## 3.2 Tropical Region (GAME-Tropics)

### 3.2.1 Scientific background

#### 3.2.1.1 Scientific goals

Among GEWEX/GAME research components, GAME-T's role is to observe and investigate the energy and water cycle in the warm humid areas of the Asia Monsoon region, from tropics to sub-tropics. These areas are characterized by small seasonal change of temperature and a predominant diurnal cycle of temperature and precipitation. The annual variability of precipitation and surface soil wetness is quite large where dry and rainy (wet) seasons are defined, and the intraseasonal and interannual variations of precipitation are as significant as diurnal cycle in the tropical area. As a heat source for the atmosphere, the release of latent heat in this region is the largest on the earth, and it drives the circulation of the Asian monsoon.

The tropical precipitation and its variabilities mentioned above are governed by mesoscale convection (cumulonimbus clouds) and its organizations (cloud clusters and super clusters). The tall convective clouds reflect the solar irradiance and absorb/re-emit the terrestrial infrared radiation, which controls the atmospheric energy budget and general circulation. Strong convection also emits various propagating wave disturbances which organize the convective motions (clouds) themselves in the troposphere and induce variations other than annual and diurnal, such as the quasi-biennial oscillation (QBO) in the lower stratosphere. The water vapor and heat pumped up by local convection and global circulation are returned down to the lower troposphere by the so-called 'cold-trap' mechanism at the tropical tropopause where the altitude and temperature are highest and lowest, respectively, on the earth. This mechanism prevents the water from escaping to the space, and maintains the global energy budget and environment.

On the other hand, the population density in this region is generally high, and the crop (rice) production supporting these large population is directly related to the variation of the precipitation during the Asian monsoon. Therefore, the seasonal prediction of precipitation by the development of an adequate combined land-atmosphere numerical model is not only scientifically challenging but also will contribute to societal issues through improving the accuracy of water resource prediction. The high population density is closely related to the relatively high density of the existing observational network of hydrological and meteorological stations.

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 GEWEX/GAME.

#### 3.2.1.2 Scientific objectives

As a part of GEWEX/GAME, the objective of GAME-T is the quantitative monitoring of vapor flux, precipitation, evapotranspiration, radiative flux and their seasonal, intra-seasonal and interannual variation at the target areas of the warm humid region in the south-east Asia. Especially, focus is on

- the surface wetness which differs significantly in the dry and wet season, and
- the diurnal cycles of precipitation and other hydro-meteorological variables which are dominant in the tropical area,

and their effect on the energy and water flux from land surface including vegetation will be carefully observed and investigated. Of course,

- dynamical studies on the hierarchical structures of cloud-precipitation systems which consist of:
  - individual clouds generated locally and micro-physically,
  - cloud clusters or tropical cyclones moving from the South China Sea or the Bay of Bengal,
  - super clusters or convection centers organized by coupled effects of the Indian and Pacific Oceans, and
  - theory and quantitative description on the role of atmospheric wave disturbances in organization of the hierarchical structures and interannual variabilities of clouds and precipitation.
- the better understanding of the effect of the interannual variation of precipitation on the yield of rice in this region, and
- improving the accuracy of the seasonal prediction of precipitation

are vital issues of the research in GAME-T. In a global sense, Fig.3.2-1 shows the correlation of rainfall in Thailand from May to July and the SOI of November at the same year. Their inter-annual variations synchronize and it is suggested that at least the energy and water cycle in Thailand can be a good measure of the variation of the global climate system.

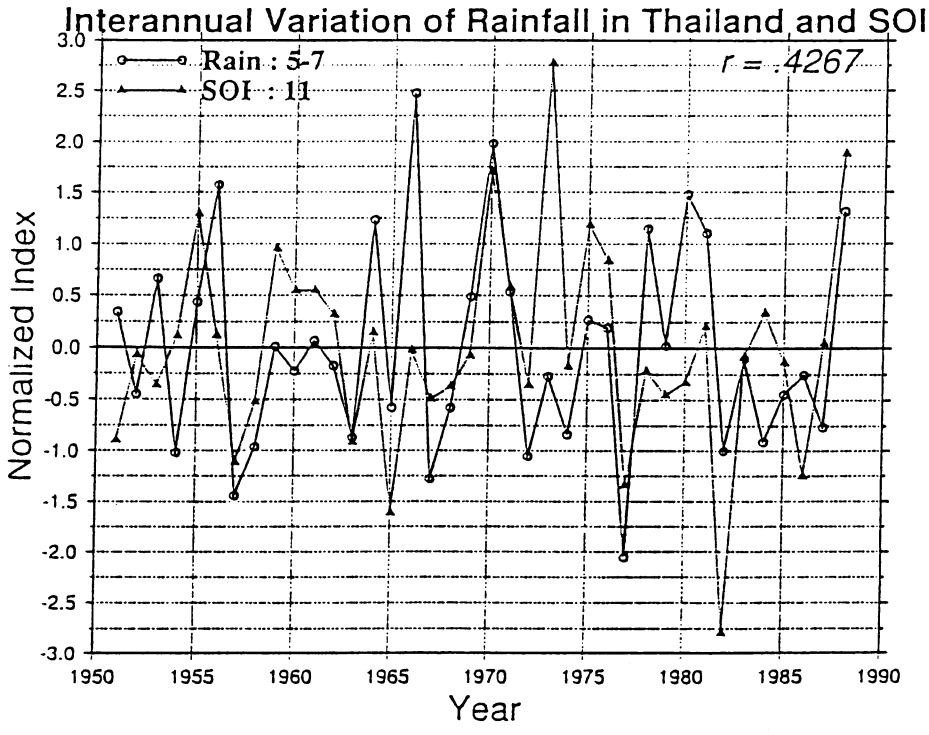


Fig. 3.2-1 Inter annual variation of rainfall in Thailand from May to July and the Southern Oscillation Index (SOI).

For the collection of existing hydrometeorological observations, the target area of GAME-T covers as much as possible the warm humid region of the South East Asia. Additional observational instruments and enhanced observations, including flux observation sites, will be made in the Chao Phraya River basin in Thailand, and in the forest in Sarawak, Malaysia, and Sri Lanka (Fig.3.2-2).

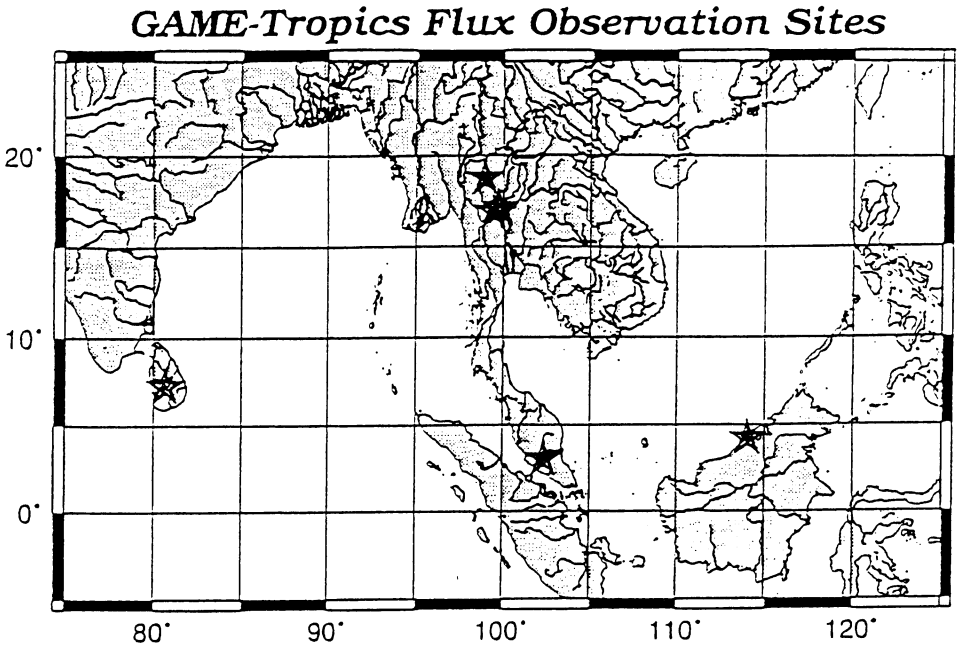


Fig. 3.2-2 Illustration of flux observation stations in whole GAME-T.

