A MOISTURE ADJUSTMENT SCHEME USING GEOSTATIONARY SATELLITE AT THE JAPAN METEOROLOGICAL AGENCY

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1. INTRODUCTION

Moisture is one of the most important parameters for weather phenomena. In particular over the tropics, since atmospheric activities are mainly driven by convection, the impact of moisture fields on developing or decaying disturbances is remarkable. Therefore, introducing accurate initial moisture conditions is essential to improve the performance of NWP models. However, especially over the oceans, a scarcity of observations limits the accuracy of moisture analyses.

Geostationary meteorological satellites offer cloud images several times a day. They show clear features of clouds over very wide areas. From the images we can estimate a moisture pattern. The atmosphere in highly cloud-active areas must be wet and that in cloud clear zones must be dry. An interpretation of the cloud images into initial moisture fields of NWP models should have a good effect on not only data assimilation but also on the following forecasts. *Walcott and Warner* (1981) applied satellite cloud data to a moisture analysis with additional information of the present weather observations as follows: if precipitation is observed, relative humidity is assumed to be 100% from the surface to the cloud top level; if not, it is assumed to be 100% only at the cloud top level. They showed that these data allowed a NWP model to improve the forecast of rainfall rates.

At the Japan Meteorological Agency (JMA), vertical moisture profiles are estimated using digitized cloud data retrieved from GMS (HIMAWARI) and used in operational data assimilations. The scheme is very simple: if there is cloud cover, moist data are created. If there are no clouds, dry data are created. The impact on the data assimilation is remarkable particularly over the tropics. Because moisture fields are always corrected by the moisture data at every analysis stage, other fields are also revised by the subsequent analysis/forecast cycling. *Kuma* (1993) showed that NWP performance for the Australian Summer Monsoon onset during AMEX phase II period was remarkably improved by using a moisture field derived from satellite images. The Australian Bureau of Meteorology also operationally derives moisture data from cloud images (*Mills and Davidson*, 1987).

In this paper, an interpretation scheme of digitized cloud data into vertical moisture profiles at JMA are described. Some results of impact studies using the data are also presented.

2. GMS CLOUD GRID DATA

GMS cloud grid data, often called T_{BB} data, are compiled from equivalent black body temperature (T_{BB}) data retrieved from infrared radiation observed by GMS. The data are processed at the Meteorological Satellite Center (MSC) (*MSC*, 1980).

The data cover an area from 50°N to 50°S north-south and from 90°E to 170°W west-east. The horizontal resolution is 0.5 x 0.5 degrees latitude/longitude. It is equivalent to 55km resolution over the tropics. There are about 100 pixel data in one 0.5x0.5 degree grid box. The main variables retrieved from the data are cloud amount, mean cloud top temperature and standard deviation of cloud top temperature. The cloud amount is a ratio of the number of pixels judged as a cloud to the total number of pixels at the grid box. The mean cloud top temperature and the standard deviation of cloud top temperature are calculated using cloud pixel data.

They are observed 4 times a day, 00, 06, 12, 18UTC. The data received are digitized and made available online. We normally receive them within 2 hours after observation.

Figure 1 shows a cloud image represented by the GMS cloud data. Contours show mean cloud top temperature and shaded zones show cloud covered areas which were derived from the cloud amounts. The map clearly shows where the cloud-active area is. Since the data have many advantages, such as being easy to handle numerically, high resolution with time and space, good data coverage and homogeneous quality over the area, they have practical applications not only for a NWP system but also for climatological studies.

3. CONCEPT OF THE JMA'S MOISTURE BOGUS

We can estimate a vertical moisture profile over each grid box using the cloud grid data. Let's think about a case where a cloud amount is 100%, a mean cloud top level is 700 hPa, a standard deviation of cloud top temperature is small and drizzle at surface. This may be a case where stratus cloud, whose cloud top level is 700 hPa, covers the whole grid box and it drizzles at all surface stations. Estimated mean vertical moisture profile over the grid box may be as follows: it is wet from surface to 700 hPa and it sharply turns to dry over 700 hPa.

The relation between parameters of the cloud grid data and estimated vertical moisture profiles could be summarized as shown in Fig 2. The mean cloud top level represents a height of a transitional level from wet to dry; the atmosphere should be wet below the level and dry over it (top). The standard deviation of cloud top temperature represents a situation of the transitional zone from wet to dry (middle). If it was small, the cloud type was probably stratus and the thickness of the transition layer should be thin; the atmosphere changed from wet to dry sharply at the cloud top level. If it was large, the cloud type was probably cumulus and the thickness of the transition layer should be thick; the atmosphere changed from wet to dry gently around the mean cloud top level. The cloud amount represents the degree of wetness (bottom). Because an estimated moisture profile represents a mean moisture situation over a grid box, the smaller the total cloud amount is, the dryer the relative humidity of the cloud layers.

No information is obtained from below. Surface observations offer supplemental information. Coupling cloud grid data and surface observations, and vertical moisture profiles can be better estimated. For example, if rainfall was observed at a grid box, we can estimate that the atmosphere is wet from the top of the cloud down to the surface. If there is no low level cloud and a cloud base is very high, the atmosphere at low levels should be dry even if the grid box is completely covered by cloud.

