**P8.15 PHYSICAL RETRIEVALS OF TEMPERATURE, WATER VAPOR and CLOUD PROFILES FROM AMSU**

Quanhua Liu[1] and Fuzhong Weng[2]
[1]QSS Group Inc, Camp Springs, Maryland
[2]NOAA/NESDIS/Office of Research and Applications, Camp Springs, Maryland

## 1. INTRODUCTION

Accurate measurements of cloud liquid and ice water contents from satellites are important for improving our understanding on the interaction between clouds and radiation. It has been known that the net radiative forcing due to clouds is highly dependent on cloud microphysical parameters (Poetzsch-Heffer et al., 1995) and cloud types. With satellite microwave measurements, we are routinely producing retrievals of various cloud hydrological parameters for weather and climate studies. Over oceans, cloud liquid water path were derived from the special sensor microwave imagers (SSM/I) (Weng and Grody, 1994). With the Advanced Microwave Sounding Unit (AMSU) on board NOAA satellites, the cloud ice water path is also derived (Weng et al., 2003). In addition, total precipitable water, cloud liquid water path, rain rate, snow cover, sea ice concentration, land surface emissivity and temperature are also developed (Ferraro et al., 2000; Weng et al., 2003).

Retrievals of atmospheric parameters and hydrometeors from satellite microwave sensors under severe weather conditions are challenging problems because brightness temperatures are non-linearly related to the scattering from clouds and precipitation. In this study, we test uses of a scattering radiative transfer model in physical retrievals and understand how the model will improve the quality of temperature, water vapor, and cloud profiles.

## 2. RETRIEVAL ALGORITHM

The key components of our microwave retrieval algorithm include a forward model for calculating radiance and its jacobian and a minimization process for the cost function. Assuming that the errors in the observations and in the priori information are neither biased nor correlated, and have Gaussian distributions, the best estimate of **x** will minimize the cost-function

$$J=\frac{1}{2}\left(\mathbf{x}-\mathbf{x}^{b}\right)^{T}\mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}^{b}\right)+\frac{1}{2}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^{o}\right]^{T}(\mathbf{F}+\mathbf{E})^{-1}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^{0}\right], \tag{1}$$

where **B** is the error covariance matrix associated with the background state variable $\mathbf{x^b}$ , **F** the error in the forward calculation and **E** the sensor noise assuming that bias in measurements is calibrated. **I** is the simulated radiance vector for a set of channels (or frequencies) at the state variable **x**, and $\mathbf{I^0}$ is the observed radiance vector. The error covariance matrices are often treated as diagonal matrices. Thus, the minimum of the cost function is found from an iterative process that computes a descent direction at the state **x**.

The radiative transfer model is an improved two-stream model (Liu and Weng, 2002). The radiance at the top of the atmosphere is contributed from path radiance at the sensor looking direction and the multiple scattering from the two-stream model. By neglecting azimuth dependence, radiative transfer for a plane-parallel atmosphere can be expressed as (Liou, 1980)

$$-\mu\frac{dI(\tau,\mu)}{d\tau}=I(\tau,\mu)-\frac{\varpi}{2}\int_{-1}^{1}P(\mu,\mu^{'})I(\tau,\mu^{'})d\mu^{'}-(1-\varpi)B(T), \tag{2}$$

where $I$ the intensity or radiance, $B(T)$ the Planck function of a temperature, $P$ the azimuth-averaged phase function. $\tau$ is the cumulative optical thickness increasing from 0 at the top of the atmosphere to $\tau_s$ at the surface.

