AAN Report

M. Sugita,T. Nakajima and S. Miyazaki

[Heat budget group]
1. Background and General Information

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

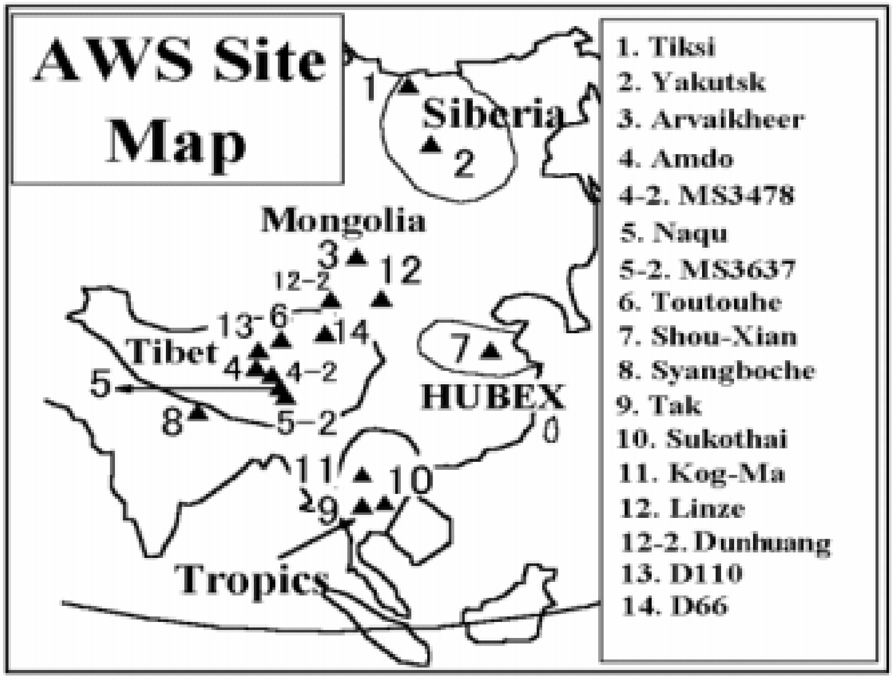

Fig. 1. A map showing the location of GAME-AAN flux stations currently in operation. Triangles indicate those stations expected to operate through phase II of GAME-AAN, while circles represent those that will operate only during phase I.

2. Phase I activity summary

- AWS test and operation

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

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

- The AAN data

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

- Scientific Issues

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

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

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

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

3. Future Plan

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

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

References

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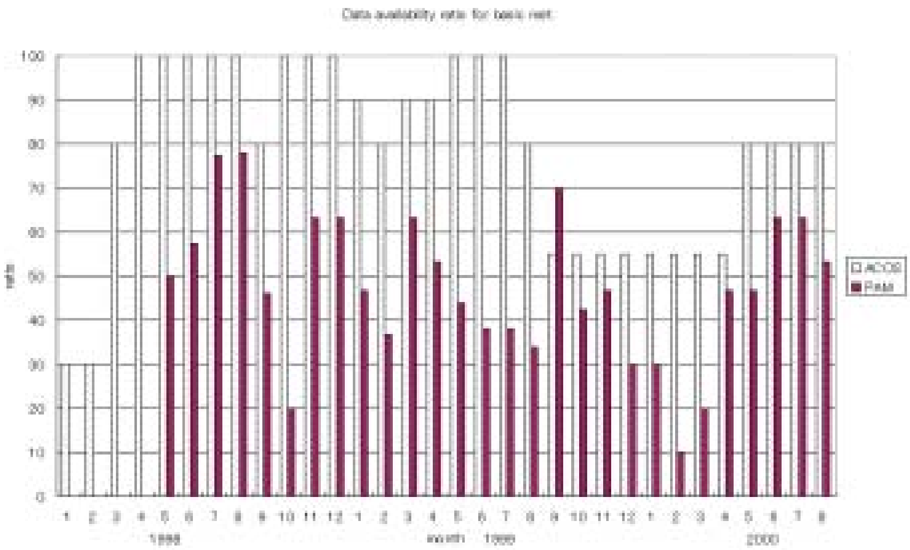

Fig. 2. Time series of the data availability for basic meteorological elements (e.g., air temp., precipitation, wind speed) obtained by ACOS (Automated Climate Observing system) and PAMIII. These values were calculated by using raw data for ACOS but processed data for PAMIII.