4. CREATION OF MOISTURE BOGUS DATA

Practical algorithms for creation of the moisture bogus data are based on a statistical relationship between the cloud parameters and collocated radiosonde observations. Briefly, the procedure to create the data is as follows: first cloud types are defined by combinations of the GMS cloud grid data, surface observations and the location. Next, collocated radiosonde observations were accumulated for every cloud types and their statistics were calculated. A mean moisture profile for each cloud type was assigned to the moisture bogus profile, data at standard levels on the profile become bogus moisture values and standard deviations of the

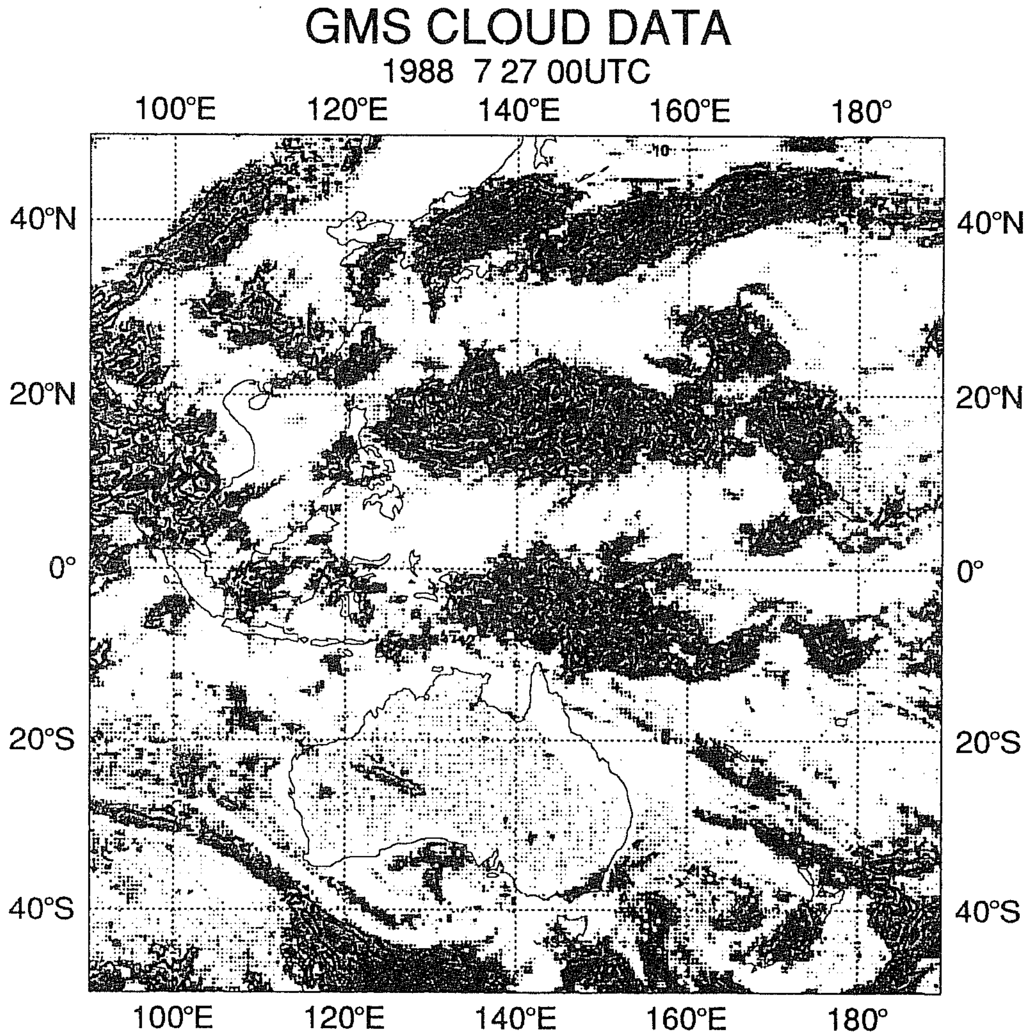

Fig 1 Cloud image represented by GMS cloud data at 00UTC July 27 1988. Cloud areas are represented by shading and contours show mean cloud top temperature.

