P4.27

ICE MICROPHYSICAL PROPERTIES AND THEIR RELATION TO DISSIPATION PROCESS OBSERVED BY SHIP-BORNE CLOUD RADAR

Kaori Sato * [(1)], Hajime Okamoto [(1)], and Toshihiko Takemura [(2)]

[(1)] *Tohoku University, Aoba, Aramakiaza, Aoba-ku, Sendai 980-8578, Japan,*

[(2)] *Kyusyu University, 6-1 Kasugakouen, kasuga, 816-8580, Japan*

1. INTRODUCTION

Recently there are some efforts to evaluate cloud fields reproduced by ECMWF compared with those observed [*Mace et al.,* 1997, *Hogan et al.,* 2002]. And the retrieved microphysics by active remote sensing is vital to improve ice cloud modeling in the GCM as well as other smaller scale models. Current studies are quite limited to ground based active sensors and it is therefore also quite important to evaluate the performance of GCM over ocean. *Okamoto et al.,* [2005] performed similar comparison for clouds in GCM over ocean for Mid-latitude. They further compared the observed radar reflectivity and lidar backscattering coefficient to those simulated for clouds in the model. These enabled estimates in the reproducibility of the effective radius (r_{eff}) and grid scale ice water content (*IWC*) in the model in an indirect way. This encourages further investigation into the vertical profile of model's microphysics itself. Here we make an effort to validate simulated ice cloud microphysics directly by the retrieved microphysics obtained by 95-GHz cloud profiling radar located on the Research Vessel Mirai of JAMSTEC (Japan Agency for Marine-earth Science and TECnology).

In section 2, the method for microphysics and air motion (V_{air}) retrieval by radar and the model description are provided. In section 3, vertical profile of the microphysics estimated in GCM is evaluated against observed values and the results are further explored in section 4. Finally, concluding remarks are provided in section 5.

2. METHOD

2.1 Observation

Here the method used for microphysical retrieval by radar (hereafter RMM) is briefly described. The method combines multi-parameter of radar, i.e., radar reflectivity factor (dBZ_{e}), Linear depolarization ratio (*LDR*) and Doppler velocity (V_{D}). Among them, *LDR* is capable of discriminating particle habit [*Sato and Okamoto*, 2006]. Therefore in RMM, particle habit is derived as well as r_{eff} and *IWC* where co-existence of column and bullet rosette types with varying mixing ratio is assumed. In addition, V_{air} is estimated simultaneously with the microphysical retrieval. The main concept of the V_{air} estimation by RMM is the use of positive (upward) V_{D} portion within each observation record as information for V_{air}, provided that if V_{air} is negligible, V_{D} equals the reflectivity-weighted particle falling velocity (V_{tz}) and will be negative. The velocity of the ice particles is iteratively adjusted according to the mean value of the (remaining) positive V_{D}. Taking into consideration the inhomogeneity in V_{air} as reported by wind profiler measurements, such correction is performed only for the area of V_{D} smaller than the mean upward value in magnitudes. We also make use of lidar backscatter and extinction information for support for such V_{air} retrieval when available. Figure 1 shows an example of the vertical profile of the retrieved V_{air} in Mid-latitude by ship-borne cloud radar.

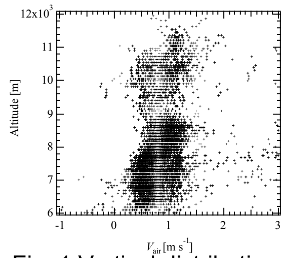

Fig. 1 Vertical distribution of V_{air} retrieved by radar in mid-latitude cruise.

The performance for the *IWC* retrieval by RMM was within ±20 % accuracy when compared against that obtained by co-located in-situ measurement in Mid-latitude during APEX-E3/ECAV campaign.

