SCIENTIFIC REPORT

ACTION: ES1303 TOPROF
STSM: COST-STSM-ES1303-34044
TOPIC: MWR real observations assimilation with 1D-Var and RTTOV-gb
VENUE: Météo-France, Toulouse, France
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Introduction

The purpose of the STSM was to visit Météo-France in order to test the NWPSAF (Numerical Weather Prediction Satellite Application Facility [2]) 1D-Var tool [1], interfaced with the fast radiative transfer model RTTOV-gb by Dr. Pauline Martinet [3,4], for the assimilation of real ground-based microwave radiometer (MWR) observations. The RTTOV-gb has been developed by Dr. Domenico Cimini (IMAA-CNR) and myself in previous STSM/SWG [6,4] funded by the COST Action ES1303 TOPROF, to handle MWR observations. RTTOV-gb has been tested against dependent and independent line-by-line models simulations, and against real measurements. The ground-based version of RTTOV [5] and tests that have been made to validate the model are presented in the manuscript De Angelis et al. (2016) [8], currently under review in the journal *Geoscientific Model Development*.

Within a previous STSM, the new version of the NWPSAF 1D-Var interfaced with the RTTOV-gb was evaluated with an Observing-System Simulation Experiment (OSSE) with successful retrievals of Temperature (T), Humidity (H) and Liquid Water Path (LWP) [9]. Thus, in that case simulated MWR observations were used. The aim of this new STSM is to retrieve T profiles in both clear- and cloudy-sky conditions by assimilating real MWR brightness temperatures (TB) with RTTOV-gb through a 1-dimensional variational approach. This STSM was suggested in the context of the microwave radiometer working group (WG3) of the TOPROF.

Motivations and objectives

The aim of the 1D-Var is to find the atmospheric state x that minimizes both the distance to the background x_b and the distance to the observation y. To do that we need to minimize the following cost function J modifying the different variables defined in the control vector *x*:

$$J = [y - H(x)]^T R^{-1} [y - H(x)] + [x - x_b]^T B^{-1} [x - x_b]$$

The atmospheric state that minimizes the cost function is called the “analysis”. The background profile can come from nearby radiosondes, from a climatological dataset of profiles or from a short-range forecast of a Numerical Weather Prediction (NWP) model. B represents the background-error covariance matrix and R the observation error covariance matrix. H represents the observation operator that allows to pass from the model state to the observation state. In this analysis this operator is equal to the radiative transfer model RTTOV-gb that converts an atmospheric profile into brightness temperature spectra in the frequency channels and at the elevation angles of the instruments HATPRO from RPG, and MP3000A from Radiometrics. Moreover during the minimization Jacobians (i.e. the sensitivity of observations to the atmospheric thermodynamical state) need to be computed. In addition to the forward model the tangent linear (TL), adjoint (AD) and K modules of RTTOV [5] have been modified to provide Jacobians for ground-based geometry [4]. Jacobians calculated with RTTOV-gb have been validated against Jacobians computed with a reference line-by-line model [8].

Therefore, the objectives of this STSM are:

1) Observations-minus-Background (O - B) analysis in the radiance space to account for systematic instrumental errors of the observations.
2) Evaluation of T profiles in clear- and all-sky conditions using MWR observations only at zenith (90° elevation angle).
3) Use of MWR observations at lower elevation angles (90-30-19.2°) to improve the 1D-Var T retrievals in the Planetary Boundary Layer (PBL).
4) Modification of the 1D-Var to handle a new MWR instrument (from HATPRO to MP3000A).

