Expected Performance Evaluation of ATOVS Sounding Products
- A Preliminary study of ATPP Retrieval Algorithm

H.-L. Huang, W. L. Smith, M. S. Whipple, Bormin Huang, S. J. Nieman, and H. M. Woolf

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison, Wisconsin, USA

ABSTRACT

The ATOVS (AMSU/HIRS) system is expected to provide improved sounding accuracy and vertical resolution, as well as lead to the development of new sounding products. A simulated orbital pass consisting of HIRS infrared radiances, AMSU-A (15 channels, 50 km IFOV at nadir) and AMSU-B or MHS (5 channels, 17 km IFOV at nadir) microwave thermal and moisture brightness temperature measurements are used to demonstrate the expected performance of the ATOVS. The analytical procedures used in this study and to be used in the Advanced TOVS Processing Package (ATPP) are described in detail. The expected improvements due to ATOVS are also compared to the capabilities of contemporary and proposed advanced infrared and microwave sounding systems.

1. INTRODUCTION

The early 1998 launch of the NOAA-K polar orbiting satellite, which will carry the Advanced TIROS Operational Vertical Sounder (ATOVS) , will initiate a new era of much improved sounding capabilities and microwave measurements. The increase in the number of measurement channels from the current 4 (MSU) to 20 (AMSU) channels is expected to lead to more accurate sounding products. As a consequence of these upcoming changes, CIMSS is developing the ATPP (Advanced TOVS Processing Package) to process the forthcoming ATOVS data (Nieman et al., 1997). The following section describes the generation of the simulated ATOVS data used in this work. Next, the analytical procedures used to perform the retrieval analysis are presented. We conclude with sounding capability comparisons for TOVS, ATOVS and proposed advanced high spectral resolution infrared and AMSU sounding systems.

2. SIMULATION OF ATOVS

The microwave component of ATOVS data consists of 15 microwave oxygen AMSU-A channels and 5 microwave water vapor AMSU-B channels. The transmittance model used for these channels was developed by Rosenkranz (1995); in this model oxygen, water vapor, and cloud liquid water are the absorbing gases. Since only clear conditions are being considered, no liquid water absorption is included in the simulation of microwave measurements. Both non-unity and spectral variations of surface emissivity for land and sea surfaces are modeled. Expected AMSU noise is shown in Table 1. The odd numbered profiles in the TIGR data set are used to construct a dependent training data set consisting of 881 profiles of the 1761 profile data set. Linear regression is used to establish the relationship between the dependent profiles and their corresponding microwave and HIRS/2 brightness temperatures. The HIRS/2 forward model is the same as that used in ITPP with surface emissivity assumed to be unity. The 880 even numbered independent TIGR profiles are then used to simulate all 39 ATOVS channels for both land and sea surfaces and various configurations of microwave emissivity.

Table 1. Expected AMSU Noise Equivalent Brightness Temperature (NEdT)

AMSU	1	2	3	4	5	6	7	8	9	10
NEdT	0.3	0.3	0.4	0.25	0.25	0.25	0.25	0.25	0.25	0.4

AMSU	11	12	13	14	15	16	17	18	19	20
NEdT	0.4	0.6	0.8	1.2	0.5	0.5	0.5	0.5	0.5	0.5

An actual NOAA-12 orbit is also used to simulate an orbit of ATOVS measurements where profiles used in the AMSU-A and AMSU-B field of view are linearly interpolated from ITPP-5 (Smith et al., 1993) retrievals using TOVS data. The ITPP-5 retrievals used NCEP analyses of radiosonde observations as a background (i.e. first guess) field thereby providing an accurate set of soundings for each TOVS radiance measurement location. Cloud contamination of the HIRS and AMSU brightness temperature is assumed to be negligible. Figures 1 and 2 show the simulated brightness temperature from AMSU-A and AMSU-B for the March 22, 1996 NOAA-12 orbit.

