JP1.4 STUDIES OF CLOUDS BY SHIPBORNE 95GHZ RADAR AND LIDAR SYSTEM DURING THE MIRAI CRUISES .

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1. INTRODUCTION

Clouds are known to play an important role in the energy and water cycles of our climate system through their feed back processes. However, there are especially large uncertanties in the vertical distributions of clouds and therefore, the large uncertainties remain in the estimation of longwave cloud radiative forcing at the surface. This is partly due to the fact that clouds often coexist with other cloud layers at different altitudes, and in such cases passive satellite sensors fail to provide macrophysical information such as cloud boundaries. The active instruments such as the 95-GHz cloud radar or lidar are expected to improve the situation. As an element of NASA's Earth System Science Pathfinder (ESSP) program, CloudSAT with cloud profiling radar will be launched in 2004. After CloudSAT, plans are being coordinated to realize cloud profiling radar with lidar satellitte measurements.

For the estimation of the particle size, there is an essential difficulty in the single use of the instrument. This is partly because the radar or the lidar signals depend on the particle size distribution and it may change for each cloud. By using these two active sensors, we have a great opportunity to retrieve such information. Thus, we have developed the synergy algorithm by using the two active instruments in Okamoto et al. (2000a), and further developed in Okamoto et al. (2002). We have proposed a forward type algorithm. One unique feature of the algorithm is the attenuation correction for the radar and the lidar signals. There is another difficulty in the interpretation of the lidar signals because of the strong attenuations in this wavelength compared with the mm-wavelength region. The attenuations in the signals are automatically corrected in the algorithm.

In section 2, we describe the theoretical procedure that has been applied to the synergy observational data. In section 3, we report the observations taken by the co-located shipborne 95GHz cloud radar and the lidar systems installed in Mirai vessel during the two cruises performed in 2001: two weeks in May for MR-K02 cruise over Pacific Ocean near Japan and three months between September and December for MR-K05 mainly over tropical region.

2. THEORETICAL PROCEDURE

We have developed the co-located 95GHz radar and lidar with dual wavelengths in Mirai vessel. The system enables us to study the longitudinal and latitudinal distributions of cloud fields. The 95GHz cloud radar has also a Doppler function. The lidar has a function to estimate depolarization ratio of the particle and also has two channels, i.e., 0.532μm and 1.064μm.

The comprehensive description of the synergy algorithm is found in Okamoto et al., (2002). The paper includes several numerical analyses for the potential source of errors in the retrieval values. The algorithm consists of four components, i.e., interpolation of lidar and radar data to have the same time and vertical resolution, cloud masking, retrieval of size and ice/liquid water content and correction of attenuations. There are four files to perform the algorithm. The first two are radar and lidar observational data. For these two data, the interpolation scheme is applied. The last two files are look-up tables in order to derive the cloud microphysics.

Starting from the cloud bottom, the algorithm is applied to retrieve the size and ice/liquid water content for the layer. Then the attenuation to the next layer is corrected on the basis of the finding of the cloud microphysics. We can apply the similar procedure to determine the microphysics of each layer until the cloud top.

For the analysis of radar and lidar data, there are four important issues to be discussed; (1) the attenuation to the lidar

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and radar signals (2) Non-sphericity of ice crystals (3) Shape of the size distribution and (4) Contribution of multiple scattering in lidar signal.

Concerning attenuation, we developed the new forward algorithm that correct attenuations in both radar and lidar signals according to the cloud microphysics determined by the look up tables for radar and lidar as well as the observational data for radar and lidar. It is important to note that we do not rely on inversion method , and thus, we do not have to specify the far end value of the observational data.

Concerning non-sphericity of the particle shape, we considered hexagonal ice crystals with various aspect ratios and the intensive computations have been performed for the 95GHz. It turns out that the differences in the radar reflectivity factor for different shapes are within 2dB unless the particle size exceeds 200mm in Okamoto (2002). For larger particles, those differences can be as large as 7dB. For the non-sphericity in the lidar signals, the situation is more complicated. The most of the particles are much larger than the wavelength, and ray tracing method is usually applied. The applicability of the method is tested by using Kirchhoff diffraction theory and it turns out the validity is especially limited in the backward direction in Iwasaki and Okamoto(2001). We actually estimated the backscattering coefficients by rectangle particles as an analogue of hexagonal crystals on the basis of Kirchhoff diffraction theory and show when the perfect orientation of plate-like particles with flat surfaces in horizontal plane is achieved, it is contemplated to have one order larger signals than that of the equivalent volume spheres. The use of Mie theory is not justified in such cases. While, the randomly oriented particles produce the analogous signals as the sphere. Currently we rely on the Mie theory for the analyses of radar and lidar signals.

For the shape of size distribution, we provide two look up tables; radar reflcetivity factor for radar and extinction coeeficients for a specific ice/liquid water content as a function of effective radius for radar and the other one is for lidar. To prepare these tables, we compared the results based on lognormal distribution with the width of 1.5 with those based on modified gamma one with p=2 where p denotes the dispersion of the distribution. The retrieval differences due to the assumption of one specific distribution turn out to be about 5% in both effective radius and IWC.