2.2 Model description

For the model in comparison, SPRINTARS (Spectral Radiation-Transport Model for Aerosol Species) based on the CCSR-NIES GCM [*Takemura et al.,* 2005] is used, where temperature, pressure, and relative humidity estimated in SPRINTARS are nudged with NCEP/NCAR reanalysis data every forty minutes. It treats 20 vertical levels from the surface to about 33 km height and the horizontal resolution is 100 km. The direct outputs of SPRINTARS for ice cloud microphysics are the grid mean *IWC* (IWC_{GM}) and ice cloud fraction ($CF_{\mathrm{ice}} \leq 1$). The *IWC* generated in cloud (IWC_{IN}) can be obtained by dividing the estimated IWC_{GM} by CF_{ice}. In the current version of SPRINTARS, r_{eff} of the ice particles is not predicted and is fixed to 40 μm throughout the layers for radiation calculation.

2.3 Comparison between observation and GCM

The comparison between the observed and simulated microphysics are performed along the cruise tracks of Research Vessel MIRAI. The target data obtained by ship-borne radar and lidar system are those for observation in the Tropical Western Pacific (TWP) for three months from the end of September 2001 (cruise MR01K05), in northeast off shore Japan (MD) for two weeks in May 2001 (cruise MR01K02), and in the Arctic (ARC) for a month from September 2002 (cruise MR02K05) (Fig.2).

For adequate comparison of the quantities, only *IWC* and CF_{ice} for cloud layers that pass the threshold for radar sensitivity for one minute are selected as " observed cloud properties", which would otherwise be set to zero in the model for the comparison. Note that attenuations in the radar signal e.g., due to water vapor and precipitation on the redome, are consistently taken in to consideration for observation and model.

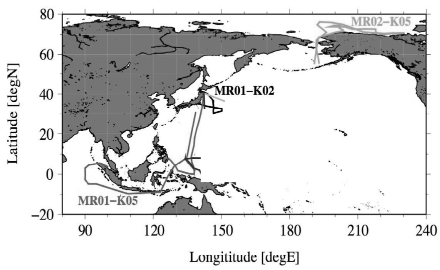

Fig.2 Cruise Tracks of MIRAI for the three cruises

3. RESULTS

Time-height cross sections for the simulated and observed IWC_{IN},and observed r_{eff} are shown in Figures 3a, b, and c for the Arctic case. The average cloud fields are relatively well reproduced, though SPRINTARS rather overestimates them near cloud boundaries

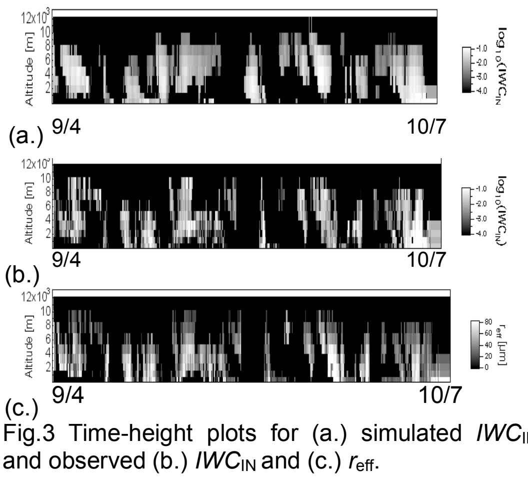

Fig.3 Time-height plots for (a.) simulated IWC_{IN} and observed (b.) IWC_{IN} and (c.) r_{eff}.

To investigate the ice cloud microphysics scheme in SPRINTARS, comparisons are provided for their vertical structure and frequency distribution against observation. The vertical profile of the average IWC_{IN} ($IWC_{IN,ave}$) in the model is underestimated for altitude (R) > 6 km, while the difference from observation becomes smaller for 2 < R < 6 km (Fig. 4a). Since the comparison is performed in concern of the radar sensitivity, such underestimation for the model in the upper layers is not entirely due to the contribution by small particles, which may be missed by radar observation. IWC_{GM} is a product of both IWC_{IN} and CF_{ice} and the differences in the estimations of IWC_{GM} depend on the deviation of IWC_{IN} and CF_{ice} from those observed. Contrary to $IWC_{IN,ave}$, $IWC_{GM,ave}$ is overestimated in the model at R > 6 km (Fig. 4b). Comparison in the simulated and observed CF_{ice} shows overestimation at R > 6 km. Therefore, comparison for IWC_{ave}s and CF_{ice} suggests that CF_{ice} in the model is the major factor (compared to IWC_{IN}) in the IWC_{GM} at R > 6 km.