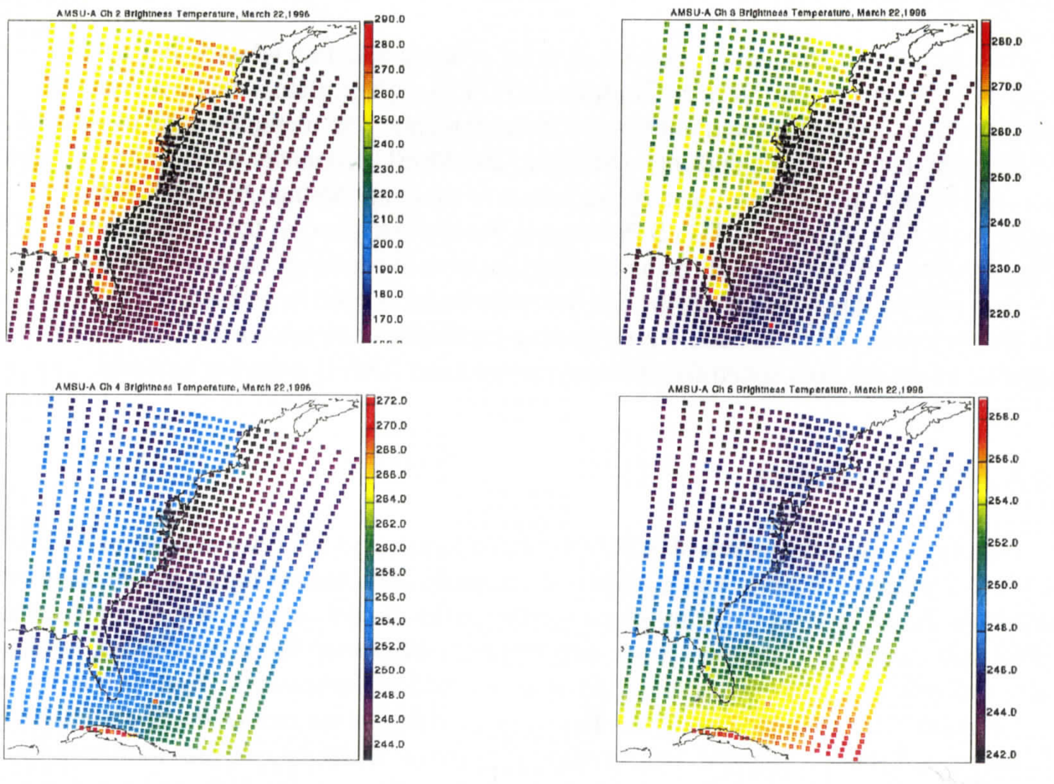


Figure 1, Simulated AMSU-A brightness temperature for the March 22,1996 NOAA-12 orbit.

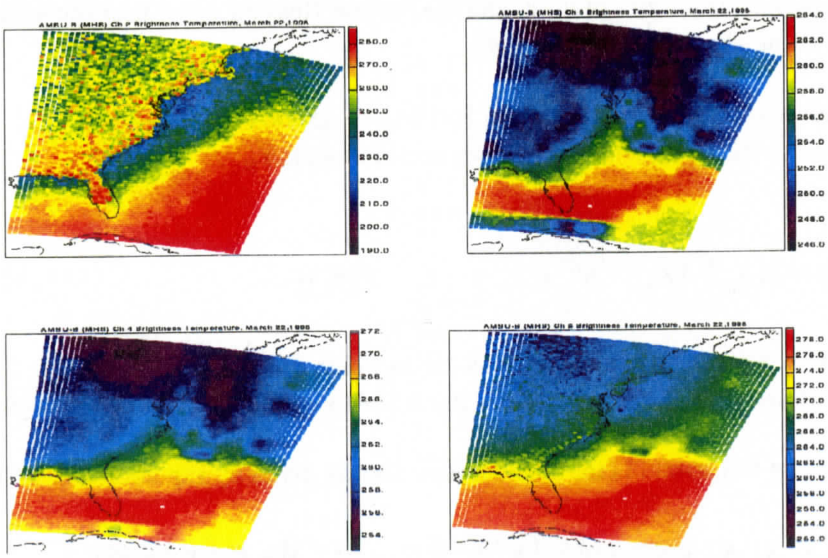


Figure 2. Same as Figure 1 except for AMSU-B.

