GEWEX Asian Monsoon Experiment

GAME Letter

No.3 October 2001

Activity Review of GAME-T

GAME-T Review Group

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) Hydrometeorological 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.

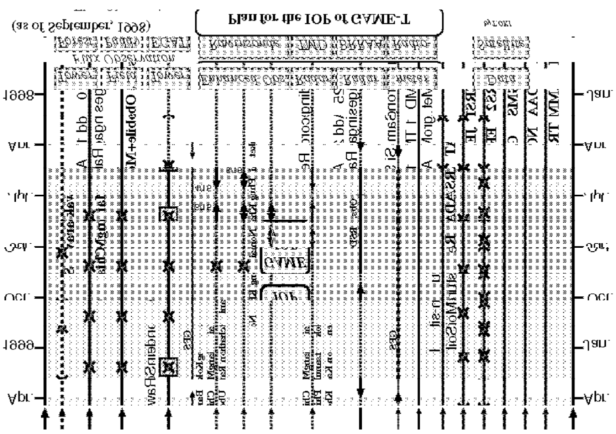

Fig. 1. The schedule of each observation during IOP

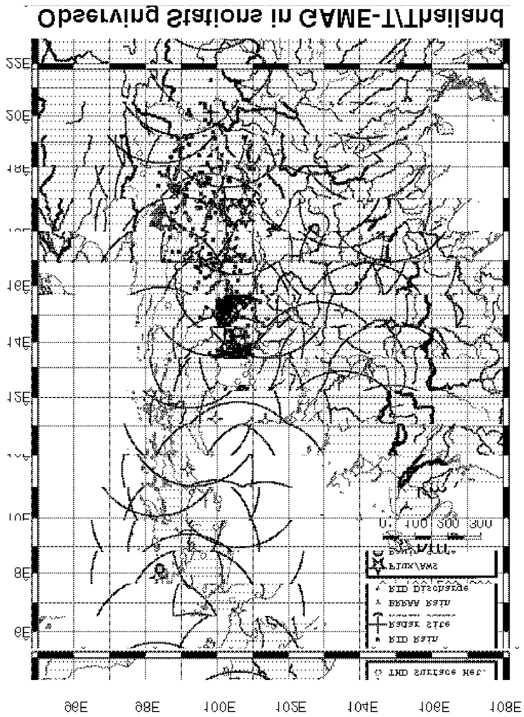

Fig. 2. The locations of the observing stations

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

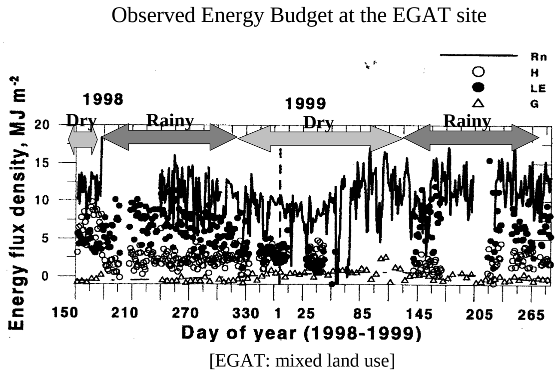

Fig. 3. Seasonal pattern of energy budget observed at the EGAT site

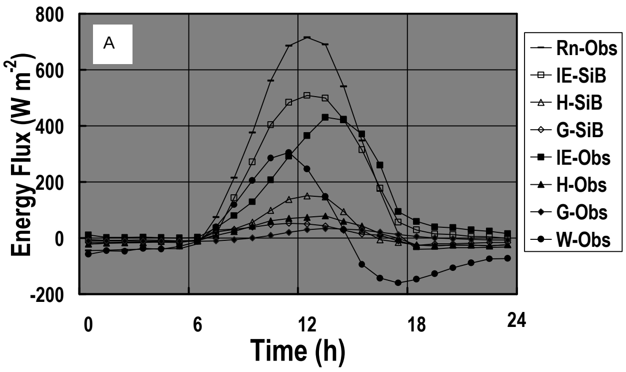

Fig. 4. Simulation of the diurnal evolution of surface energy components by the original SiB2 (upper) and the revised SiB2 with paddy scheme (lower). The simulated results are compared with observations.

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

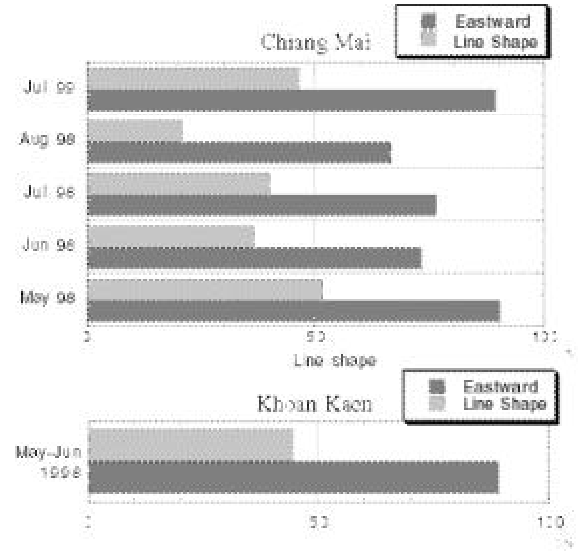

Fig. 5. Ratio of days when eastward-moving echoes and line-shaped echoes were observed to total days of observation in each month at Chiang Mai (upper) and Khon Kaen (lower).