3.2.1.3 Program strategy

Corresponding to the strategy of GEWEX/GAME, water and energy cycles will be studied using several approaches.

(i) Boundary layer observations will be carried out in order to measure the flux and the balance of energy and water at land surface. The study areas are selected to cover typical landscapes of the target region of GAME-T, such as forest, cultivated area (paddy field) and bare soil. Some new scientific information is expected to be obtained.

- The effect of soil wetness on the evaporation from land surface with vegetation, and the effect of rain water storage on runoff generation will be observed in the Chao Phraya River basin in Thailand where the difference between dry and wet season is large.
- The interaction between the diurnal cycle of precipitation and evapotranspiration, especially from intercepted water, will be studied.
- A method to estimate evaporation from soil temperature data will be developed and validated.
- Large scale evapotranspiration will be estimated using the data of the lower part of the atmospheric boundary layer from frequent rawinsonde observations combined with satellite observations by NOAA/AVHRR/IR.

(ii) Ground truth data will be observed for the validation of earth observing satellites, and various hydrometeorological information over a large domain will be retrieved in order to estimate the energy and water fluxes. In GAME-T,

- data from ground based radar, raingauges, and raindrop size distribution for TRMM,
- the area of water surface and the distribution of surface soil wetness for ERS-1/AMI and JERS-1/JSAR,
- surface soil wetness for RADARSAT,
- surface radiation and cloud for GMS/SVISSR, and
- landscape and the vegetation cover for LANDSAT/TM, NOAA/AVHRR, and MOS-1/MESSER,

will be collected, observed and estimated. Algorithms should be developed and/or implemented to retrieve precipitation using satellite remote sensing by GMS and/or TRMM.

(iii) Corresponding to the GAME strategy,

- flux observations by GAME/AAN/AWS at three points of monsoon forest, paddy field and shrub forest in Thailand (Fig.3.2-2 ).

- installation of a precise radiometer and several radiometers, which observe net radiation, in addition to the existing observational network.

will be done. Combining these observations with the hydrometeorological data from the existing stations and longterm monitoring of the energy and water balance are planned. These observations are for the development and the improvement of a one dimensional model to estimate energy and water flux from land surface which may be covered with vegetation. This activity in GAME corresponds to that of PILPS in GEWEX.

(iv) As the diurnal variation, mesoscale convection and wave propagation are all quite large (say, 5 and 17 km, respectively), a special observation station at which rawinsondes are launched eight times a day and tracked up to more than 20 km altitude must be constructed. The location must be near the center of Thailand, or another suitable place remote from any operational stations. Horizontal divergences and vertical fluxes of water vapor, energy and momentum are to be calculated on the basis of this special observation combined with the enhanced operational observations.

(v) In order to obtain better atmospheric data from four dimensional data assimilation, the rawinsonde observations should be enhanced in the GAME-T region where upper air sounding by rawinsonde is currently operated only once a day at 00 UTC (07 LST). Four times daily soundings by radiosonde are expected at least at three stations in Thailand, and two times daily or four times daily observations will be recommended at other stations in the target region of South-East Asia during the Intensive Observational Period of GEWEX/GAME. These special observations should be communicated in real time through GTS line, and 4DDA will be performed at Japan Meteorological Agency.

(vi) As a modelling study of the atmosphere, a regional meteorological model, RAMS ( Regional Atmospheric Modeling System developed at Colorado State University/ASTER ) is used with modification for GAME-T, and this will be nested in the atmospheric general circulation model developed by CCSR/NIES. Land-surface parameterization which calculates areal mean flux

from each grid by weighted averaging of the fluxes from a few typical landscapes will be employed in CCSR/NIES AGCM and the regional model. A distributed hydrological model which uses output from the regional model, such as precipitation and evapotranspiration as its input, will be independently developed and the model is expected to have an ability to consider he effect of artificial inputs or storage.

(vii) Objective analysis will be carried out for the data sets obtained in order to perform error checks and to make data handling easier for everybody including possible scientific users of the data outside of GAME project. Various data sets are objectively interpolated and extrapolated into 10 km grids, at least in the Chao Phraya River basin, and gridded data of water and energy flux will be made. In a larger domain, energy and water balance estimated by 4DDA will be provided, and physical parameters such as precipitation, evapotranspiration and net radiation will be adjusted to satisfy the energy and water budget.

(viii)The data collection, validation and archiving methodologies established through the above-mentioned activities mainly in Thailand are expected to be the basic approaches for subsequent projects (under CLIVAR/GOALS) covering broader areas in the next century. From this point of view, limited but quite similar efforts must be made in parallel over the countries surrounding Thailand (i.e., Malaysia, Indonesia, Myammar and Vietnam). The involvement of younger scientists from these countries is also important to obtain more complete activities in the next century. Furthermore, communications and collaborations with the SCSMEX project and other projects (e.g., concerning cross-equatorial lower stratospheric observations, biomass burning observations, etc.) must be also promoted.

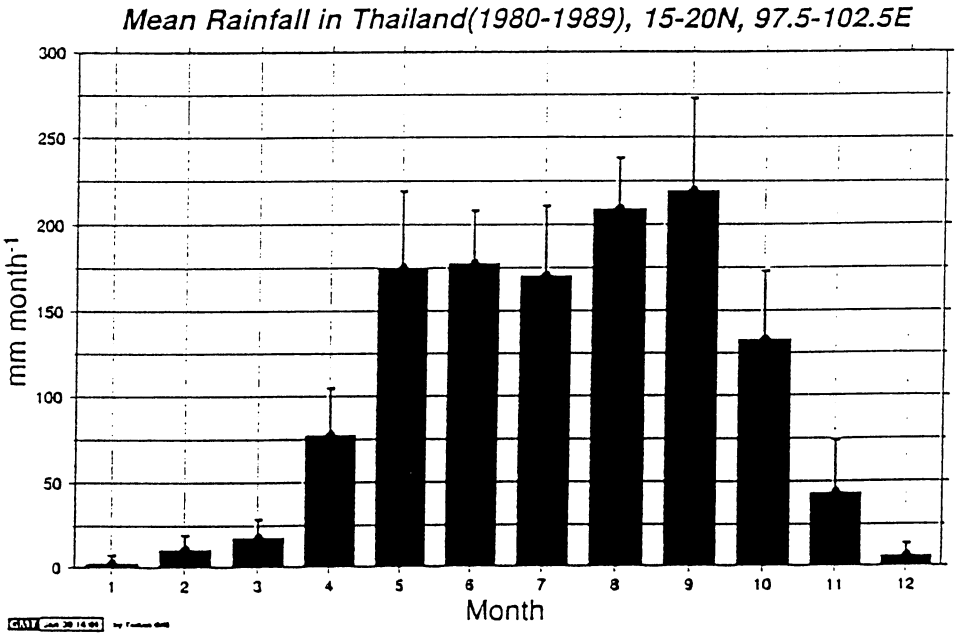


Fig. 3.2-3 Mean monthly rainfall in Chao Phraya River basin. Mean from 1980 to 1989 is calculated from the data provided by the Thai Meteorological Department. Error bars indicate the standard deviation over 10 years.