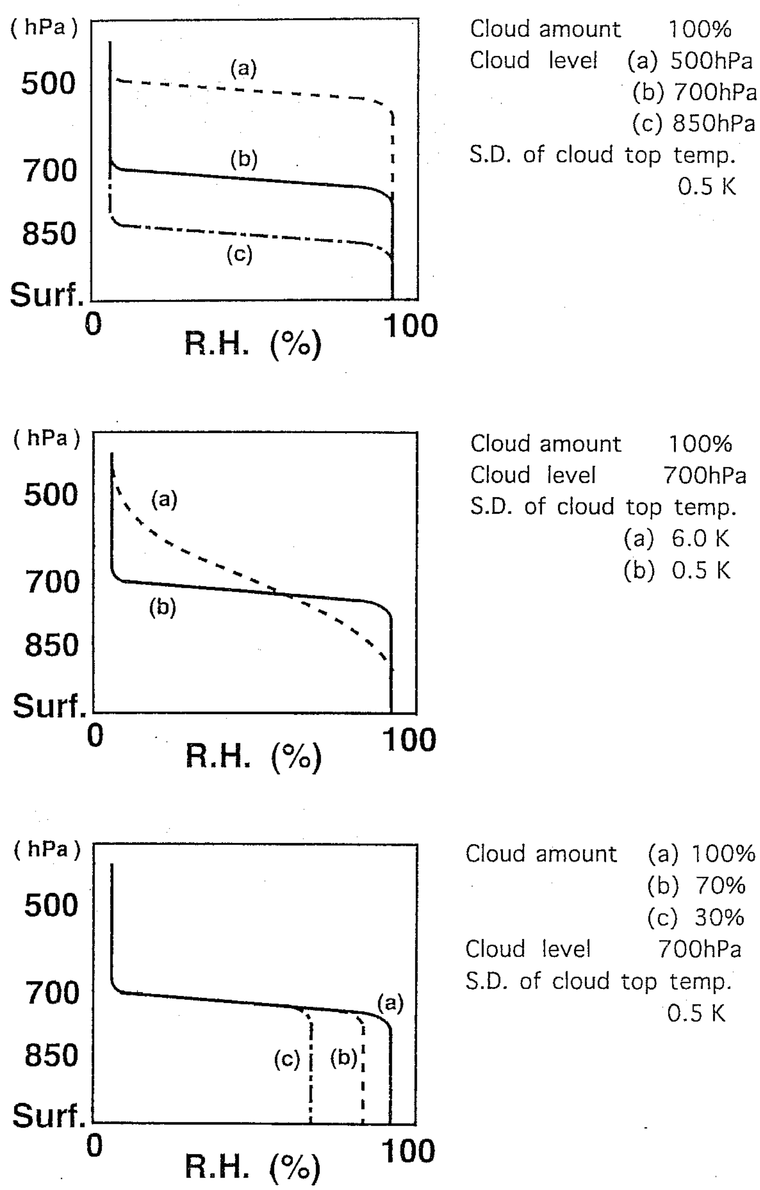

Fig 2 Vertical moisture profiles as a function of the cloud parameters. Top plate shows the relation between the moisture profile and mean cloud top level. Middle plate shows as the top ones but standard deviation of cloud top temperature. Bottom plate shows as the top ones but cloud amount.

data was assigned to observational error of the bogus value. The observational error term is one of the merits of the scheme; we can set not only moisture data but also reliability of the values.

4.1 Classification of cloud type

We used 5 parameters to define the cloud type. These parameters are shown in table 1. Three parameters were obtained from GMS cloud grid data. They were total cloud amount (%), mean cloud top level (hPa) and standard deviation of cloud top temperature (K).

The cloud amount was classified into 5 classes; 0%, 1-20%, 21-70%, 71-99% and 100%. The mean cloud top level was classified into 6 classes according to standard levels; over 300 hPa, 301-400 hPa, 401-500 hPa, 501-700 hPa, 701-850 hPa and below 850 hPa. It was valid for a case that cloud amount was greater than 20%. The standard deviation of cloud top temperature was classified into 2 classes; lower than 3.0 K and greater than 3.0 K. The former was assigned to stratus type clouds and the latter to cumulus type clouds. It was valid only for a case that the cloud amount was greater than 70%. Parameters for surface observations were classified into 5 classes. They were raining, rained, not rain or dry, fair and no surface observation. The fair means that there was no low level clouds or the cloud base height was upper than 850 hPa. The position or latitude of the data was also introduced to define the cloud type. We divided it into 2 categories; tropical region and extra-tropical region, their borders were 23.5N and 23.5S. These classification totally created 320 categories for the cloud type.

4.2 Creation of typical moisture profiles for every cloud types

To create typical moisture profiles, radiosonde observations for cloudy situations were accumulated for 2 years. If 5 or more observation could be accumulated for a cloud type, a mean moisture profile and its standard deviation were calculated and assigned to moisture values (relative humidity) and their observational errors at standard levels. If a sufficient number of samples could not be accumulated for some categories, the most similar categories were used.

Figure 3 shows examples of the moisture profile for a case that total cloud amount is 71-99%, mean cloud top level is lower than 500 hPa but higher than 700 hPa, standard deviation of cloud top temperature is lower than 3.0 K (solid line) or greater than 3.0 K (dash line), rainfall is observed in the grid box and its position is in the tropics; namely stratus type clouds(solid line) or cumulus type clouds (dash line) whose mean top level is between 700 hPa and 500 hPa cover almost all over a grid box. The mean determined moisture profiles are consistent with those estimated from these parameters; they are dry upper than 500 hPa level and wet lower than 700 hPa level and transition from wet to dry is very sharp in stratus type cloud (solid line) and gentle in cumulus type cloud (dash line).