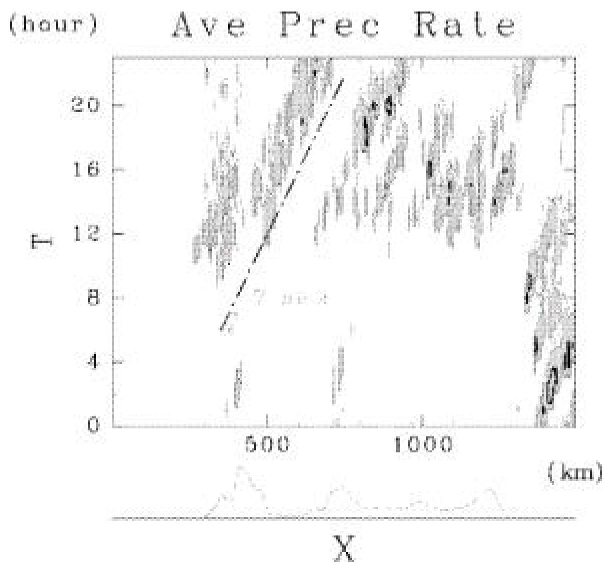

Fig. 6. Horizontal-time section diagram of precipitation rate averaged on the second and the third days. Contours of precipitation are 0.5, 1 and 10 mm/h. Shaded area indicates precipitation rate is greater than 1 mm/h. Dash-dotted line indicates moving speed of 7 m/s. The surface topography is depicted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

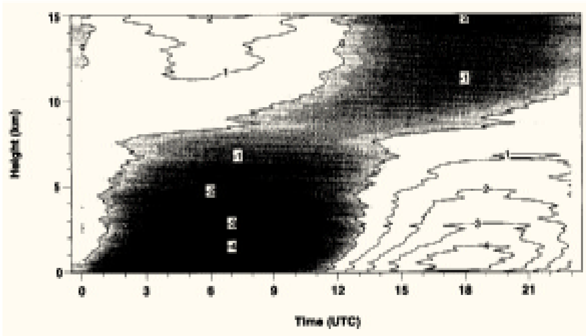

Fig. 7. A time-height section of diurnal component of equivalent potential temperature variations in the rainy season.

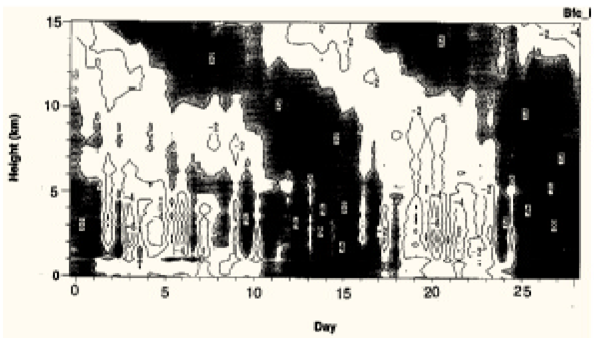

Fig. 8. A time-height section of equivalent potential temperature in the pre-monsoon period (composite of 1, 7, 9.3 and 14 day period component).

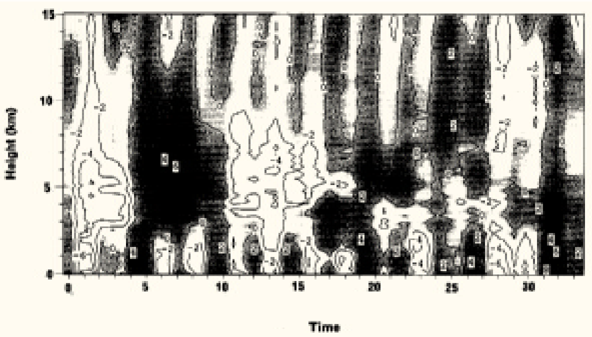

Fig. 9. A time-height section of equivalent potential temperature in the mature monsoon period (composite of 1, 8.5, 11.3 and 17 day period component).

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

One of the main objectives of GAME-T is to collect hydrometeorological data and to construct comprehensive hydrometeorological 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., and 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

GAME/HUBEX Research Group

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.

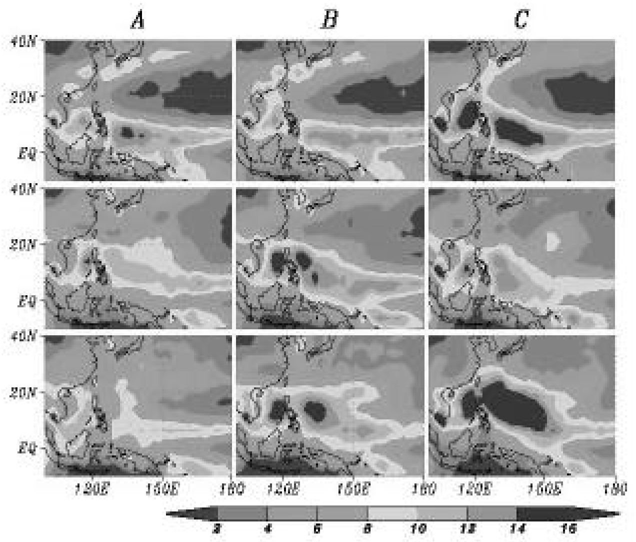

Fig. 1. Averaged monthly precipitation amount in the patterns A, B and C from June to August.

