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COMPARISONS OF OBSERVED AND SIMULATED MICROWAVE IMAGES OF EXTRATROPICAL CYCLONES

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1. INTRODUCTION

Satellite passive microwave observations are of interest for improving our understanding of surface rainfall and three-dimensional latent heating distributions over the globe. The Goddard Profiling Algorithm (GPROF) was selected for the Tropical Rainfall Measuring Mission (TRMM) to provide precipitation estimates on an operational basis from the TRMM Microwave Imager (TMI), and therefore GPROF has been optimized to obtain good performances in tropical regions. The performance of GPROF is partially determined by the representativeness of the cloud-radiation database. Currently, the database of GPROF is based on tropical and subtropical simulations. Since cloud and precipitation structures in the extratropics are quite different from those in the tropics, further evaluations of the relations between cloud structures and corresponding upwelling radiance at higher-latitude area will be beneficial for the GPROF applications.

The observational and model-simulated study of extratropical cyclones has experienced remarkable progress. Meteorological direct and indirect measurements have indicated natural variations in microphysical parameters. However, little modeling research has addressed how these uncertainties influence the mesoscale cloud and precipitation structure of oceanic midlatitude cyclones. In addition to the deficiencies of explicit moisture schemes themselves, the uncertainties may lead to significant errors in both cloud model and radiative transfer model. Furthermore, it still remains unknown how the errors and deficiencies affect retrieved rain rate and hydrometeor profiles obtained from a database-type algorithm.

The primary goal of the study is to systematically evaluate the impacts of microphysical parameters on simulated precipitation structures and microwave radiance of extratropical oceanic cyclone systems. The adopted approach utilizes the Pennsylvania State University-National Center for Atmospheric Research mesoscale model version 5 (MM5) and a backwards Monte-Carlo model as a common framework. Section 2 briefly describes the methodology, and results of the numerical experiments are shown in section 3. The conclusions will be given in section 4.

2. METHODOLOGY

An extratropical cyclone over the Atlantic in December 1992 was simulated at 36- and 12- km horizontal resolutions using MM5. These two nested domains both had 37 vertical levels and were run simultaneously for 48 hours. The model was initiated from ECMWF archived global analyses, and the lateral boundary conditions were updated at 12-h interval. Important physical processes in MM5 included the Blackadar planetary boundary parameterization and the Kain-Fritsch cumulus parameterization. A four dimensional data assimilation (FDDA) scheme was employed during the first 24-hr simulations.

Model-simulated dynamic and thermodynamic fields were verified using conventional objective measures, such as root-mean-square error, mean error, and skill scores. Sensitivities of the precipitation distribution to varying explicit moisture schemes were also examined. Two separate microphysics schemes in MM5 were employed: Tao

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scheme (Tao and Simpson, 1993; Lin et al., 1983), and Reisner2 (Reisner et al., 1998), which treated graupel density as a prognostic variable. Several numerical experiments were constructed and summarized in Table 1, and the paper will only emphasized on the effect of graupel species. The sensitivity test was evaluated by the noise/signal ratio (Li et al., 1995), and the variances of vertical distributions of hydrometeors were investigated by Empirical Orthogonal Function (EOF) analysis.

The employed Monte-Carlo model is a three-dimensional and time-reversed radiative transfer model with a specular lower boundary (see the details in Petty, 1994). It should be noted that the parameters in all numerical experiments were tuned only in MM5, and no parameters changes in the radiative transfer model. Simulated brightness temperatures were examined on horizontal distributions of cyclone structure and multi-channel relations comparing to a coincident Special Sensor Microwave Imager (SSM/I) overpass.

Experiment ID	Scheme	Key Parameters
STDG	Tao	ρ_g = 0.4, $N_{o,r}$ = 8.E6 $N_{o,g}$ = 4.E6, $N_{o,s}$=1.E8
HAIL	Tao	ρ_h = 0.9, $N_{o,r}$ = 8.E6 $N_{o,h}$ = 2.E5, $N_{o,s}$=1.E8
G-GH	Tao	ρ_g = 0.4, $N_{o,r}$ = 8.E6 $N_{o,g}$ = 4.E8, $N_{o,s}$=1.E8
G-GL	Tao	ρ_g = 0.4, $N_{o,r}$ = 8.E6 $N_{o,g}$ = 4.E4, $N_{o,s}$=1.E8
STDR	Reisner2	ρ_g = 0.4, $N_{o,r}$ = 8.E6 $N_{o,g}$ = 4.E6, $N_{o,s}$=2.E7
RR-1	Reisner2	ρ_g = 0.4, $N_{o,r}$ = 8.E6 $N_{o,g}$ = 4.E6, $N_{o,s}$=1.E8

Table 1: Numerical experiments tested in the study. The key parameters are the density of graupel ρ_g (g/cm^3), the intercept for rain $N_{o,r}$ (m^{-4}), the intercept of graupel $N_{o,g}$ (m^{-4}), and the intercept for snow $N_{o,s}$ (m^{-4}). STD means control or standard run. These changes are only made in MM5, not in the radiative transfer model. Detailed drop size distribution, fall speed relations, and all process parameterizations are described in Lin et al. (1983), Tao and Simpson (1993) and Reisner et al. (1998).