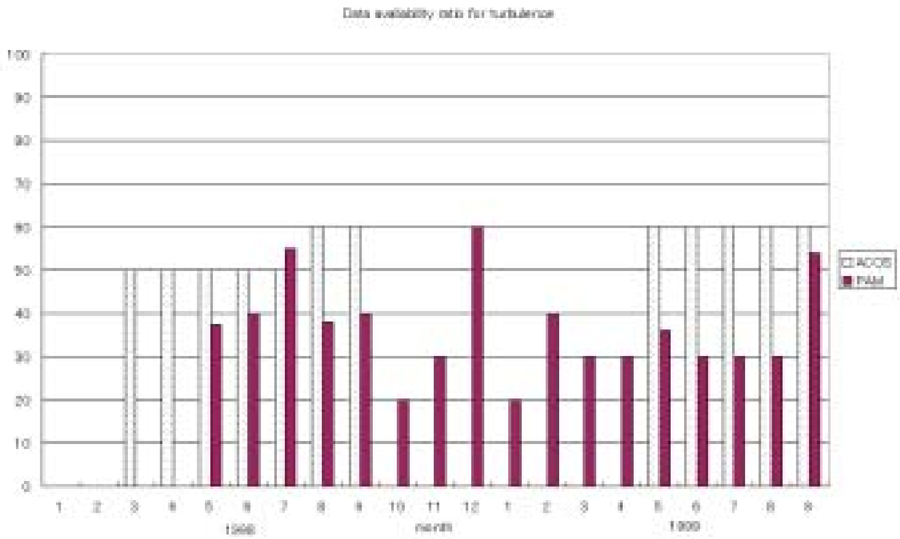

Fig. 3. Same as Fig. 2 but for surface fluxes (sensible heat flux, latent heat flux, momentum flux).

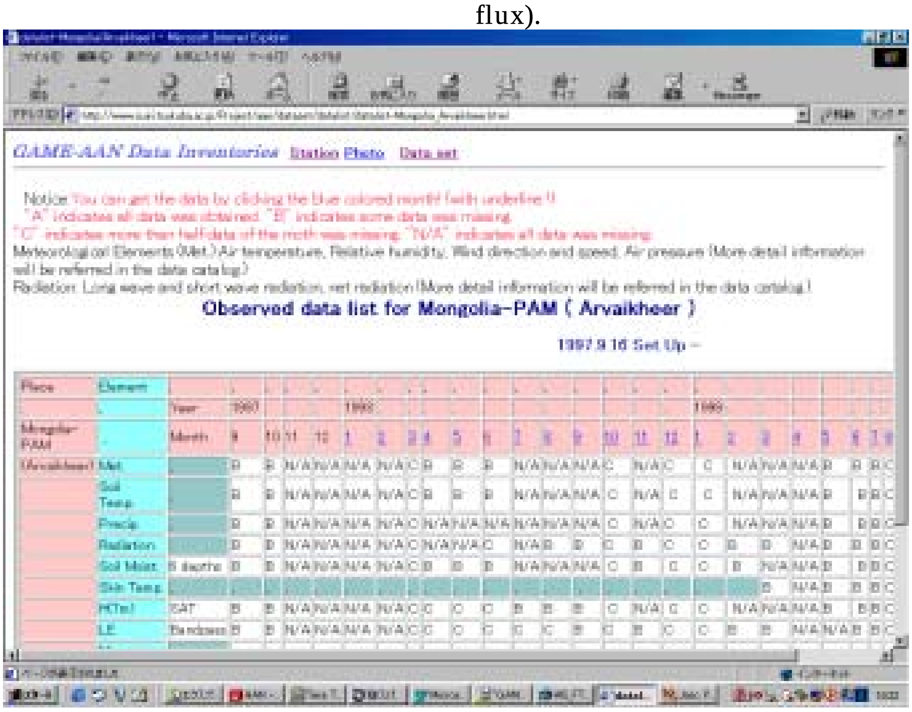

Fig. 4. An example of the GAME-AAN data inventory list as seen on the AAN web site.

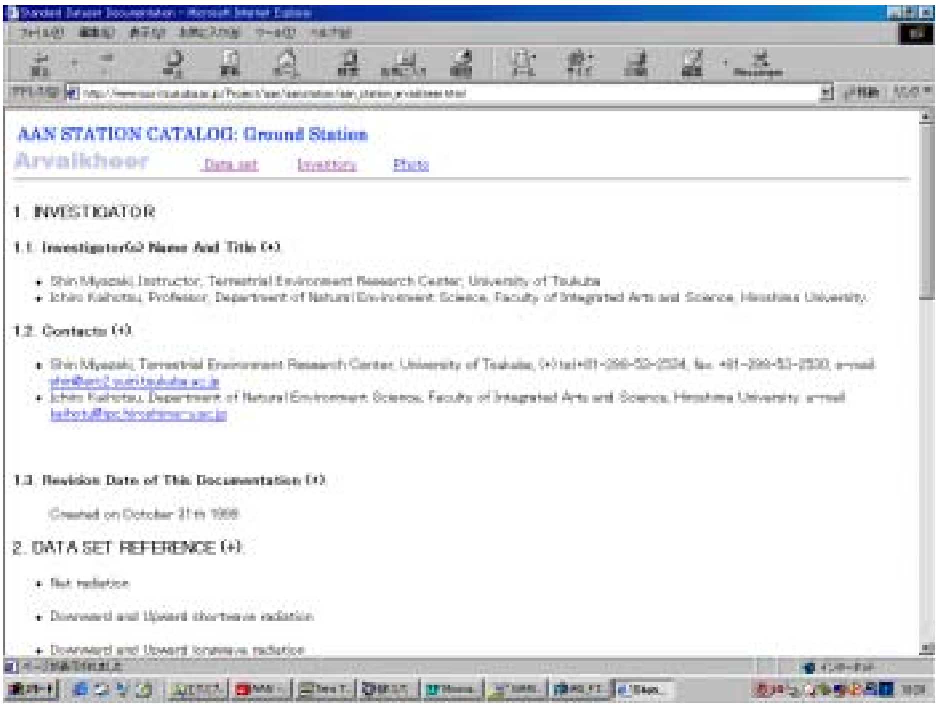

Fig. 5. Same as Fig.4 but for dataset documentation.