1998 is the target period of intensive observations, but preliminary observations are carried out at 1996 and 1997, and additional observations are expected in 1999. Intensive observations, which cannot be done continuously for long periods, will focus on the comparison between the wet and dry seasons: two to three weeks each during the dry season in March and during the wet season in August. Intensive observation by rawinsonde are expected to cover the onset and the decay of the South-West Asian monsoon. These are planned from April to June and August to October. Ten year (1980-89) mean monthly rainfall in Thailand is shown in Fig. 3.2-3. The rainy season starts late April to the beginning of May, and the interannual variation is large in May. During the dry season, from December to March, the rain is considerably less and the soil largely dries. Intensive observations are planned taking account of these climatological phenomena.

### 3.2.2 Experimental strategy

GAME-T covers the sub-tropical region of South-East Asia, including countries such as Philippine, Vietnam, Thailand, Malaysia, Singapore, Indonesia and Sri Lanka. Data analysis will cover the entire region but observations are planned mainly in Thailand, Malaysia and Sri Lanka. Because a lot of resources will be spent in Thailand, this implementation plan mainly covers what is planned for GAME-T in Thailand and Malaysia (Fig.3.2-4).

#### 3.2.2.1 1-dimensional flux observation

One dimensional energy and water fluxes will be measured in GAME-T at the stations listed below. The distribution of the planned stations for flux observation are illustrated in Fig. 3.2-2 for the whole GAME-T area. Net radiation and basic hydrometeorological parameters will be continuously observed in stations described below, and time series of energy and water flux will be estimated and monitored. Observing stations within the Chao Phraya River basin are a) – d) and i). From the statistics of land use classification in Thailand (Table 3.2-1 1991, unit 1,000 rai = 160 ha), the Northern region and the Central Plain almost correspond to the upper and the lower part of Chao Phraya basin, respectively. Further, the land use of the Farm Holding Land can be divided in detail (Table 3.2-2).

From these tables, one can see that half of the upper Chao Phraya River basin is covered by forests, 30% is 'unclassified' and half of cultivated areas, namely 15% of total, is paddy field. The landscapes of a), c) and b) are corresponding these major land uses. However, the Kog-Ma experimental basin, a), is located in higher altitude compared to whole forest region in the Chao Phraya River basin, and it may not represent the energy and water fluxes of the forest region in the area. Shrub forest area, c), is established assuming that most 'unclassified' area corresponds to such a landscape. In this region, shrubs in the plains are mixed with bare soil or small grasses. Further detailed study on the land use is required, especially to investigate 'what is unclassified'.

Station h) and i) are operated by the National Institute for Earth Science and Disaster Prevention (NIED, Japan), Research Development Corporation of Japan (JRDC, Japan) and Royal Irrigation Department (RID, Thailand). The basic time interval of operational hydro-meteorological data in Thailand is daily for TMD, RID, RFD and EGAT, but for more than thirty agrometrological stations of TMD, three hourly data are manually recorded and soil temperature at several depths are regularly observed. The data from these agrometeorological stations may be used for flux estimation with additional measurement of net radiation. The experimental basin in Sri Lanka, g), will be serviced during the fiscal year of 1998. Among these stations, a), b), and c) will be equipped with GAME/AAN-AWS and it is possible that f) will, too.

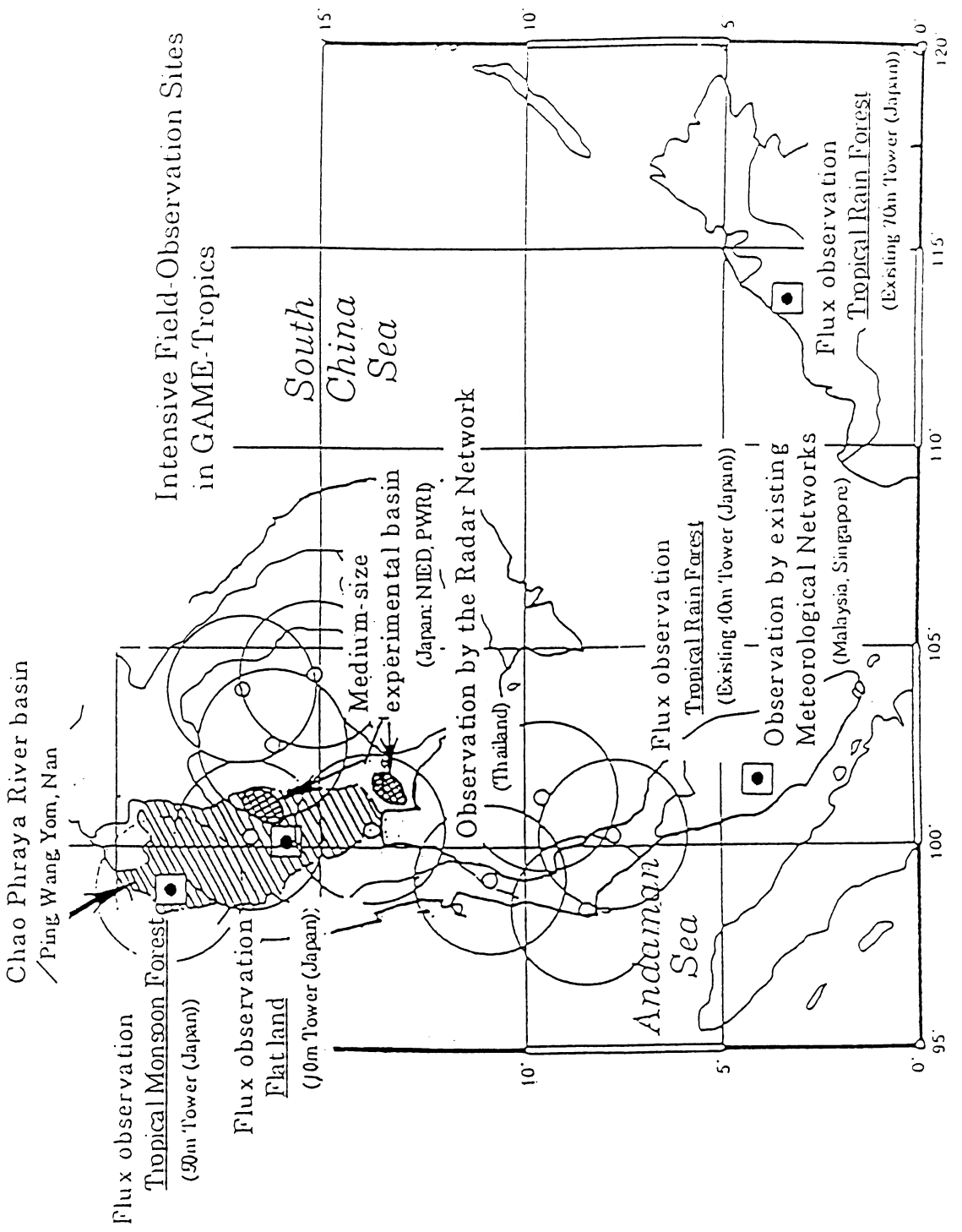


Fig. 3.2-4 Comprehensive illustration of planned observations in Thailand and Malaysia.