Results

For this analysis, we used as Background 240 AROME 3 hour-forecasts in April 2014, extracted over two different sites: Payerne (MeteoSwiss – Alpine Valley) and Lindenberg (DWD – Continental flat land). These forecasts are made of 60-level pressure, temperature, and humidity profiles. AROME is the French convective scale model with 2.5 km of horizontal resolution in the configuration operational in 2014, developed by Météo-France. In Particular the profile of the model grid point closest to the MWR observations is used as background. In Payerne MWR TB from HATPRO at 14 frequency channels (7 in the water vapor band 22-31GHz and 7 in the Oxygen band 51-58GHz) and on 7 elevation angles (90-42-30-19-10-5-0°) have been collected in April 2014 in addiction to 60 radiosondes (2/day), used as “reference”. In Lindenberg we have available MWR TB from MP3000A at 12 frequency channels (5 between 22 and 31 GHz and 7 between 51 and 58 GHz) and on 2 elevation angles (90-15°), and 113 radiosondes as the “truth” (4/day). Ceilometer data (Cloud Base Height) at the two sites have also been collected for the clear-sky selection. In this study the B-matrix used operationally at Météo France, computed from an AROME ensemble assimilation system, has been chosen. Moreover the diagonal elements of this B-matrix have been increased in the first kilometers from the ground according to the RS-minus-AROME T analysis performed in each site.
During this study we monitored O - B TB differences during April 2016. TB have been simulated with RTTOV-gb from 3-h AROME forecasts. This monitoring is crucial to take into account systematic errors coming from the measurements, the radiative transfer model or the NWP forecast. From this monitoring, we can remove TB biases to verify the assumption of unbiased observations, necessary for optimal estimation retrieval. Figure 1 shows the O - B departures in clear-sky conditions (75 AROME profiles) for all the HATPRO channels and at 4 elevation angles (90 - 42 - 30 - 19.2°), in terms of biases, standard deviations, and RMS. Similar statistics have been obtained up to 30° elevation angles. Large biases are observed in the V-band more transparent channels 51-52 GHz, due to the combination of water vapor and oxygen absorption, and in the K-band channels, that however do not influence the T retrievals. Biases are smaller in the opaque channels 54-58 GHz, that are not affected by water vapor. Larger differences are found at 19.2° elevation angles because the current version of RTTOV-gb allows for monochromatic and pencil-beam synthetic observations in plane parallel atmosphere assumption. Thus, with respect to zenith, higher O - B differences are expected at low elevation angles. Standard deviations smaller than 1 K are observed at the V-band channels. A constant bias offset is

removed from observations at the channels used in the retrieval according to the O – B analysis shown in Figure 1.

