Study on the Cloud Radiative Effects on Climate
Part I: Calculation of Cloud Radiative Forcing Utilizing the Satellite Cloud Data

Contact Person Senior Researcher, Yukari N. Takayabu
Atmospheric Environment Division, National Institute for Environmental Studies,
Environment Agency of Japan.
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1. Background

According to IPCC reports, radiative forcing by doubled CO_2 is estimated to be several watts per square meters. Therefore, in order to discuss the climate change, it is necessary to estimate the effects of other radiative elements such as clouds in the same accuracy. However, not to mention the disagreements among the climate model prediction due to the treatments of clouds as pointed out in IPCC92, even the atmospheric absorption of the cloudy atmosphere is still in dispute with the amount of 20-30 W/m^2 (Cess et al. 1995, Ramanathan et al. 1995). On the other hand, cloud radiative forcing has often been discussed with the value at the top of the atmosphere (Ramanathan and Collins 1991). However, while the longwave (4-200μm) cloud heating is distributed in the atmosphere, the shortwave (0.2-4μm) cloud cooling is the surphace phenomena. Therefore, in order to discuss the cloud-radiation interaction, we need to know the vertical profile of cloud effects, which is difficult to obtain observationally at the state of the art.

2. Objectives

The goal of this study is to obtain the vertical profile of the cloud radiative effects with the actual observation. Cloud radiative effects vary with the cloud optical properties and the fractions of different cloud types. Therefore, in order for the evaluation of cloud effects in the climate system, it is necessary to know how the clouds are generated and what radiative effects they have in reality. In this study, we aimed to develop a method to incorporate the cloud optical information to an advanced radiative transfer model and to apply it to the level-D1 data of International Satellite Cloud Climatorogy Project (hereafter ISCCP D1) to obtain the cloud radiative forcing with individual cloud type separately. We also discuss the accuracy of the method and the problem of utilizing the ISCCP D1 data.

3. Data and the Method

The cloud optical depth, top temperature and fraction provided by ISCCP D1 data (2.5°×2.5°, 3 hourly) were utilized. Physical depth of the clouds was parameterized following Minnis et al.(1990). Atmospheric profiles, such as relative humidity and air temperature, were obtained from ECMWF objective analysis data. These values for each 15 cloud types were input to an advanced radiative transfer model 'fstar5b' (Nakajima et al., 1996) for the radiative flux calculation.

We further compared the calculated surface flux with the IMET buoy observations during the Intensive Observation Period of Tropical Ocean and Global Atmpshere - Coupled Ocean-Atmosphere Responce Experiment (TOGA-COARE IOP). Then tested the sensitivity of model calculation to the low-clouds insertion to show the underestimate of low clouds in ISCCP D1 data.

4. Results

'Cloud radiative forcing' is defined as a increase of downward net radiative flux at a specified level of the atmosphere due to the existence of clouds.

$$CF=F(total)-F(clear) \qquad (1)$$

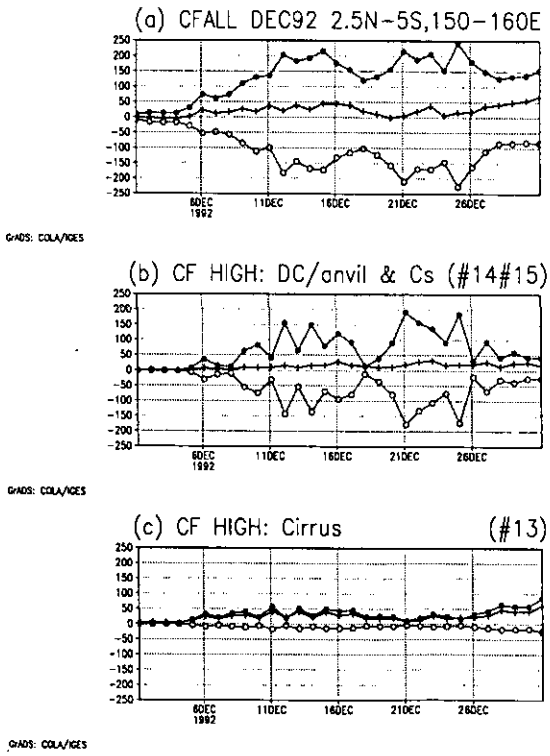

Figure 1: Time series of the cloud radiative forcing at the top of the atmosphere over the western Pacific ocean for different cloud classes: (a) total, (b)thick high-level (2) thin high-level (d) mid-level and (e) low-level clouds. Closed circles: LW forcing, Open circles: SW forcing, Crosses: Net forcing. Units are in $W\,m^{-2}$.