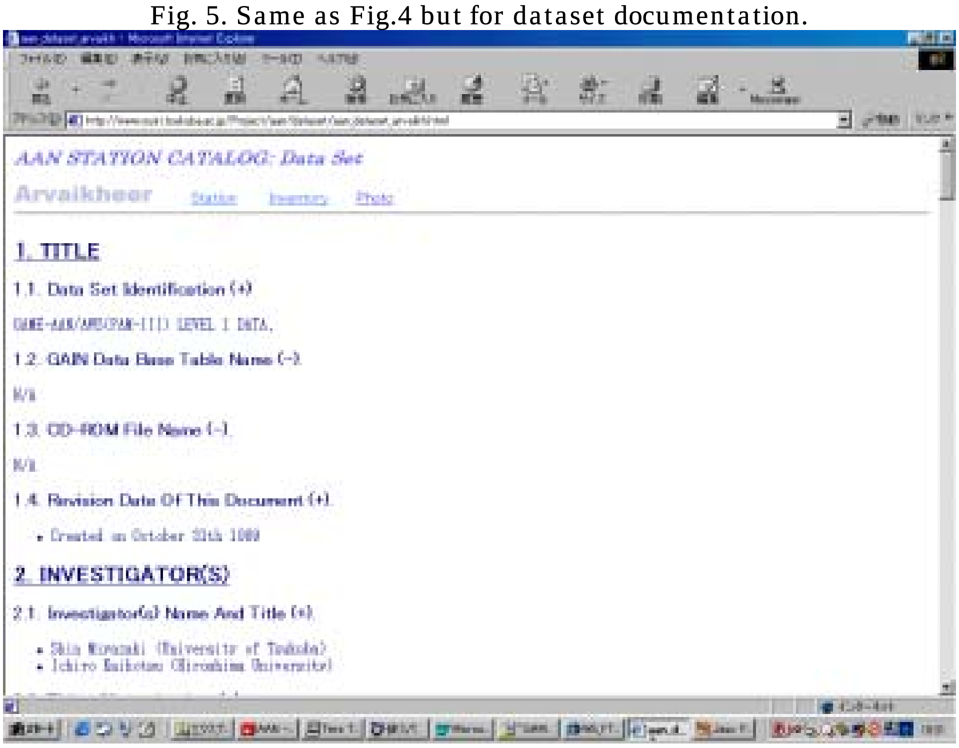

Fig. 6. Same ad Fig.4 but for station documentation.

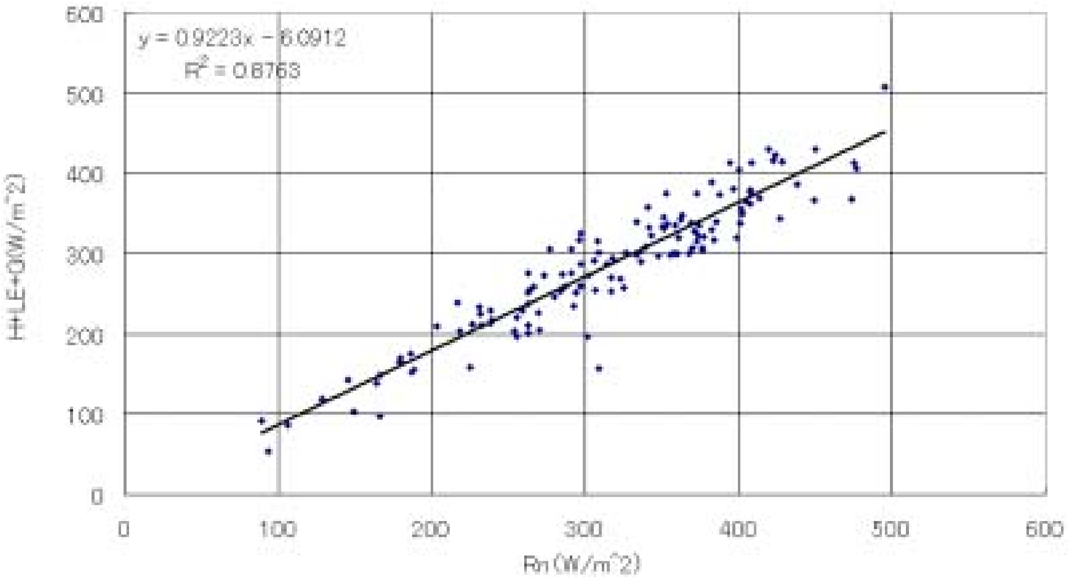

Fig. 7. An example of energy balance closure as reported from an AAN station located in Mongolia.