3. RESULTS

Validation of the MM5-simulated sea level pressure, temperature and water vapor fields at 36-km resolution using error measures (as described in section 2) suggested that simulations with varying explicit moisture schemes did not have appreciable differences (figures not shown). However, Reisner2 (STDR) tended to produce smaller rainy regions with larger stratiform but smaller convective surface rain rate than that of Tao scheme (STDG). Compared HAIL with STDG, the switch of graupel/hail regime did not make a significant difference. In addition, sensitivity tests demonstrated that Tao and Reisner2 were both sensitive to the slight change of microphysical parameters, but showed different reactions to the uncertainty of microphysical assumptions.

Results of the EOF analysis for vertical distributions indicated that the patterns of mean profiles and the first EOF component in all categories were close, except cloud ice. All experiments based on the Tao scheme (STDG, HAIL, G-GH and G-GL) produced much less cloud ice content than that in the STDR and RR-1. In addition, Reisner2 control run predicted more snow with a deeper layer, and the phenomenon would be amplified in the RR-1 run. Furthermore, the peak of mean graupel distribution from the Tao scheme was three times larger than the STDR and RR-1. The increase in $N_{o,g}$ (G-GH) levitated the peak level of the mean and first EOF snow profile associated with a smaller amount of snow content, while generating three times larger graupel density than the standard run. The increase of $N_{o,g}$ tended to produce more graupel at a higher vertical level, which may have been due to smaller graupel particles (corresponding to a larger intercept of drop size distribution) having less chance to convert to snow and accumulate at upper levels due to smaller terminal velocities.

The horizontal structures of calculated radiance from STDG and STDR were examined by comparing to the observed SSM/I brightness temperature (Figures not shown). Results revealed that these two microphysics schemes both produced separate rain bands and cold cores caused from high graupel content. The model-simulated background brightness temperatures at some places were too low compared to SSM/I, and they were a result of the less water vapor content generated from MM5. In addition, calculated brightness temperature fields indicated that the simulations were able to represent multi-channel relations of actual observations (Figure 1, for the STDG experiment). The shift of larger polarization at the range of lower values of T_{22V}-T_{19V} (shown in Figure 1(d)-(f)) may be because the wind roughness effects were not accounted for in the current version of the Monte-Carlo model. Figure 2 revealed that the increase in the intercept for graupel decreased significantly both vertical and horizontal brightness temperatures at 85 GHz (around 20 K) due to a higher graupel content based on EOF analysis, while the G-GL run showed an increase at TB_{85V} to a lesser of degree.