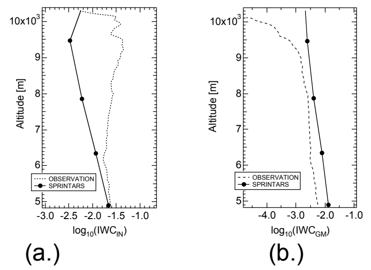

Fig 4 Vertical profiles of averaged (a.) IWC_{IN} and (b.) IWC_{GM} for observation (dotted line) and model (solid line with symbols).

SInce the comparison between the averaged *IWC* may be affected by the existence of small fraction of large *IWC*, we examined the frequency distribution for the *IWC*s in order to validate the distribution of small *IWC* as well as large ones in the model. It is noted that for the observed frequency distribution, we relied on the retrieved *IWC* for 1 minute. The frequency of occurrence for IWC_{IN} at R > 3 km shows that the peak value of its maximum occurrence exists near 10^{-2} g m^{-3} for both observation and model, while in the model, the distribution shows much narrower dispersion than observed. Similar tendency is also seen in the comparison of IWC_{GM}. Since the frequency distributions for forty minutes and six hours are almost the same, results for the comparisons between observed and simulated values may not be the artifact due to difference in the time resolution between observation and the model.

Results for the other regions are summarized in table 1 together with that for the Arctic. The same conclusions among the latitudes are the over/under estimate for the assumption of r_{eff} = 40 um to that observed at high/low altitudes, respectively, and the narrower frequency distribution of the simulated *IWC*s. Notable features for the Tropics and Mid-latitude compared to the result for the Arctic is the overestimation in IWC_{IN} around R=6km. Dominance of the importance of IWC_{IN} in IWC_{GM} rather than CF_{ice} at 6<R<8 km may be related to the convective activity and large amount of precipitation in the model's Mid-latitude than observed. *Okamoto et al.,* [2005] estimated the frequency of precipitations in the model and compared it with rain-gauge observation and found more than five times larger precipitation produced in the model than actual. Therefore large value of model's IWC_{IN} at 6<R<8 km might be the cause to generate the overestimation in the occurrence of precipitation in SPRINTARS. It is noted that SPRINATARS does not provide the three-dimensional information of precipitation. Instead, it produces two-dimensional rain rate. Thus, the IWC_{IN} in the model does not include the precipitation that consists of ice and thereby the simulated IWC_{IN} should be larger than the current value of IWC_{IN} when this fact is taken into account. Since simulated IWC_{IN} is already overestimated, the conclusion remains the same. Note that the observation period in Mid-latitude may not be sufficiently long enough to convince the above results. On the other hand, the differences in the simulated *IWC*s for ice clouds with and without precipitation in Tropics show that the mean vertical profiles as well as the frequency distribution for the *IWC*s (Figures not shown) are not much related to the existence of precipitation in the model's Tropics. This implies that the precipitation occurrence in the model did not play much role in the discrepancies between the observed and simulated *IWC*s for the Tropics. At R>8 km, the magnitude of the overestimation in the simulated IWC_{GM} in Mid-latitude is found to be much larger than that for the Arctic. For the case of tropics at 8 km < R, the dominant cause (Cf_{ice} or IWC_{IN}) of the predicted IWC_{GM} in the model varies with altitude. These different features in the comparison among latitudes imply that the applicability of the cloud schemes may be different among latitudes.

		IWC_{IN} (SP-Obs.)	CF_{ICE} (SP-Obs.)	IWC_{GM} (SP-Obs.)	r_{eff} (SP-Obs.)
8 km< R	TWP	–	+	14 < R + 11 < R <14 – 8 < R <11 +	+
	MD	–	+	+	+
	ARC	–	+	+	+
6 < R < 8 km	TWP	+	–	+	–
	MD	+	–	+	–
	ARC	–	+	+	–

Table 1 summary of the comparison. The signs, +/-/= stands for over-/under/similar (within about 50 %) estimation in SPRINTARS.