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).

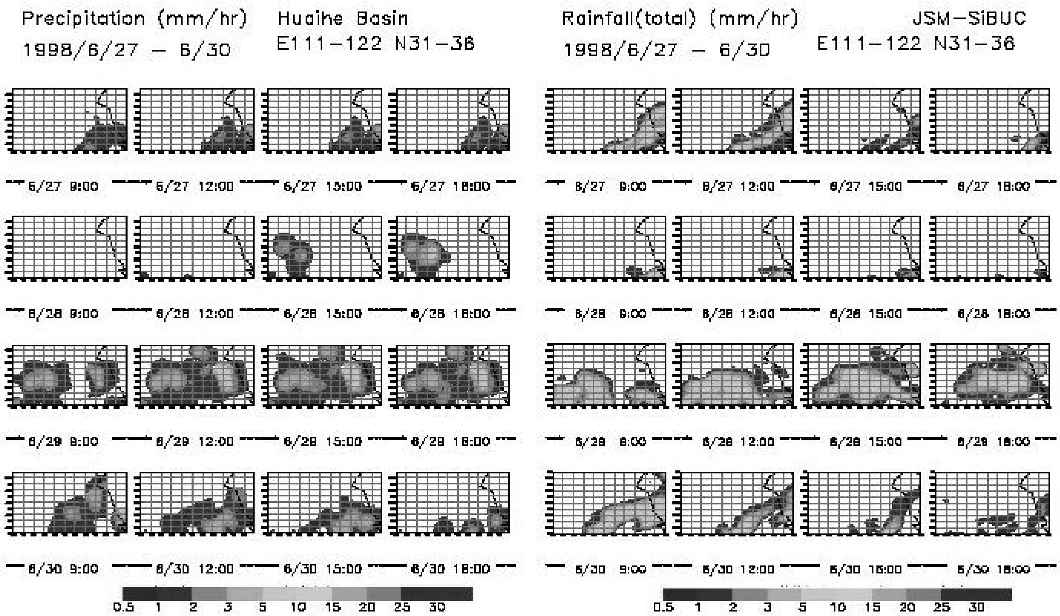

Fig. 2. Simulated and observed (surface station's data) precipitation in Huaihe River Basin (11 deg. × 5 deg.)

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.)

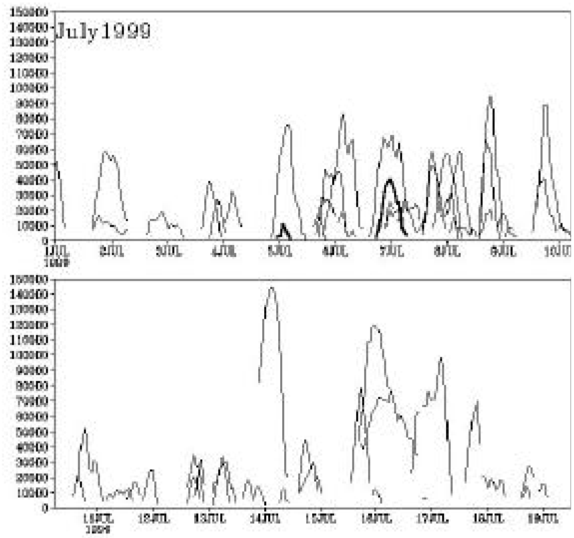

Fig. 3. Time variation of area of cloud clusters with Tbb lower than -60 C.

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 substructures, 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.

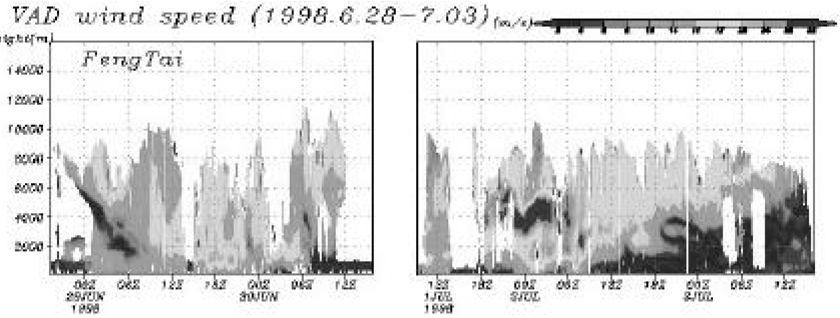

Fig. 4. Time-height cross section of wind speed measured by a Doppler radar at Feng Tai. The left panel (from 29 to 30 June) showed a warm frontal structure and the right panel (from 1 to 3 July) showed a cold frontal structure.

