Activity Review of GAME-T

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1. Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

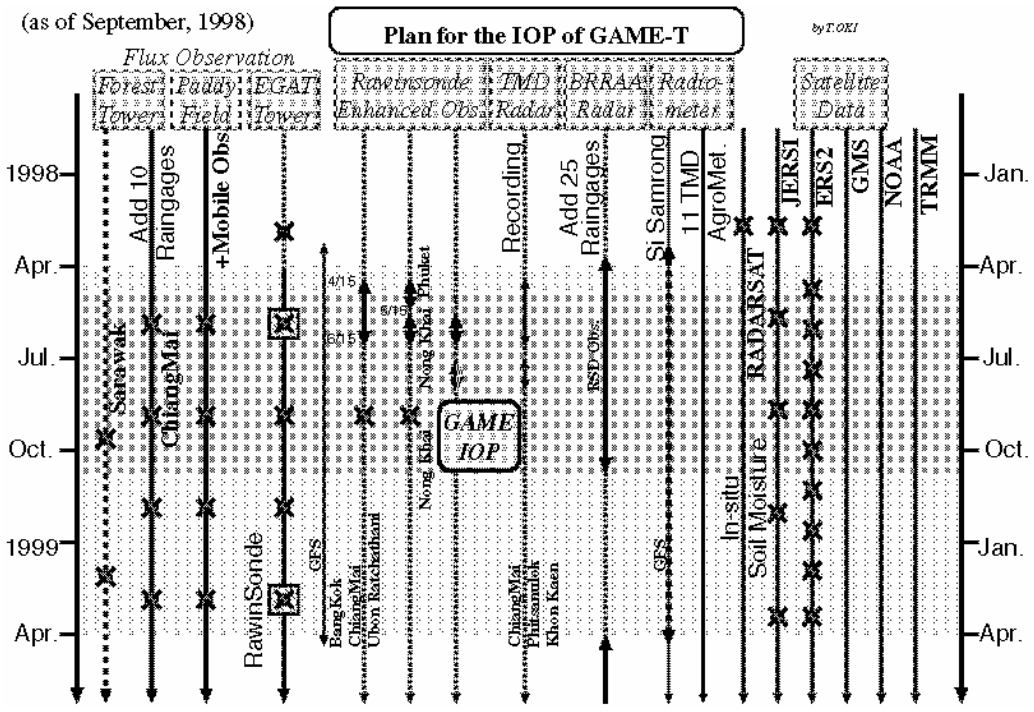


Fig. 1. The schedule of each observation during IOP

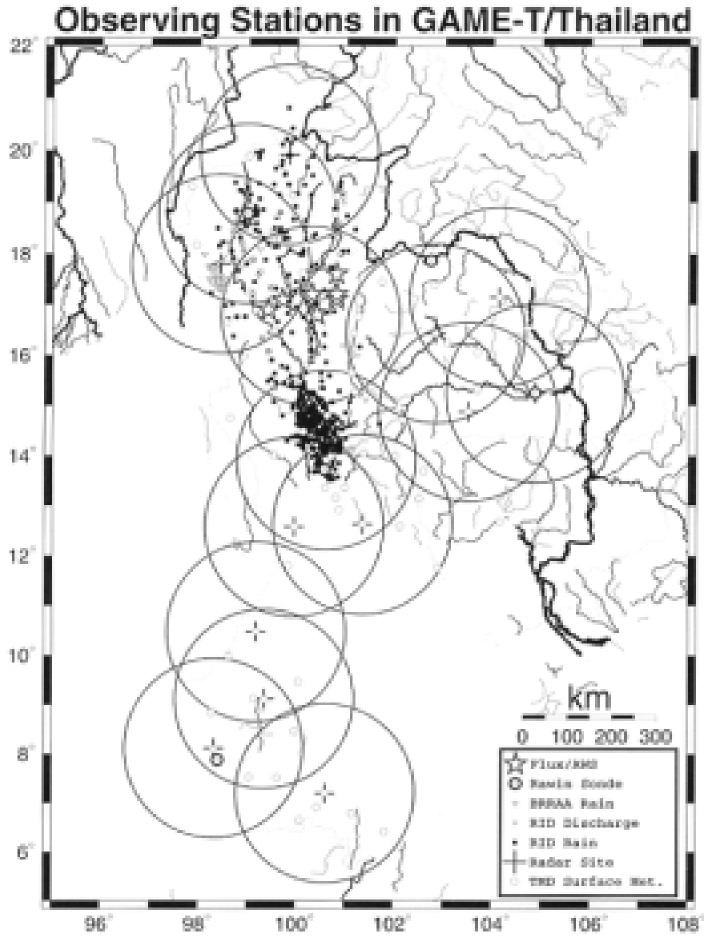


Fig. 2. The locations of the observing stations

2. Land surface flux observation and modeling

2-1. Land surface flux observation

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

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

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

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

References:

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

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

2-2. Land surface modeling

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

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

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

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

References:

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

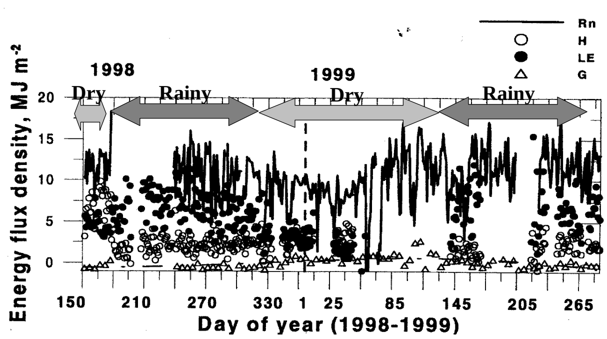
2-3. Rainfall observation in a mountainous area

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

References:

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

Observed Energy Budget at the EGAT site



[EGAT: mixed land use]

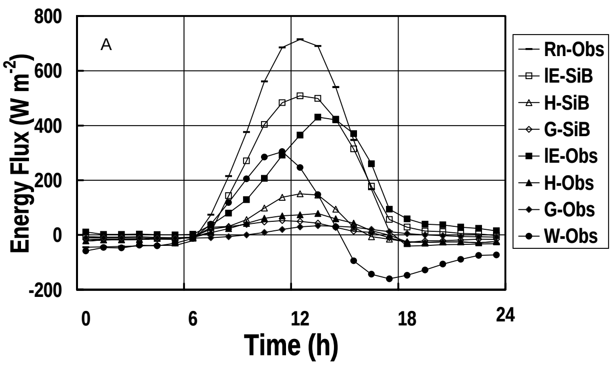


Fig. 3. Seasonal pattern of energy budget observed at the EGAT site

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

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

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

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

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

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

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

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

the inland areas far eastward from the mountain.

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

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

References:

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

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

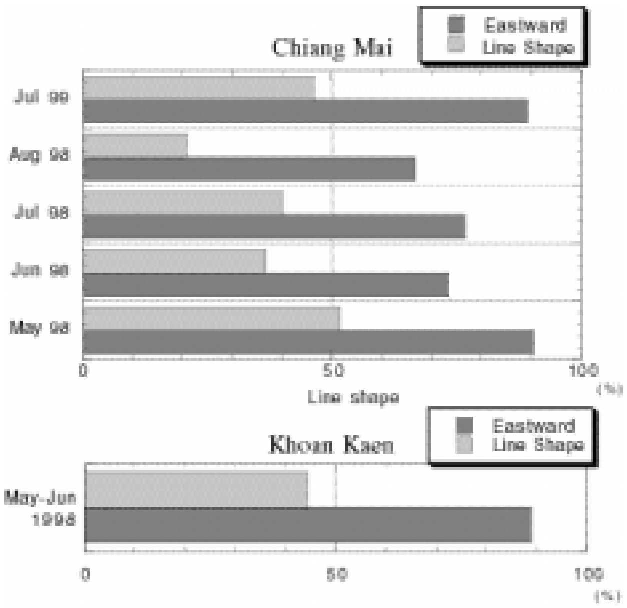


Fig. 5. Ratio of days when eastward-moving echoes and line-shaped echoes were observed to total days of observation in each month at Chiang Mai (upper) and Khon Kaen (lower).

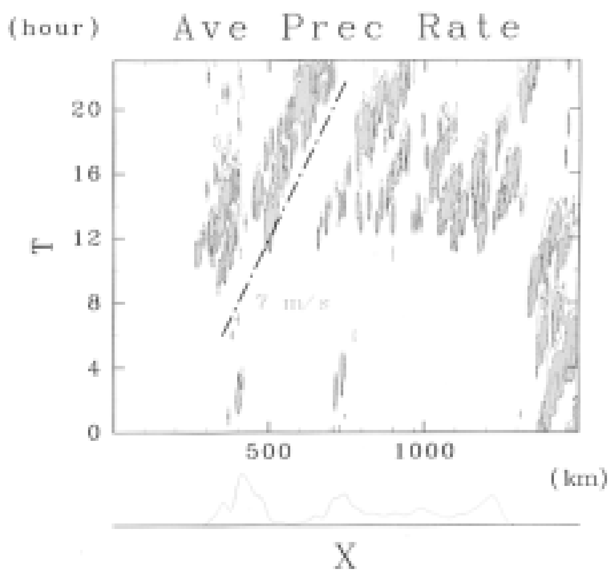


Fig. 6. Horizontal-time section diagram of precipitation rate averaged on the second and the third days. Contours of precipitation are 0.5, 1 and 10 mm/h. Shaded area indicates recipitation rate is greater than 1 mm/h. Dash-dotted line indicates moving speed of 7 m/s. The surface topography is depicted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