Figure 1 shows a time series of the cloud radiative forcing at the top of the atmosphere over the warm pool region in the western equatorial Pacific

ocean for December 1992. In the latter half of this months, a large scale organized cloud system, called Madden-Julian Oscillation (MJO), propagated over this region.

The cloud forcing by total cloud (Fig.1(a)) shows the large amplitude variation of long and shortwave radiative flux associated with this MJO. By examining the forcing by different types clouds separately, we can notice that upper thick clouds, such as anvils, have large amplitudes in LW and SW but almost canceled each other (Fig.1(b)). While upper thin clouds, cirrus, shares the most part of the total net heating (Fig.1(c)). Mid- and low-level clouds have cooling effects, though their amplitudes here are small.

Next, we evaluated the ISCCP D1 cloud amount by comparison with the TOGA-COARE ship observation. Since the satellite visible and infrared measurements used for this data cannot convey the information for cloud overlapping, effects of the lower clouds shielded by the upper clouds may be underestimated.

Figure 2 compares the total and the low-level cloud amounts between the ISCCP D1 data and the observation by R/V Xiangyanhong#5. It is found that total cloud amounts show a good agreement, while for the low-level clouds, ISCCP D1 data exibits a significant underestimate especially when the total cloud cover is near 100% and convective activity is high.

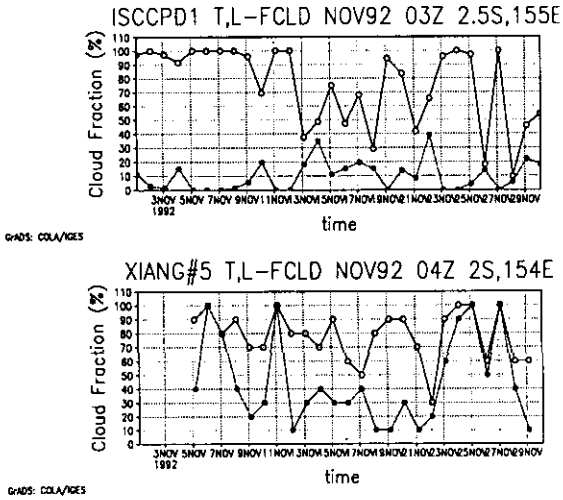

Figure 2: Comparison of total (○) and low-level (●) cloud amounts between the ISCCP D1 at 03Z (upper panel) and the observation by R/V Xiangyanhong#5 at 04Z (lower panel).

Above results clearly indicated that the low-level cloud fraction sometimes has erroneous values (underestimate) due to the single-layer approximation of the ISCCP cloud retrieval. For the next step, we examined the sensitivity of the radiative flux to the low-level cloud amounts with the radiative model calculation. Besides the 'Control-Run' with the original ISCCP cloud amonts, two other experiments were performed: 'Exp-L' with the low clouds in 1-3 km layer with optical thickness of 3.6 were inserted under all the high-level and mid-level clouds; and 'Exp-B' with similar low-clouds insertion but with dependency on total cloud amounts.

Figure 3 compares the calculated surface longwave flux with the observed flux values by IMET buoy moored at 2°S, 156°E for the period of December to November 1992. Two-months-mean LW flux by IMET buoy observation was 58W/m^2. The same amount for the control calculation was 69W/m^2, while that for the Exp-L was 56W/m^2 indicating the sensitivity of 13W/m^2 to the low-cloud insertion and an improvement by such treatments.