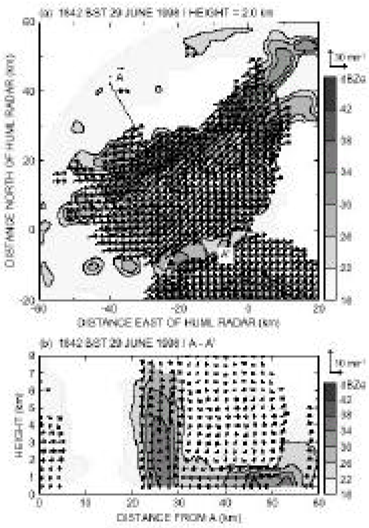

Fig. 5. Dual-Doppler radar analysis for 1842 BST on 29 June 1998. a) Horizontal plane at 2.0 km in height. b) Vertical cross-sections along A-A' lines in (a). The vector denotes the wind on the plane. Vectors of (b) are subtracted from the averaged wind. The shading denotes the radar reflectivity.

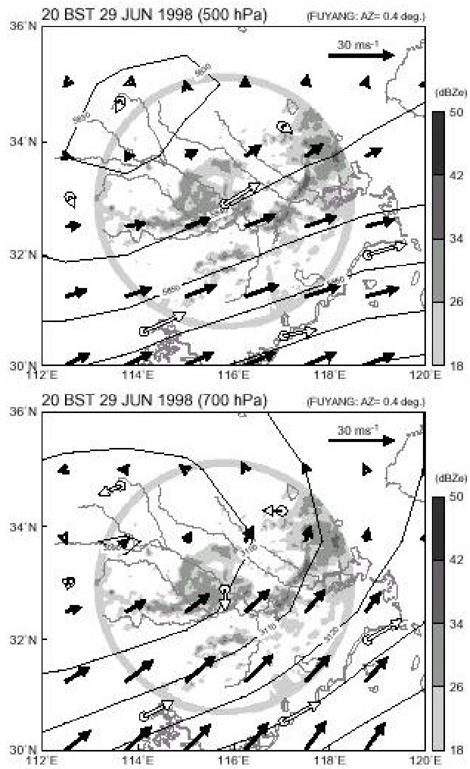

Fig. 7. GANAL wind (solid arrows) and geopotential height (contoured every 10 m) superimposed Fuyang radar reflectivity (0.4 PPI scan) at 700 hPa and 500 hPa (20 BST 29 June 1998). Open circle shows the sounding point and open arrows denote the wind by sounding at the level.

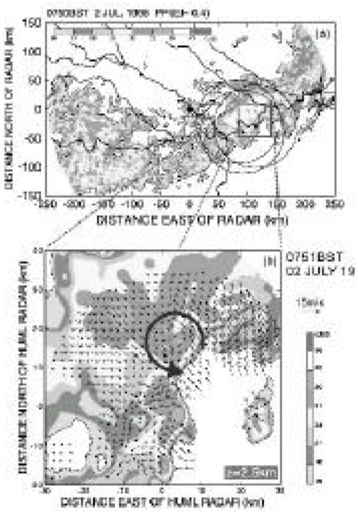

Fig. 6. The reflectivity (PPI, El=0.4) of Fuyang radar at 0750 BST on 2 July 1998 (top panel). Horizontal plane of dual-Doppler radar analysis at 2.5 km in height (bottom panel). The round arrow indicates the vortex .

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.

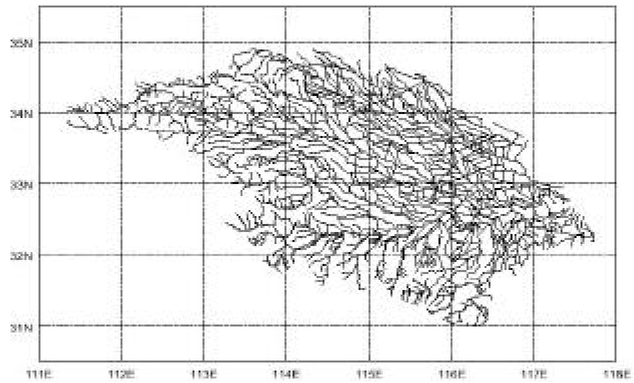

Fig. 8. Channel network for the Huaihe River above Bengbu

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

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.

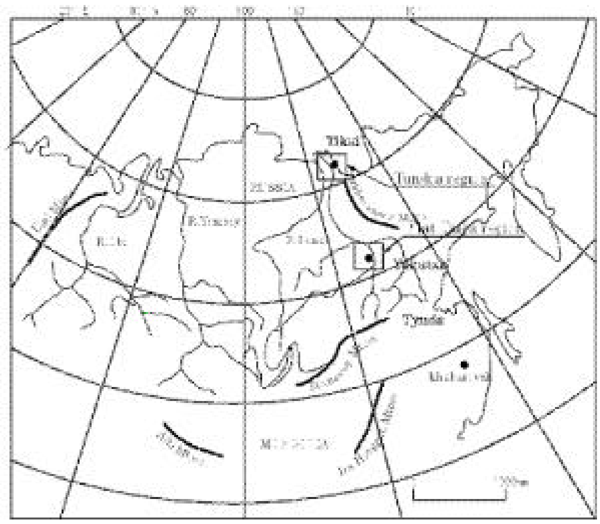

Fig. 1. The map of the study region and position of local observation sites.

