SCIENTIFIC REPORT

ACTION: ES1303 TOPROF
STSM: COST-STSM-ES1303-260916-080646
TOPIC: Coupling the RTTOV-gb with COSMO-DE reanalysis
VENUE: L'Aquila, Italy
PERIOD: 26-30 September, 2016

Host: Francesco De Angelis (Cetemps – University of L'Aquila, Italy)
Applicant: Maria Toporov (University of Cologne, Germany)
Submission date: 03.11.2016

Contribution by: PD Dr Ulrich Löhnert (University of Cologne, Germany), Dr. Domenico Cimini (Cetemps – University of L'Aquila, Italy).

Introduction

The major objective of the ARON project (A virtual Remote sensing Observation Network for continuous, near-real-time monitoring of atmospheric stability) is to design a network of ground based MWR and DIAL for continuously monitoring of atmospheric convective stability. For this a synergistic retrieval method combining satellite measurements, ground based microwave radiometers and DIAL will be developed. Since such a network doesn't yet exist, a virtual network will be simulated by using the reanalysis of COSMO-DE model. This goal is directly coupled to the TOPROF MoU objective 8 "*To investigate optimized means of using down-welling radiance observed with the microwave radiometer network to derive profiles of temperature with highest accuracy in the boundary layer, lower resolution humidity profiles and the integrated water vapour and cloud liquid water path in the observed column*."

For simulation of microwave measurements, as well as for the following variational retrieval of temperature and humidity profiles, a fast radiative transfer model is required.

The simulations of IR and MW satellite measurements will be carried out with the RTTOV model, which is widely used in the NWP community. The ground-based version of RTTOV, recently developed at the University of L'Aquila, enables fast simulations as well as assimilation of ground-based microwave radiometer measurements (De Angelis et al. 2016).

The aim of the STSM was to visit University L'Aquila in order to learn how the new ground based version of the radiative transfer model RTTOV can be used to simulate measurements of MWR for the ARON virtual network.

Given a state vector *x*, which describes the atmospheric state, the radiative transfer model *H* (i.e. RTTOV-gb) provides the radiance vector *y*:

$$y=H(x)$$

For an upward-looking radiometer viewing non-scattering medium RTTOV-gb computes radiance using an approximated form of the radiative transfer equation (RTE):

$$L_{ATM,\nu} = t_{\nu,toa} \cdot B_\nu(T_c) + \int_{t_{\nu,toa}}^{1} B_\nu(T)\,dt, \qquad (1)$$

Where $L_{ATM,\nu}$ is the radiance at the ground for frequency ν, neglecting scattering effects, B_ν is the Planck function at frequency ν and temperature T, $t_{\nu,toa}$ is the transmittance from the surface to the top of the atmosphere, and T_c is the cosmic background brightness temperature of 2.728 K.

In order to solve Eq. (1) the atmospheric transmittance t must be known. Transmittance is given by $t=exp(-\tau)$, where τ is the optical depth and expresses the attenuation of incident radiation by molecules and hydrometeors. Transmittances from Line-By-Line (LBL) models are very accurate but the calculations are computationally expensive in operational context. RTTOV-gb computes transmittances by means of a linear regression in optical depth. The optical depth in each channel *i* from the surface to the level *j* can be calculated as:

$$\tau_{i,j} = \tau_{i,j+1} + \sum_{k=1}^{K} c_{i,j,k} X_{i,k}\,(P, T, q, \Theta), \quad (2)$$

where c are the regression coefficients between optical depth and predictors X (with total K values). Predictors are derived from the input state vector and are functions of elevation angel Θ, pressure P, temperature T, and specific humidity q. The number of predictors depends on the absorber. (e.g. H2O, O3, CO2).

The coefficients are precalculated by linear regression of τ against predictors X from a training dataset of 83 atmospheric profiles. These profiles were chosen to represent the naturally variability of the Earth's atmosphere (Matricardi, 2008).

From the derived optical depth RTTOV-gb calculates transmittances $t_{i,j} = \exp(-\tau_{i,j})$. Finally the output radiances are computed from transmittances and input temperature profiles by using the radiative transfer equation (1).

Results

The simulations were performed for the JOYCE (Jülich Observatory for Cloud Evolution) which is located at 50.87°N and 6.36°E.

From the COSMO-DE reanalysis 89 clear sky temperature and humidity profiles were selected. The highest level of these profiles lies at the 40 hPa level, thus standard atmospheric midlatitude summer profiles were used to extend the T and q profiles up to 0.005 hPa. Brightness temperatures were simulated for each profile and a set of channels with RTTOV-gb and a LBL model. Simulations were performed for 14 channels of the Humidity And Temperature PROfiler (HATPRO, Rose et al. 2005): 22.24, 23.04, 23.84, 25.44, 26.24, 27.84, 31.40, 51.26, 52.28, 53.86, 54.94, 56.66, 57.30, and 58.00 GHz.