3. ATOVS SIMULTANEOUS RETRIEVAL ALGORITHM

The CIMSS non-linear retrieval algorithm uses the simulated infrared and microwave brightness temperature together with a regression first-guess atmospheric state to simultaneously determine an optimal solution for surface temperature T_S, microwave emissivity ε, temperature $T(p)$ and water vapor $Q(p)$ profiles.

The clear radiative transfer equation written in a linearized form as a perturbation from a first guess is

$$\delta T_B = K_S \delta T_S + K_\varepsilon \delta\varepsilon + \int_0^{P_S} K_T \delta T(p) dp + \int_0^{P_S} K_Q \delta Q(p) dp \qquad (1)$$

where δ denotes a departure from the first guess. T_B is the HIRS/AMSU brightness temperature; δT_S, $\delta\varepsilon$, $\delta T(p)$, and $\delta Q(p)$ are the unknowns of surface skin temperature, microwave emissivity, temperature, and water vapor profiles respectively. K is the Jacobian , the derivative of channel brightness temperature with respect to variable (i.e. T_S; ε; T(p) or Q(p)).

A hybrid Newtonian iteration scheme initially developed by Levenberg (1944) and Marquardt (1963) which incorporates the inverse Hessian and steepest descent methods is used to obtain the solution of Equation (1). The Levenberg-Marquardt approach is formulated (Huang et al., 1997) as

$$Y_{n+1} = Y_n - \left[\nabla^2 \chi_n^2 + \gamma I\right]^{-1} \nabla \chi_n^2 \qquad (2)$$

where Y is the solution vector of δT_S, $\delta\varepsilon$, $\delta T(p)$ and $\delta Q(p)$; γ is a parameter used to control the rate of convergence (a key element of this unique approach) χ^2 is a cost function to be minimized; and n and $n+1$ are the previous and current iterative state, respectively. Mathematically, when $\gamma \rightarrow 0$, the solution tends to the inverse Hessian, and if $\gamma \to \infty$, it tends to be the solution of steepest descent with a small step size. For each iteration a value of γ is chosen so that the method of steepest descent is used when far from the solution, and the inverse Hessian when near the solution. This is accomplished by using the following criterion:

If χ^2 increases (divergence), increase γ and do not update Y_n.
If χ^2 decreases (convergence), decrease γ and do update Y_n.

χ^2 is defined as

$$\chi^2 = \left(T_B - F(Y_n)\right)^T \left(K_n S^{-1} K_n^T + S_b^{-1}\right)^{-1} \left(T_B - F(Y_n)\right) \quad (3)$$

where F is the ATOVS forward model, and K is the Jacobian of T_S, ε, $T(p)$ and $Q(p)$. S is a diagonal matrix representing the covariance of the ATOVS data noise. S_b is the first-guess error covariance.

Transforming Equation (1) into the iterative format given by Equation (2), we have

$$\delta Y_{n+1} = \left(K_n^T S^{-1} K_n + S_b^{-1} + \gamma I\right)^{-1} \left(K_n^T S^{-1}\left(\left[T_B - F(Y_n)\right] + K_n \delta Y_n\right) + \gamma \delta Y_n\right) \quad (4)$$

4. RETRIEVAL RESULTS

In order to best demonstrate the improvements in sounding performance that occur when going from the 4-channel MSU to the 20-channel AMSU, retrieval analyses are presented for these combinations of measurements, namely AMSU only, ATOVS, and AMSU combined with a future advanced infrared sounder which for this case is a Fourier Transform Spectrometer (FTS) similar to HIS (Smith et al., 1995).