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.

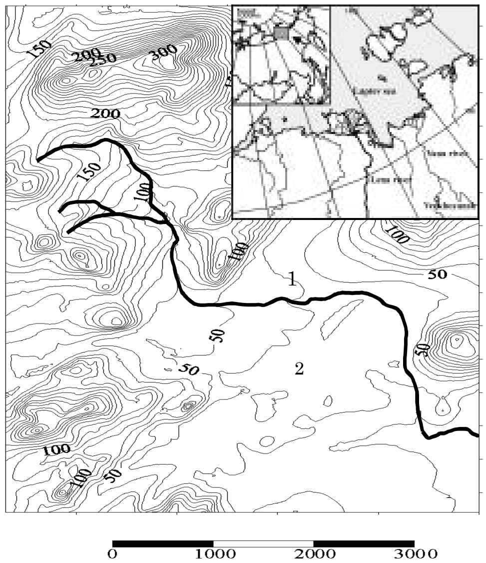

Fig. 2. Map of observational site at Tiksi (tundra) 1: hydrological station, 2: meteorological station

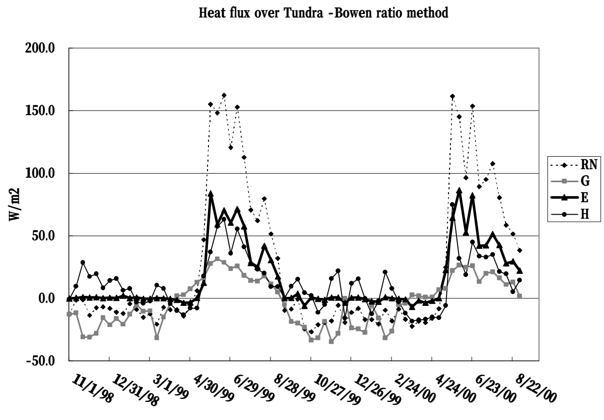

Fig. 3. Seasonal variation (10 days mean) of heat balance components at Tiksi from 1998 to 2000.

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 evapotranspiration 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.

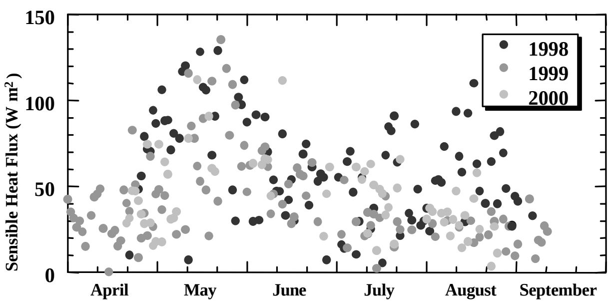

Fig. 4. Seasonal variation of sensible heat flux above the larch forest.

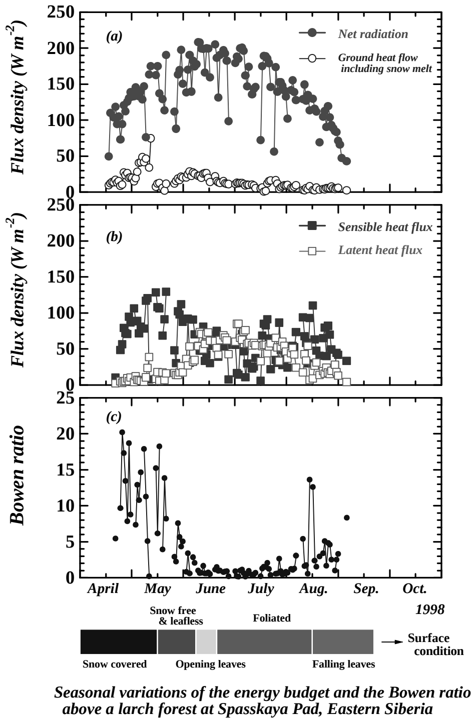

Fig. 5. Seasonal variation of each component of energy budget and Bowen ratio at above the larch forest in 1998. (Ohta et al., 2001)

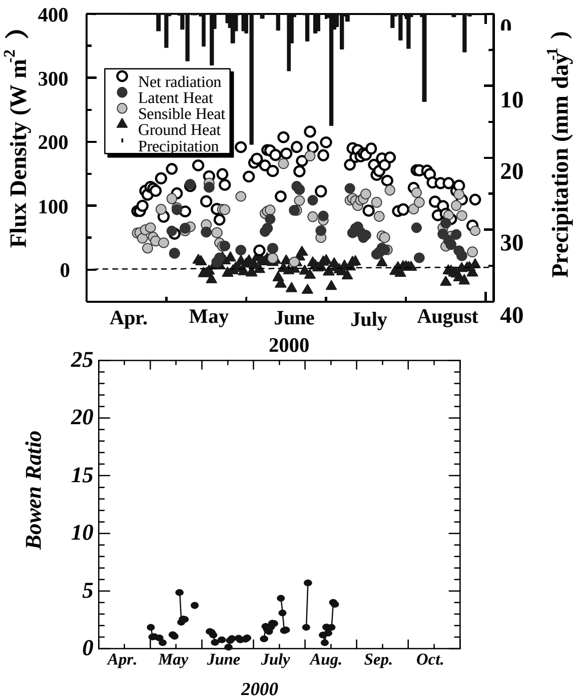

Fig. 6. The seasonal variations of energy budget components and Bowen ratio above the pine forest in 2000.

