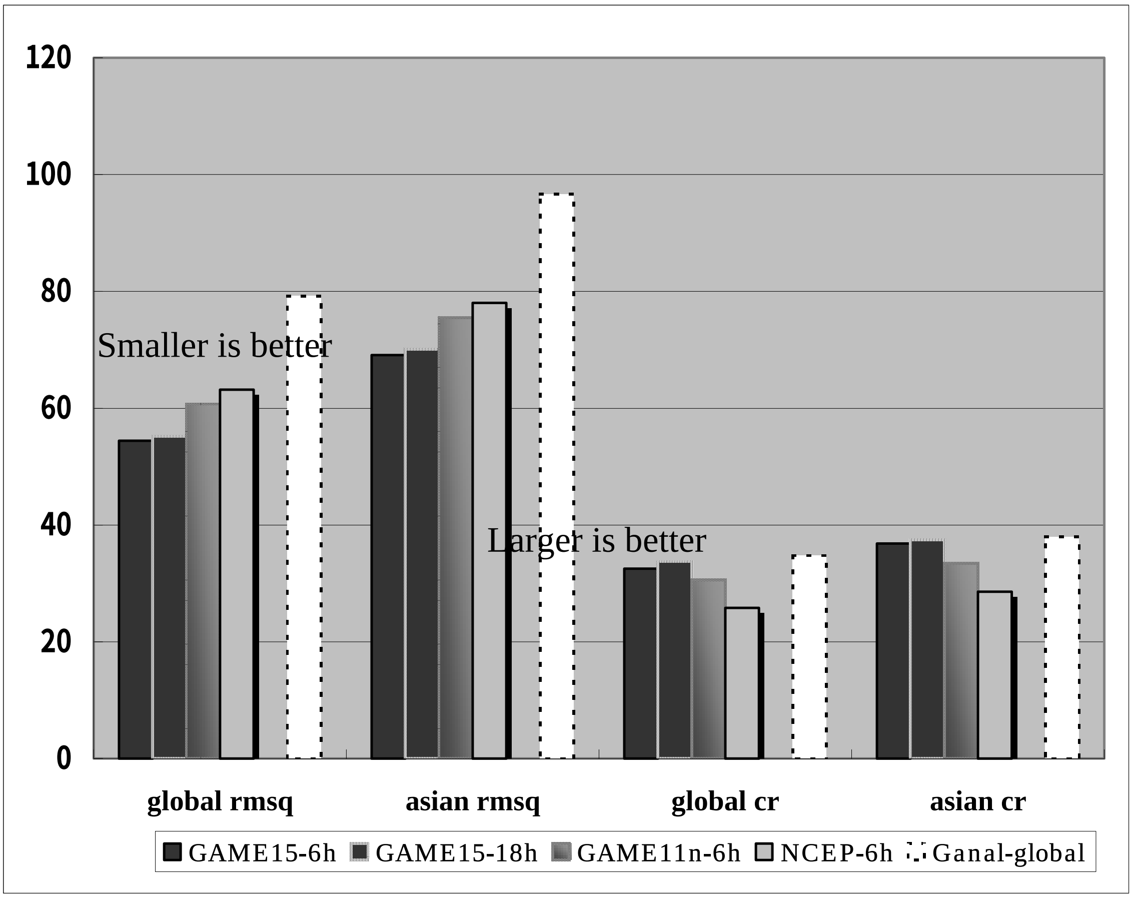

Fig.4 Comparison of TRMM TMI+PR vs Reanal Precipitation

Report on the GAIN activity

Kiyotoshi Takahashi (MRI)

GAIN is an abbreviation of GAME Archive & Information Network. Its function is divided into two parts, that is, the establishment of the GAME data management policy and the construction of the system that disseminates GAME data and information.

The first work as GAIN was to work out the GAME data management policy. As you know, the GAME is an international research project, so international cooperation is crucial for its success. The data policy is the base of such an international cooperation, and gives the guideline for various aspects concerning the GAME data, for example, definition of the GAME data and basic strategy of data provision, and so on. The original draft of the data policy was prepared by the late Dr. M. Murakami, and was proposed in the 2nd GAME International Science Panel for the first time. Finally this GAME data policy was adopted at the 3rd GISP in January 1998 just before the GAME IOP (Intensive Observation Period).