5. MOISTURE ANALYSIS USING GMS MOISTURE BOGUS DATA

Moisture bogus data were created only over the ocean because the performance of estimated bogus data over the land was not good compared with that over the ocean, and radiosonde observations were relatively dense over the land for GMS covered areas. Bogus moisture profiles were created on every 2.0 degree latitude/longitude. Since reliability of created data with surface observations were higher than these without surface observations, they were selected by preference. If there was a radiosonde observation within 300 km no bogus data was created.

Cloud classification parameter table

elements		range	cloud state
GMS cloud grid data	cloud amount (%)	0 1 - 20 21 - 70 71 - 99 100	Clear Fair Scatter Broken Overcast
	mean cloud top level (hPa)	- 300 301 - 400 401 - 500 501 - 700 701 - 850 851 -	high level | | | | low level
	standard deviation of cloud top temp. (K)	0.0 - 2.9 3.0 -	stratus type cumulus type
surface observations (ww, h, Nh)		rain wet dry clear no data	moist | | dry --
location (latitude)		50.0N - 23.5N, 23.5S - 50.0S 23.5N - 23.5S	extra-tropical tropical

Table 1 Cloud parameters to be used in classification of cloud types.

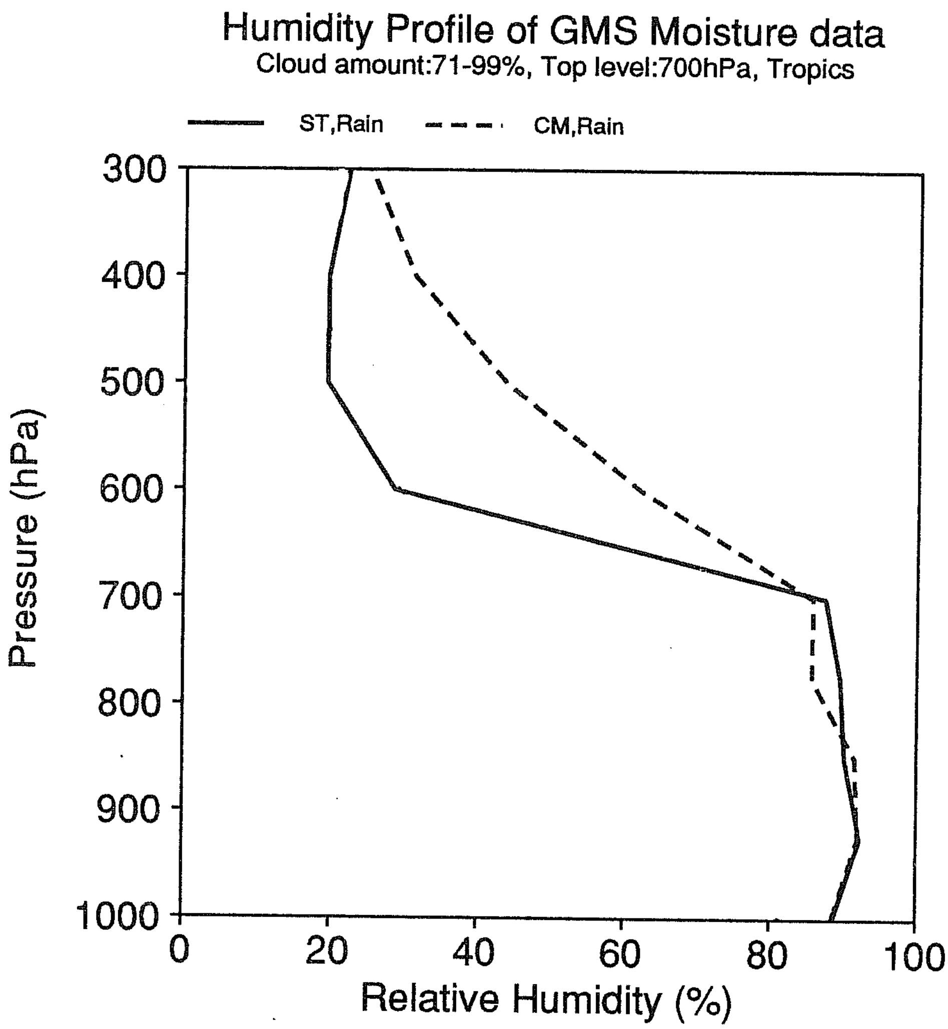

Fig 3 Vertical mositure profiles of a case that cloud amount is 71-99%, mean cloud top level is 700-500 hPa and its location is in tropics. Solid line shows an example of stratus type cloud which is defined that standard deviation of cloud top temperature is lower than 3.0 K. Dashed line shows that of cumulus type cloud which is defined that the standard deviation is greater than 3.0 K.