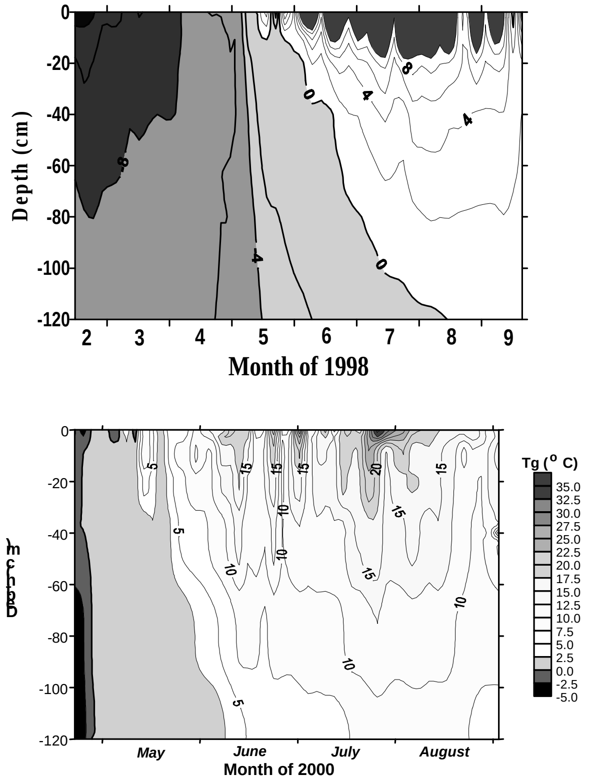

Fig. 7. Spatial and temporal distribution of soil temperature at the larch site in 1998 and at the pine site in 2000.

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.

(1) 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.

(2) 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.

(3) 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.

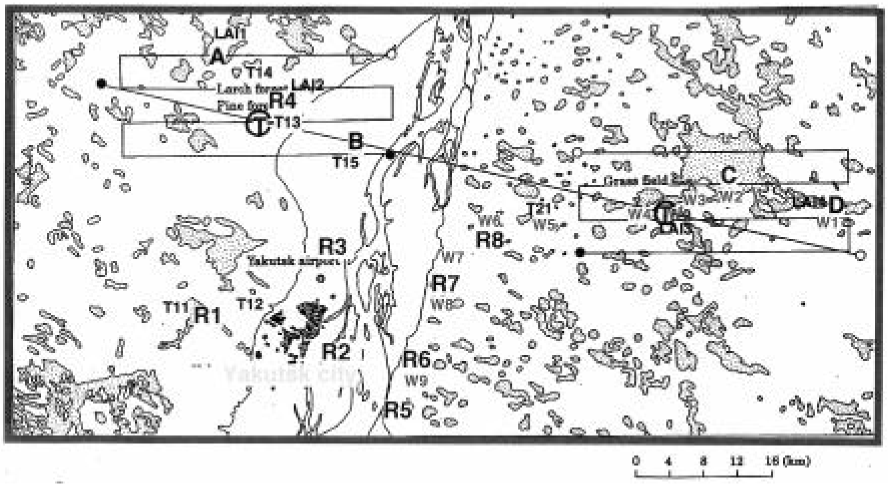

Fig .8. The map showing the position of ground station during the intensive observation year 2000 and the flight course made from April to June. The shaded area in the map is the grasslands,and Lena River runs south-north at the center.

A-D : Radiation and precipitation and precipitation sampling

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

W0-9 : Alas and lake water sampling T11-21 : 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