4. DISSCUTION

Overestimation in the *IWC*s at 6<R<8 km in Mid-latitude might be related to the degree of over-prediction in the duration time of falling ice particles. Therefore estimation of the loss of ice mass flux (Q_v) from clouds may be effective to explain such discrepancies in the simulated and observed microphysics. Also, this may be helpful to interpret the results for the Tropis, i.e., over-/under prediction in CF_{ice}/r_{eff} and IWC_{IN} at high altitudes in the model.

The dissipation rate of ice clouds are estimated from the retrieved V_{air}, sedimentation velocity (V_t) and IWC_{IN} of non-spherical ice particles as,

$$Q_v = \frac{4\pi\rho_{ice}}{3} \int_{r_{eq,min}}^{r_{eq,max}} r_{eq}^3 [V_t(r_{eq}) + V_{air}] \frac{dn(r_{eq})}{dr_{eq}} dr_{eq} , \qquad (1)$$

where Q_v is derived once the size distribution, dn/dr_{eq} , is determined. The ρ_{ice} and r_{eq} in Eq. (1) denote the density of ice and mass equivalent radius, respectively. In the above estimation, V_t is used instead of the V_{tz} and the contribution from V_{air} is taken into account, which becomes possible by the separation of V_{air} from V_D in RMM.

The time-height cross section of the mass flux for the Arctic for a month is shown in Fig. 5. It seems that the value are mostly negative, i.e., downward, and large with decreasing altitude.

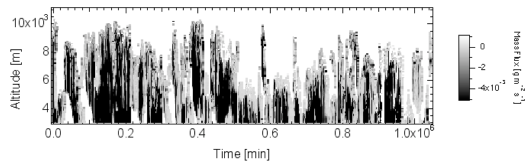

Fig. 5 Time-height plots of the mass flux during cruise MR02K05 in the Arctic.

The vertical profiles of the mass flux averaged over the observation periods for the three regions are shown in the figures 6a, b, and c. In all latitudes, the averaged loss rate increases with decrease in height. Both, the value and rate of change in the mass flux in the vertical become larger in the next order, the Arctic, Mid-latitude and Tropics. The smallest values of mass flux in the Arctic are understandable from the smallest values in both *IWC* and r_{eff}, as well as V_{air}, compared to the other regions. The largest mass flux in Tropics is mostly due to the largest values in the observed IWC_{IN} on average. The rapid replacement of ice particles in Mid-latitude and Tropics compared to the Arctic at higher altitudes may indicate the discrepancies in the magnitude of deviation of the model's *IWC*s from that observed among the latitudes, i.e., overe-/under estimation of IWC_{IN} at 6<R<8 km for Tropics and Mid-latitude/Arctic case in the model.

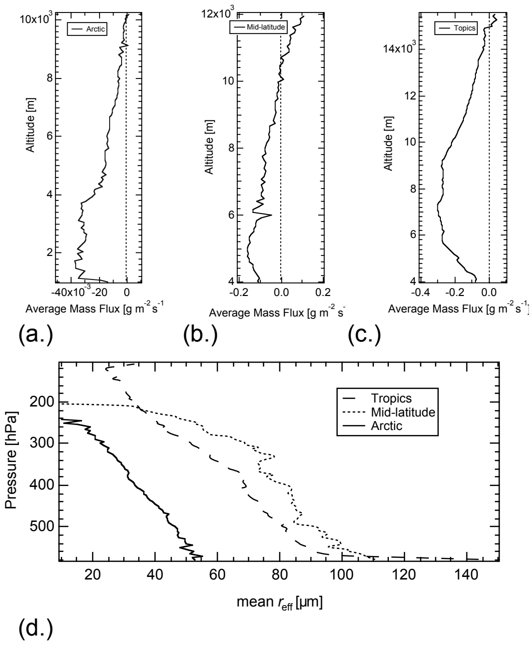

Fig. 6 Vertical variations of the average mass flux in the Arctic (a.), Mid-latitude (b.) and Tropics (c.). (d) The vertical profile for averaged r_{eff}.

