P7.7

AN OPERATIONAL CLOUD VERIFICATION SYSTEM AND ITS APPLICATION TO VALIDATE CLOUD SIMULATIONS IN OPERATIONAL MODELS

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1. INTRODUCTION

Clouds play an important role in regulating atmospheric dynamics and thermodynamics by redistributing momentum, thermal and moisture through mixing, latent heat release, and microphysical processes. However, conventional observational data for such important parameters are usually not available. An operational cloud verification system is being developed at the Joint Center for Satellite Data Assimilation, aiming towards validating the cloud simulations in the operational models and guiding further improvement of the prognostic cloud schemes. The system collects satellite-retrieved cloud products such as liquid water and ice paths (LWP/IWP), total precipitable water (TPW), surface rain rate, cloud top pressure and temperature, cloud amount and the others from Microwave Surface and Precipitation Products System (MSPPS), Advanced Television InfraRed Observation Satellite (TIROS) Operational Vertical Sounder (ATOVS), Clouds from Advanced Very High Resolution Radiometer (AVHRR) (CLAVR) from Polar Operational Environmental Satellites (POES) and Automated Surface Observing System (ASOS) from Geostationary Operational Environmental Satellites (GOES).

2. VALIDATION OF CLOUD SIMULATIONS WITH AMSU-RETRIEVED CLOUD PRODUCTS

The Cloud simulations in NCEP/Global Forecast System (GFS) are validated with the TPW, LWP, and IWP from the MSPPS. The root-mean-square (RMS) differences of the PW between the GFS and MSPPS over global oceanic tropics are 3 mm over clear-shy regions and 5 mm over cloudy regions respectively (Fig. 1). The RMS difference of the TPW over cloudy regions has the similar magnitude of the mass-integrated mixing ratios of cloud hydrometeors (Fig. 2), indicating that the GFS may have difficulty to accurately simulate the cloud properties. Thus, calculations of the moisture budgets in the GFS need to be improved.

Figure 2 shows the IWP versus LWP using the MSPPS and GFS data over global oceanic tropics on March 2003. The IWP simulated by the GFS has the similar magnitudes to that observed in the MSPPS data (2 mm) whereas the LWP in the MSPPS data (3 mm) is three times as large as the GFS simulated LWP (1 mm). Since the IWP and LWP shown in Fig. 2a include both non-precipitating ice and water and precipitating ice and water whereas those shown in Fig. 2b include non-precipitation ice and water (cloud ice and cloud water) only, the comparison may suggest that the GFS simulates the unrealistically large mixing ratio of ice clouds.

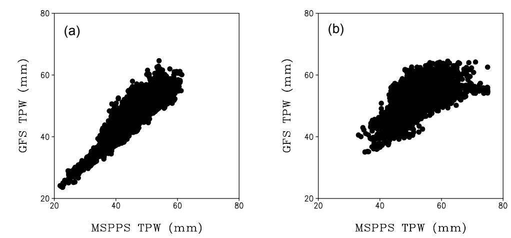

Fig. 1 MSPPS TPW (mm) versus GDAS TPW on March 2003 over clear-sky regions in (a) and cloudy regions in (b) in global oceanic tropics.

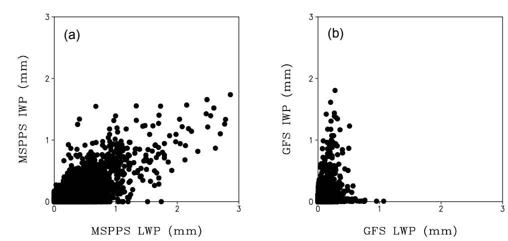

Fig. 2 (a) MSPPS IWP versus LWP and (b) GFS IWP (cloud ice) versus LWP (cloud water). Unit is in mm.

Li et al. (2004) carried out the sensitivity tests with a 2D cloud-resolving model to explain the large cloud ice anomaly. The experiment with the prognostic cloud scheme excluding the depositional growth of snow from cloud ice that is similar to the scheme used in the GFS shows that the mixing ratio of cloud ice grows rapidly, which leads to more than 20% increase of fractional cloud covers and unrealistic vertical stratification compared to the experiment with full cloud microphysical parameterization package, indicating that the exclusion of the depositional growth of snow from cloud ice in the simulation could

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cause anomalous growth of cloud ice. Thus, the depositional growth of snow from cloud ice should be included in the GDAS for better cloud ice simulations.

3. SIMPLIFICATION OF PROGNOSTIC CLOUD SCHEME WITH SATELLITE MEASUREMENTS

Improvement of numerical weather and climate predictions relies on accurate calculations of hydrometeor convergence and cloud-radiation interaction that require physical presence of cloud hydrometeors in so-called prognostic cloud scheme in the models. Since Sundqvist (1978) first developed a prognostic cloud-water scheme for general circulation models (GCMs), the prognostic cloud schemes have been applied to the GCM and regional models that led to improvement of numerical weather prediction in global and regional scales. Computations of prognostic cloud schemes are time consuming. To meet the needs for the operational forecasts, the prognostic cloud schemes have to be simplified. Zhao and Carr (1997) developed a prognostic cloud scheme in which only non-precipitating hydrometeors are physically present in the models and the 18 cloud microphysical terms are included compared to 29 cloud microphysical terms included in the cloud resolving model (Tao and Simpson 1993). The prognostic cloud scheme has been used in the NCEP/GFS. Li et al. (2004) showed that the GDAS simulated mixing ratio of cloud ice is much larger than the satellite observations. They carried out a series of sensitivity experiments with a 2D cloud-resolving model and found that unrealistic growth of cloud ice results from the exclusion of the depositional growth of snow from cloud ice that is the important sink for cloud ice. Li et al. (2002) analyzed the cloud microphysical processes in the cloud resolving simulation in the tropical deep convective regime, and found that 12 terms out of 29 cloud microphysical processes do not have significant impacts on thermodynamic and cloud simulations and can be excluded in the simulations. Combined with Li et al. (2002, 2004), prognostic cloud scheme can be simplified by