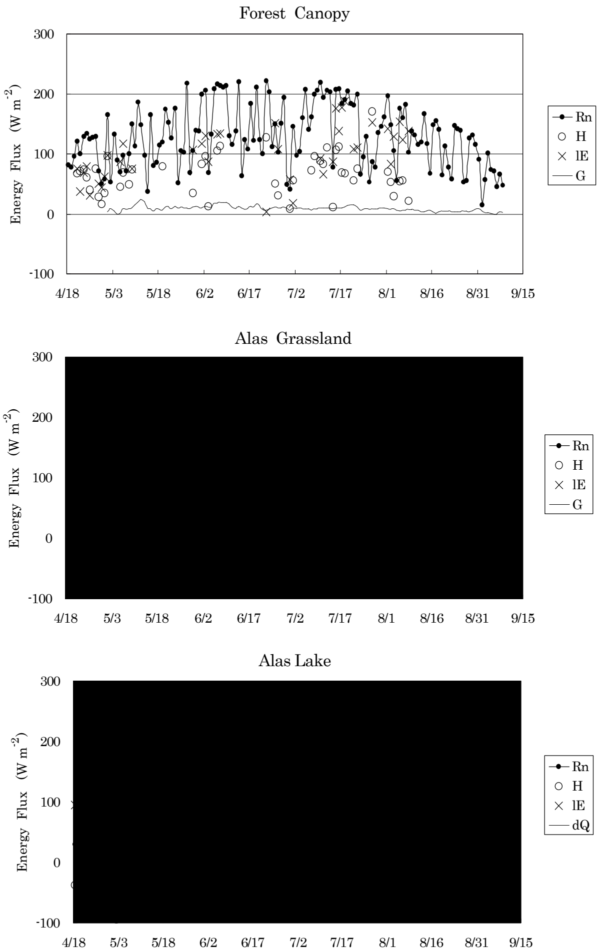

Fig. 9. Seasonal change in daily mean energy fluxes over the forest/grassland/lake in the Alas area.

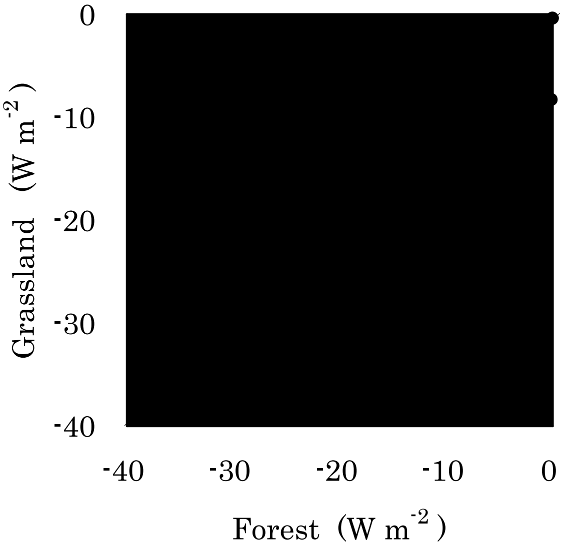

Fig. 10. Comparison of soil heat flux between forest and grassland at the Alas area in the summer season. Negative value show that heat is conducted into the ground from the surface

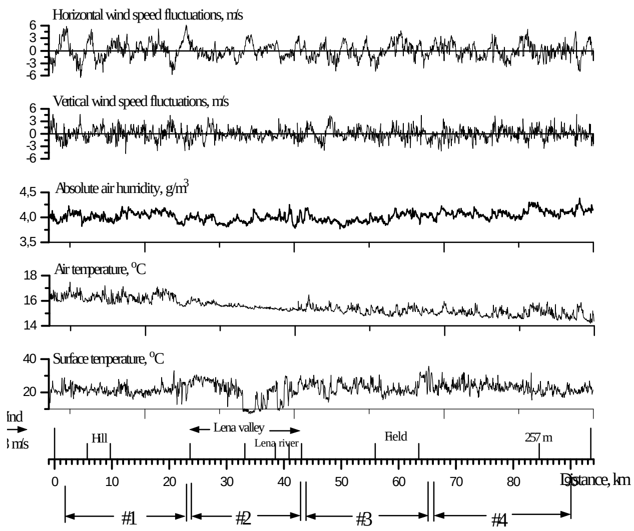

Fig. 11. The meteorological and turbulent elements at 100 m along the regional leg (NW to SE) during the flight on May 1.

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.

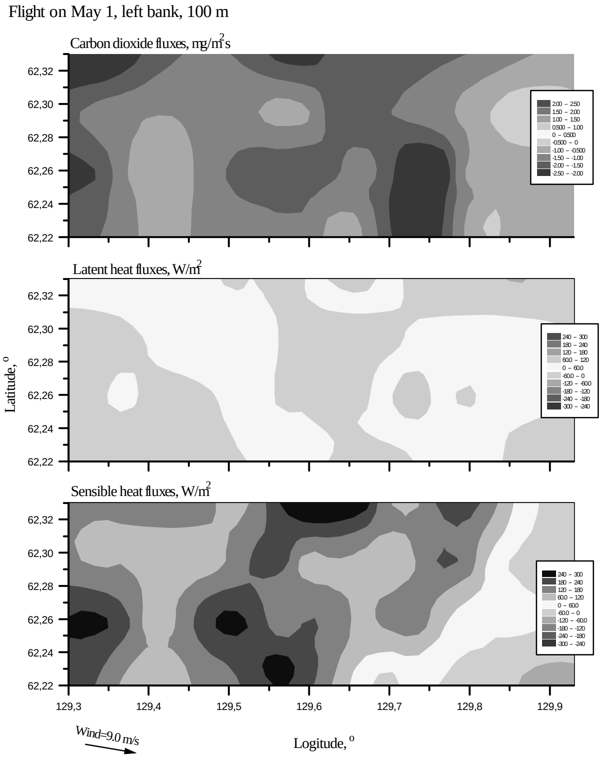

Fig. 12. Spatial distribution of CO2, sensible/latent heat on May 1 at the right bank.