One of important matters in this data policy is the time schedule of the GAME data release to the international research communities. We finally reached the following agreement.

Data obtained as part of the observations during the IOP will be made available according to the following schedule.

1) By the end of June 1999 (6 months after the IOP), for the participating institutes and scientists.
2) By the end of June 2000 (one year later), for the international research community.

Data obtained as part of the GAME observations during the non-IOP will be made available according to the following schedule.

3) By the end of one year after the observation, for the participating institutes and scientists.
4) By the end of two years after the observation, for the international research community.

At present (March 2003), almost all of the GAME data have been open to the international research communities according to the above-mentioned agreement although it was behind the schedule as a whole. Now opening of GAME-Siberia data is delayed, but they will be open soon.

In addition, we requested supplementary data (surface station data) mainly to India and the southeast Asian countries for the validation of the GAME Reanalysis data. Some countries kindly provided us the data in response to our request.

Next, we will move onto the second function of GAIN. In the data policy main means for data provision is planned to be the online access via Internet, and each sub-project group is requested to have his own responsibility in data provision.

The GAIN system is composed of GAIN-hub and GAIN-DAACs as shown in Fig. 1. The function of the GAIN-hub is to offer catalogue information for GAME data and some selected data, mainly GAME-reanalysis data. Presently all of sub-groups have established their own ftp/web sites (DAACs) for data dissemination since the summer of 2000. Everyone who is interested in the GAME data can obtain data and information by starting from this gain-hub (http://gain-hub.mri-jma.go.jp).

Besides the online provision, five CD-ROM sets (GAME-Tibet, GAME-Reanalysis Ver.1.1 & 1.5, GAME-Tropics, GAME Standard data) have been published and distributed in the world. Now it is planned to publish more CD-ROMs for GAME-AAN and GAME-Siberia because CD-ROM is very useful media in the case that the online access is unavailable.

As mentioned in the above, the GAIN system is successfully being operated now. We are going to continue making efforts to improve the GAIN system and keep it well for at least more several years.