Common features in the average mass flux among the latitudes are the positive (upward) values at higher altitudes. In order to qualitatively investigate how it is important to take into consideration the suspension and descent of ice particles due to V_{air} (how it differs from determining the sedimentation rate for use in GCM by temperature and pressure or by only particle size and amount) we seek to estimate the sedimentation rate at various time scales and in relation to the surrounding conditions from radar in further analyses. Note that since vertical pointing radar lacks information in the horizontal direction, additional use of satellites or scanning radar products may improve the situation.

5. SUMMARY

We compared the microphysical properties retrieved by cloud profiling radar with those simulated by GCM, SPRINTARS, along the Mirai cruise tracks in Tropics, Mid-latitude and the Arctic. Prior to the detailed comparison of microphysics, the cloud patterns in GCMs were tested against observations and in general, good agreement was achieved.

The comparison was focused on the *IWC*s (IWC_{GM} and IWC_{IN}), r_{eff} and their inter-relationship. Common features in the model's r_{eff} and *IWCs* were the narrow dispersion and large peak value in their frequency distribution. For comparison in the mean vertical profiles of the microphysics, over/under estimation were found in the model's r_{eff} at high (above 8 km)/low (from 6 km to 8 km) altitudes despite the latitude. Notable difference among latitudes are 1) the over-/under prediction of IWC_{IN} in model at 6<R<8 km in the Tropics and Mid-latitude/the Arctic, and 2) The differences in the dominant contributor (s) (Cf_{ice} or/and IWC_{IN}) in the predicted $IWC_{\mathrm{GM.}}$ These results may indicate the latitudinal dependence in the applicability of the cloud schemes used in GCM.

The dissipation rates of ice clouds are estimated by the vertical distribution of V_{air}, V_{t} and IWC_{IN} obtained by the radar. It is shown that the mass fluxes are positive on average in the upper troposphere despite the region, while they become negative and large in magnitude as the altitude decreases. Such sedimentation rate, especially at 6<R<8 km, is the smallest in the Arctic and largest for the Tropics, and may account for the difference seen in the model validation results for IWC_{IN} among the latitudes.

Further validation of the retrieved V_{air} and microphysics by simultaneous measurements will be provided, and investigation on the relation of the horizontal structure of clouds, cloud microphysics and V_{air} will be reported during the conference. Then the importance of V_{air} and V_{t} at various scales will be addressed in relation to the discrepancies between the observed and simulated microphysics and their effects on the estimation in cloud radiative properties and duration in the model.

6. ACKNOWLEDGEMENTS

We thank Dr. Kumagai and Dr. Ohno of the NICT for the radar and Dr. Sugimoto of NIES for lidar data available, respectively.

7. REFERENCES

Mace, G. G., C. Jakob and K. P. Moran, 1998: Validation of hydrometeor occurrence predicted by the ECMWF model using millimeter wave radar data, *Geophys. Res. Lett., 25,*1645-1648,

Hogan R. J., C. Jakob, A. J. Illingworth, 2002: Comparison of ECMWF Winter-season cloud fraction with radar derived values, *J. Appl. Meteor., 40,* 513-525..

Okamoto, H. et al., 2005: Cloud vertical structure obtained from the shipborne radar and lidar, : Part (I) Mid-latitude case study during Mirai MR01/K02 cruise of the R/V Mirai, *J. Geophys. Res., in revision*

Sato, K., and H. Okamoto, 2006: Characterization of Ze and LDR of nonspherical and inhomogeneous ice particles for 95-GHz cloud radar; its implication to microphysical retrievals, *J. Geophys. Res.,* in revision.

Takemura, T., et al., 2005: Simulation of climate response to aerosol direct and indirect effects with aerosol transport-radiation model, *J. Geophys. Res., 110, D02202,* doi:10.1029/2004JD005029.