Figures 3 and 4 demonstrate that the retrievals can fit the simulated brightness temperature measurements to the level of measurement noise (Table 1) for land and sea conditions when the microwave emissivity is a function of wavelength and is retrieved. A similar fit to the measurements is obtained for the case when the surface microwave emissivity is known. This goodness of fit to the measurements for both cases demonstrates that the non-unity surface microwave emissivity effects can be treated properly.

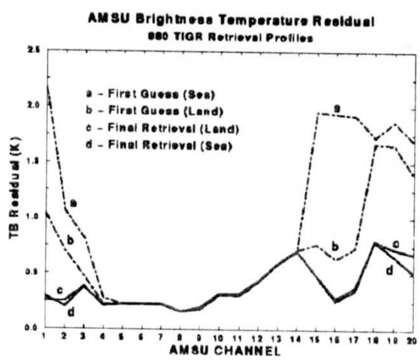


Figure 3, Brightness temperature RMS Error of retrievals for land and sea conditions.

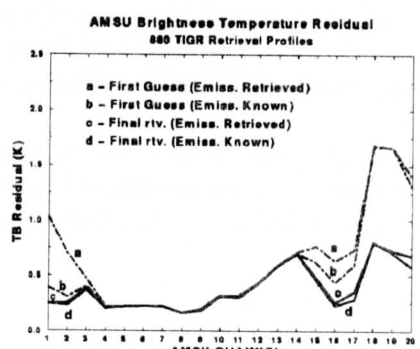


Figure 4, Brightness temperature RMS Error of retrievals for known and unknown emissivity.

The retrieval accuracy for the 880 independent TIGR profiles is shown in Figures 5 and 6. Root mean square error profiles of temperature and water vapor (relative humidity) for ATOVS and AMSU serve to demonstrate the ATOVS sounding capabilities. Figure 7 displays the enhanced water vapor sounding capabilities for low microwave emissivity sea surface conditions. The ability to obtain accurate water vapor information over remote oceanic areas is one of the key assets of NOAA-K. Figure 8 displays the root mean square error of temperature profiles using AMSU only, ATOVS, and HIS-like infrared spectra with AMSU. It is obvious that further improvements in temperature sensing can be made by making high spectral resolution infrared measurements available for polar orbiting systems.

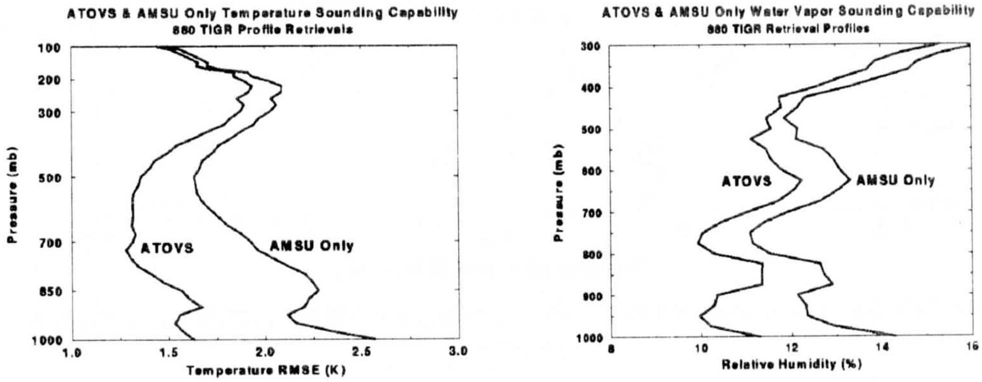


Figure 5 and 6 display root mean square error profiles for temperature and relative humidity, respectively.