The solution of the radiative transfer equation in a layer with an optical depth $\tau_b$ at the layer bottom can be written as

$$I(\tau,\mu)=I(\tau_b,\mu)e^{-\frac{\tau_b-\tau}{\mu}}+\int_{\tau}^{\tau_b}(1-\varpi)B(T)e^{-\frac{\tau_b-\tau^{'}}{\mu}}\frac{d\tau^{'}}{\mu}, \tag{3}$$
$$+\int_{\tau}^{\tau_b}[\int_{-1}^{1}d\mu^{'}\frac{\varpi}{2}P(\tau^{'},\mu,\mu^{'})I(\tau,\mu^{'})e^{-\frac{\tau_b-\tau}{\mu}}]\frac{d\tau^{'}}{\mu}$$

The first term on the right side of Eq. (3) is the transmitted radiance from the layer bottom. The second term the emission part of the layer. The radiance from the first two terms on the right side is called path radiance since they act the same as in the emission model. The third term on the right side is the scattering part and it can be evaluated using the solution from a discrete ordinate model. The radiances calculated from Eq. (3) become more accurate with increasing discrete streams in the scattering model. The accuracy of the radiative transfer model is about 1.0 K under cloudy conditions. In the model, gaseous absorption coefficients are calculated from the optical transmittance model, OPTRAN (McMillin, 1995). Optical properties of clouds are taken from a simple look-up table.

Another important component is the land surface and snow/ice emission models (Weng et al., 2001). With better emissivity models and radiative transfer models, we can retrieve the atmospheric and surface parameters from the satellite microwave measurements over land and oceans.

## 3. PRELIMINARY RESULTS

The retrieval algorithm is first tested using simulated AMSU–A and AMSU-B data. The AMSU data is composed of microwave measurements at window channels of 23.8, 31.4, 89, and 150 GHz and sounding channels near 60 GHz and 183 GHz. Using the profiles over oceans and the profiles over land from Global Data Assimilation System (GDAS), we simulate AMSU brightness temperatures at the top of the atmosphere.

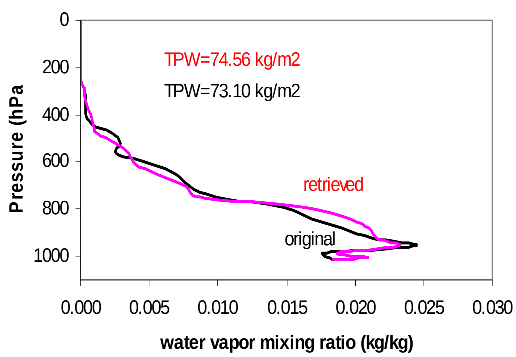


**Figure 1**. Retrieved and actual water vapor profiles over oceans.

Figures 1 and 2 display the errors for retrieved water vapor profiles over oceans and land. In general, the retrieved water vapor profiles agree with true profiles. The water vapor derived in the profile peaks where clouds occur. Note that total precipitable water is more accurately derived over oceans than that over land since microwave window channels measured over oceans are more sensitive to the lower tropospheric water over oceans.