4. Rawinsonde observation and analysis, and climatological description

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

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

4-1. Results of the enhanced rawinsonde observations

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

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

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

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

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

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

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

4-2. Climatological description of the Southeast Asian monsoon

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

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

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

References:

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

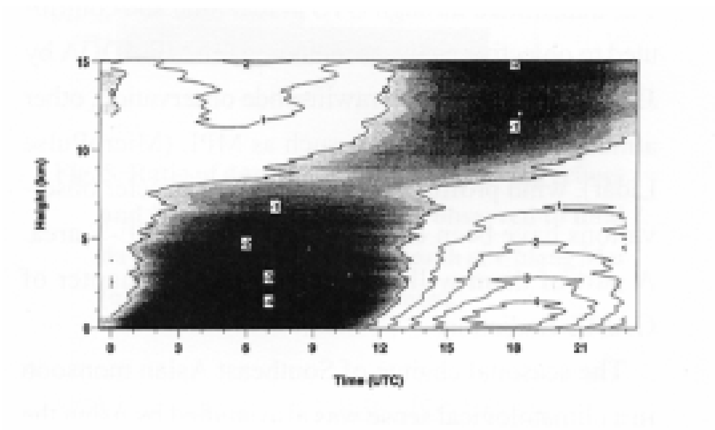


Fig. 7. A time-height section of diurnal component of equivalent potential temperature variations in the rainy season.

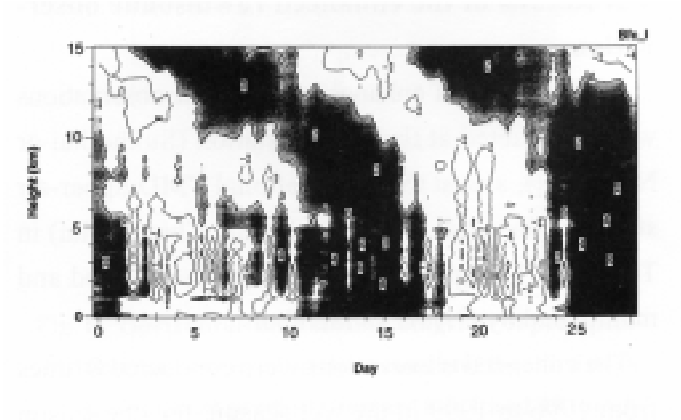


Fig. 8. A time-height section of equivalent potential temperature in the pre-monsoon period (composite of I, 7, 9.3 and 14 day period (composite of I, 7, 9.3 and 14 day period component).

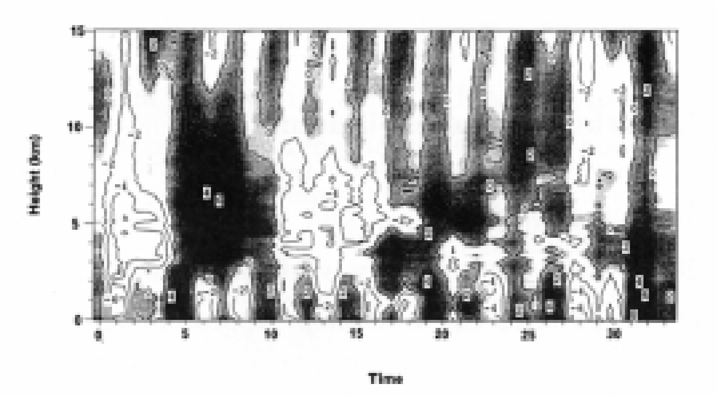


Fig. 9. A time-height section of equivalent potential temperature in the mature monsoon period (composite of 1, 8.5, 11.3 and 17 day period component).

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

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

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

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

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

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

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

6. Hydrological modeling, regional atmospheric modeling and their coupling

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

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

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

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

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

References:

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

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

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

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

7. Workshops and publications

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

List of Publication

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

8. Future perspective

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

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

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

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

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

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