a) Kog-Ma experimental basin, Thailand, the Monsoon Forest:
98.9 E 18.8 N, 1268 m (by KU, RFD in Thailand, and Prof. Suzuki)

b) West Sukhothai along with Route 1113, Thailand, non-irrigated paddy field:
99.7 E 17.1 N, 50 m (by KU, RID in Thailand, Prof. Aoki, and Prof. Sunada)

c) EGAT Tower Thailand, shrubbery forest:
99.4 E, 16.9 N, 140 m (by RID, EGAT in Thailand, Prof. Sunada, Dr. Sugita and Dr. Ohte)

d) Mobile observation in Y32/Y4 river basin, Thailand, various landscapes:
(by Prof. Aoki)

e) Pasoh forest reserve, Malaysia, tropical rain forest:
102.3 E 3.0 N, 120 m (by FRIM in Malaysia, FFPRI: Dr. Tani)

f) Sarawak, Malaysia, tropical rain forest:
114.0 E, 4.2 N, 300m (by Prof. Suzuki)

g) Experimental basin at University of Peradeniya, SriLanka, forest and grass land:
80.6 E, 7.3 N, 800 m (by University of Peradeniya in Sri Lanka, Prof. Tanaka, Prof. Shimada and Prof. Tase)

h) Khuwae-Noi meso-scale experimental basin, Thailand:
100.3-101.1E 16.8-17.7N, 2,100-45m (by NIED: Mr. Nakane, JRDC: Mr. Kurauchi and RID)

i) Lam Phra Phloeng micro-scale experimental basin, Thailand:
101.7E, 14.5N, 600 — 300m (by NIED: Mr. Kishi, Dr. Kuzuha and RID)

Table 3.2-1 Areas of land use in Thailand (rais)

| Region | Total | Forest | Farm Holding Land | Unclassified |
|---|---|---|---|---|
| North-Eastern | 105,534 | 13,624 | 57,719 | 34,191 |
| Northern | 106,028 | 48,214 | 29,394 | 28,419 |
| Central Plain | 64,938 | 15,192 | 28,629 | 21,117 |
| Southern | 44,197 | 8,406 | 17,334 | 18,457 |
| Total | 320,697 | 85,436 | 133,076 | 102,184 |

Table 3.2-2 Areas of land use classification of farm holding land in Thailand (rais)

| Region | Total | House | Paddy | Crop | Fruit | Flower | Corn | Idle | Other |
|---|---|---|---|---|---|---|---|---|---|
| North-Eastern | 57,719 | 1,253 | 37,973 | 13,445 | 1,844 | 209 | 395 | 2,069 | 521 |
| Northern | 29,394 | 942 | 15,197 | 10,475 | 1,754 | 276 | 134 | 432 | 184 |
| Central Plain | 28,629 | 853 | 12,531 | 9,438 | 4,379 | 309 | 124 | 445 | 550 |
| Southern | 17,334 | 488 | 3,612 | 150 | 12,121 | 64 | 53 | 676 | 168 |
| Total | 133,076 | 3,536 | 69,313 | 33,519 | 20,098 | 858 | 707 | 3,621 | 1,423 |

Secondary products estimated from these observations are:

*Longterm, hourly data, at every station

- inter-calibrated radiation budget at land surface
- cross-calibrated heat transfer into soil layers
- sensible and latent heat flux by energy balance/Bowen method, at paddy fields
- sensible and latent heat flux by bulk method
- sensible and latent heat flux by bulk method/Penman-Monteith method, at forests

*Longterm, hourly data, at some stations

- albedo
- sensible heat flux by GAME-AAN/AWS-SAT and latent heat flux by energy balance

*IOP, hourly data, at some stations

- sensible heat flux by Sonic Anemometer-Thermometer (SAT) and latent heat flux by energy balance
- sensible heat flux by SAT and latent heat flux by covariance measurement by infrared
- sensible and latent heat flux by profile method, roughness parameters in each direction (time independent)
- sensible and latent heat flux using lower boundary layer information obtained by rawinsonde

Table 3.2-3 summarizes the observed items at each observation station.

Table 3.2-3 Observed items at each observation station.

| Item | a) | b) | c) | d) | e) | f) | g) | h) | i) |
|---|---|---|---|---|---|---|---|---|---|
| Radiation Budget | I | I | I | C | I | I | I | I | I |
| Downward Shortwave | I | I | I | C | I | I | I | - | - |
| Upward Shortwave | I | - | I | C | I | I | I | - | - |
| Downward Longwave | I | - | I | C | I | I | I | - | - |
| Upward Longwave | I | - | I | C | I | I | I | - | - |
| Vertical Profile of R | C | - | C | - | C | C | - | - | - |
| Wind Velocity (V) | I | I | I | C | I | I | I | I | I |
| Vertical Profile of V | C | C | C | - | C | C | C | - | - |
| Wind Direction | I | I | I | C | I | I | I | I | I |
| Temperature (T) | I | I | I | C | I | I | I | I | I |
| Vertical Profile of T | C | C | C | - | C | C | C | - | - |
| Humidity (q) | I | I | I | C | I | I | I | I | I |
| Vertical Profile of q | C | C | C | - | C | C | C | - | - |
| Surface T by IR | C | I | C | C | C | C | C | - | - |
| T in soil layers | I | I | I | C | I | I | I | I | - |
| Heat flow into ground | I | I | I | C | I | I | I | I | I |
| Pan evaporation | - | - | - | - | - | - | - | I | I |
| Water temperature | - | I | - | - | - | - | - | - | - |
| Water depth | - | I | - | - | - | - | - | - | - |
| Sensible heat by SAT | C | C | C | C | C | C | C | - | - |
| Latent heat by IR | C | C | C | C | C | C | C | - | - |
| Soil moisture | I | I | I | - | I | I | I | I | I |
| Precipitation | I | I | I | C | I | I | I | I | I |
| Interception by crown | C | - | - | - | C | - | - | - | - |
| Stomata conductance | C | - | - | - | C | C | - | - | - |
| Leaf area index | C | - | - | - | C | C | - | - | - |
| Sap velocity | C | - | - | - | C | C | - | - | - |
| Rawinsonde obs. | C | C | - | - | - | - | - | - | - |
| Data transmit by Sat. | C | I | C | - | - | C | C | - | - |
| Hight (m) of obs. tower | 50 | 10 | 100 | 10 | 40 | 50 | 30 | 6 | 6 |
| Soil properties | C | C | C | C | C | C | C | C | - |
| vegetation | C | C | C | C | C | C | C | C | C |
| land use | C | C | C | C | C | C | C | C | C |
| digital elevation map | C | C | C | C | C | C | C | C | - |

I : continuous observation
C : only during the IOP
- : not planned

3.2.2.2 Meso-scale process studies

(i) General Heat sources in the tropics are mostly due to the condensation in convective clouds, and it is driving the general circulation. The convective activity is most intense particularly in the western Pacific region in the tropics. Therefore it is very important to investigate convections of cloud and associated meso-scale phenomenon in the tropical region.

We have planned the following observations for the research of meso-scale meteorology:

- upper air sounding by enhanced rawinsonde observation

- rainfall observation by ground based rain gauges

– We will have a collaborative study to install extra rain gauges around the northern Thailand, and will observe rainfall.

- observation of raindrop size distribution by disdrometer at Chiang Mai

- boundary layer wind observation using wind profiler

- radar rainfall estimates by conventional weather radars operated by TMD

– Digital composite images of all over Thailand is completed in 1997. Spatial structure, motion, and transformation of rainfall system can be analyzed from this information.

- radar rainfall estimates by Om Koi radar operated by BRRAA

– It is a S-band radar located at N17 47'54", E98 25'57", 1160 m, and the data within a range of 125 km are quantitatively used. Three dimensional scans are made each five minutes by changing the elevation angle up to 27 degrees. All radar data, both reflectivity and Doppler velocity, are recorded in 8 mm tape regardless of rain or no rain. This radar data are also used as one of the TRMM validations, and all the data will be sent and archived at NASA/GSFC.

