EVALUATION OF SATELLITE REMOTE SENSING OF CLOUD

T. Hayasaka, H. Iwabuchi and N. Kikuchi

Center for Atmospheric and Oceanic Studies, Faculty of Science
Tohoku University, Sendai 980-8578, JAPAN
Phone: (81)-22-217-6742, Fax: (81)-22-217-6739
E-mail: hayasaka@mail.cc.tohoku.ac.jp

1. INTRODUCTION

Satellite remote sensing of cloud is quite useful for climate and meteorological studies because of its global coverage. Many cloud parameters such as optical thickness, effective particle radius, and liquid water path are obtained by measuring reflected or emitted radiation at various wavelengths from visible to microwave spectral region. Recent progresses in computer science enable us easily to handle those huge satellite data. Retrieval of cloud parameter is generally carried out by comparing the radiance measured by satellite with that calculated. However, various assumptions such as plane parallel atmosphere are necessary for the radiance calculation, and those may cause errors in the retrieved results. Also the spatial resolution of radiometer on board satellite is limitted so that retrieved results contain some uncertainties.

In this study, these uncertainties in the satellite remote sensing of cloud are assessed from various points of view. Uncertainties caused by cloud model assumption in the retrieval of cloud optical thickness, effective particle radius, and liquid water path are investigated by using Landsat data, AVHRR data, SSM/I data and Monte Carlo simulation.

2. CLOUD INHOMOGENEITY

In most cases radiance calculated with plane parallel cloud model is compared to satellite measurement to determine the cloud parameters although the cloud inhomogeneity affects the cloud radiative properties. Cloud inhomogeneity as seen for cumulus cloud is closely related to finite spatial resolution of sensor (as beam filling error) and modification of radiation field due to complicated shape of cloud.

Landsat data were analyzed to investigate the cloud shape effects in the retrieval of optical thickness and effective particle radius from reflected solar radiation. The data used here correspond to wintertime stratocumulus cloud field to the west of Japan. The cloud size is distributed from a few to several kilometer in diameter while the spatial resolution of Landsat TM data is 30m. Optical thickness and effective particle radius were retrieved from channels 4 (λ=0.776-0.905μm) and 5 (λ=1.568-1.784μm) by using an algorithm similar to that of Nakajima and King (1990) where plane parallel cloud is assumed.

The results suggest that the effect of cloud inhomogeneity on the reflected radiance depends on the geometrical relationship between directions of satellite and the sun. Since the region facing the sun is much brighter than the opposite region where direct solar radiation is shaded, optical thickness in the region facing the sun is overestimated while effective particle radius is underestimated. This property was systematically seen in the AVHRR data analysis in which geometrical relationship between the sun and satellite was classified.

Simulation of these effects in AVHRR analysis with Monte Carlo radiative transfer calculation for cubic type inhomogeneous cloud was consistent with the Landsat and AVHRR data analyses described above. Figure 1 shows an example of the relationship between reflected radiances (AVHRR ch1 and ch3) and cloud parameters (optical thickness and effective particle radius). Solid lines shows the relationship calculated with plane parallel cloud layer while the broken lines correspond to that with cubic broken cloud. Solar zenith angle is assumed to be 60° and satellite viewing angle is almost nadir. This figure suggests large error in the retrieval of both optical thickness and effective particle radius if the plane parallel cloud assumption is used for the analysis of broken cloud. Cloud top morphology effects were also evaluated for non-broken cloud, i.e., field of view of the sensor is fully covered with cloud. In this case it is suggested that the data where the scanning angle is large are not appropriate for the remote sensing of cloud by using reflected solar radiation measurements.

3. CLOUD MICROPHYSICS

Microphysics of cloud model also affects the accuracy in remote sensing, because cloud droplets are generally assumed to be spherical water particles with a size distribution although actual cloud often consists of drizzle particles or non-spherical ice particles. However, it is impossible to retrieve the ice cloud properties from AVHRR ch1 and ch3 data with sufficient accuracy. Also the sensitivity of near infrared rsdiance to the effective particle radius is insufficient in the retrieval of very large droplet such as drizzle or rain. Moreover it is quite difficult to distinguish ice particles from liquid particles. On the other hand, microwave remote sensing such as SSM/I can detect liquid water only while small ice particles cannot be retrieved quantitatively. Cloud vertical profile is also important for both remote sensing methods. AVHRR observes the effective particle radius of upper part of cloud layer. Since SSM/I observes the thermally emitted radiation from almost entire cloud layer, vertical profiles of temperature and liquid water content are important. Thus discrepancies of liquid water path between the results from AVHRR and SSM/I, which are particularly observed for the convective cloud, may be ascribed to these effects as well as beam filling errors particularly in SSM/I analysis.