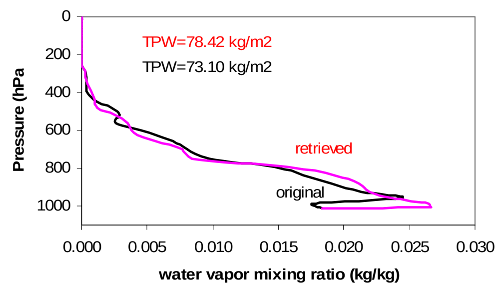


**Figure 2.** Retrieved and original water vapor profiles over land.

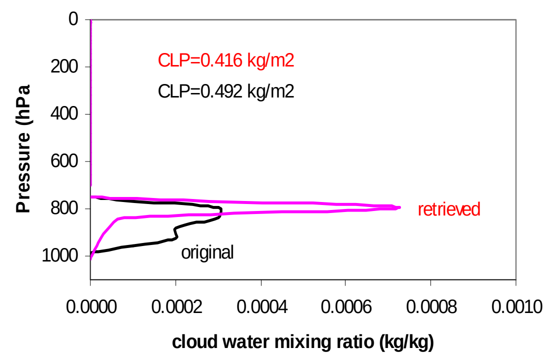


**Figure 3.** Retrieved and original cloud liquid water profiles over oceans.

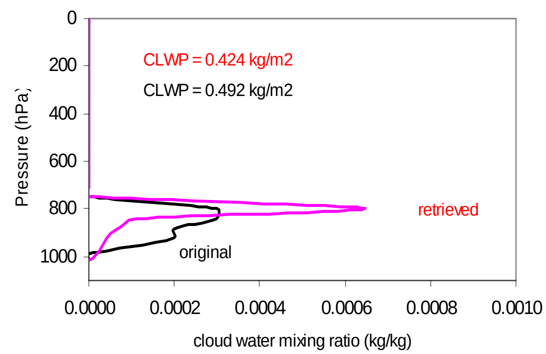


**Figure 4**. Retrieved and original cloud liquid water profiles over land.

Figures 3 and 4 compare cloud liquid water path derived over oceans and land. While cloud liquid water paths agree, the vertical distributions are different. Retrieved cloud water concentrates near the cloud top due to the poor vertical cloud information from the AMSU sounding channels.