- Analysis of NOAA/GMS/TRMM satellite data

These data are useful to understand the environment of meso-scale phenomenon. Using these information, following studies will be possible.

– relation between the motion of monsoon front and the variation of precipitation ,

– intra-annual and seasonal changes of the global and continental-scale rainfall variations,

– study of monsoon front structure and its formation process,

– meso-scale circulation in the tropics, diurnal and semi-diurnal circulation,

– surface soil wetness on the development of atmospheric mixing layer,

– relationship between heat and water vapor budgets and cloud activity,

– modulations of precipitating cloud clusters by super clusters or convection centers organized by coupled effects of the Indian and Pacific Oceans through equatorial planetary-scale waves,

– development and organization of precipitating cloud clusters by topographic effects and by gravity waves,

– generation of mesoscale gravity waves by topography and by cloud convection,

– troposphere-stratosphere exchange of water vapor, energy and momentum due to penetrating clouds and propagating waves through the tropopause,

– study of meso-meteorological simulation in the tropics using the data.

We have started pre-observation since 1996. We have got some new observational results of diurnal and semi-diurnal circulation.

(ii) Enhanced rawinsonde observations

The following enhanced rawinsonde observations were implemented.

Location :

| | | | |
|---|---|---|---|
| CHIANG MAI | 98 59' E | 18 47' N | 312 m |
| UBON RATCHATHANI | 104 52' E | 15 15' N | 123 m |
| BANGKOK METROPOLIS | 100 34' E | 13 44' N | 2 m |

Period :

| | | |
|---|---|---|
| 1996 | May 15 – 29, | 4-times observation (6-hourly) |
| | August 22 – September 6, | 4-times observation (6-hourly) |
| 1997 | March 1 – 15, | 4-times observation (6-hourly) |
| | May 15 – 29, | 4-times observation (6-hourly) |
| | August 25 – September 5, | 4-times observation (6-hourly) |

Special enhanced rawinsonde observation was implemented as following.

Place :

| | | | |
|---|---|---|---|
| SUKHOTHAI | 99 42' E | 17 03' N | 50 m |

Period :

| | | |
|---|---|---|
| 1996 | August 23 – September 6, | 4-times observation (6-hourly) for a week and, 8-times observation (3-hourly) for a week |
| 1997 | March 1 – 15, | 4-times observation (6-hourly) for a week and, 8-times observation (3-hourly) for a week |

Location :

| | | | |
|---|---|---|---|
| NONG KHAI | 102 43' E | 17 52' N | 173 m |

Period :

| | | |
|---|---|---|
| 1997 | August 25 – September 8, | 4-times observation (6-hourly) for a week and, 8-times observation (3-hourly) for a week |

These data were sent to all over the world in real time by GTS, and were used for the routine meteorological analysis and forecast.

NONG KHAI is a key station for the analysis of heat and water budgets all over Thailand. These four stations will make a rectangular shape baseline surrounding the Thailand.

(a) The following observations are planned for the GAME-IOP in 1998.

Location :

| | | | |
|---|---|---|---|
| CHIANG MAI | 98 59' E | 18 47' N | 312 m |
| UBON RATCHATHANI | 104 52' E | 15 15' N | 123 m |
| BANGKOK METROPOLIS | 100 34' E | 13 44' N | 2 m |
| PHUKET | 98 24' E | 07 53' N | 2 m |

Period :

1998 April 15 – May 14, 4-times observation (6-hourly)

These observations aim to find out the behaviors of monsoon onset and its variation.

Location :

| | | | |
|---|---|---|---|
| CHIANG MAI | 98 59' E | 18 47' N | 312 m |
| UBON RATCHATHANI | 104 52' E | 15 15' N | 123 m |
| BANGKOK METROPOLIS | 100 34' E | 13 44' N | 2 m |
| NONG KHAI | 102 43' E | 17 52' N | 173 m |

Period :

1998 May 15 – June 15, 4-times observation (6-hourly)
1998 August 15 – September 15, 4-times observation (6-hourly)

These observations aim to study the relationship between energy and water budget and cloud developing.

(b) Further, the following observations are planned under certain circumstances.

Location :

| | | | |
|---|---|---|---|
| CHIANG MAI | 98 59' E | 18 47' N | 312 m |
| UBON RATCHATHANI | 104 52' E | 15 15' N | 123 m |
| BANGKOK METROPOLIS | 100 34' E | 13 44' N | 2 m |
| NONG KHAI | 102 43' E | 17 52' N | 173 m |

Period :

1998 June 15 – June 25, 4-times observation (6-hourly)
1998 July 5 – July 20, 4-times observation (6-hourly)

These periods are those of GAME-TIBET, INDIA , HUBEX, and KORMEX IOP.

(c) Finally, the following observations are planned.

Location :

| | | | |
|---|---|---|---|
| CHIANG MAI | 98 59' E | 18 47' N | 312 m |
| UBON RATCHATHANI | 104 52' E | 15 15' N | 123 m |
| BANGKOK METROPOLIS | 100 34' E | 13 44' N | 2 m |
| NONG KHAI | 102 43' E | 17 52' N | 173 m |

Period :

1999 March and August, each 2 weeks 4-times observation (6-hourly)

These observations are planned in order to verify the expected findings in the previous years. These intensive rawinsonde observations in the south-east Asia are the first one in the history of meteorological operations and studies. The reliablity of rawinsonde observation itself will be checked very carefully throughout these intense observations. The special observations at Sukhothai and Nongkhai will use a GPS-sonde system which is the newest rawinsonde system and must be compared with the other conventional rawinsonde systems in details. The problems in ground check and data transmission at each stations will be also surveyed and checked carefully.

These examinations as well as re-analysis (4DDA) based on the corrected data set after the examinations will produce the most reliable three-dimensional atmospheric structure over this region which have never been obtained so far. Furthermore, the reliability and predictability of the present numerical models will be examined for the first time by using the data sets obtained in this projects.

(iii) Boundary layer wind observation using wind profiler

A L-band Doppler radar (called wind profiler) is operated in Bangkok by the King Mongkut's Institute of Technology Ladkrabang (KMITL) in cooperation with the Communications Research Laboratory (CRL). The wind profiler measures wind directions and velocities in boundary layer (300 m - 3,000 m) continuously. The hourly averaged wind data measured by the radar will be offered to GAME-T researcher. The data will be useful for study on seasonal and diurnal wind variation and helpful for the analysis of the enhanced rawinsonde observation.