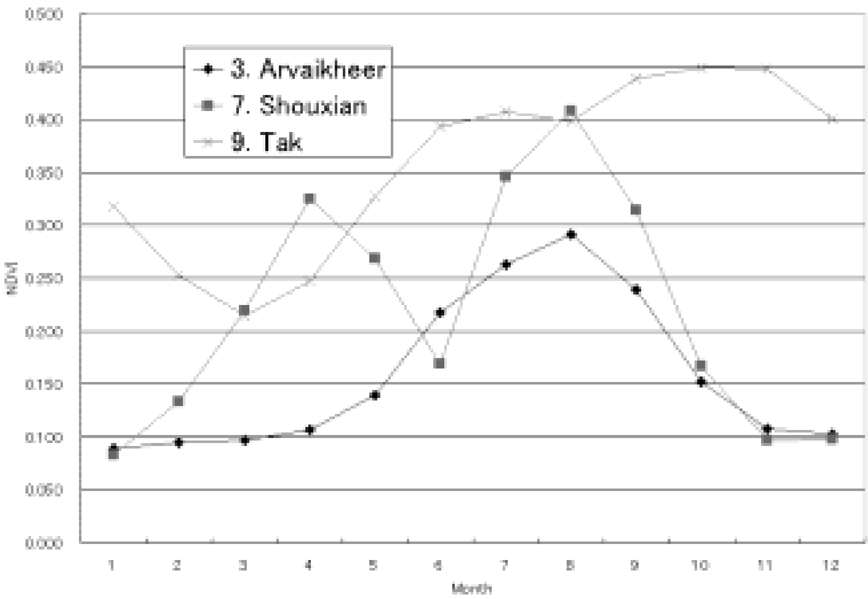

Fig. 8. Seasonal variation of NDVI at three AWS locations as given with 20-year means.
(see Fig. 1 for the exact location)

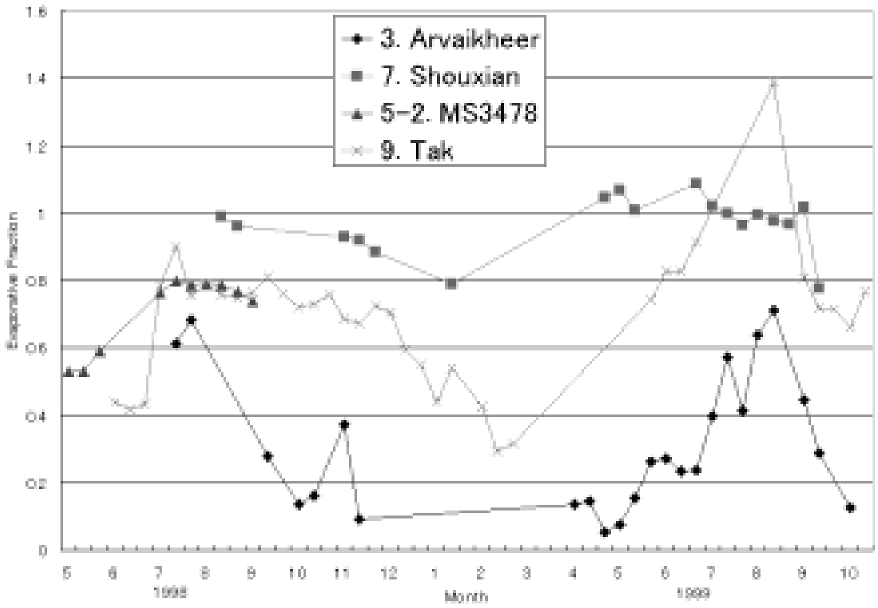

Fig. 9. Seasonal march of evaporative fraction
[=LE/(Rn-G), the ratio of latent heat flux and available energy]

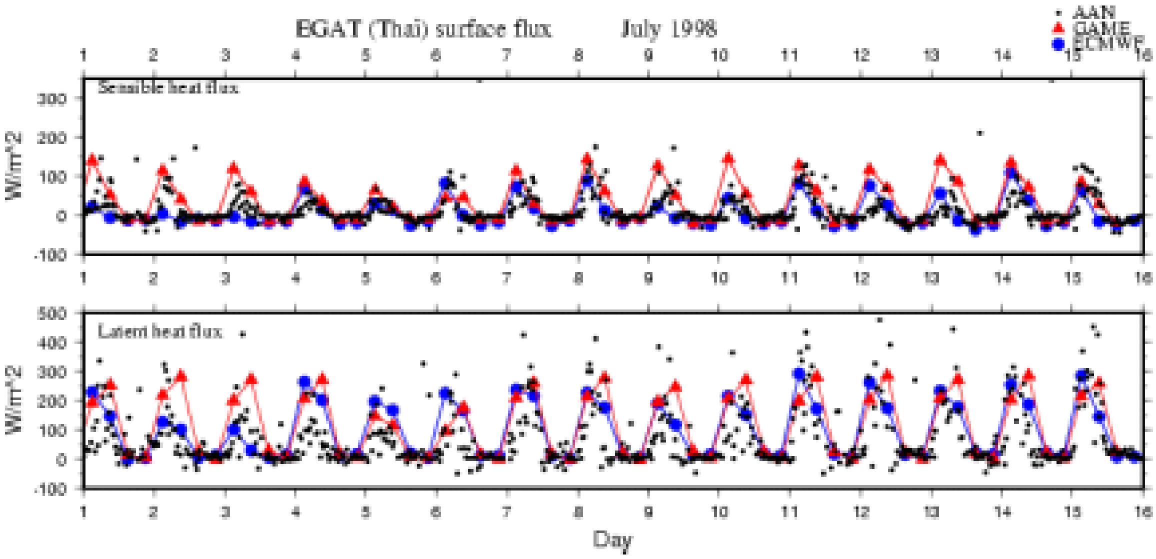

Fig. 10. Comparison of sensible heat flux (upper panel) and latent heat flux (lower panel) between GAME reanalysis Ver. 1.1, ECMWF operational dataset and AAN observation (EGAT tower at Tak in Thailand). Small dots indicate AAN observation (every 30 minutes); triangles, GAME reanalysis; and circles,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