4. VALIDATION

As mentioned in the previous section, results obtained from satellite remote sensing are compared with results of other satellites. Also ground or aircraft based observations of cloud are generally used to evaluate the satellite remote sensing results.

Since the orbit of each satellite is different from each other, it is quite difficult to observe the same cloud at the same time. However, statistics of the cloud cluster does not change if the observation time difference is not so large. Therefore it is possible to compare statistical results between different two satellites. This comparison can suggest some errors contained in the results, which are caused by dynamic range or calibration issues.

Aircraft observation measures in situ cloud liquid water content and droplet size distribution, and then effective particle radius. Some problems occur in the comparison of these cloud parameters between satellite and aircraft, when the cloud is horizontally inhomogeneous. Figure 2 shows the effective particle radius obtained from AVHRR and that from in situ aircraft observation synchronized with satellite overpass (Kuji et al., 2000). It is found from the figure that result of aircraft and satellite remote sensing are inverse correlation. This result may be ascribed to the cloud edge properties. The satellite data containing both cloud and sea surface suggest small optical thickness and large effective radius if the data are analyzed with an assumption of plane parallel cloud. On the other hand, small droplet particles are generally observed at the cloud edge part.

Direct comparison between satellite observation and ground based observation is quite difficult because of spatial resolution, accuracy of pixel location and cloud inhomogeneity. In this comparison, it is also effective to use statistical method as well as comparison between different satellites as mentioned before. It is well studied that rainfall distribution is expressed by log-normal distribution both temporally and spatially if the data size is sufficiently large. For example, rain gauge data and SSM/I data are statistically compared although it is impossible to compare them directly (Hayasaka et al., 1998). The investigation similar to rain observation will be necessary.

References

Hayasaka, T. H. Murata, B. Zhao, Y. Zhu, and W. Li, 1998: Rainfall distribution over Asian continent retrieved from SSM/I data. Microwave Remote Sensing of the Atmosphere and Environment, Proceedings of SPIE, Volume 3503, 108-114.

Kuji, M., T. Hayasaka, N. Kikuchi, T. Nakajima, and M. Tanaka, 1999: The retrieval of the optical thickness and effective particle radius of low-level marine clouds by NOAA/AVHRR data. J. Appl. Meteor. (in press).

Nakajima, T. and M. D. King, 1990: Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. Part I: Theory. J. Atmos. Sci., 47, 1878-1893.