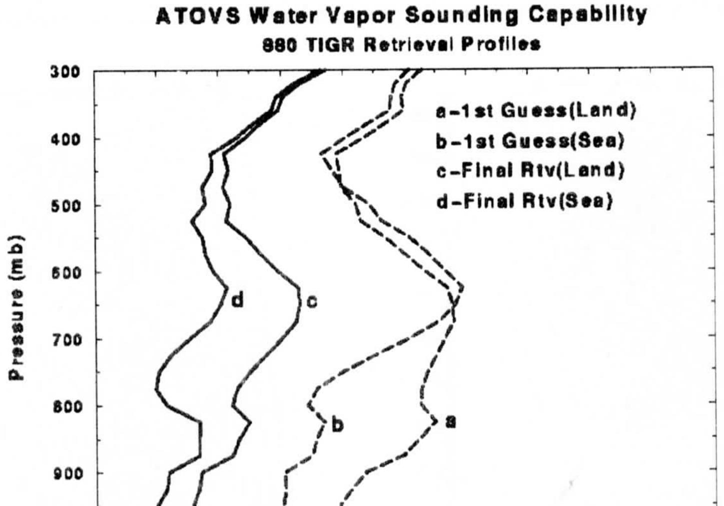


Figure 7, Water vapor retrieval performance for land and sea surface conditions.

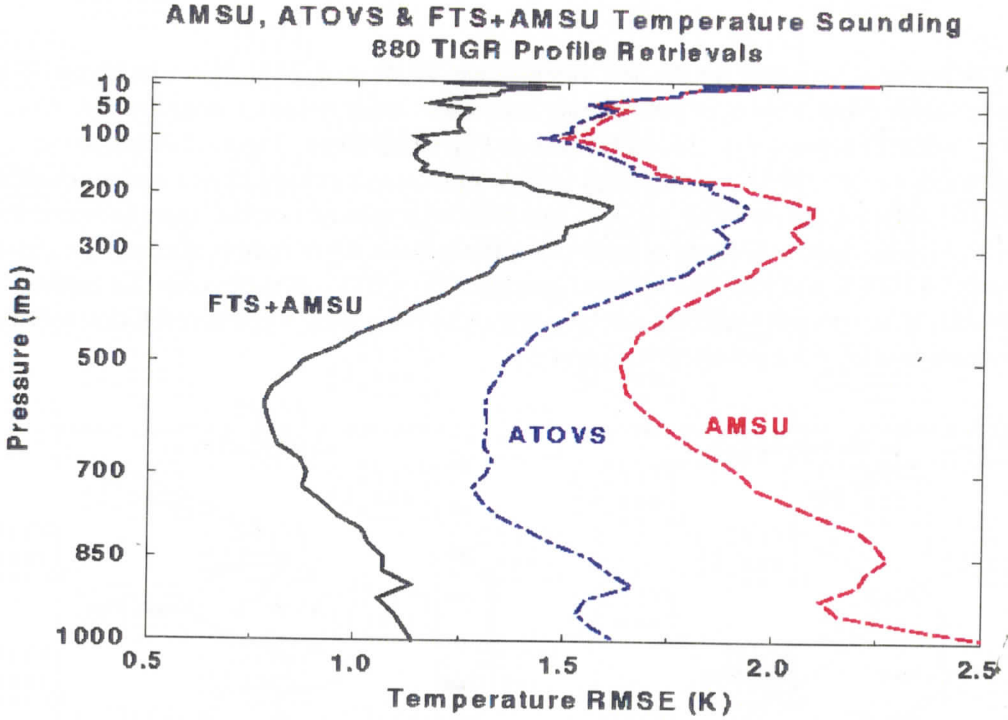


Figure 8, Comparisons of temperature retrieval accuracy for AMSU, ATOVS and advanced IR sounder.

Figures 9 and 10 provide examples of an orbital path retrieval performance based on the simulated AMSU brightness temperature observations for the case showing in Figures 1 and 2. The 500 mb temperature and water vapor are displayed on the left hand side and the retrieval error in each AMSU field of view is displayed on the right hand side of this figure, respectively.