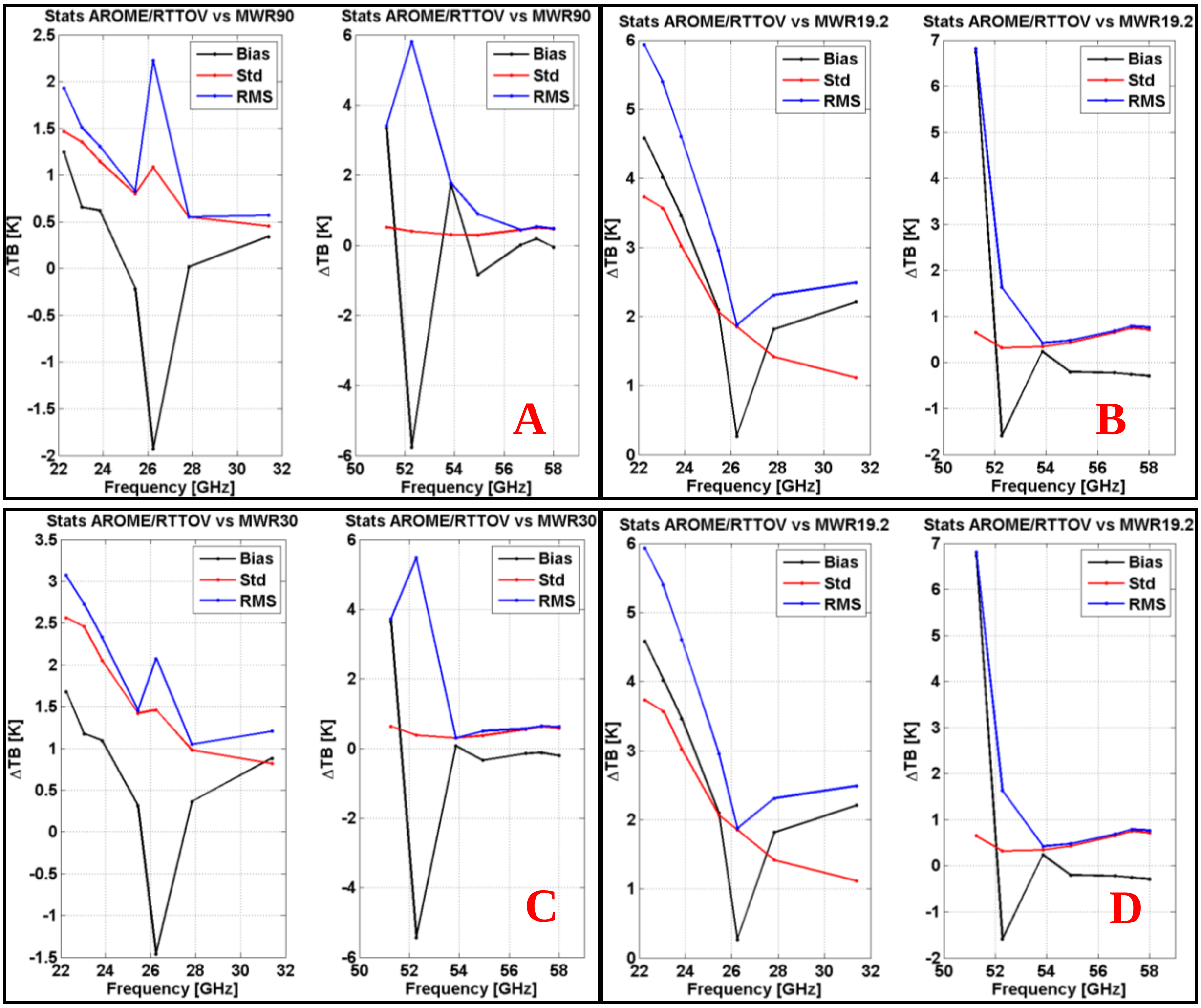

FIGURE 1 – Statistics of the differences between measured TB and TB simulated with RTTOV-gb from 75 AROME profiles for Payerne in clear-sky conditions. Biases are in black lines, standard deviations in red lines and RMS in blue lines. Panels A, B, C and D refer respectively to 90, 42, 30 and 19.2° elevation angle.

For the 1D-Var retrievals the R-matrix has been chosen diagonal with elements selected according to the O - B TB standard deviations (for Payerne 22-31 GHz: 1.5-1K, 51-53 GHz: 1.0 K, 54-58 GHz: 0.3-0.5 K).

Subsequently we used the 1D-Var tool to minimize the differences between the background and the bias-corrected observations, starting from the dataset collected in

Payerne for the retrieval of temperature profiles. The analyses are then compared with the collocated radiosonde T profiles considered as the “truth” .
We started to evaluate the 1D-Var in all-sky conditions using observations at all the frequency channels and only at zenith, T as control variable, and Jacobians computed with the K-module of RTTOV-gb.
A comparison between T retrievals obtained with 1-DVAR, the corresponding RS, the background and the manufacturers regression profiles for an example of good 1D-Var behavior is shown in Figure 2.