For the contribution of multiple scattering, this is especially important for the lidar signals from optically thick clouds. However, when the optical thickness is less than 0.3, the errors in the retrieved values are very small, i.e., less than a few %, as long as the field of view of the receiver is 1mrad or smaller. For optically thick clouds such as water clouds, this effect becomes important and should be included in the algorithm.

3. APPLICATION OF THE ALGORITHM TO THE SHIPBORNE RADAR/LIDAR DATA

During the MIRAI01-K02 and K05 cruises, the synergy observations with radar and lidar have been continuously performed. The cloud profiling radar is developed by CRL and the lidar system is developed by NIES. As far as we know, this is the first time to perform the observations by shipborne 95GHz-cloud radar and lidar systems. The obervational period of K02 cruise is from May 14 to May 27, 2001 and that of K05 is from September 21 to December 17, 2001. Among the K02 data, we show the results of the retrieved cirrus cloud microphysics by the application of the algorithm to the synergy data taken from 11:00 to 12:00 am (JST) on May 22, 2001 in Figure 1. Both radar and lidar detect the cloud boundaries with sufficiently good agreements and the application of the algorithm is successful. The effective radius tends to increase with the altitude decreases. And the effective radius ranges from 30μm to 120μm. The ice water content ranges from 10^{-4} to 10^{-2} g/m^3. Depolarization ratio derived by the lidar for the clouds ranges from 30 to 70%, suggesting that clouds consist of ice crystals (figure is not shown).

Then we examined the relationship between effective radius and ice water content (in Figure 2a and b). Figure 2a is for the data observed from 11:00 to 12:00 am on May 22 and 2b is for the one from 8:00 to 9:00 am in the same day. In Figure 2a, though rather scatter, the positive correlation is found between radius and IWC, i.e., as effective radius increases, IWC increases. The analyses of the ground based observations of the cirrus clouds often show the similar trend between effective radius and IWC and also between the terminal velocity of the ice crystals and effective radius as in Okamoto et al. (2001), Okamoto et al., (2002), though in K02 cruise Doppler capability was not able to be performed. In Figure 2b, in addition to the similar positive correlation between effective radius and IWC, it is also possible to find other trend, i.e., negative slope. That is, as effective radius increases, IWC decreases. This might be understood as follows; these data corresponds to the end satge of the cloud evolution. In the end of cloud evolution, clouds are evaporating and thus, ice water content decreases. While, the ice crystal still aggregates and thus effective radius increases.