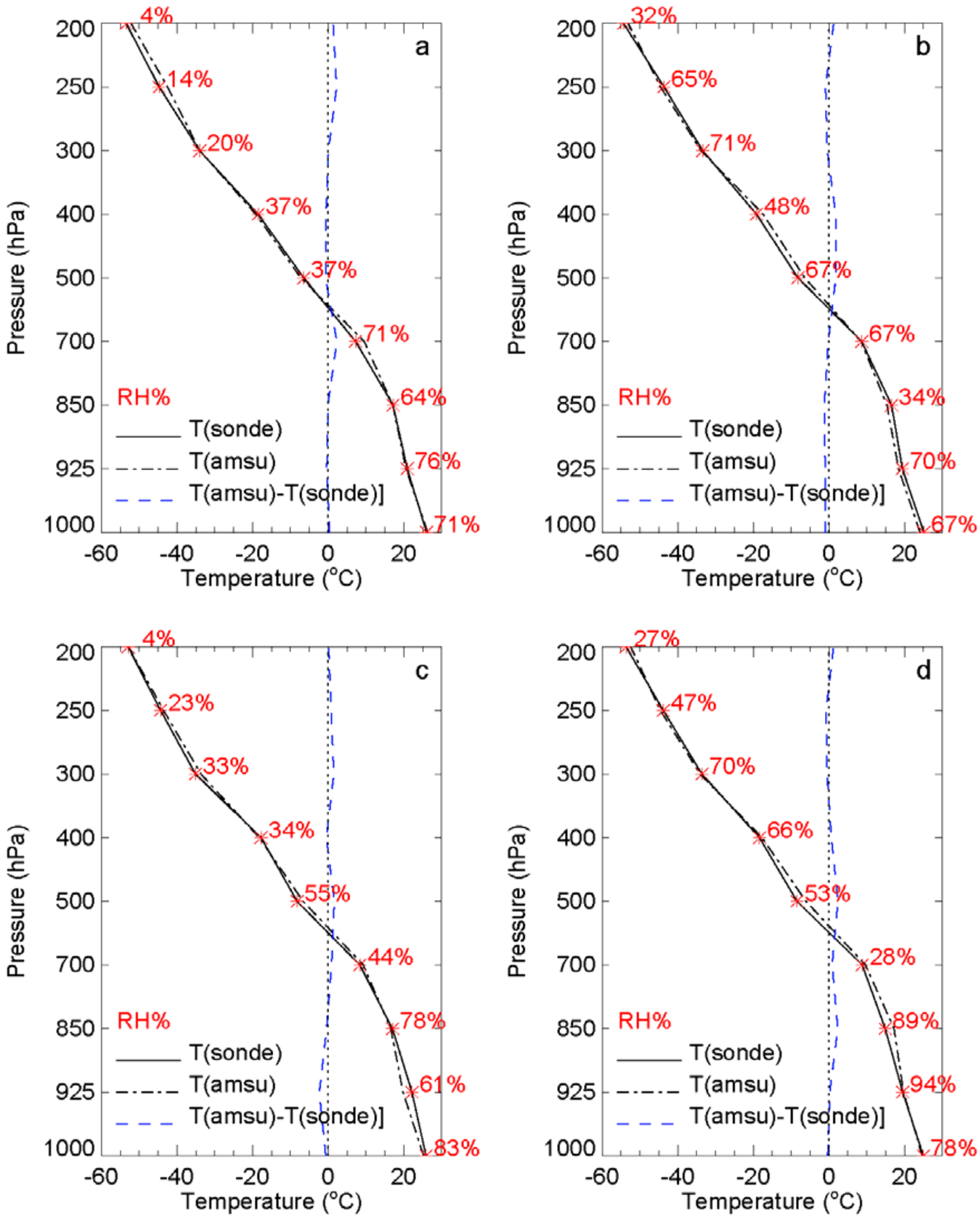


**Figure 5**. Vertical distributions of atmospheric temperatures from dropsondes (solid line) and the retrievals from AMSU measurements (dash-dotted line). The dashed lines are the difference of the atmospheric temperature between dropsondes and retrievals. The values in percentage represent measured relative humidity.

More microwave sounding measurements are needed to gain better vertical structure of clouds.

The algorithm is also applied for retrievals of atmospheric profiles under Hurricane Isabel. Isabel is considered to be one of the most significant tropical cyclones affecting eastern part of the United States and was a long-lived hurricane that reached Category 5 on 12th September 2003. To validate the temperature retrievals, we use collocated atmospheric temperature profiles from dropsondes and retrieved temperature profiles from AMSU for Hurricane Isabel. The comparison is carried out for Hurricane Isabel on 15th September, 2003. Figure 5 shows the dropsonde measurements and retrievals under various atmospheric conditions. The differences between satellite retrievals and dropsondes measurements are typically less than 2 K. Even under heavy precipitation conditions (Fig. 5(d)), retrievals are robust and achieve a good accuracy.

**Acknowledgments:** The views expressed in this publication are those of the authors and do not necessarily represent those of NOAA.

**References**

Ferraro, R.R, F. Weng, N.C. Grody and L. Zhao, Precipitation characteristics over land from the NOAA-15 AMSU Sensor. Geophysical Research Letters, **27**, pp. 2669-2672, 2000.

Liou, K. N., *An introduction to atmospheric radiation*, Academic Press, New York, 1980.

Liu, Q., and F. Weng, 2002: A Microwave Polarimetric Two-Stream Radiative Transfer Model. *J. Atmos. Sci.*, **59**, 2396-2402.

McMillin, L., L. J. Crone, M. D. Goldberg, and T. J. Kleespies, “Atmospheric transmittance of an absorbing gas. 4. OPTRAN: a computationally fast and accurate transmittance model for absorbing gases with fixed and variable mixing ratios at variable viewing angles,” *Appl. Opt.*, **34**, pp. 6269-6274, 1995.

Poetzsch-Heffter, C., Q. Liu, E. Ruprecht, and C. Simmer, Effect of cloud types on the earth radiation budget calculated with the ISCCP C1 Dataset: Methodology and Initial Results. J. Climate, **8**, pp. 829-843, 1995

Weng, F., L. Zhao, R. Ferraro, G. Poe, X. Li, and N. Grody, “Advanced Microwave Sounding Unit Cloud and Precipitation Algorithms,” *Radio Sci.*, **38**, pp. 8086-8096, 2003.

Weng, F., B. Yan, and N. C. Grody, “A microwave land emissivity model,” *J. Geophys. Res.*, **106**, pp. 20115 – 20123, 2001.

Weng, F., N. C. Grody, 1994: Retrieval of cloud liquid water using the Special Sensor Microwave/Imager. *J. Geophys. Res.*, **99**, 25535-25551.