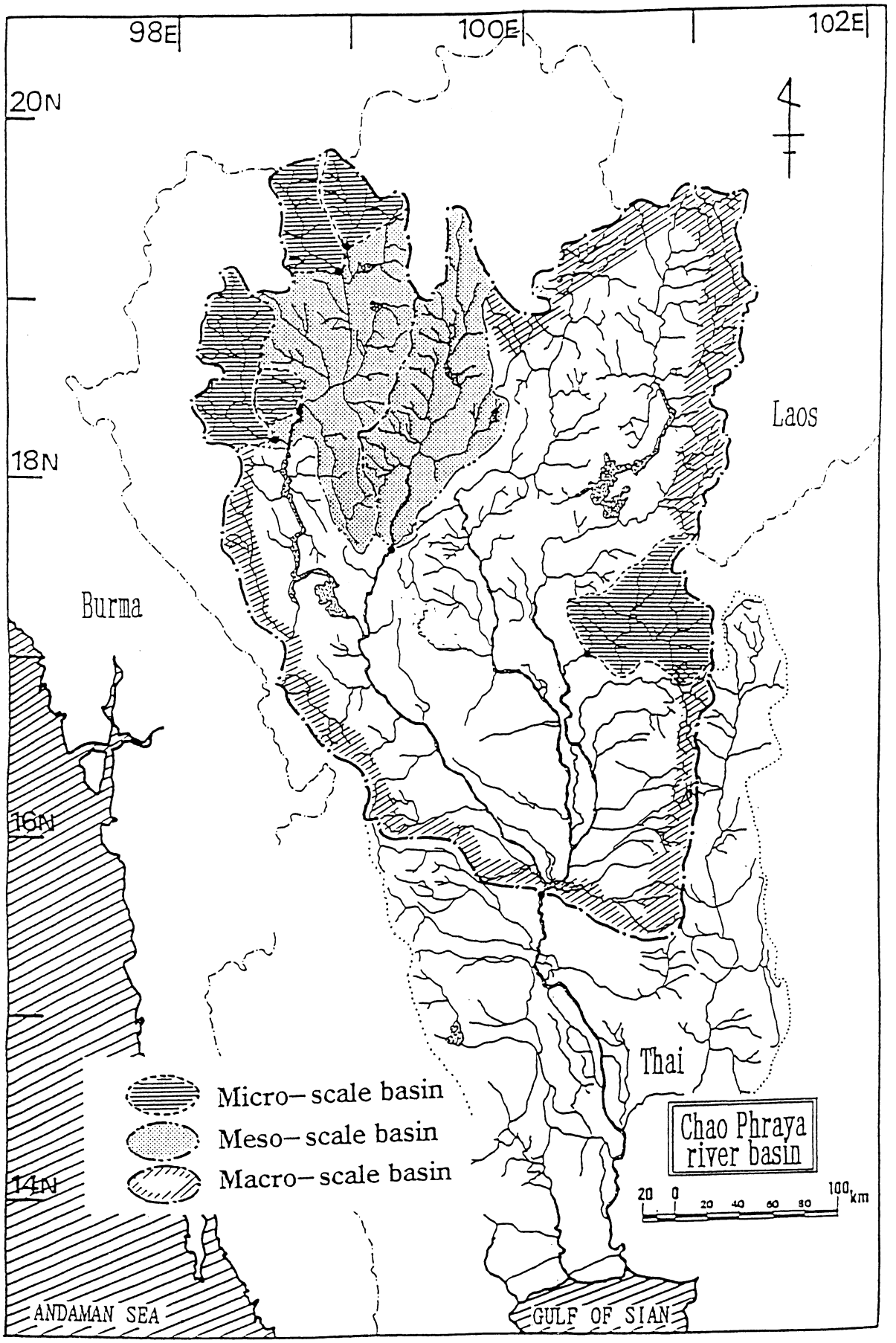


Fig.3.2-5 Scales of Hydrologic Modelling for Chao Phraya River Basin.

Table3.2-4 List of candidate basins for hydrological budget studies and modelling

| Scale | Gauging Station (Town) | River | Catchment area ($km^2$) | Observation | Rain gauges | Land use | Remarks |
|---|---|---|---|---|---|---|---|
| Micro Scale | P.20 (Chiang Dao) | Ping | 1,355 | Automatic Gauge Stuff Gauge | 5 | Mountainous Forest | main stream |
| | P.4A (Mae Tang) | Mae Tang (Ping) | 1,902 | Automatic Gauge Stuff Gauge | 15 | Mountainous Forest | PWRI |
| | P.24A (Chom Thong) | N.Mae Klang (Ping) | 460 | Stuff Gauge | 8 | Mountainous Forest Paddy | Doi.Inthanon irrigation, w-intake much rainfall |
| | P.14 (Oblung gorge) | N.Mae Chaem | 3,353 | Automatic Gauge Stuff Gauge | | Mountainous Forest | uniform cross-section |
| Meso Scale | EGAT Point (Hot) | Ping | 18,990 | Automatic Gauge Stuff Gauge | | Mountainous basin | upstream of Bumibol reservoir |
| | W.3A (Theon) | Wang | 8,985 | Automatic Gauge Stuff Gauge | | Mountainous basin | major tributary |
| Macro Scale | C.2 (Nakon Sawan) | Chao Phraya | 110,569 | Automatic Gauge Stuff Gauge | | | key point |

3.2.2.3 River-basin scale budget studies

Several river catchments are designated for water balance studies and hydrological modelling in the Chao Phraya River basin (Fig.3.2-5, Table 3.2-4). These catchments are selected to make hierarchical structure in terms of catchment size, as macro scale ( 100,000 $km^2$), meso scale (10,000 $km^2$) and micro scale (1,000$km^2$). Various hydrometeorological parameters are objectively analyzed into 10 km grids by interpolation and extrapolation using sensible and latent heat fluxes, the precipitation distribution, and the existing operational network. In addition, an intensive rawinsonde observation are planned specially for the estimation of evapotranspiration in the middle of the Chao Phraya River basin, and also installation of extra raingauges in the target area are planned.

(i) Enhanced Rawinsonde observations for the estimation of evapotranspiration

Evapotranspiration over a large area will be estimated at least twice during daytime using rawinsonde observations, and the evapotranspiration at other times of the same day will be calculated using other continuous measurements at ground surface. From this method (Brutsaert and Sugita 1992; Sugita and Brutsaert 1991), daily (and diurnal cycle maybe with lesser accuracy) evapotranspiration will be obtained in large scale.

Place : flux observational station b) or c) in the section of 3.2.1.1, the middle of the Chao Phraya River basin.

Frequency : 4 – 8 times per day at 00, 03, 06, 09, 12, 15, 18 and 21 UTC, it corresponds to 07, 10, 13, 16, 19, 22, 01 and 04 LST, respectively.

Period :

1999 2 weeks at March and August, each

*Large scale evapotranspiration will be estimated on a day of favorable weather condition during the scheduled period.

(ii) Hydrological experimental basins

Corresponding to flux station a), an existing weir will be improved at the Kog-Ma hydrological experimental basin and discharge will be precisely observed. Katsesaert University will be

mainly responsible for the operation and management of this basin. Instrumentation of discharge-gauging stations may be installed in some mesoscale and microscale river basins if required.

*Runoff data will be provided at 10 minutes to 1 hour intervals.

(iii) Installation of extra raingauges

The raingauges in the existing operational network tend to be located in residential areas, and are rare in mountainous region. BRRAA is trying to distribute the raingauges as evenly as possible, and approximately twenty five raingauges will be offered in order to support their activity. Another ten rain gauges will be distributed in the Mae Chaem River basin in order to improve the mean areal rainfall rate estimate. For example in the mountainous area, the installation of stations at 400 m, 700 m, 1260 m, and 1685 m are planned at Mt. Doi Pui where the Kog-Ma hydrological experimental basin is located. Possibly temperature and humidity will be simultaneously measured. In the Mae Chaem River basin where discharge is measured at P.14, there are many experimental basins of the RFD and it will be possible to estimate areal mean rain rate accurately.

3.2.2.4 Use of satellite remote sensing

(i) Scientific Goals

One of the major goals in GAME is to understand the interaction between the Earth's surface and the atmosphere. The landcover characteristics vary at a much finer spatial scale than that of atmosphere. On the other hand this variability contributes to the overall hydrologic response of a catchment and therefore the heterogeneity of the land surface should be investigated well so as to represented in modeling studies. Satellite remote sensing is the best method to obtain land cover information at high resolution covering a large area. As the satellite monitoring is essentially an indirect approach where observed reflectance at different wave lengths are related to required distribution of physical characteristics, observations and process studies are essential to evaluate algorithms and data. For the above procedure, various remote sensing data and data sets of physical state variables and fluxes derived from satellite data will be archived for the GAME-T research and for the international research community related to GEWEX.

