Retrieval of upper tropospheric humidity from AMSU data

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Abstract

Water vapor in the upper troposphere is one of the largest uncertainties in NWP and climate research. Advanced microwave sounding unit (AMSU) on-board NOAA satellite series is capable of providing water vapor data even in the presence of non-precipitating clouds. The study presents the retrieval of three quantities, namely, water vapor, temperature, and surface emissivity from AMSU data based on optimal estimation method. The covariance matrices of temperature and water vapor are calculated using radiosonde observations. AMSU-A channels are used for temperature retrieval and AMSU-B channels are used for water vapor retrieval. The retrieval of water vapor and temperature is validated using high resolution radiosonde data. One of the challenges encountered while the retrieval was the uncertainty in determining microwave surface emissivity. For surface emissivity retrieval, three window channels at 23.8 GHz and 31.4 GHz are used. The retrieved emissivity values show diurnal and seasonal variations. The emissivity retrieval is validated in two ways. One way is to compare the retrieved values with results from other emissivity algorithm. Another way is to see whether simulated brightness temperature agree with the measured brightness temperature. The data from NOAA-15 and NOAA-16 are used in this study.

1. Introduction

The knowledge of spatial and temporal variability of water vapor in the atmosphere is important due to its "green house effect". Currently the understanding of the variability of water vapor is poor due to unavailability of data especially in the upper troposphere. Radiosonde data measurements alone cannot improve the knowledge as the global coverage of radiosondes is sparse. So the only source of global water vapor data is satellite measurements. Thermal infrared part of the radiation spectrum [HIRS, METEOSAT] is widely used for this purpose but this method will not work in cloudy conditions. Water vapor products derived infrared measurements do have a "dry bias". Microwave passive measurement is a better alternative as it can partially penetrate clouds unless the clouds are precipitable in nature. Advanced Microwave Sounding Unit (AMSU) is an instrument of this type [2].

AMSU is a 20 channel passive, cross track scanning, microwave instrument. Channels 1 - 3 and 15 - 17 are window channels, 4 - 14 are temperature sounding channels, and 18 - 20 are water vapor sounding channels. Channels 1 - 15 are on AMSU-A instrument and the rest in AMSU-B. The horizontal resolution is about 45 km for AMSU-A and 15 km for AMSU-B at nadir.

The article is organized as follows. The dataset description is given in section 2, forward model validation is given in section 3, the retrieval method is described in section 4, results are presented in section 5, and the concluding remarks are presented in section 6.

2. Dataset Description

The study described in this article involves two datasets - the AMSU data and the high resolution radiosonde data recorded at Lindenberg.

a. AMSU data

Level 1b data of AMSU is obtained from satellite active archive of NOAA. It has been converted to level 1c by AVHRR and ATOVS processing package (AAPP) [6]. The brightness temperature, latitude, longitude, time, and field of view (FOV, this varies from 0 - 14 for AMSU-A and 0 - 44 for AMSU-B) of each pixel are the outputs of AAPP. These information was used for collocation with radiosonde launches.

b. Radiosonde data

Lindenberg (52.21^0N, 14.12^0E) is one of the reference stations of German Weather Service, DWD. There are four radiosonde launches per day starting around 22, 5, 11 and 16 hours. Every launch starts at an altitude of 112 meters above sea level and terminates approximately at a height of 30 kilometers. The measurements are taken every 10 seconds at every 60 to 80 meters of altitude. Measurements were conducted using the RS80-A radiosonde. The absolute accuracy of the measurements are given in Table 1 [3].

	Vert. range	Vert. resolution	Abs. accuracy
Temperature	0.1–35 [km]	$\leq$ 50 [m]	$\pm$0.2 [K]
Pressure	0–35 [km]	$\leq$ 50 [m]	$\pm$0.5 [hPa]
Relative Humidity	0 to $\approx$15 [km]	$\leq$ 50 [m]	$\pm$2 [%]

Table 1: The absolute accuracy of radiosonde measurements. Here, vertical range, vertical resolution, and absolute accuracy of temperature, pressure, and relative humidity are given.

3. Forward model validation

The **A**tmospheric **R**adiative **T**ransfer **S**ystem (**ARTS**) is a new radiative transfer model [1] which can handle any millimeter or sub-millimeter instrument in all viewing geometries; down, up, and limb. ARTS is now a one dimensional model and is limited to cases where scattering can be neglected. However, work is in progress to implement scattering, so that ARTS will be able to simulate radiance for a cloudy atmosphere. The main features of the program are modularity, extendibility, and generality. Besides producing spectra ARTS calculates weighting functions for temperature, trace gas concentrations, continuum absorption, ground emission, and pointing off-sets. ARTS is publicly available on the website: http://www.sat.uni-bremen.de/arts/.