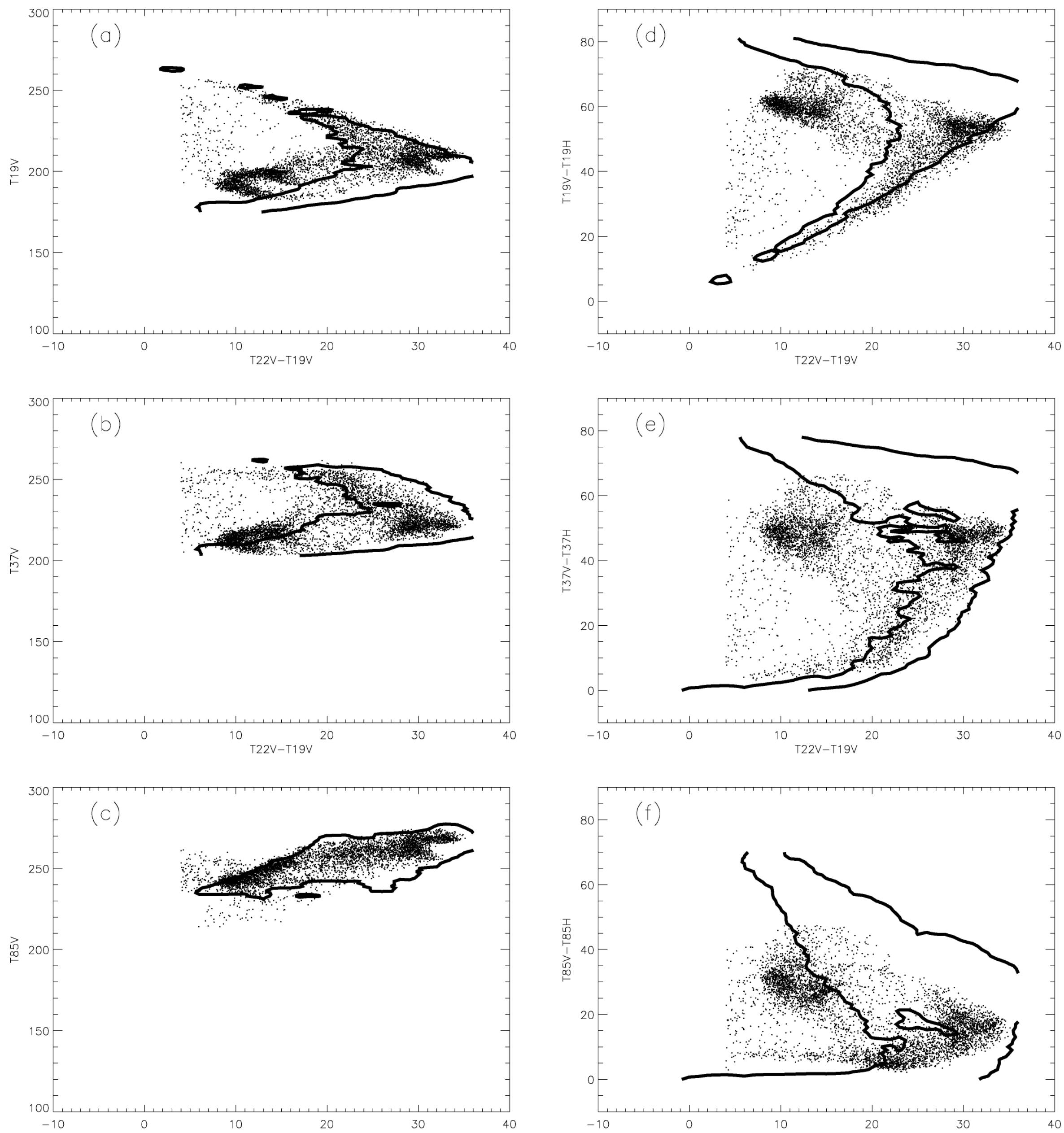

Figure 1: Multi-channel relations of SSM/I observations (dots) and simulated radiances (inside contour line). (a)-(c) depicts vertically polarized brightness temperature versus T22V–T19V. (d)-(f) depicts polarization differences versus T22V–T19V.

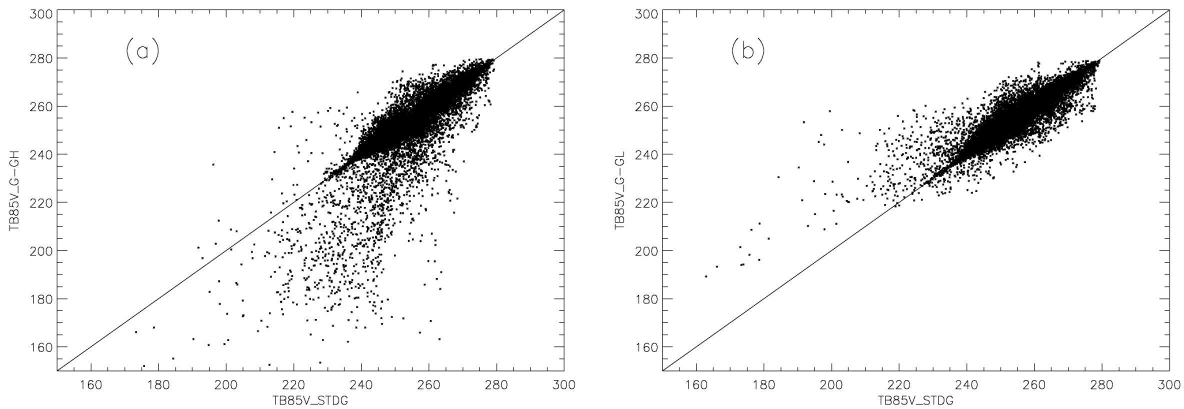

Figure 2: Inter-comparisons of T85V of STDG (control run) with (a) G-GH (larger $N_{0,g}$), and (b) G-GL (smaller $N_{0,g}$).

4. CONCLUSIONS

The study has shown that the model-simulated dynamic fields are not affected dramatically by various explicit moisture schemes and microphysical parameters in 48hr simulations for the oceanic midlatitude cyclone system. However, the variations of microphysics schemes have a significant impact on the hydrometeor fields and their corresponding simulated radiance. Results indicate that simulations could capture the main horizontal structure of the cyclone, and the multi-channel relations of simulated brightness temperatures are consistent with SSM/I data. In addition, the increase of the intercept for the graupel size distribution in the Tao scheme tends to produce larger graupel content at a higher vertical level, and then significantly decreases brightness temperatures at 85 GHz.

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