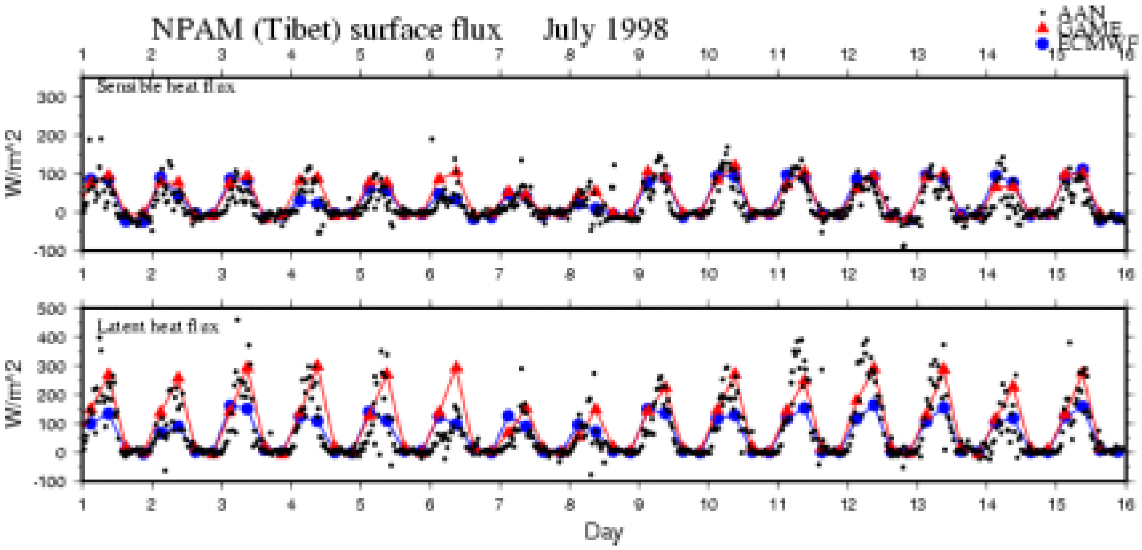

Fig. 11. Same as Fig. 10 but for the site of AAN observation (north PAMIII on Tibetan Plateau).

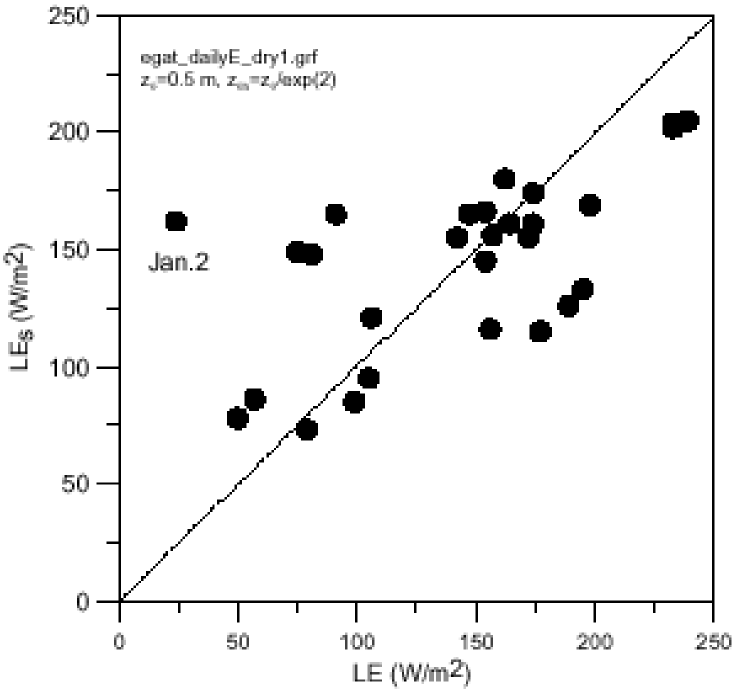

Fig. 12. Comparison of model derived latent heat flux (LEs) and AAN measurements at Tak in Thailand during dry season (Sugita *et al.*, 2001).

[Radiation group]

1. Objectives of the GAME Radiation Study

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

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

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

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

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

2. Activities of the GAME Radiation Group

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

- SKYNET and GAME high precision radiation Sites

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

- Solar flux distribution from GMS satellite

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

- Lidar measurements

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

-Aerosol characterization by surface measurements

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

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

- Satellite remote sensing of aerosols and clouds

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

Cloud microphysical parameters were also retrieved in this study with the solar reflection method (Kuji *et al.,* 2000; Kawamoto e*t al.,* 2001). The radiative forcing of the indirect effect of anthropogenic aerosols was further estimated by Nakajima *et al.* (2001) using the correlation between aerosol and low cloud microphysical parameters derived from AVHRR remote sensing. It is found, for example, the columnar aerosol number density has a correlation with that of low clouds as $\Delta\log10\ Nc \approx 0.5\ \Delta\log10\ Na$. These correlations thus obtained give an estimate of the indirect forcing of anthropogenic aerosols as RF= -0.7 to -1.7 W/m^2 over ocean.