The optimal estimation method [9] demands very accurate forward model to calculate brightness temperature and Jacobian. The more accurate the forward model the more reliable the retrieval. This section explains the exercises which have been carried out to test the accuracy of the forward model. ARTS has been validated for simulating AMSU instrument in two different ways - model intercomparison and model-data comparison.

a. model intercomparison

The model has been validated as part of the ITWG model intercomparison [5]. The comparison of brightness temperatures shows good agreement [10].

It is also very essential to make sure that the forward model is able to calculate the Jacobian accurately. ARTS calculates Jacobians analytically for species concentrations and semi-analytically for temperature. Water vapor and temperature Jacobians for AMSU channels calculated by ARTS is shown in figures 1 and 2. The unit of the temperature Jacobian is K/K, so the peak value of 0.05 means that the simulated brightness temperature will change by 0.05 K if the atmospheric temperature is changed by 1 K at one grid point. The water vapor Jacobian is in fractional units (K/1), so the curves correspond to the change in brightness temperature for a doubling of the mixing ratio at one grid point.

The Jacobians were also compared with those calculated by other models in the ITWG comparison and fit was found to be excellent as per ITWG criteria.

b. model - data comparison

The comparison between satellite measured brightness temperature and the model simulated brightness temperature can reveal some possible bias in the forward model [4]. High resolution radiosonde data is used for ARTS simulation. This data was provided by Lindenberg reference station of DWD. AMSU pixels close to the radiosonde site was taken with the condition that the distance between the radiosonde site and the center of the pixel should be less than 35 km for AMSU-A and 15 km for AMSU-B and the satellite pass should be with in 90 minutes of the radiosonde launch. Each simulation has been done for the same looking angle as the AMSU pixel to account for the limb effect. In order to make sure that the satellite and the radiosonde measured the same atmosphere, a filter was developed in such a way that the standard deviation of brightness temperature of all the pixels in a circle of radius 50 km around the radiosonde site should be less than a threshold value. The threshold was 1 K for AMSU-A and 1.4 K for AMSU-B and this filter was named as 'Inhomogeneity Filter'. Although, most of the cloudy pixels were filtered out by the inhomogeneity filter, a rough filter against cloud was also used as the ARTS version used in this study cannot handle cloud effects. The radiosonde launches where the relative humidity was more than 90 % above an altitude of 2 km were discarded. The result of this comparison is shown in the figure 3.

The remaining pixels after applying all the filters were separated corresponding to morning and evening satellite passes and plotted in different colors. The distinction of pass time is evident for window channels as surface has strong diurnal variations which is not included in the simulations. So High RMS in the window channels can be reduced by adjusting surface emissivity and surface temperature.

The RMS is very close to the noise equivalent temperature for the sounding channels as seen in figures 4 and 5. Stratospheric channels were excluded from the comparison as Zeeman's splitting is not included in the forward model. The results for AMSU-B channels are explained in [8].

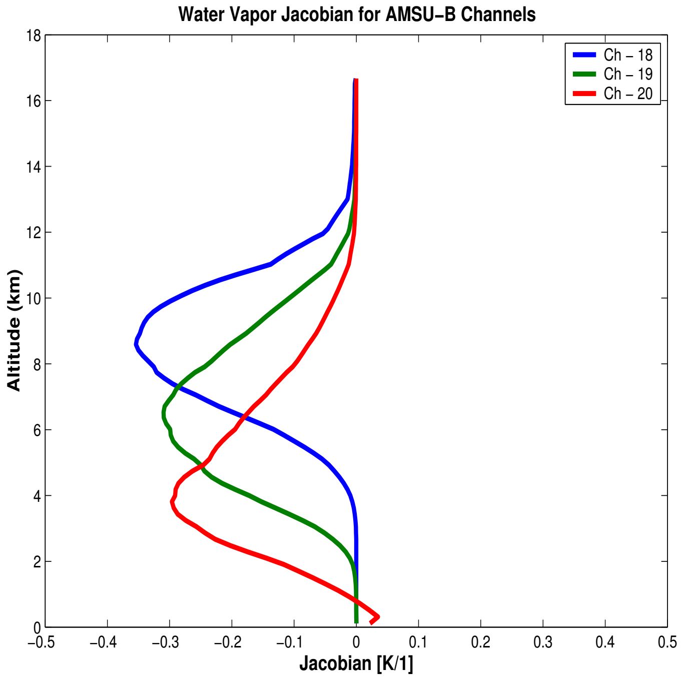

Figure 1: Water vapor Jacobian for three AMSU-B water vapor channels for the midlatitude-summer atmospheric scenario.

