Upper Tropospheric Humidity and Ice from Meteorological Operational Sensors (UTH-MOS)

Stefan A. Bühler
Universität Bremen, Institut für Umweltphysik, Otto-Hahn-Allee 1, D-28359 Bremen
sbuehler@uni-bremen.de

Introduction

The objective of the UTH-MOS project is to develop and interpret an upper tropospheric humidity climatology product from microwave data collected by the polar orbiting operational meteorological sensors AMSU-B and SSM-T2. This data record goes back to 1995 and will extend into the future for at least the next decade. For the correct interpretation of these data, the impact of cirrus clouds on the measurement in the microwave channels has to be well understood and taken into account in the retrieval. An auxiliary objective is to explore the potential of these data for deriving information on cloud ice particles. The research work in UTH-MOS is split between the modeling of the radiative transfer in the presence of cirrus clouds on one hand, and the actual data analysis and atmospheric research applications on the other hand.

The Advanced Microwave Sounding Unit AMSU

AMSU is a cross-track scanning instrument consisting of two parts, AMSU-A and AMSU-B. AMSU-A has 15 channels which provide information on surface properties and atmospheric temperature up to the mid-stratosphere. AMSU-B has 5 channels and gives information on water vapor. The instrument is described for example in an article by Saunders et al. [1995]. The main source of humidity information in the upper troposphere is channel 18 of AMSU-B (Figure 1).

Radiative transfer model development

The Atmospheric Radiative Transfer Simulator ARTS is an open source radiative transfer (RT) code developed jointly by the Institute of Environmental Physics, Bremen and the Department of Radio and Space Science, Chalmers University of Technology, Gothenburg. The code and documentation is freely available at: http://www.sat.uni-bremen.de/arts/. It can simulate radiances for up, limb, and down looking instruments for a wide frequency range. An overview of the clear-sky version of ARTS is given by Buehler et al. [2003], a detailed description can be found in the ARTS User Guide [Eriksson et al., 2003]. Particular attention was paid to ensure that the model correctly represents the absolute value of atmospheric absorption, not just the component that varies quickly with frequency. This requires the addition of absorption continua for water vapor, oxygen, and nitrogen [Kuhn, 2003; Kuhn et al., 2002].
As part of the UTH-MOS project, ARTS has been extended to include the effect of ice particles in cirrus clouds, which mainly interact with the radiation by scattering. The version with scattering is described by Emde et al. [2003]. The algorithm solving the radiative transfer problem uses a successive order of scattering approach in discrete ordinates. It can handle all four components of the Stokes vector in a 1D, 2D, or 3D spherical atmosphere. The algorithm was first described for the simpler plane parallel atmospheric geometry by Sreerekha et al. [2002].

Model – data comparison

A necessary condition for accurate retrieval is that the forward model, in this case the RT model ARTS, accurately predicts the measurement from a given atmospheric state, and that all errors in RT model and measurement are well understood. There are two different ways to compare ARTS simulations to AMSU measurements, one based on radiosondes, the other based on a mesoscale numerical weather forecast (NWP) model.

For the radiosonde comparison, brightness temperatures simulated by ARTS were compared to space and time collocated AMSU data. Radiosonde data from the operational radiosonde network was used for the study. AMSU pixels close to the radiosonde site were taken under the condition that the distance between the radiosonde site and the center of the pixel should be less than 15 km and the satellite pass should be within 90 minutes of the radiosonde launch. In order to make sure that the satellite and the radiosonde measured the same atmosphere, a homogeneity filter was developed. It checks that the standard deviation of the brightness temperature of all the pixels in a circle of radius 50 km around the radiosonde site is less than a threshold value, in this case 1.4 K. Figure 2 shows the comparison result for some German radiosonde stations and the NOAA 15 satellite. More details on the comparison setup and first results can be found in the Master thesis of Kuvatov [2002], and in the article by John et al. [2002]. A summary article about the comparison is currently in preparation.

![Figure 2: A scatter plot of AMSU radiance versus predicted radiance, based on radiosonde data. Colored lines indicate linear fits for the different stations. The general level of agreement is very satisfactory, but there are small differences between the different radiosonde stations, pointing to potential problems in the humidity data of some stations. In the context of COST Action 723 these data are planned to be used for a systematic European radiosonde site intercomparison.](image)

For the NWP model comparison, humidity and ice water content fields from the UK Met Office operational mesoscale (UKMES) model are used. The model is designed to provide mesoscale detail of cloud, precipitation, wind, and temperature. It assimilates observations of surface pressure, temperature, relative humidity, and wind from radiosondes, aircraft, and surface stations. It also assimilates a 3-dimensional cloud analysis produced from surface observations, radar, and satellite images. The model has a resolution of about 12 km horizontally, with 38 vertical levels.

Figure 3 shows in the top left plot the UKMES model ice water path of the T+4 forecast run at 09:00 UTC on January 25, 2002. The bottom left plot shows AMSU-B channel 20 observations for 13:00 UTC. The top right plot shows the simulated cloud signal, which qualitatively agrees well with the observed AMSU data. A quantitative comparison will relate these results to the assumed shape and size distribution of ice particles. In the example shown, particles were assumed to be spherical and following a gamma distribution with an effective radius of 200 microns.
Upper tropospheric humidity retrieval

Although there is a straightforward relationship between atmospheric humidity content and temperature on the one hand, and top-of-the-atmosphere radiances, on the other hand, the task to invert this relationship and obtain humidity values from measured radiances is far from trivial. In principle, two approaches are possible, a variational profile retrieval [Eriksson et al., 2003; von Engeln et al., 2003; John et al., 2002], or a simpler statistical regression approach. With both approaches, it must be kept in mind that radiances are mostly sensitive to the absolute amount of humidity and that converting to relative humidity may introduce additional errors [Buehler and Courcoux, 2003].

The second approach is computationally cheap and thus allows the analysis of large amounts of satellite data. It requires a set of atmospheric states and matching radiances, which could in principle be obtained by collecting in-situ measurement and correlated satellite measurements. However, it is in practice difficult to get enough global data this way. Another possibility is to use a collection of atmospheric states covering the atmospheric variability, and use the radiative transfer model to generate matching radiances. We are using the dataset of Chevallier [2001] for this task. (With the same methodology it is possible to derive limb correction coefficients [Miao et al., 2003].)

Clear sky radiances for AMSU-B channels 18 and 19 can be used to retrieve the integrated water vapor content (WVC) in the upper tropospheric layer extending from 200 to 500 hPa. Assuming prior knowledge of the tropospheric lapse rate, the corresponding radiances were scaled to a global mean reference temperature profile. The scatter of radiances due to temperature differences is greatly reduced with this preprocessing step, so that the brightness temperatures can be considered as functions of absorber amount only.

The left and middle plots of Figure 4 show WVC versus corresponding channel 18 and 19 brightness temperatures (TB18 and TB19), as well as a fitted exponential. For channel 18 the fit is better at low WVC (high TB18), for channel 19 it is better at high WVC (low TB18). Therefore, TB18 was used to divided the data into three domains. Depending on the domain, the TB18 regression, the TB19 regression, or a linear combination of both is used. The right plot shows a scatter plot of WVC retrieved this way versus the true WVC. The bias is approximately zero, the absolute retrieval uncertainty is 0.37 kg/m².
Figure 4: Simulated regression retrieval of upper tropospheric water vapor content (WVC) from AMSU-B channels 18 and 19. Left: WVC versus channel 18 brightness temperature, middle: WVC versus channel 19 brightness temperature, right: retrieved versus true WVC.

References
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