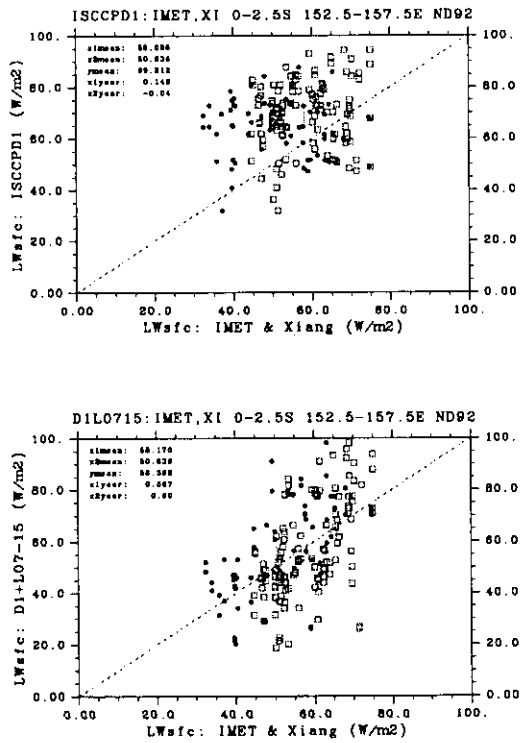

Fig.3: Comparison of scatter diagrams of calculated surface net long wave flux (a) with original ISCCP D1 cloud data and (b) with low-level clouds inserted against the observed flux by IMET buoy and R/V Xiangyanghong #5.

Figure 4 compares the shortwave and longwave cloud radiative forcing for the Control-run and Exp-L calculaion. In average, the sensitivity values of longwave cloud radiative forcing to the low-level-cloud insertion were 16W/m^2 and 1W/m^2 for at surface and for at TOA, respectively. Those for the shortwave cloud forcing were -20W/m^2 and -14W/m^2. The esitmate of TOA cloud radiative foricng with cloud insertion seems to correspond better with the ERBE observations.

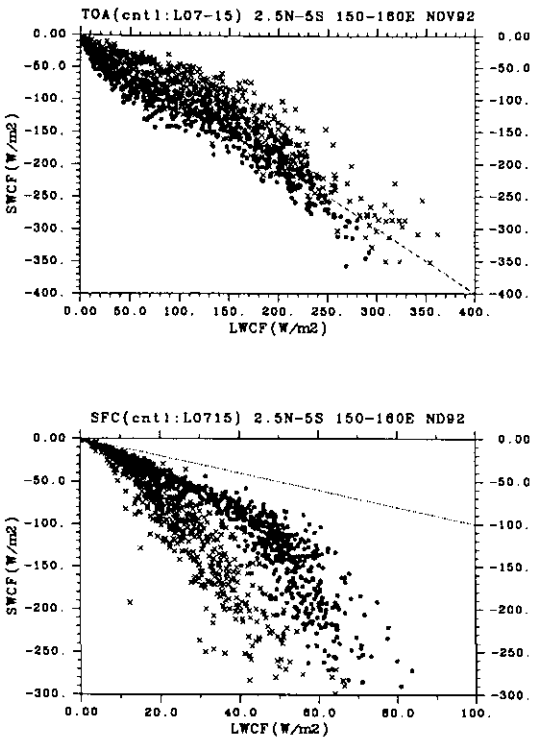

Fig.4: Scatter diagram of shortwave vs longwave cloud radiative forcing (1) at the top of the atmosphere and (2) at the surface. × s indicate the values with original ISCCP cloud data and ● s indicate those for low-level cloud insertion calculation.

4. Conclusions

A method to calculate cloud radiative forcing was developed with the ISCCP D1 cloud data for 15 cloud categories and ECMWF objective analysis data as input. Secondly, ISCCP D1 cloud amount was evaluated by comparison with the TOGA-COARE ship observation. The surface radiation budget is sensitive to the low-level clouds so that the accurate data for low-level clouds are indispensable for its accurate estimation. However, the satellite estimation has a drawback in the low-level clouds estimation due to the unavailability of the cloud overlapping information. By comparison with TOGA-COARE ship observation, it was clarified that the ISCCP data significantly underestimate the low-level cloud amount especially when the total cloud amount is large, while the total cloud amount is comparable with the surface observation data.

Thirdly, sensitivity of cloud radiative forcing for the low-level cloud insertion experiments were performed and evaluated with the surface radiation observation data by the IMET buoy moored at 2.0°S, 156°E during TOGA-COARE IOP. The experiment of 100% low-level cloud insertion under the middle- and high-level clouds resulted 10-20 W/m^2 changes for both shortwave and longwave surface cloud radiative forcing in the opposite direction. In comparison with IMET buoy data, estimated longwave radiation showed a significant improvement in by low-level clouds insertion.

Although it is necessary to incorporate the satellite observation to estimate the cloud radiative forcing globally, it was shown there still remain difficulties in adequately use the satellite cloud data for the flux calculations. For the next step, we are now in progress with very accurate evaluation of the surface shortwave cloud radiative forcing utilizing the high quality observations of the radiation, the atmospheric profiles, and the aerosol optical properties at Tateno.

Acknowledgements

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