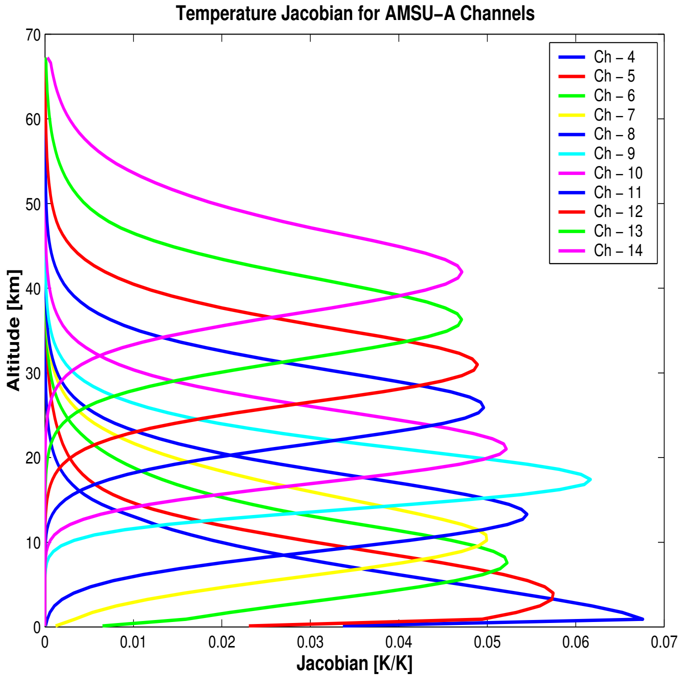

Figure 2: Temperature Jacobian for AMSU-A temperature sounding channels for the midlatitude-summer atmospheric scenario.

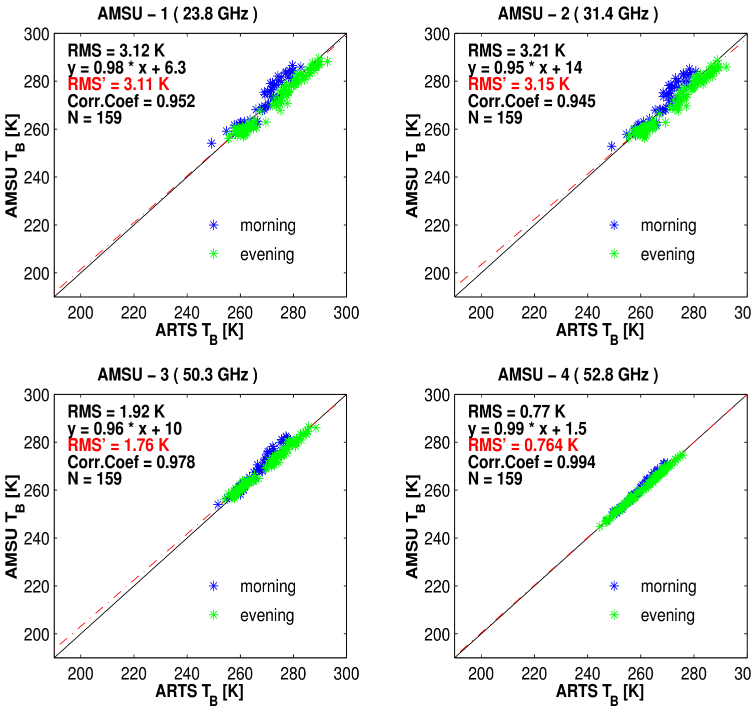

Figure 3: Result of the model - data comparison for AMSU channels 1-4. On the x-axes calculated T_B in [K] and on the y-axes measured T_B in [K] are plotted.