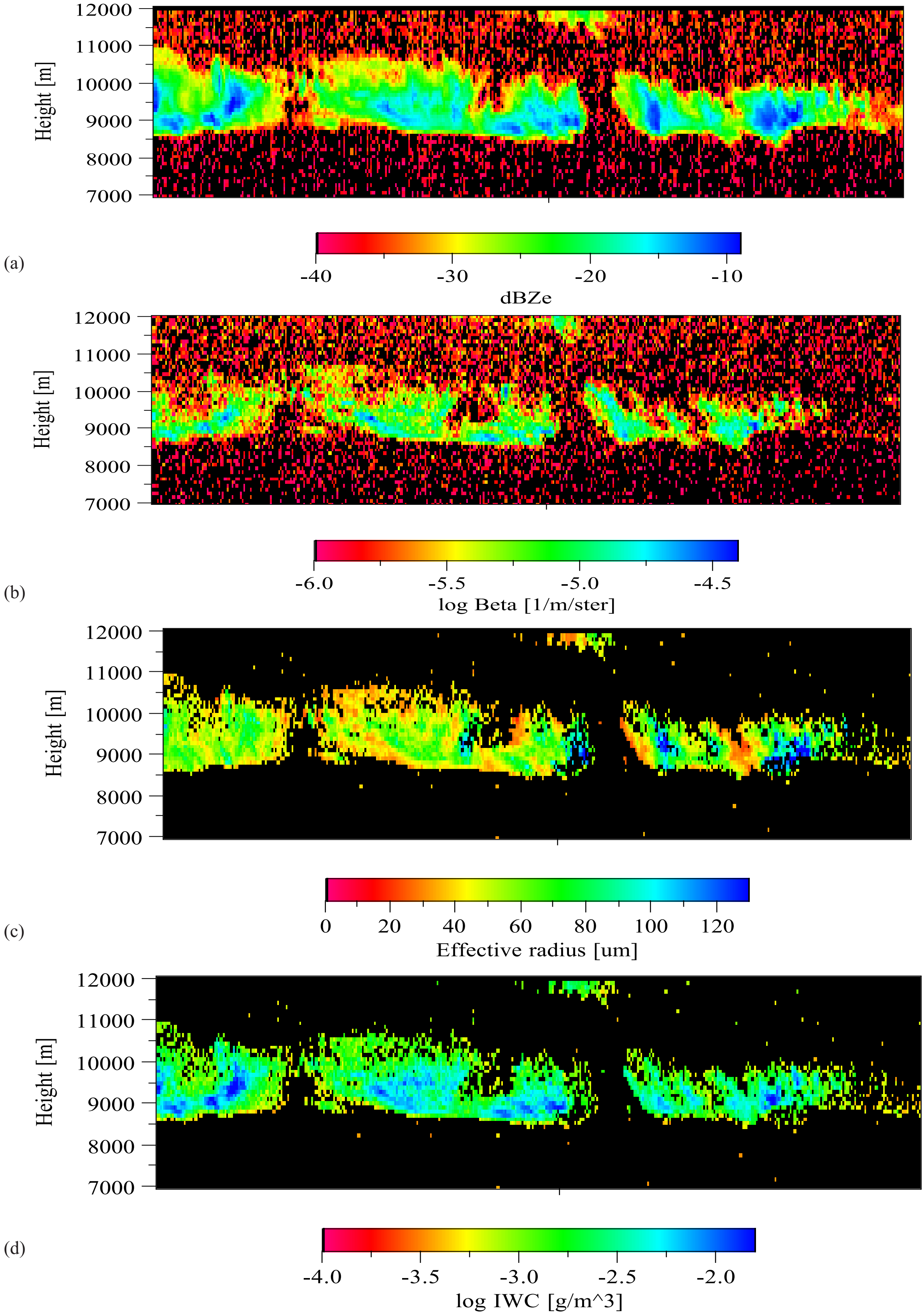

Figure 1 (a) The height time profile of the radar reflectivity factor of cirrus clouds in dB observed from 11 am to12 am on May 22 , 2001 over Pacific Ocean near Japan. (b) The lidar backscattering coefficients. (c) The retrieved effective radius and (d) The retrieved IWC.

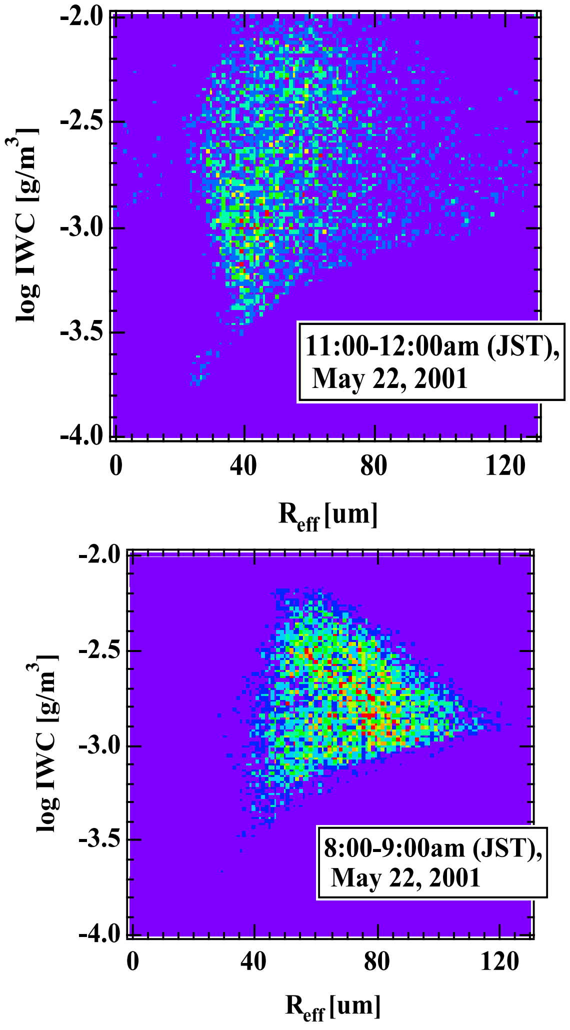

Figure 2. (a) The relationship between IWC and effective raidus for the data shown in Figure 1. (b) The same but for the different time period, i.e., 8:00 am to 9:00 am.

4. SUMMARY

The principal findings are as follows;

1) We have developed the algorithm to derive the ice/water cloud microphysics by the synergy use of the 95GHz cloud profiling radar and the lidar with dual wavelengths. The unique feature of the algorithm is that this is based on the forward type algorithm and has a capability of attenuation correction, which is especially important for the analysis of lidar signals.

2) We have developed the shipborne synergy system installed in Mirai vessel as well as the ground based system. And we have performed the observations of clouds by using the shipborne system over Pacific Ocean near Japan between May 14 - 27, 2001 for K02 cruise and September 21 - December 17, 2001 for K05 cruise
over tropical region.

3) The application of the algorithm to the cloud signals obtained by the ship-borne system is described for the cirrus clouds during Mirai K02 cruise. It turns out that as effective radius increases, IWC increases for one datum but it is also found that as effective radius increases, IWC decreases in other set and this might corresponds to the life cycle of the clouds.

5. References

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