3. Future Prospect

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

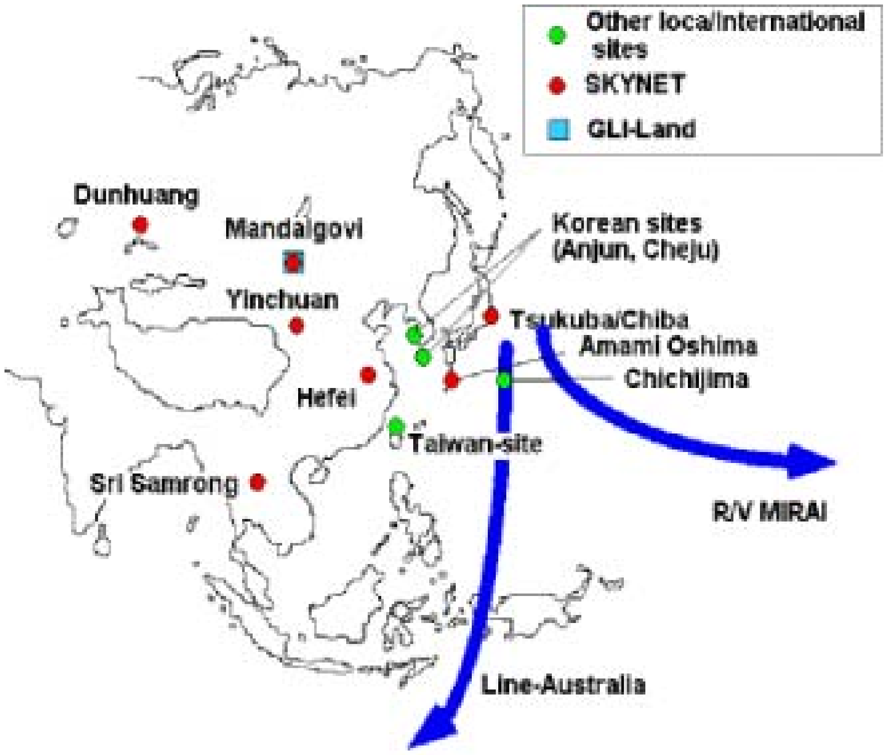

Fig. 1. Radiation observation sites.

Major publication list for the contribution to the GAME radiation studies (1998-2000)

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Takemura, T., H. Okamoto, Y. Maruyama, A. Numaguti, A. Higurashi and T. Nakajima, 2000: *J. Geophys. Res.*, **105**, 17853-17873.