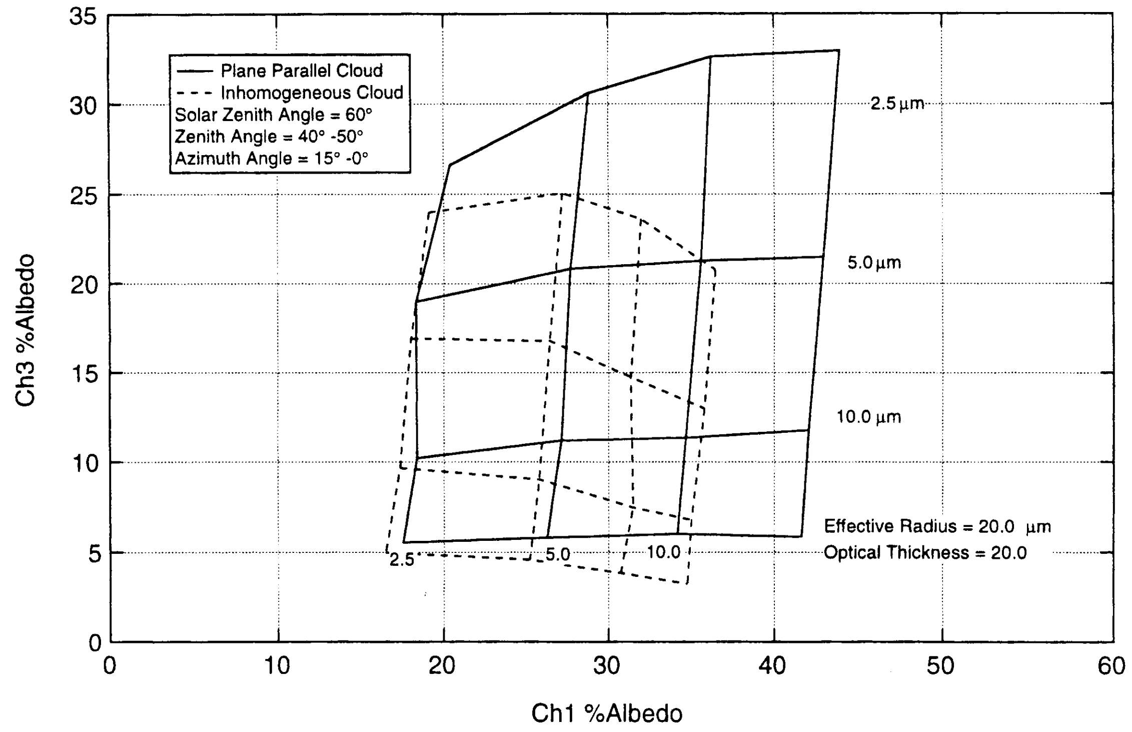

Fig. 1. The relationship between reflected radiances (AVHRR ch1 and ch3) and cloud parameters (optical thickness and effective particle radius). Solid lines shows the relationship calculated with plane parallel cloud layer while the broken lines correspond to that with cubic broken cloud.

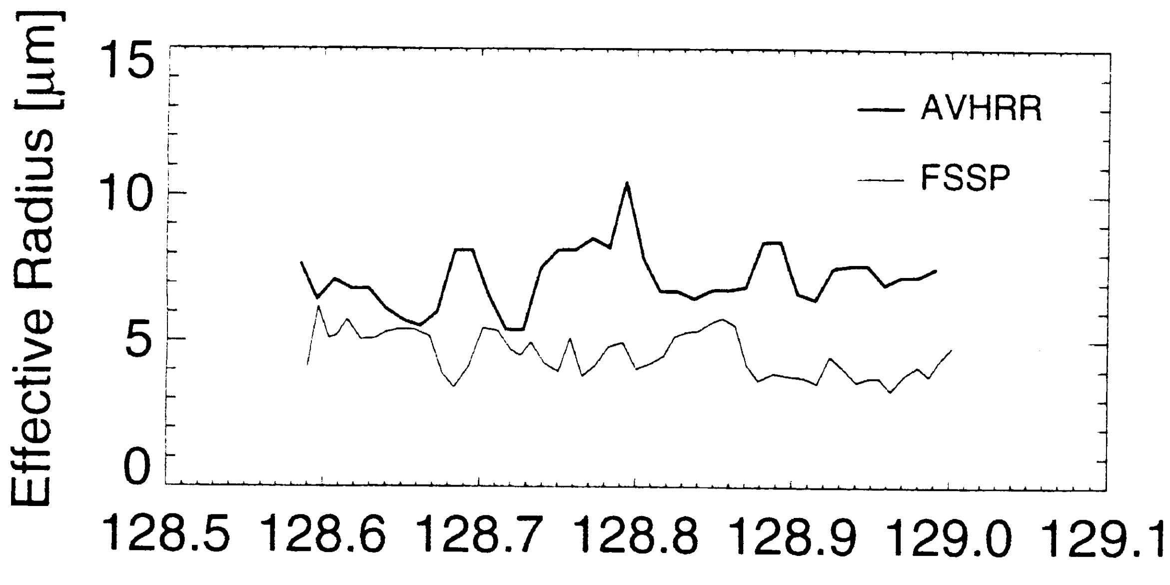

Fig. 2. The effective particle radius obtained from AVHRR and that from in situ aircraft observation synchronized with satellite overpass. Horizontal axis shows longitude (E) corresponding to the flight distance.