Figure 4 shows a moisture analysis at 700 hPa level over the north western Pacific Ocean at 12UTC July 24 1989 (left plate) and a cloud image at the same time (right plate). A typhoon (JUDY=TY8911) whose centre surface pressure was 960 hPa was at (20.2N, 138.2E). Wet areas where relative humidity is greater than 80% are shaded on map (a). The analysed moisture pattern is consistent with the cloud image. The moisture field around at (13N, 146E) seems to be too dry considering the cloud image. It was due to the dry data from a radiosonde observation at Guam island. The radiosonde might pass through dry air such as subsidence by cumulous clouds. To do a better analysis on a synoptic scale, the data should have been rejected from the analysis.

Using the moisture bogus data at every analysis stage (i.e. using them iteratively in a data assimilation) obviously impacts the results. To check the impact of the moisture bogusing on data assimilation, a data assimilation without the moisture bogus was conducted from 20 July 1988 for 7 days. Figure 5 shows the results. The bottom figure is a cloud image at 00UTC on 27 July 1988; this image is a part of Fig 1. Three remarkable zonal cloud systems can be seen along 40N, 20N and just south of the equator. Cloudless regions between them are also clearly recognized. Upper 2 maps show moisture analyses at 700 hPa level at the time. The top map is that by data assimilation with the moisture bogus data and the middle one is that by without them. The analysed moisture pattern on the top map is consistent with the cloud image, however, it is not so good on the middle map, particularly around the cloud band along 20N. As mentioned above, a moisture field is very sensitive to cloud activities over the tropical oceans. If a cloud active area in a model is coincident with one of those represented by a cloud image, the activities are maintained or even promoted by wet data. However, if not they are suppressed by dry moisture data. If there is no convection in a model despite that high cloud activities were observed by cloud images, wet data promote convection. If we do not use the moisture bogus, it is very difficult to do such a correction of tropical atmospheric field driven by forecast model because data density is too sparse. This is the reason why the moisture pattern in the middle map shows large discrepancy with the actual one.

Using the moisture bogus data, synoptic scale moisture fields can be obtained as those estimated from cloud images. Figure 6 shows performance of data assimilation using moisture bogus data for a history of a cloud cluster. Left pictures show cloud images every 12 hours from 00UTC 9 January 1994 to 12UTC 12 January over the western tropical Pacific Ocean (20N-7S, 120E-160E). The cloud images show a successive history of a large cloud cluster; it appeared at (5N 140E) at 00UTC on the 10th and its growth was at its maximum at 12UTC on the 11th. Then it was decaying through the next 36 hours and a new cloud cluster appeared and started to grow at (5N 132E) at 12UTC on 12th. Right maps show 700 hPa relative humidities analysed using the moisture bogus at the time of the left pictures. The analysed moisture fields represent well the features of these large cloud clusters. Note that not only over the clusters, but also over the other areas, moisture fields are consistent with those estimated from cloud images.

We can expect to get a good climate rainfall estimation over the ocean through the model outputs using the moisture bogusing system. Figure 7-a shows precipitations accumulated during 24 hour forecasts by JMA's operational global model. Initial time is at 12UTC on 23 July 1991. Figure 7-b shows cloud image at 00UTC on 24 July 1991. The precipitation area by the NWP model and actual cloud distributions are consistent with each other.