For the whole 89-profile dataset Fig. 1 shows statistics (bias, standard deviation and RMS) of the differences between the output of RTTOV-gb and LBL model at 90° elevation angle. Bias and RMS are less than 0.2 K for K-band and 0.15 K for the V-band, thus below the uncertainty associated with TB observations (0.5 K) for all channels.

Further, measurements at different elevation angles were simulated from the single profile (Fig.2). As expected the simulated radiance is higher at the lower elevation angles, especially at the channels sensitive to water vapor (22-31 GHz) and at transparent V-band channels (51-54 GHz). By assuming a horizontal homogeneous atmosphere, the observed radiation originates from higher atmospheric layers the higher elevation angle. At the opaque V-band channels (54-58 GHz) all of the received radiation originates from the environment close to the instrument. Thus, the lower elevation angles provide information about the temperature in the lower layers, while measurements at higher elevation angles contain information from layers above. Therefore additional angular information can enhance the accuracy of temperature profiles in the boundary layer.

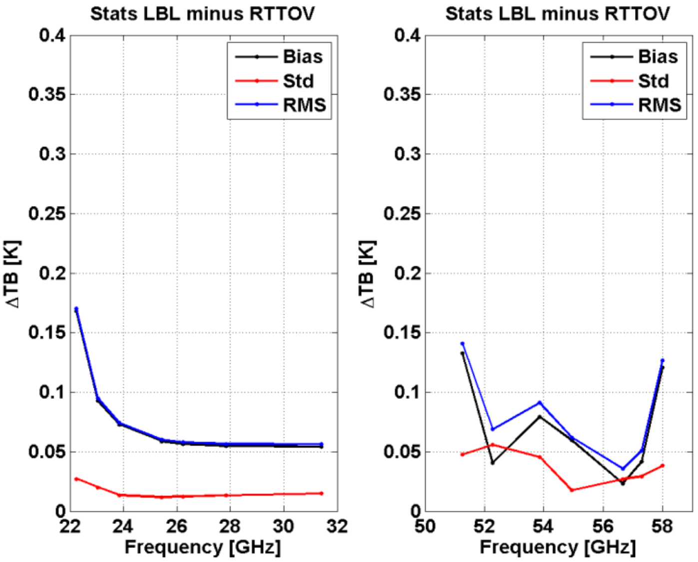

Figure 1: Bias (black), standard deviation (red), and RMS (blue) of differences between Tb simulated with RTTOV-gb and LBL model for clear sky conditions and at 90° elevation angle. Left: K-band channels. Right: V-band channels.

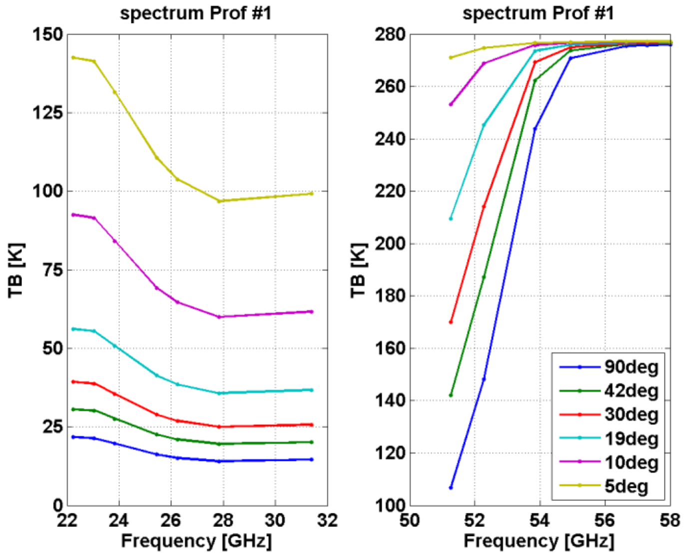

Figure 2: Brightness temperatures at 14 frequencies in the K- and V-band, simulated with RTTOV-gb from a single atmospheric profile

Further the performance of RTTOV-gb was tested for cloudy conditions. The cloud liquid water values within a single clear sky profile were modified at different pressure levels. Four cloudy profiles were considered with a thin and thick cloud at 700 and 900 hPa pressure levels. RTTOV-gb takes the liquid water as an absorber into account, which influences the calculated transmittance profile. The contributions of different cloud types to the total brightness temperatures are shown in the Fig. 3. The K-band frequencies and optically thin V-band frequencies are strongly affected by cloud liquid water and the influence is increasing with height and cloud liquid water (CLW). The sensitivity of channels to the changes in T-, q- and CLW-profiles can be illustrated by Jacobians (s. below).

