NOTES AND CORRESPONDENCE

On the Comparison of Computed Cloud Mass Fluxes with Observations over the GATE Area

By Tsuyoshi Nitta

Geophysical Institute, University of Tokyo, Tokyo, Japan

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Abstract

The cumulus mass flux obtained by the diagnostic analysis is verified by using digital SMS-1 IR brightness data and precipitation calculated from radar measurements. The time variations of the cloud mass flux due to deep clouds correlate quite well with those of IR brightness and precipitation. The precipitation calculated from the model is comparable to that observed. Relationships of the cloud mass flux, IR brightness and precipitation to the African wave disturbance are also discussed.

1. Introduction

In recent years computations of the cloud mass fluxes based on large-scale heat and moisture budgets and parameterized cloud models have been performed by many authors to study the interaction between cumulus convection and its environment (Yanai et al., 1973; Ogura and Cho, 1973; Nitta, 1975; Johnson, 1976; and others). Using observations from the GARP Atlantic Tropical Experiment (GATE) Nitta (1977, 1978) and Johnson (1978) made similar computations including both convective updrafts and downdrafts.

While these diagnostic studies clarified the important role of the cumulus cloud in the large-scale field, the results of the cloud mass flux computations are dependent on the adopted cloud models and should be verified by other independent observations for clouds. However comparison between computed cloud mass fluxes and other directly observed cloud parameters has not been thoroughly made mainly due to the lack of direct observations for cumulus clouds.

The GATE observation systems have been planned to provide the data for estimating the effects of the smaller-scale systems on the large-scale fields in the tropics and a variety of observations have been carried out to measure different scales of meteorological phenomena. Therefore it is possible to test the computed cloud mass fluxes by different types of observation data obtained in GATE.

This study is an extension of the previous study by Nitta (1978) in which the cloud mass fluxes were computed using the GATE A/B-scale upper-air observations for Phase III. The purpose of this study is to compare the computed cloud mass fluxes with the observed convective activity based on the satellite and radar observations and to verify the cloud mass flux computations.

2. Data

The results of the cloud mass fluxes obtained by Nitta (1978) are used in this study. The cloud mass flux computations have been carried out for each 6 hourly observation time using upper-air observations over the GATE A/B-scale area during Phase III (31 August-18 September 1974). Fig. 1 shows observation networks for A/B- and B-scale areas in GATE. The reader is referred to Nitta (1978) for further details of the computation method.

Digital SMS-1 IR brightness data and precipitation calculated from radar measurements are used for comparison with the cloud mass flux. 3-hourly IR brightness data averaged over the A/B-scale area were kindly supplied by Dr. M. Murakami of Meteorological Research Institute of Japan. Additional details of the data processing are described by Murakami (1979). Short period variations less than 1 day are filtered out.
in order to make comparison with 6-hourly cloud mass fluxes whose short period fluctuations are also eliminated.

Six-hourly precipitation described by Thompson et al. (1979) is used. The precipitation was calculated from radar measurements and averaged over the B-scale area. Although the B-scale area is much smaller than the A/B-scale area as shown in Fig. 1, the former is located near the center of the latter and most active cloud clusters move along the longitudinal belt crossing the B-scale area, and hence comparison between the cloud mass flux for the A/B-area and the precipitation for the B-area could be justified.

Since IR brightness data mostly measure the deep convective activity, the cloud base mass flux due to deep clouds with tops above 400 mb is used for comparison.

3. Time variations of deep cloud mass fluxes, IR brightness and precipitation

Fig. 2 shows time variations of the IR brightness, precipitation and cloud base mass fluxes for deep clouds during Phase III of GATE. It is found that large mass fluxes for deep clouds correspond quite well to high IR brightness and heavy precipitation. Especially, similar time variations with a period of about 2–4 days which would be associated with the African wave disturbances can be seen in all three parameters.

We compute the correlation coefficients between the deep cloud mass flux and the other two parameters with different time lags to examine more detailed relationships (Fig. 3). The result shows that the deep cloud mass flux $M_{BD}$ correlates very well with both IR brightness $B$ and precipitation $P$. While there is no time lag between $M_{BD}$ and $P$, the curve of the correlation coefficient between $M_{BD}$ and $B$ is slightly shifted to the positive time lag ($\Delta t>0$) indicating that IR brightness has its maximum a few hours after the peak of the deep cloud mass flux. This is likely due to the fact that the area of upper-level cirrus canopy would expand even after the cease of development of cumulonimbus clouds.

If we parameterize the conversion from cloud droplets to raindrops in the cloud model, we can estimate the precipitation rate in the updraft as well as the cloud mass flux (see Nitta, 1977). In the diagnostic cloud model developed by Nitta (1977) it is assumed that the air inside convective downdrafts is saturated and maintained by evaporation from the falling raindrops. By taking into account generation of raindrops in updrafts and evaporation in downdrafts, we...
can calculate net precipitation rate falling on the sea surface. Fig. 4 shows the time variations of calculated and observed precipitation, respectively. Though the areas used for taking the average of precipitation are different between the model computations and observations, both variations of precipitation generally agree well with each other, especially for the latter half of GATE Phase III.