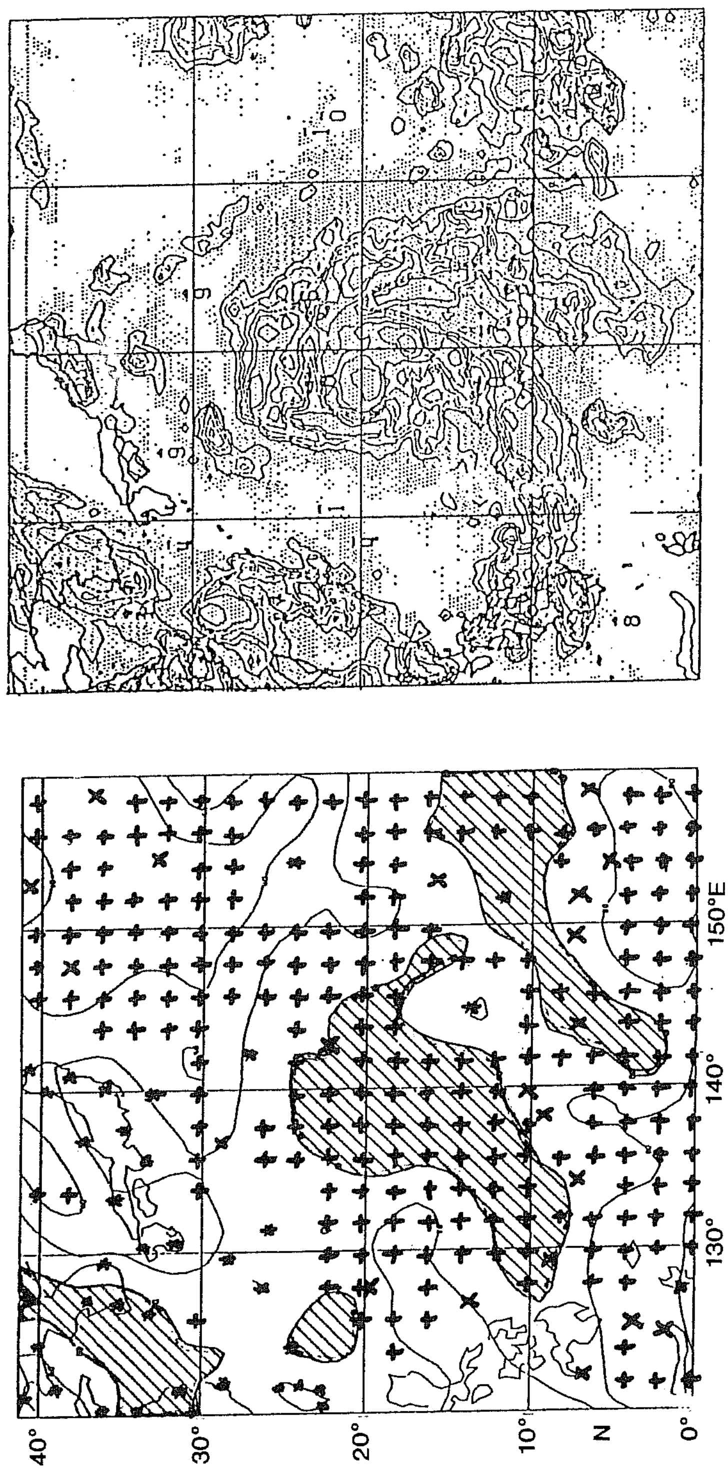

Fig 4 Relative humidity analysis at 700 hPa with moisture bogus(right map) at 12UTC July 24 1989 and cloud image at the same time (left map). Wet areas where relative humidity was greater than 80% were shaded. The plots '*', 'x' and '+' represent readiosonde data, moisture bogus data with surface observations and moisture bogus data without surface observations respectively.