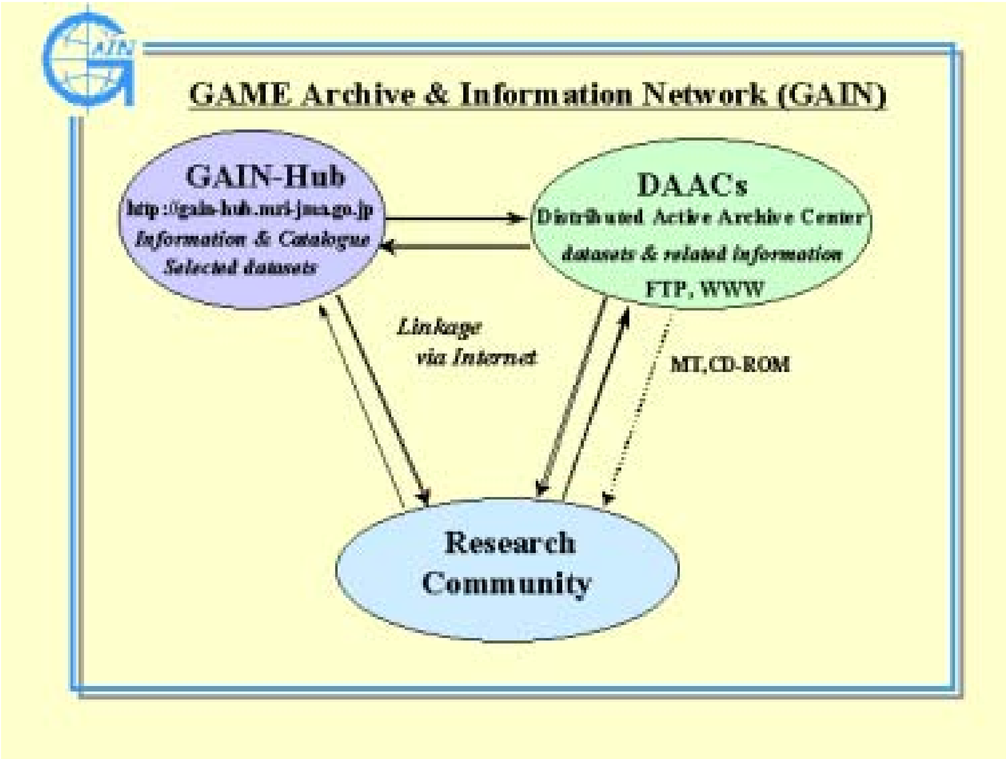

Fig. 1. GAIN structure

Toward GAME Synthesis

Tetsuzo Yasunari
Institute of Geoscience, University of Tsukuba, and
Frontier Research System for Global Change

1. Introduction

Nearly five years have passed since GAME started in 1996. The regional experiments on energy and water cycle processes have been conducted in Thailand (GAME-Tropics), in the Huai-he river basin in China (GAME-Hubex), in the Tibetan Plateau (GAME-Tibet) and in the Lena river basin in Siberia (GAME-Siberia). The long-term radiation and energy fluxes in various sites of the monsoon Asian region have been operated by the automatic weather stations (AWS) as the Asian AWS Network (GAME-AAN).

In 1998, we conducted the Intensive Observing Period (IOP) in cooperation with many Asian countries and the international/national projects such as South China Sea Monsoon Experiment (SCSMEX), Chinese Tibetan Plateau Experiment (TIPEX) and Korean Monsoon Experiment (KORMEX). The enhanced radiosonde observations, as well as surface hydrometeorological observations, were operated at more than hundred stations in the monsoon Asian countries. We conducted the 4-dimensional data assimilation (4DDA) of the atmospheric field over the whole monsoon Asia, and the first version of this reanalysis data have been released as version 1 of GAME-reanalysis. Some scientific results, particularly from GAME-Tropics and GAME-Tibet were reported in the special issue of Journal of the Meteorological Society of Japan (Yasunari, ed., 2001).

These data obtained through the regional experiments, AAN, including the reanalysis data for the IOP have been compiled and archived as part of GAME Information and Archive Network (GAIN). Some data are being released to the international science community under the data policy of World Meteorological Organization (WMO).

As documented in the GAME Letters (No. 3 and this letter), we have obtained various new scientific results on the hydro-meteorological processes in the Asian monsoon region from the Tropics to the Siberian Arctic region. Particularly, the land-atmosphere interaction processes in some typical climate and vegetation in monsoon Asia have been revealed in diurnal through seasonal time scales. Cloud and precipitation processes have also been scrutinized in the tropical region, the Meiyu-Baiu frontal zone in the subtropical China and on the Tibetan Plateau area.

What we have to do now and from now is to synthesize these scientific results to reach the final goals and objectives of GAME (GAME International Science Panel, 1998). The fifth session of the GAME International Science Panel (GISP) held in June, 2000 in Tokyo proposed the GAME Phase-II for further research, including data analysis, some additional process studies and modeling needed for the synthesis of the overall GAME objectives. Here, I would like to briefly comment on some key issues for the synthesis of GAME.

2. Large-scale land-atmosphere interaction and regional/continental-scale climate

Energy and water cycle processes in various plot-scale and meso-scale regions have been revealed in the diurnal to seasonal time scales. In some areas, year-to-year variability has also been obtained. An important issue, as a next step, may be how to scale-up or integrate these surface processes in a small area to larger-scale processes in the atmosphere. The IOP of GAME-Siberia in the spring/summer of 2000 conducted the aircraft measurement of heat and CO_2 fluxes over the meso-scale region near Yakutsk. These data will help us to understand the time-space structure of the atmospheric boundary layer in terms of the land surface energy and water fluxes. The comparison and validation of surface fluxes in the models and observations are also being conducted, from the viewpoint of scaling-up and down. In this respect, GAME will contribute to modeling activity of the GEWEX Atmospheric Boundary Layer Study (GABLS), which is a new initiative of the GEWEX Modeling and Prediction Panel.