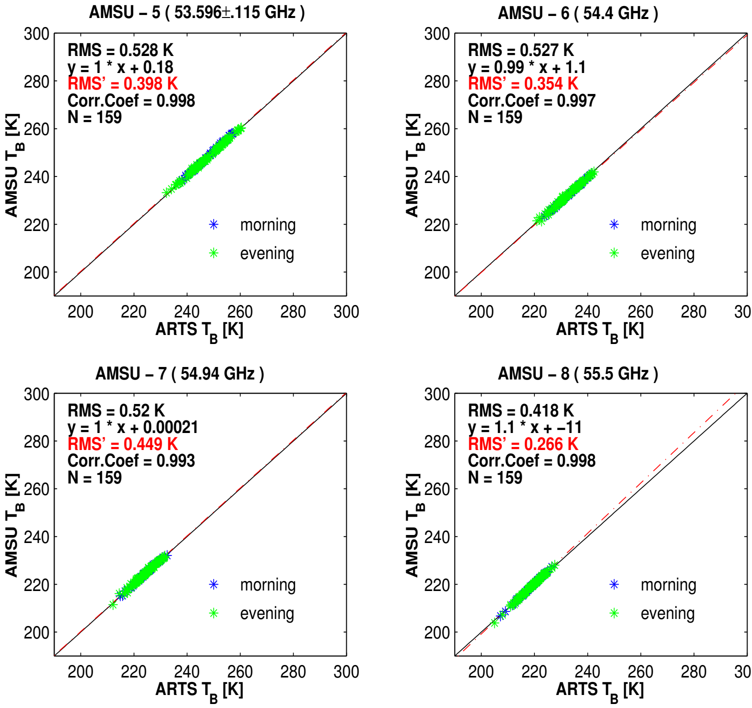

Figure 4: Result of the model - data comparison for AMSU channels 5-8. On the x-axes calculated T_B in [K] and on the y-axes measured T_B in [K] are plotted.

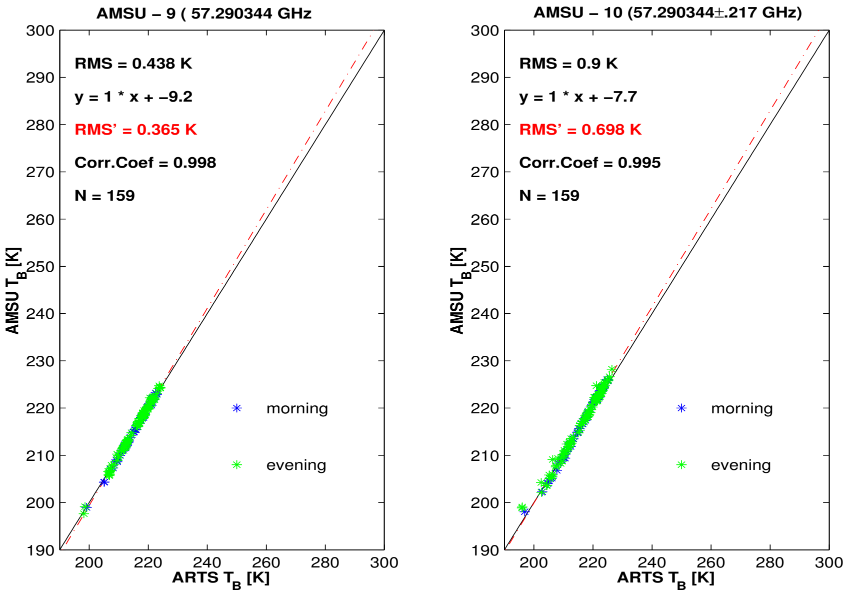

Figure 5: Result of the model - data comparison for AMSU channels 9-10. On the x-axes calculated T_B in [K] and on the y-axes measured T_B in [K] are plotted.

4. Retrieval Methodology

Figure 6 shows characteristics of water vapor retrieval from AMSU data using channels 1 - 8 and 16 - 20. Averaging kernel matrix A shows the sensitivity of the retrieval to the true state. In the ideal case A would be a unit matrix but in reality rows of A are generally peaked functions as in the figure, peaking at appropriate altitudes. In the figure, rows of A corresponding to altitudes from 4 - 9 km peak at the appropriate altitudes indicating that the retrieval is sensitive to true profile at these altitudes. The full width at half maxima of these curves can roughly represent the vertical resolution of the observing system. The vertical resolution of AMSU is about 4 km. High vertical resolution around lowest and highest altitudes is misleading because the corresponding averaging kernels do not have their peaks at the correct altitude. The width is about where the peak is, but not where the peak should be. The area of the averaging kernels should be approximately unity at altitudes where the retrieval is accurate. In these altitudes the information comes mostly from the measurements rather than from the a priori, so this is a measure of the measurement response of the observing system. AMSU has good measurement response from 4 - 9 km. The error in the retrieval comes mostly due to error in the measurement and error due to smoothing because of low resolution of the observing system. In the case of AMSU, total error is mostly contributed by smoothing error but is much lower than the a priori error.