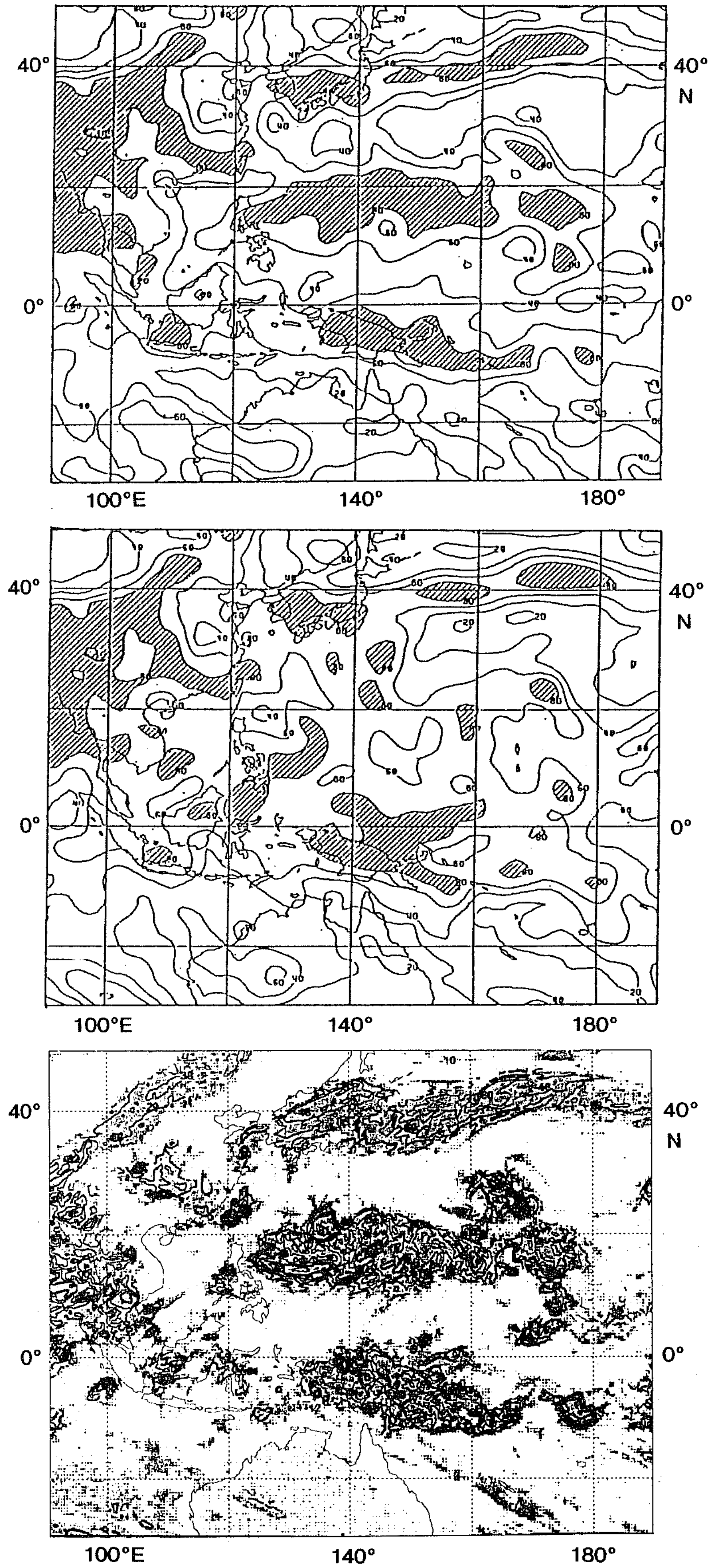

Fig 5 A history of cloud clusters over the western tropical Pacific Ocean and relative humidity analyses at 700 hPa with moisture bogus at the same period. The plates are shown every 12 hours from 00UTC January 9th 1993 to 12UTC 12 January. The covered area is 20N-7S north-south and 120E-160E west-east. In analysis plates, wet areas where relative humidity is greater than 80% are shaded and emphasized if it is over 95%.

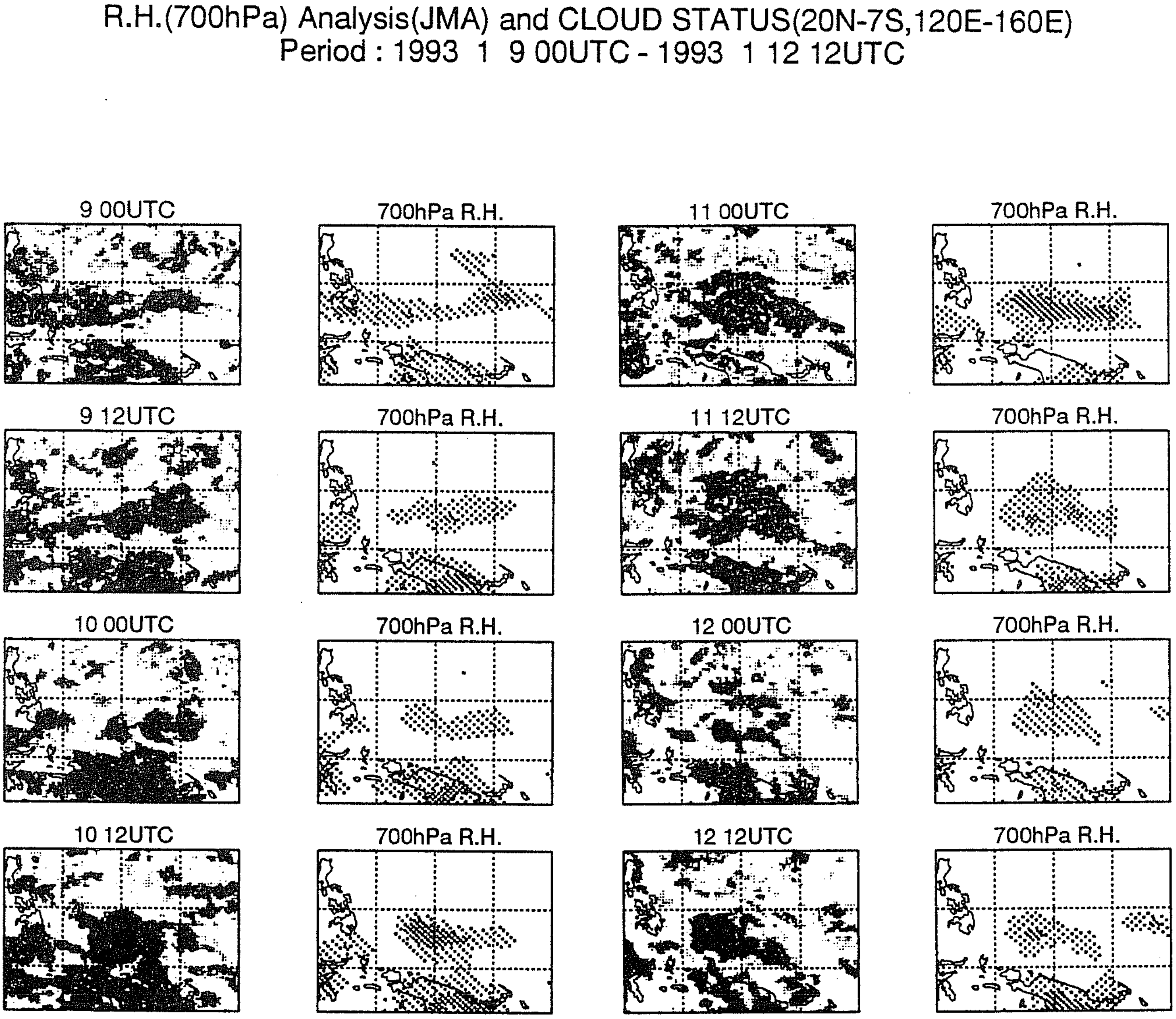

Fig 6 Relative humidity analyses at 700 hPa level at 00UTC 27 July 1988 (top and middle plates) and cloud image at the same time (bottom plate). The contour interval is 20% and areas where it is over 80% are shaded. Top plate shows the analysis with the moisture bogus. Middle plate shows the analysis from test data assimilation without the moisture bogus for the last 7 days.