(ii) Development of algorithms and verification using regional experiment data

GAME-T aims to develop algorithms and verify the products using ground truth data collected during the project periods. Two representative experimental regions covering areas over 100× 100 $km^2$ are selected to collect high resolution data (spatial resolution less than 100 m and time resolution 1 day) at flood plain near (scene center Lat. 16°45' N, Lon. 100°10' E) and at mountainous area near Chaing Dao (scene center Lat. 19°10' N, Lon. 98°40' ). These locations are selected to cover the two dominant landscapes in the region as described in the section of 3.2.2.1.

(a) land use

Land use is an essential information required not only for the understanding of human activities, but also for modeling and analysis of climate and hydrological systems. Historical land use maps of '70s, early '80s, and early '90s will be made with 100 – 300 m resolution. These maps are obtained from data fusion techniques using LANDSAT/TM, NOAA/AVHRR, and MOS-1/MESSR. The following land use types are classified in the maps: water body, forest (evergreen and deciduous), paddy field(irrigated and non-irrigated), crop land, bare and glass land, urban and residential area, and unclassified area. (by NRCT, LDD, and Prof. Sibasaki)

(b) Vegetation

Vegetation covers the largest area in the GAMET region, and its physiological activity and interaction with the climatic and hydrological processes are of great importance to GAME-T project. NDVI and its related indexes will be obtained by NOAA/AVHRR and LANDSAT/TM with 100 m – some 10 km resolution. However, forest structures cannot be obtained from visible sensors' data. Therefore SAR data are expected to provide some structural information. For this purpose, forest structure, LAI , vegetation moisture content will be measured for the validation of the algorithm and products with about 200 m resolution.
(by RFD, Prof. Kazama, Prof. Ohte, and Dr. Nakaegawa)

(c) Topography

Global digital elevation models (DEMs) are being produced under several global projects. However, their resolution and accuracy are not always sufficient, especially to the surface hydrology. Interferometry and radar image correlation method are new techniques expected to resolve the above problems using radar DEMs are generated using these methods from JERS-1/SAR, ERS-1,2/AMI, and RADARSAT/SAR Stereopair images with about 100 m resolution. High resolution Kinematic GPS would be used for collecting ground truth data for calibration and verification of algorithms. (by AIT, KKU, and Prof. Herath)

(d) Precipitation

TRMM is a very unique mission specialized for measuring precipitation and targeted in tropical regions, while retrieval of precipitation from spaceborne sensors is widely studied using visible and infra-red data up to now. Calibration and and validation of TRMM/PR and TRMM/TMI estimates will be carried out using ground truth data collected and analyzed during GAME-T project. Precipitation from GMS data will be estimated by the conventional algorithms, and it will be compared with the above estimates. (by TMD, BRRAA, Prof. Oki, Dr. Ueno, Prof. Kazama, and Prof. Watanabe)

(e) Cloud

Cloud system represents a part of the interaction between the atmosphere and the earth's surface, and drives the surface heat budget through the radiations. $T_{bb}$ analysis using GMS data during IOP is planed, and focused on cloud variation (diurnal and spatial variations), regional structure of cloud propagation, mean of cloud distribution, and comparison of ground based radar. Real time computation and archives of cloud parameters, cloud coverage, cloud top height, cloud optical thickness, and surface temperature are planned from the radiation model using GMS data at IIS, University of Tokyo. These will improve the understanding of the interaction of radiationcloudsurface heat partitioning. (by TMD, Prof. Oki and Prof. Watanabe)

(f) Radiation

This is a part of GAME Radiation activities and its scientific goals are to understand the distribution of surface radiation budget over the Asian monsoon region. The role of clouds, aerosols, etc., will be studied. High-accuracy radiometers and a spectrometer were installed in agrometeorological station, TMD at Si Samrong, in order to measure the surface radiation budget. The satellite products will be estimated based on GMS/SVISSR, NOAA/AVHRR, and SMM/I,T2. (by TMD, Prof. Nakajima, Prof. Takeuchi, and Prof. Oki)

(g) Surface temperature

Surface temperature has an important role in the surface heat budget because it determines the outgoing long wave radiation from the surface, and is related to the surface status, such as soil wetness. Surface temperature will be estimated from NOAA/AVHRR and archived.

(h) Surface soil wetness

SAR has been expected to make a break through of surface soil wetness detection from space-borne sensors, but the backscatter is sensitive not only to soil surface but also to surface roughness. Soil wetness will be detected accurately using the roughness maps made from the land classification and the inverse technique. As a consequence, the distribution of soil wetness over flood plain area will be produced with about 200 m resolution. GAME-T plans to obtain the ground truth values of soil wetness and surface roughness for the development, and to evaluate the algorithms. (by Prof. Honda in AIT, Prof. Tachikawa, and Dr. Nakaegawa)

(i) Evapotranspiration

One of the most difficult issues is to estimate the surface fluxes from a large and inhomogeneous region. Evapotranspiration from such areas will be estimated using NOAA/AVHRR and /IR combined with rawinsonde observations, and using NVDI with some km resolution. It will be compared with the values obtained from the ground based measurement and the atmosphere water budget. (by Prof. Sugita and Prof. Kazama)

3.2.2.5 Regional-nested modelling

Modelling studies can be divided in the following sub-components. These are minimum requirement of modelling studies and further sophisticated approaches would be highly appreciated.

(i) General circulation model: The latest version at that time of CCSR/NIES AGCM will be used.

(ii) Meso-scale meteorological model: RAMS with modification for GAME-T will be used.

(iii) Land surface parameterization for atmospheric models: 'Mosaic' approach which classifies land surface of a grid into limited types, and uses a uniform forcing from the atmosphere to each landscape and returns a weighted mean flux to the atmosphere will be developed and used. A runoff routing model will be also coupled with these meteorological models.

(iv) Model to estimate the exchange of energy and water between land and atmosphere : In addition to the big leaf treatment of vegetation, which is sometimes used in the above c) type models, a model which explicitly describes the vertical profiles of flux and physical parameters within the vegetation layer will be developed, validated and improved. Such a kind of model will be necessary for sparsely planted forest where energy and water are exchanged at both the crown of the trees and the bed of forest.

(v) Runoff model for water resources prediction : A distributed rainfall runoff model which utilizes digital topographic map data, land cover data, the distribution of soil property, etc., will be used. Areal hydrometeorological information given by other sub-projects of GAME-T will be used as input data. Artificial influences like intake or storage in reservoirs will be considered as possible.

*These outputs are expected from these modelling studies in GAME-T.

- Land surface parameterization schemes (c) will be calibrated or validated by estimated fluxes derived from the detailed land surface model (d).

- RAMS will be run using 4DDA data as initial and boundary condition and calibrate or validate against observation.

- Runoff model will be run by the output from above numerical experiment.

- The similar numerical experiments of (ii) and (iii) will be run but using output from AGCM or coupled general circulation model on global warming to make the prediction at regional scales.

3.2.3 Data collections

The hydrometeorological data described below have been collected or will be collected from existing observational networks. If not specified, a data catalogue will be compiled and offered to the scientific and engineering communities.

3.2.3.1 Precipitation

Daily precipitation will be collected from TMD, RID and EGAT in Thailand totally at 300 points. Hourly data will be collected from BRRAA at 40 to 50 stations.

Hourly data is available in Malaysia from the Malaysian Meteorological Service. The Drainage and Irrigation Department of Malaysia is also observing precipitation. Daily precipitation are planned to be collected from the Philippines, Vietnam, Singapore and Indonesia.

Monthly precipitation data at more than 50 stations in Sri Lanka has been collected from 1900 to 1994. This data set has been published in book form.

*Output:

- Areal rainfall distribution will be obtained in combination with radar data and extra raingauge data.