3. Cloud and precipitation processes and large-scale monsoon circulation

Another key issue for the energy and water cycle of monsoon Asia is cloud and precipitation processes and its interaction with large-scale atmospheric circulation. In the GAME region, the interaction with the monsoon circulation, including the influence of surface topography and vegetation is the most important process. As part of GAME-Hubex and GAME-Tibet, the intensive observation of the 3-dimensional cloud/ precipitating systems were observed by using the Doppler-radar systems, with the enhanced radiosonde observations. The interaction between the meso-scale cloud/ precipitation systems and the large-scale monsoon circulation are being investigated combining the objectively analyzed reanalysis data. The regional 4DDA analysis for the Hubex region is planned for the detailed interactive processes between the meso-scale cloud systems and the ambient monsoon and westerly flow regimes.

Another issue may be the interaction between the cloud/precipitation system and the land surface conditions, including topography and land use/land cover conditions. One important problem we have noticed may the important role of water-fed rice paddy field, which is a typical land surface condition in monsoon Asia, in the development and/or modifying the precipitation systems. The observational as well as model-based evidences of this aspect have been suggested in the tropical (GAME-Tropics) and sub-tropical (GAME-Hubex) region. The large-scale and regional-scale topography is also a key factor controlling the precipitation system in the monsoon region. The observational as well as modeling studies in the tropics (GAME-Tropics) and in the Tibetan Plateau (GAME-Tibet) have presented some interesting processes in the diurnal as well as in the synoptic-scale. The regional model studies are essential for these problems, including improvement of land-surface schemes and the atmospheric boundary layer processes based on the GAME data sets.

4. Key processes related to the interannual variability of the Asian monsoon

GAME has focused the interaction and feedback processes between land and atmosphere. In fact, the observational results of the regional experiments have revealed some important processes on the land-atmosphere interaction, including the roles of snow cover, soil moisture and vegetation. For example, the regional and continental-scale vegetation, such as tropical monsoon forest in southeast Asia, and the boreal forest in east Siberia, have been suggested to play an important role in controlling seasonal surface energy and water balance. This role of vegetation, in turn, modifies the seasonal cycle of the climate and atmospheric circulation. Some model experiments also have strongly suggested these processes.

GAME data sets include the full seasonal data of two or three years since 1997. Particularly, the data of 1998, the IOP year, can be compared, in many aspects, with those of 1999, when the secondary IOP was conducted in GAME-Tropics and GAME- Hubex region. The anomalies of the overall monsoon circulation and precipitation between these two years are well contrastive, so that the inter-comparison of the processes related to the monsoon activity in each region seems to be very beneficial for understanding the interannual variability of the Asian monsoon.

To fully understand the seasonal cycle and interannual variation of the Asian monsoon, we need to include the large-scale atmosphere-ocean processes and their interaction with land surface processes. GAME modeling activity includes these processes using atmospheric GCMs and coupled atmosphere-ocean GCMs. However, almost all the current GCMs have very large systematic errors in simulating the mean monsoon climate and circulation (Kang *et al.,* 2001). For example, the simulated monsoon precipitation on land, particularly near the coast in south and southeast Asia tend to be far larger than the observation, whereas that over the warm pool region in the western Pacific tend to be smaller compared to the observation. These defects in GCMs both in the seasonal cycle and spatial distribution need to overcome by improving land-atmosphere as well as ocean-atmosphere processes. The forthcoming CEOP (Coordinated Enhanced Observing Period) under World Climate Research Programme (WCRP) to be held in 2001 to 2003 will provide us a good opportunity for providing sufficient data for further understanding the Asian monsoon with its interannual variability.

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5. GAME CD-ROM Publication List

- GAME Data CD No.1: GAME-Tibet POP/IOP Dataset CD (2001)
- GAME Data CD No.2: GAME Reanalysis ver. 1.1
- GAME Data CD No.3: GAME (Standard) Data CD
- GAME Data CD No.4: GAME Tropics Dataset version 1 (2002)
- GAME Data CD No.5: GAME Reanalysis Ver. 1.5
- GAME Data CD No.6: GAME AAN Data CD-ROM
- GAME Data CD No.7: GAME Phase I Summary CD-ROM

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Together with this report, Japanese summary reports and Summary CD-ROM were published. The latter includes invariable information on the outcomes of GAME Phase I. They are available through GAME National Project Office