Results and Discussion

Brightness temperature of AMSU depends highly on surface properties such as surface emissivity. If the temperature and water vapor profiles of the atmosphere is known, then

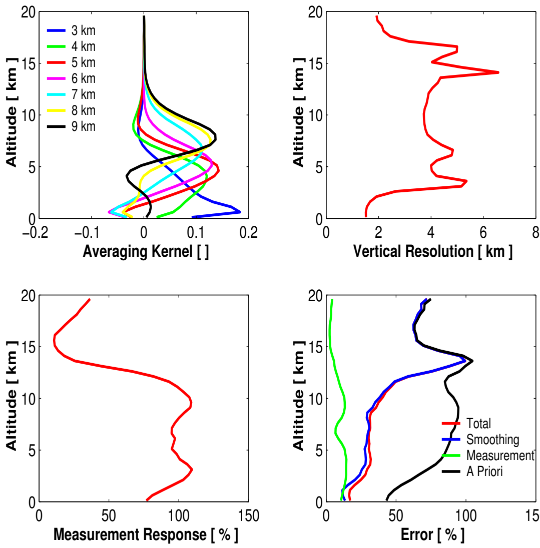

Figure 6: The figure shows retrieval characteristics of water vapor: a) averaging kernel b) vertical resolution of the retrieval c) measurement response and d) the errors.

surface emissivity can be accurately determined using brightness temperature from window channels. The result of emissivity retrieval is shown in figures 7 and 8. The diurnal and seasonal variations of surface emissivity is clearly seen. The mean value of emissivity for the whole year is 0.95 with a standard deviation of 0.02. This information has been used as a priori for the surface emissivity in the combined retrieval of water vapor, temperature, and surface emissivity. The retrieved surface emissivity values were compared with the same obtained with NOAA/NESDIS algorithm [7]. The comparison is shown in figure 9.

Concluding Remarks

AMSU data can be used to retrieve water vapor, temperature, and surface emissivity. The result for emissivity is retrieval is shown and the work for the rest is in progress.

Acknowledgments

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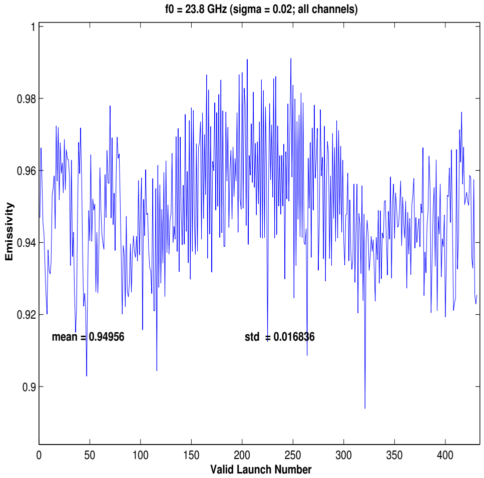

Figure 7: Surface emissivity retrieved using brightness temperature from 23.8 GHz channel.

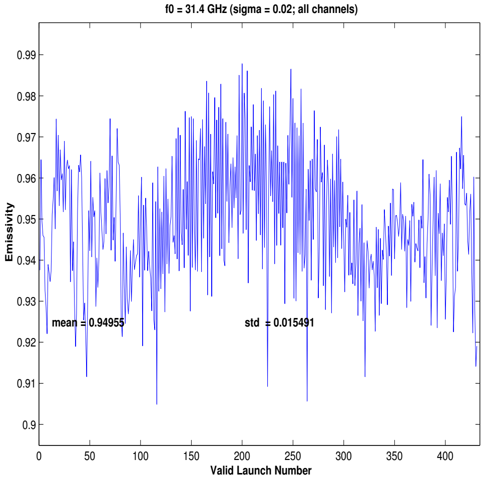

Figure 8: Surface emissivity retrieved using brightness temperature from 31.4 GHz channel.

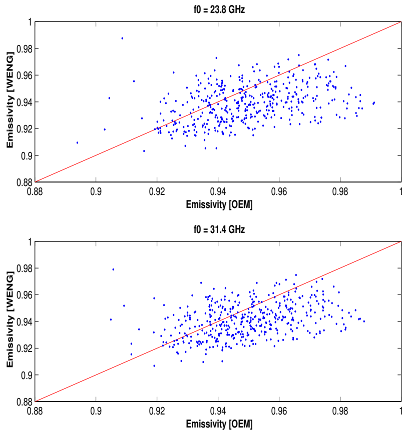

Figure 9: Comparison of retrieved emissivity using optimal estimation method and NOAA/NESDIS algorithm.

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