$$S_{q_c} = -P_{RAUT} - P_{RACW} + P_{CND}, \quad (1a)$$

$$S_{q_r} = P_{RAUT} + P_{RACW} - P_{REVP} + P_{SMLT}(T > T_o) + P_{GMLT}(T > T_o), \quad (1b)$$

$$S_{q_i} = -P_{SAUT}(T < T_o) - P_{SACI}(T < T_o) - P_{SFI}(T < T_o) + P_{DEP}, \quad (1c)$$

$$S_{q_s} = P_{SAUT}(T < T_o) + P_{SACI}(T < T_o) + P_{SFI}(T < T_o) - P_{GACS} - P_{SMLT}(T > T_o) - (1-\delta_4)P_{WACS}(T < T_o), \quad (1d)$$

$$S_{q_g} = P_{GACS} + (1-\delta_4)P_{WACS}(T < T_o) - P_{GMLT}(T > T_o) - P_{MLTG}(T > T_o). \quad (1e)$$

Here q_c, q_r, q_i, q_s, q_g are the mixing ratios of cloud water (small cloud droplets), raindrops, cloud ice (small ice crystals), snow (density 0.1 g cm^{-3}), and graupel (density 0.4 g cm^{-3}), respectively. S is the source and sink of cloud hydrometeors. P_{RAUT}, P_{RACW}, P_{SMLT}, and P_{GMLT} are growth rates of rain by the autoconversion and collection of cloud water, the melting of snow and graupel respectively. P_{REVP} and P_{MLTG} are growth rates of vapor by the evaporation of rain and liquid from graupel surface respectively. P_{SAUT}, P_{SACI}, and P_{SFI} are growth rates of snow by the conversion, collection, and deposition of cloud ice respectively. P_{GACS} and P_{WACS} are growth rates of graupel by the accretion and riming of snow respectively. P_{CND} is growth rate of cloud water by the condensation of supersaturated vapor. P_{DEP} is growth rate of cloud ice by the deposition of supersaturated vapor. Other variables and parameters can be referred in Li et al. (1999, 2002).

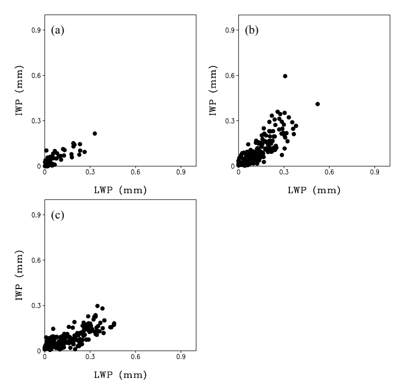

Fig. 3 (a) MSPPS IWP versus LWP (mm), (b) C-simulated IWP versus LWP, and (c) C1-simulated IWP versus LWP.

The experiments with the full set of cloud microphysical equations (in C) and with the simplified set of cloud equations (in C1) are carried out and are evaluated with the MSPPS IWP and LWP to examine the simplification of cloud scheme. Note that roughly 6-hourly data from three satellites (NOAA-15, 16, 17) are used in the MSPPS data whereas hourly data are analyzed in C and C1. The IWP (0.2 mm) is generally smaller than the LWP (0.3 mm) in the MSPPS data (Fig. 3a) whereas the IWP and LWP in C (Fig 3b) have the same values, which are up to 0.4 mm. Thus, the magnitudes of IWP and LWP simulated in C are 50% and 25% larger than those observed in the MSPPS data respectively, indicating that the full set of cloud microphysical equations produces unrealistically large cloud condensates. The IWP in C1 (0.3 mm Fig. 3c) becomes smaller than in C (0.4 mm Fig. 3b) so that the IWP is smaller than the LWP in C1 and the ratio of the IWP to LWP in C is similar to that observed in the MSPPS data (Fig. 3a). This comparison studies show that the simplified prognostic cloud scheme produces better cloud simulations than the original one.

4. CONSISTENCY CHECK FOR SATELLITE-RETRIEVED CLOUD PRODUCTS

Consistence Checks are carried out for same meteorological parameters retrieved from different satellite data as an important part of the system buildup efforts. The cloud top pressures and temperatures retrieved from the POES/ATOVS and GOES/ASOS over the Pacific Tropics show similar horizontal cloud distributions (not shown) with the high correlation coefficients of 0.8. However, the RMS differences are about 175 mb for the pressure and 15 K for the temperatures (Fig. 4). Such significant differences suggest that a caution should be exercised when the cloud products are chosen for the validation purposes.

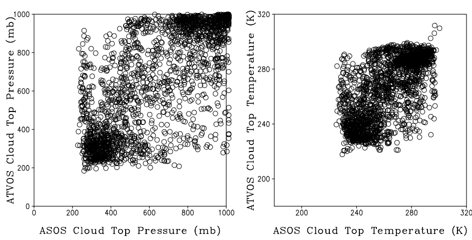

Fig. 4 ATOVS cloud-top pressure versus ASOS cloud-top pressure (left panel), and ATOVS cloud-top temperature versus ASOS cloud-top temperature (right panel).

5. SUMMARY

An operational cloud verification system is being developed at the Joint Center for Satellite Data Assimilation. The system collects satellite-retrieved cloud products, which are not available in the conventional weather data sets. This study demonstrates that the data collected in the system are very helpful for assessment of cloud simulations in the operational numerical models and can be served as the references for improvement and simplification of prognostic cloud schemes used in the operational numerical models as well as the research models such as the cloud-resolving model.

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