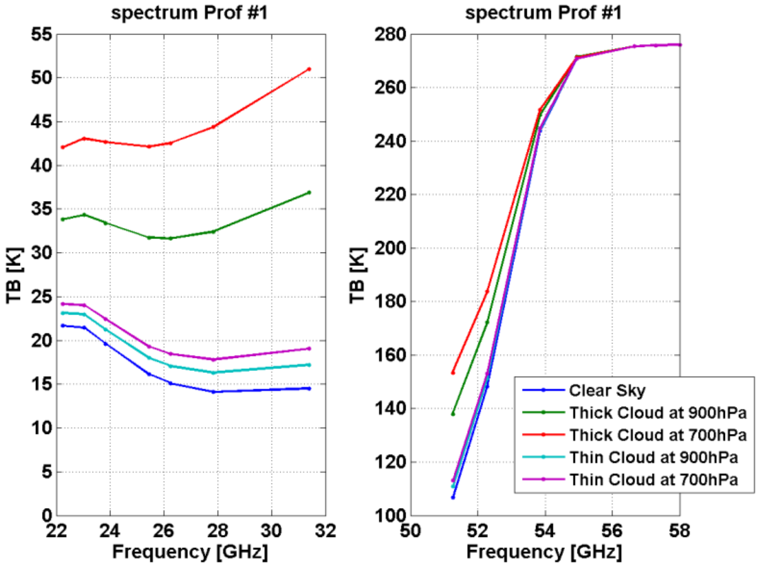

Figure 3: Brightness temperatures, simulated with RTTOV-gb from a single profile with varied types of artificial clouds.

After testing the RTTOV-gb direct module, the RTTOV-gb K-module was applied to calculate Jacobians. The Jacobian matrix gives the change in received radiance for a change in any element of the profile vector. In our case it shows, for a given profile and a set of channels, which layers in the atmosphere are most sensitive to changes in temperature, humidity and cloud liquid water. The Jacobians can be calculated with the tangent-linear (TL), adjoint (AD) and K-modules of RTTOV-gb and are necessary for the variational retrieval of temperature and humidity profiles and for variational assimilation of MWR measurements.

Fig. 4 shows the temperature and absolute humidity Jacobians for 14 HATPRO channels. As expected, the opaque V-band channels are more sensitive to the temperature changes in the lower atmosphere than optically thin channels. The sensitivity decreases with decreasing frequency and its maximum shifts to the higher atmospheric layers. Between 22 and 31 GHz the sensitivity of Tb to water vapor increases with decreasing frequency.

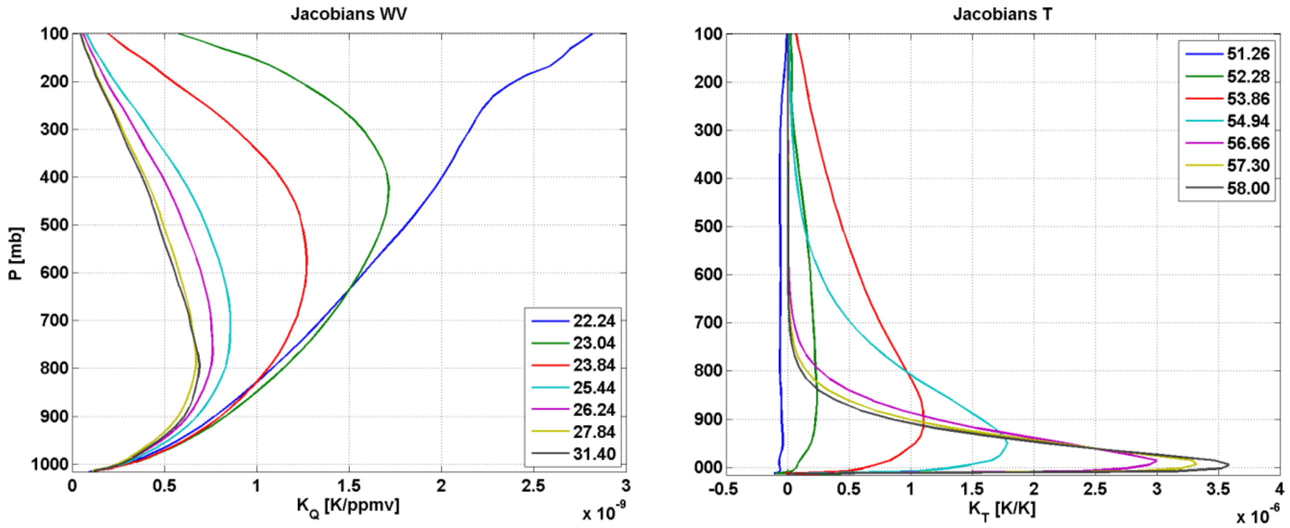

Figure 4: Absolute humidity (left) and temperature (right) Jacobians, calculated with K-module of RTTOV-gb for 14 HATPRO frequencies