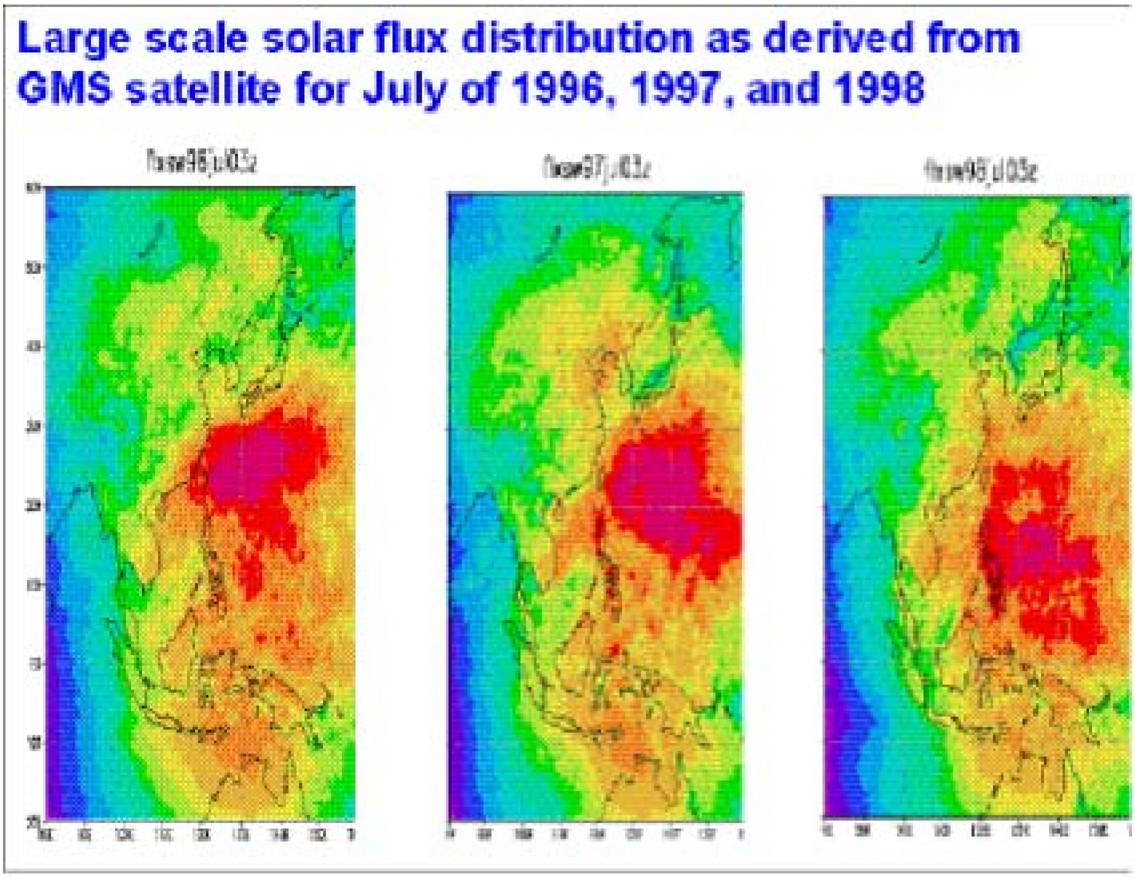

Fig. 2. Surface solar radiation was estimated from GMS data.

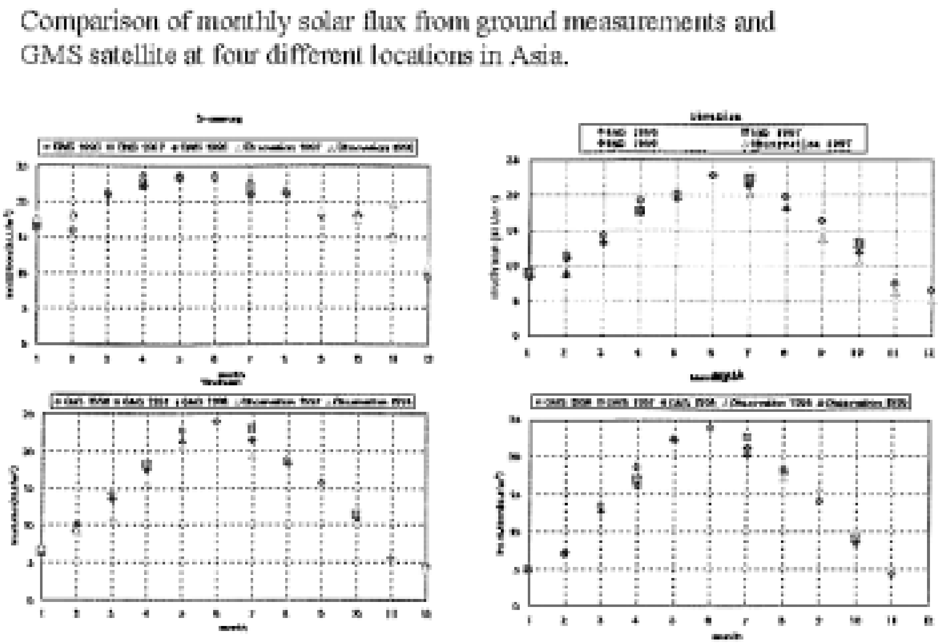

Fig. 3. Comparison of monthly solar radiation flux from the ground measurement and GMS data.

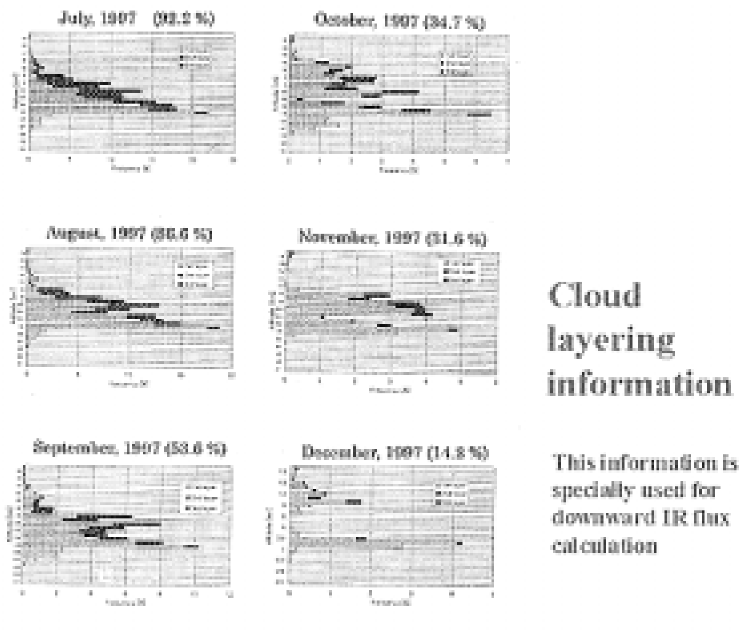

Fig. 4. Histogram of cloud height observed by lidar.