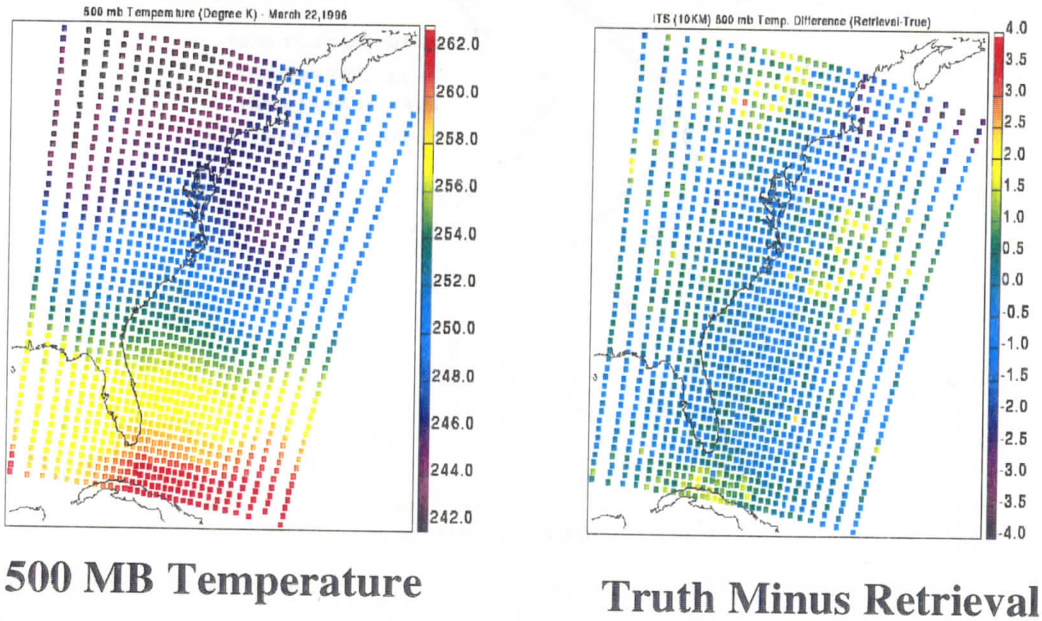
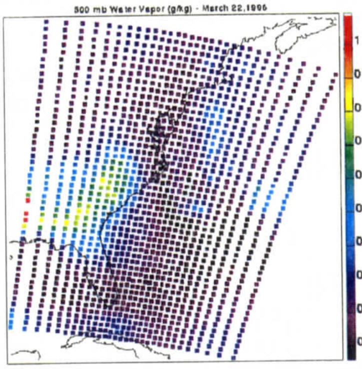
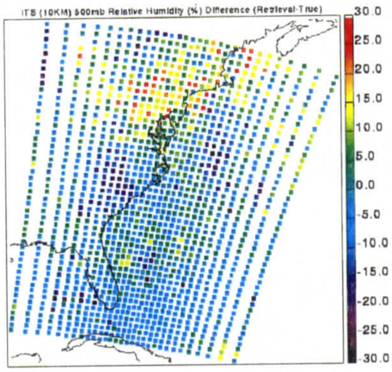


Figure 9, 500 mb temperature field and the difference between truth and retrieved temperature.





500 MB Water Vapor g/kg — **Truth Minus Retrieval R.H. %**

Figure 10, same as Figure 9 except for water vapor (mixing ratio and relative humidity).

5. SUMMARY

A generalized sounding simulation and analysis system capable of providing infrared and microwave measurements and retrievals in a real orbital observing situation is developed. While in this paper the focus has been on the simulation and analysis of results of ATOVS under clear conditions, preparations for dealing with complicated cloudy scenes are now underway. Development of the Advanced TOVS Processing Package (ATPP) which incorporates this retrieval algorithm and the ATOVS and AVHRR Processing Package (AAPP) is progressing .

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