3.2.3.2 Discharge

Discharge data will be collected from RID and EGAT in Thailand.

*Output:

- Discharge or the water stage will be converted into runoff depth for defined watershed areas.

3.2.3.3 Temperature, humidity, wind direction and speed

In Thailand, TMD is observing and archiving the above basic daily meteorological variables in digital form. RID and EGAT are also observing there but there are no plans to collect data from them. In Malaysia, MMS is archiving hourly data in digital form at major observational stations. In Sri Lanka, a part of the basic meteorological data has already collected from 1900 to 1994.

3.2.3.4 Radiation

Sunshine duration is measured at 34 agrometeorological stations of TMD in Thailand, but there is no solar radiation measurement. of TMD in Thailand. A precise radiation measuring system including Lidar subsystem was installed at Si Samrong agrometeorological station in June, 1997, and solarimeters will be installed at several agrometeorological stations in the upper Chao Phraya River basin within 1997.

In Sri Lanka, sunshine duration data at 24 stations from 1975 to 1994 and 10 stations from 1992 to 1994 have been collected.

3.2.3.5 Soil Moisture

There is no observational network of soil moisture in Thailand. LDD (Land Development Department) is joining the AARRP Phase II project by BRRAA, and they have started a study on drought prediction. Soil moisture will be observed at 50 stations at 5 day intervals in this study. They say reliable data will be obtained form at least 20 of the 50 stations.

Daily tensiometer data, which can be converted to soil moisture, at 8 depths in a soil layer have been collected at two sites in Sri Lanka from 1992 to 1994.

3.2.3.6 Soil Temperature

Soil temperature is measured at 0, 5, 10, 20, 50, 100 cm depth at 3 hourly intervals at more than 30 agrometeorological stations of TMD in Thailand. These data will be collected.

In Sri Lanka, 30 minutes interval data at 6 depths from March to October 1993 at the University of Peradeniya have been collected.

3.2.3.7 Topographic Map

A topographic map of 1:250,000 is available in Thailand, and digital elevation data is available at a 1 km grid.

In Sri Lanka, two scales of topographic map, 1:50,000 and 1 mile-1 inch, cover whole the island and they have been collected.

3.2.3.8 Geological Map

Geological maps of 1:250,000 are available in Thailand, and these will be digitized.

In Sri Lanka, a geological map of 1:1,000,000 has been collected.

3.2.3.9 Land cover

Land use maps of 1:250,000 are available in Thailand, and these will be digitized. Land cover will be classified by satellite remote sensing using NOAA/AVHRR or MOS1/MESSR.

In Sri Lanka, land use and soil maps of 1:1,000,000 have been collected.

3.2.4 Organization and coordination system of the experiment

(a) In Japan :

Communications Research Laboratory (CRL)
Study on seasonal and diurnal wind change using wind profiler

Disaster Prevention Research Institute (DPRI), Kyoto University
Macroscale hydrological modelling in Chao Phraya River basin and GIS management of hydrological and meteorological data

Faculty of Agriculture, Kyoto University
Observation of hydrological processes in the plain area

Faculty of Agriculture, Tokyo University of Agriculture and Technology
Observation of hydrological processes in forests and different vegetations, measurement of energy and water flux in paddy fields, and solar radiation measurement in Thailand

Faculty of Agriculture, University of Tokyo
Land-atmosphere interaction of forest areas in Thailand and Malaysia

Faculty of Education, Fukushima University
Mesoscale phenomena in the tropics associated with precipitation

Faculty of Engineering, Yamanashi University
Variation of hydrological variables in the plain area and estimation of hydrological variables by satellite remote sensing

Faculty of Integrated Arts and Sciences, Hiroshima University
Measurements of soil moisture in a large domain

Faculty of Science, Kyoto University
Orographic effects on mesoscale disturbances in tropical atmospheres

Faculty of Science, Tokyo Metropolitan University
Large scale water balances
Observations in a forestry experimental basin in Malaysia

Graduate School of Science, University of Tokyo
Climatological studies on the time-space variation of precipitation

Hokkaido National Agricultural Experiment Station
Longterm monitoring of energy and water flux

Institute for Hydrospheric Atmospheric Sciences (IHAS), Nagoya University
Data archive of atmospheric observations

Institute of Engineering Mechanics, University of Tsukuba
Satellite remote sensing of hydrological variables

Institute of Geoscience, University of Tsukuba
Estimation of large scale fluxes using satellite remote sensing and measurement of energy and water fluxes in Sri Lanka

Institute of Industrial Science (IIS), University of Tokyo
Research management of GAME-T, GIS/RS data-base development and management, and mesoscale meteorological modelling.

National Institute for Environmental Studies (NIES)
Vegetation maps estimated from satellite remote sensing

National Research Institute for Earth Science and Disaster Prevention (NIED)
Hydrological cycle in meso-scale and micro-scale experimental river basins

National Space Development Agency of Japan (NASDA)
Three dimensional structure of energy and water cycle in tropics and TRMM ground validation experiments

Numerical Prediction Division, Japan Meteorological Agency (JMA)
Four dimensional data assimilation

Public Works Research Institute (PWRI), Ministry of Construction
Soil moisture ground validation experiment using RADARSAT and water balance studies

Radio Atmospheric Science Center (RASC), Kyoto University
Studies on the atmospheric disturbances in tropical atmospheres

Frontier Research System for Global Change
Modelling and data assimilation

(b) Other nations:

Asian Institute of Technology (AIT), Thailand
Remote sensing and GIS

Bureau of the Royal Rainmaking and Agricultural Aviation (BRRAA), Thailand
Rain enhancement research and rainfall data collection.

Center for Water Research (CWR), The University of Western Australia
Macroscale hydrological modelling

Chulalongkorn University (CU), Thailand
Hydrological modelling and water resources assessment

Department of Energy Development and Promotion, Thailand
Operational observation of hydrometeorological data

Department of Geography, University of Peradeniya, Sri Lanka
Observation and study on energy and water cycle in Sri Lanka

Department of Irrigation and Drainage (DID), Malaysia
Operational observation of hydrometeorological data

Department of Meteorology and Hydrology, Myanmar
Operational observation of hydrometeorological data

Department of Mineral Resources, Thailand
Groundwater data

Electric Generation Authority of Thailand (EGAT), Thailand
Operational observation of hydrometeorological data

Forestry Research Institute Malaysia (FRIM), Malaysia
Study on energy and water cycle in forestry experimental basin

King Mongkut's Institute of Technology Thonburi (KMITT)
Mesoscale meteorological observation and modelling

King Mongkut's Institute of Technology Ladkrabang (KMITL)
Study on seasonal and diurnal wind change using wind profiler

Katsesaert University (KU), Thailand
Observation at hydrological experimental basin and macroscale hydrological modelling

Khon Kaen University (KKU), Thailand
Soil maps and topography

Land Development Department (LDD), Thailand
Land use data and soil maps

Malaysia Meteorological Service (MMS), Malaysia
Operational observation of hydrometeorological data

Meteorological Department, Singapore
Operational observation of hydrological and meteorological data

Nangyang Technological University, Singapore
Data analysis and modelling of observations

National Research Council of Thailand (NRCT), Thailand
Research coordination and satellite remote sensing

Royal Forestry Department (RFD), Thailand
Enhanced observation in forestry experimental basin and rainfall observation in mountainous areas

Royal Irrigation Department (RID), Thailand
Operational observation of hydrological and meteorological data and intensive observation at plain area of the Chao Phraya River basin

Thai Meteorological Department (TMD), Thailand
Operational observation of meteorological data, receiving NOAA satellite AVHRR data and enhanced rawinsonde observation