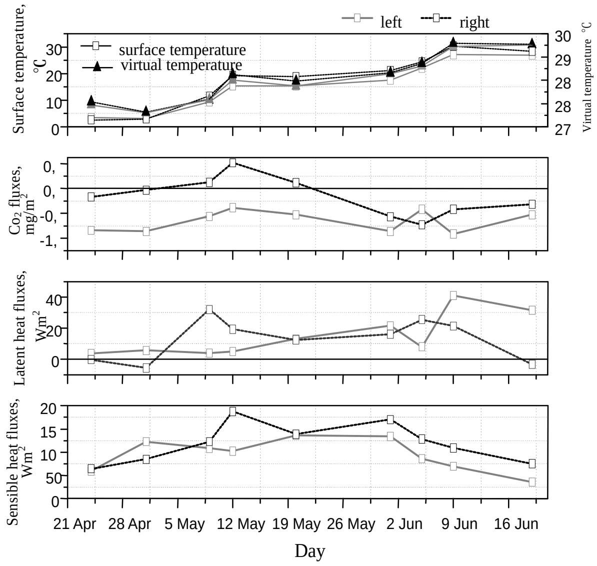

Fig. 13. Seasonal variation of meteorological elements and fluxes at the right and left bank. The values are area average.

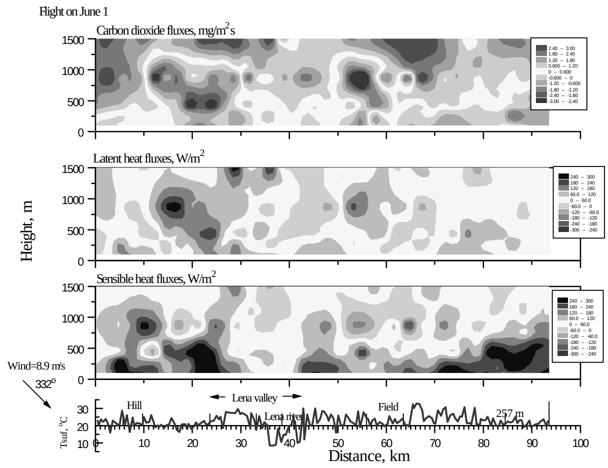

Fig. 14. The vertical distribution of fluxes along the regional leg flight on June 1.

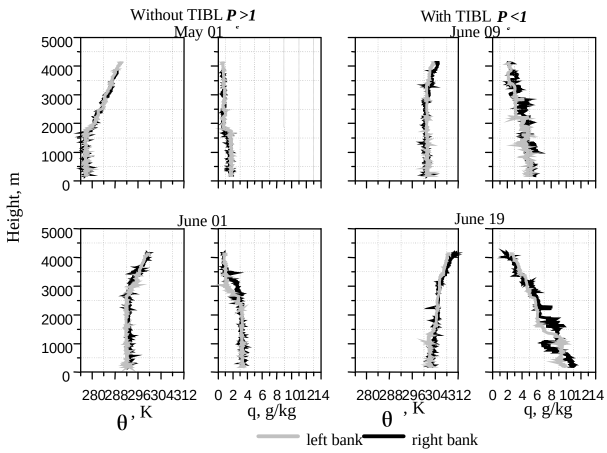

Fig. 15. Vertical profile of potential temperature and specific humidity of CBL on two days without and with TIBL.

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 (?T) between 19 and 37 GHz were taken as index for snow depth. The seasonal change in ?T was able to be classified into 9 types. There were areas where snow depth can be estimated by ?T 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.

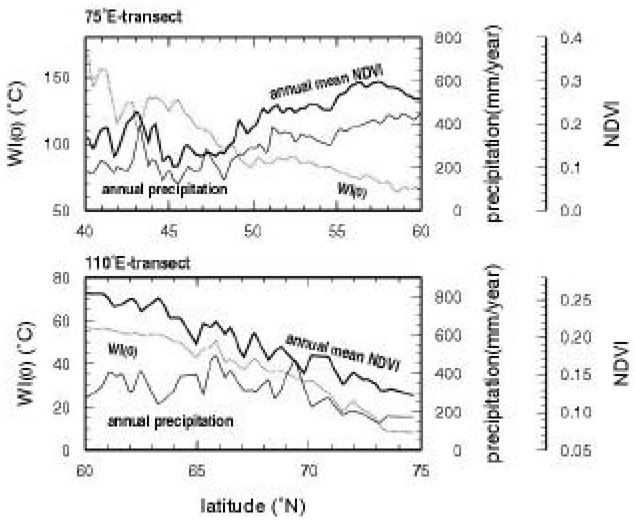

Fig. 16. Meridional profiles of the warmth index (WI(0)), annual precipitation, and the annual mean NDVI in 75 and 110E-transects

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 CO2 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.

Publications

(Publications up to now: Individual reports and papers in the Activity Reports of GAME-Siberia, GAME Conference Proceedings and GAME-Siberia Workshops are omitted)

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