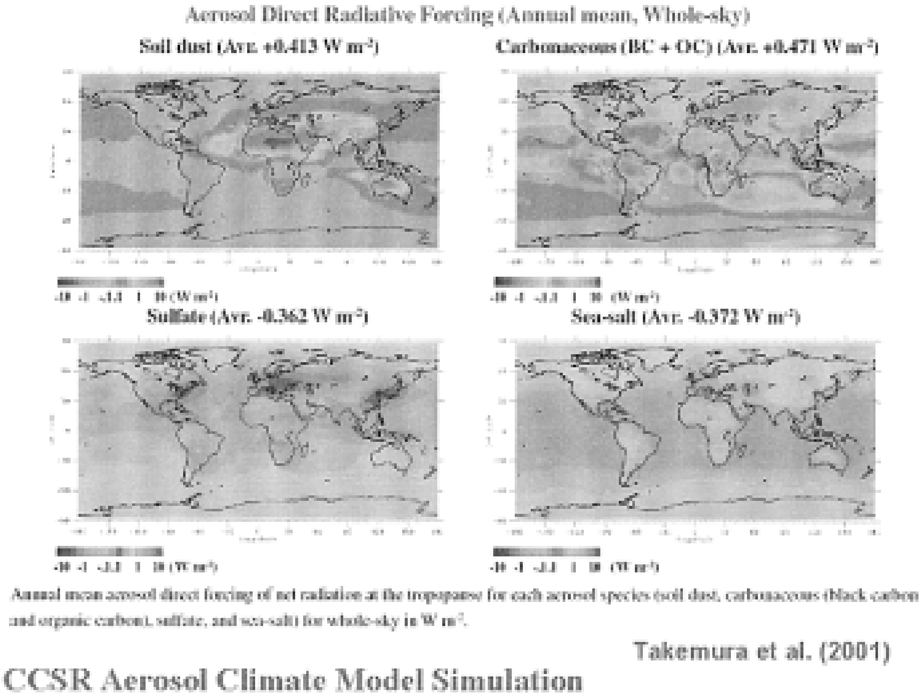

Fig. 5. Aerosol direct radiative forcing(annual mean).

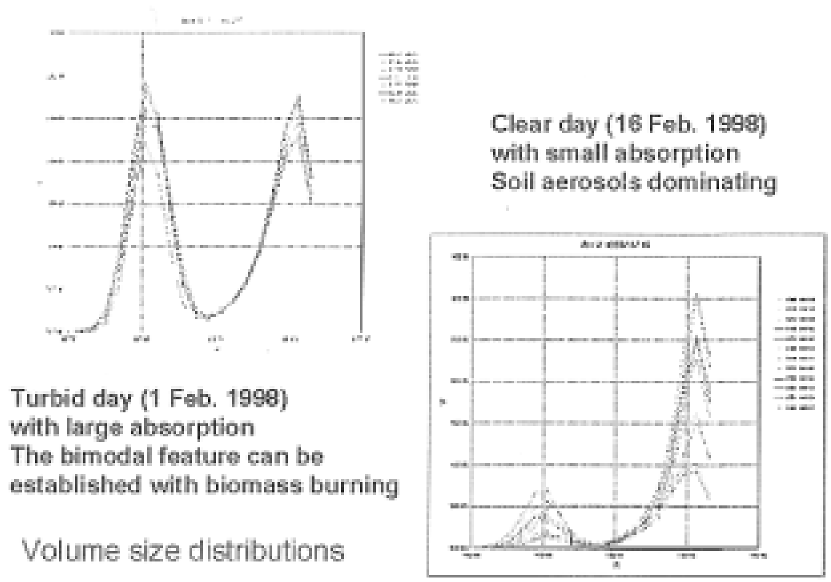

Fig. 6. Aerosol size distribution.

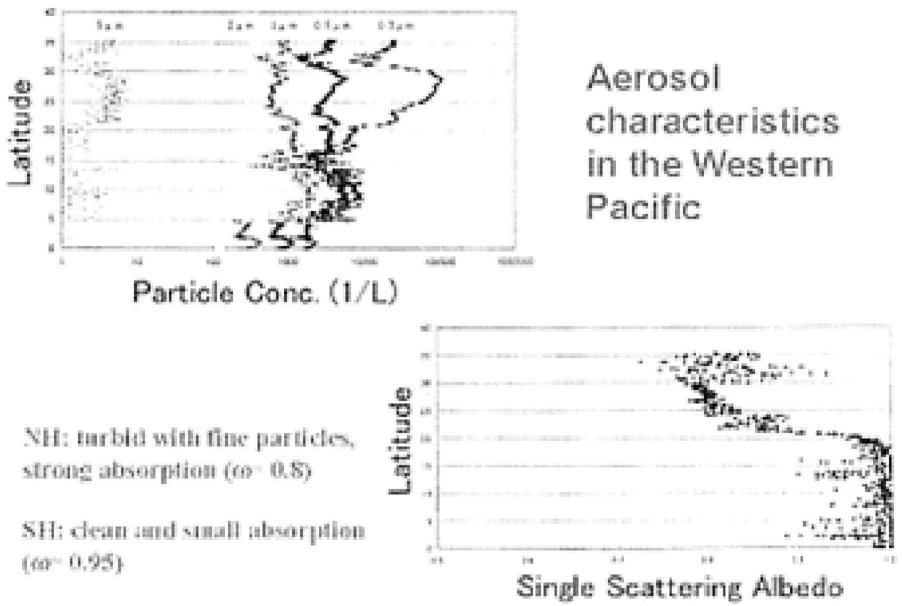

Fig. 7. Aerosol characteristics in the Western Pacific.