For the retrieval of T- and q-profiles under cloudy conditions the Jacobians for cloud liquid water are needed (Fig. 5). In the K-band the sensitivity to cloud liquid water increases with frequency and height, and reaches its maximum at about 500 hPa for all channels.

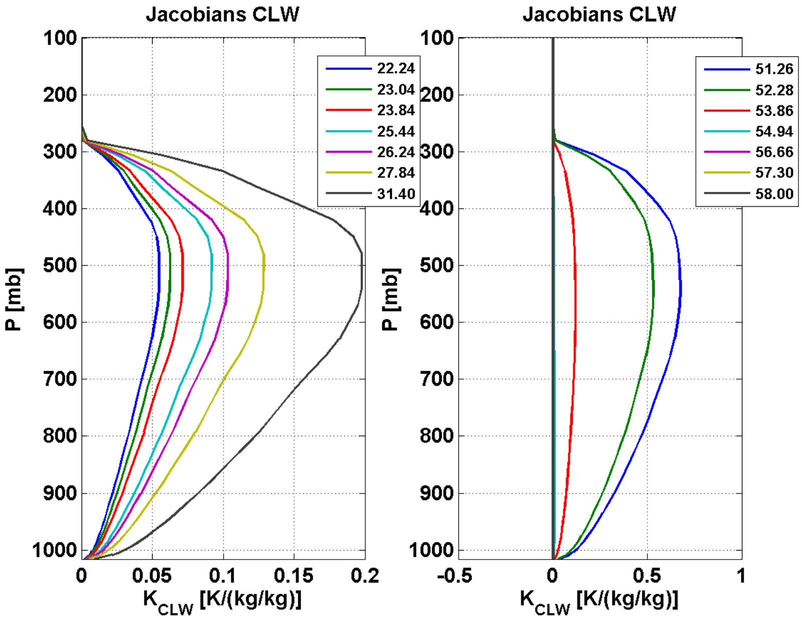

Figure 5: Cloud liquid water Jacobians, calculated with K-module of RTTOV-gb for 14 HATPRO frequencies

Since the oxygen absorption becomes increasingly dominant in the spectral range between 51 and 58 GHz, the sensitivity to CLW decreases with frequency, so that opaque channels don't provide information about CLW.

Conclusions

The objective of this STSM was the acquaintance with the ground-based version of RTTOV. In summary, the STSM was successful in achieving its objectives. During the mission RTTOV-gb was installed, tested and applied to the atmospheric profiles from COSMO-DE reanalysis. Measurements simulated with RTTOV-gb were compared to those calculated with a line-by-line model. Additionally, the K-module of RTTOV-gb was applied to calculate Jacobians, required for variational retrieval of temperature and humidity profiles and for assimilation of MWR measurements.

In the future, the simulations with RTTOV-gb will be performed for a larger set of atmospheric profiles. Simulated ground-based and satellite measurements will be combined and suitable inversion method will be developed and applied to retrieve instability indices.

References

De Angelis, F., Cimini, D., Hocking, J., Martinet, P., and Kneifel, S.: RTTOV-gb – adapting the fast radiative transfer model RTTOV for the assimilation of ground-based microwave radiometer observations, Geosci. Model Dev., 9, 2721-2739, doi:10.5194/gmd-9-2721-2016, 2016.

Matricardi, M.: The generation of RTTOV regression coefficients for IASI and AIRS using a new profile training set and a new line-by-line dataset, ECMWF Technical Memorandum 564, ECMWF, Reading, UK, available at: http://www.ecmwf.int/sites/default/files/elibrary/2008/11040-generation-rttov-regression-coefficients-iasi-and-airs-using-new-profile-training-set-and-new, 2008.

Rose, T., Crewell, S., Löhnert, U., and Simmer, C.: A network suitable microwave radiometer for operational monitoring of the cloudy atmosphere. Atmos. Res., 75, 183-200, doi:10.1016/j.atmosres.2004.12.005, 2005.

Confirmation by the host institution of the successful execution

The host institution (Cetemps – University of L'Aquila) confirms the successful execution of the STSM by Maria Toporov 26-30 September 2016.