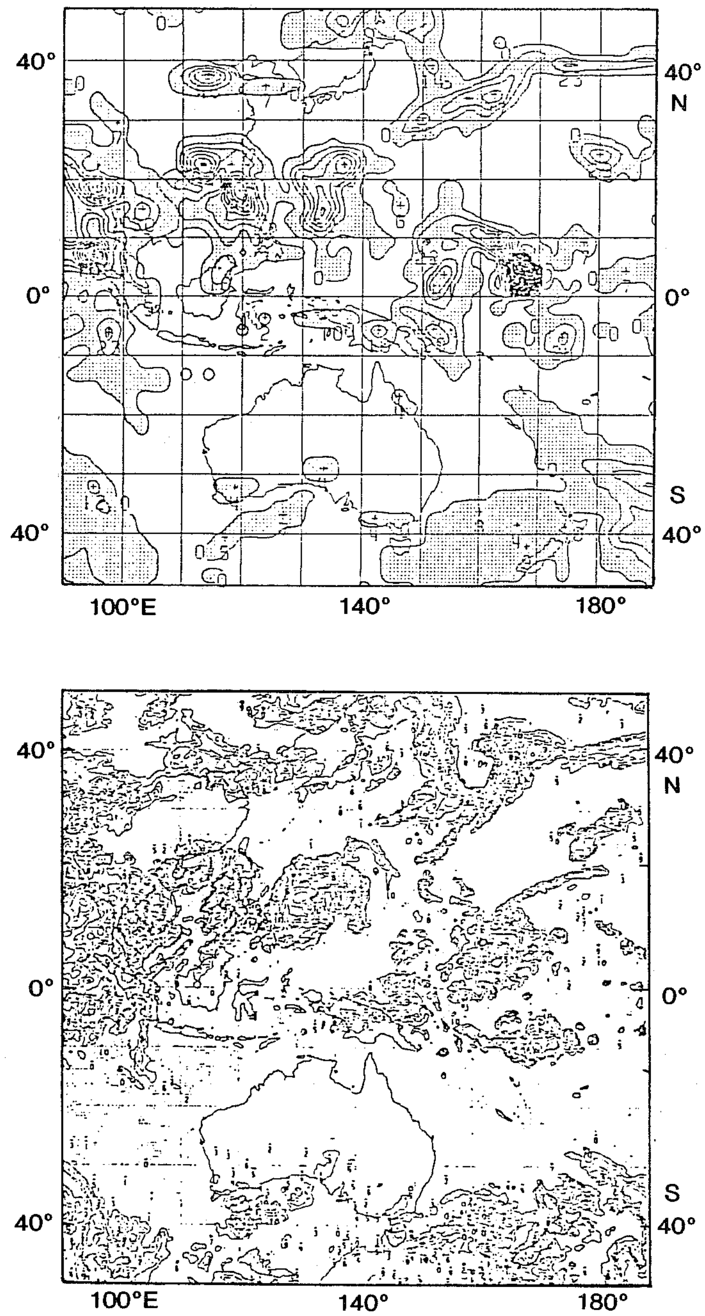

Fig 7 Accumulated precipitatioon for 1 day prediction by JMA's global model (top) and corresponding cloud image (bottom) at 00UTC 24 July 1991. Initial date of the forecast is 12UTC July 23 1991. Contour interval for precipitation is 10 mm/day.

6. CONCLUSION REMARKS

By use of the moisture bogus estimated from GMS cloud grid data in data assimilations, moisture fields were adjusted to those fitting to the cloud images. In particular over the tropical oceans, the bogusing improved performance of data assimilations and subsequent forecasts.

However, the effect is available only over the area from 90E to 170W. We have not detected any signs of negative effects using them over a limited area against global system. This is probably due to the fact that the bogus profiles were determined based on a statistical study and they were created homogeneously: not only over cloudy areas but also over clear areas. In any case it is desirable to cover the whole globe. We hope the other satellite centres also calculate the digitized cloud data similar to GMS cloud grid data and exchange them throughout the world. They must be useful not only for moisture bogusing but also for many other applications such as a verification for cloud performance of NWP models.

Thin cirrus clouds cannot be separated from thick clouds in the present cloud data. Since the moisture profiles are calculated by a mixture of the two cases, the atmosphere under a thin cirrus tends to be moister than the real and that under a thick cloud tends to be dryer since the created moisture bogus data originated from statistics of both clouds. Split window channels will be installed on the next GMS which will be launched in 1995, and the cloud grid data will be include a parameter which distinguishes thin cirrus or thick cloud. Introducing this parameter in the scheme, the bogus profiles will be more accurate.

Kasahara et al (1988) retrieved divergent winds from satellite images and used in a data assimilation. *Puri and Miller* (1990) and *Puri and Davidson* (1992) estimated not only moisture fields but also diabatic heating rates from cloud images. However we think that it is enough to retrieve moisture information from the cloud grid data and parameters like divergent wind and diabatic heating will be all adjusted reasonably by the following forecast model if we adjust moisture fields accurately.

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