Negative precipitation found on 7 and 8 September would be resulted from overestimation of evaporation in the downdraft. It is assumed in the model that the air in the downdraft is saturated and maintained by the evaporation from the falling raindrops. However non-saturated downdrafts are frequently observed as well as saturated downdrafts in GATE (Houze, 1977; and Zipser, 1977) and the above saturation condition would lead to overestimation of evaporation.

The mean value of the computed precipitation for the whole period is 9.1 mm day$^{-1}$ which is 2.8 mm day$^{-1}$ smaller than that of observed. Since the convective activity has its maximum along the longitudinal belt where the B-scale area is located as mentioned previously, it is expected that the amount of precipitation averaged over the B-scale area is greater than that averaged over the A/B-scale area where regions with small rainfalls are also included. It is also probable that the saturation assumption in the downdraft would result in underestimation of the net precipitation as discussed previously.

4. Relationship between cumulus convection and African wave disturbances

The GATE area is largely affected by the passage of the African wave disturbances which propagate westward with an average period of 3.5 days and an average wavelength of approximately 2,500 km. The relationship of convection and precipitation to the African wave disturbance has been extensively studied by Reed et al. (1977), and that between waves and cloud mass fluxes computed by the diagnostic cloud models has been examined by Johnson (1978) and Nitta (1978). In this section we reexamine the relationship between cumulus cloud activity and the African wave disturbance using observed precipitation, SMS-1 IR brightness and computed cloud mass fluxes.

The same compositing method as that in Nitta (1978) is used. Fig. 5 shows variations of $B$, $P$, $M_{BD}$ and $M_{BS}$ (cloud base mass fluxes due to shallow clouds with tops below 700 mb) relative to the phase of the wave disturbance. All parameters except $M_{BS}$ have maximum values around the wave trough and minimum around the wave ridge. While $M_{BD}$ and $P$ have their peaks at the wave trough, the maximum IR brightness occurs just behind the trough. This is consistent with the previous result of the time lag between $M_{BD}$ and $B$.

The phase relationship of $M_{BS}$ to the wave disturbance is opposite to that of other parameters, i.e., shallow cloud mass fluxes are small near the trough but large near the ridge. It is not easy to detect the activity of shallow clouds which have short life time and small horizontal scales and there is no direct observational support indicating modulations of shallow clouds by the wave disturbance. However it is likely that the
shallow clouds would be suppressed by the strong stabilization due to active deep clouds as discussed by Johnson (1978) and Nitta (1978). Recently Ninomiya and Yamazaki (1979) have found in their analysis in Asian subtropical humid region that weak radar echoes tend to be suppressed when extremely strong echoes develop.

5. Conclusions and remarks

The cloud mass flux due to deep clouds computed by the diagnostic cloud model is tested by using SMS-1 IR brightness and the precipitation calculated from radar measurements. The cloud mass flux for deep clouds correlate quite well with both IR brightness and precipitation. The IR brightness has its peak a few hours after the maximum deep cloud activity. This may be due to the horizontal expansion of the upper-level cirrus canopy after the cease of cumulus development.

The precipitation computed by the model is compared with that observed. Time variations of both precipitation are quite similar to each other, although the mean value of the former is smaller than that of the latter.

Relationships between the African wave disturbance and the IR brightness, precipitation and cloud mass fluxes are examined by using a compositing method. The maximum precipitation and the greatest cloud mass flux for deep clouds occur at the wave trough, but the IR brightness has its peak just behind the wave trough. Cloud mass fluxes for shallow clouds are small around the wave trough but large around the wave ridge. The weak shallow cloud activity near the wave trough may be resulted from the stabilization effect by intense deep clouds, but further studies about the variation of the shallow cloud activity are needed in future.

Although it is concluded in this study that the cloud mass flux for deep clouds computed by the diagnostic cloud model represents well the activity of deep clouds in the real tropical atmosphere in qualitative sense, more quantitative verification is desired in future. For that purpose we may have to develop technique to obtain more quantitative data for cumulus clouds such as mass fluxes inside clouds, precise areas covered by cumulus clouds and so on.

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References


GATE 領域における計算された雲の質量フラックス量と観測値との対応

新 田 勝
東京大学理学部地球物理学教室

GATE の高層データの解析から得られた、雲の質量フラックスと静止気象衛星 SMS-1 の IR の輝度値、およびレーダー観測より見積られた降水量との対応を調べた。背の高い雲による質量フラックスの時間変動は、IR の輝度値と降水量の変動と非常によく対応している。また解析モデルを使って計算された降水量は、観測された降水量とよい対応を示す。雲による質量フラックス、IR の輝度値、および降水量と周期3.5日、波長2,500 km を持つ西進するアフリカ波動との関係についても調べた。