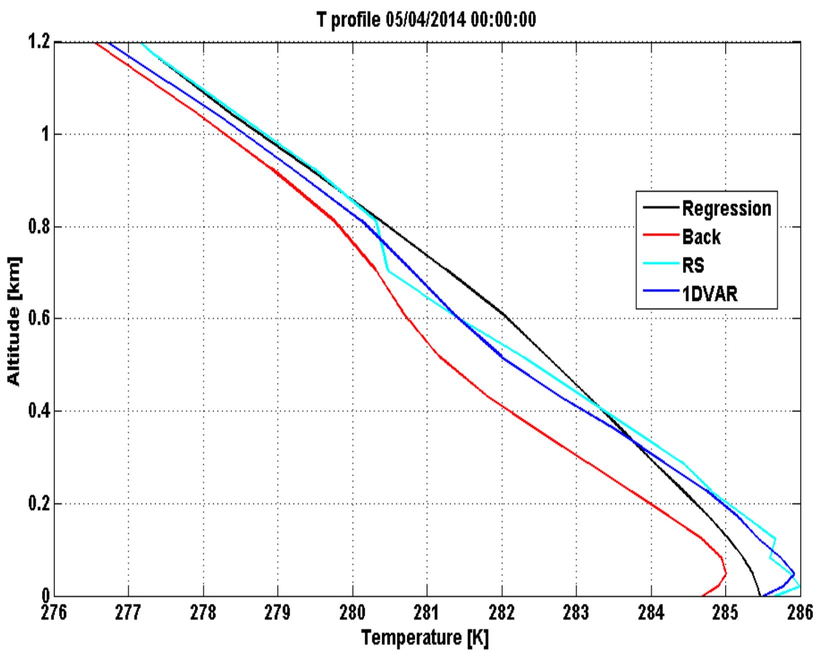

FIGURE 2 – Temperature profiles of Background (red), RS (cyan), 1D-Var retrievals (blue) and regression (black) for one clear-sky profile.

The 1D-Var retrievals are closer to the “truth” than the background and the regression profiles. In this case we obtained an improvement in the first 1km of altitude.
Figure 3 shows biases, standard deviations and RMS T profiles of the background, the regression and the 1D-Var retrievals with respect to the “truth” for all the converging profiles. The convergence rate is 87% if observations at all the frequency channels are used.

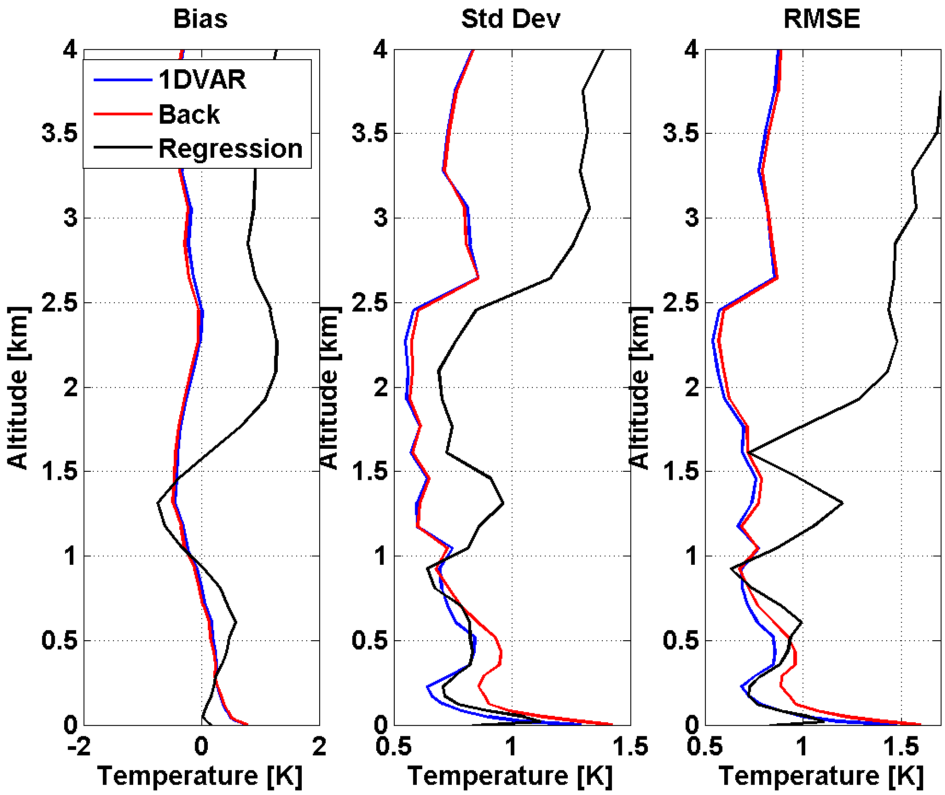

FIGURE 3 – Profiles of bias, standard deviation and RMSE temperature differences between RS and respectively the background (red line), the 1D-Var retrieval (blue line) and the regression (black line). Observations at all the frequency channels and only at zenith in all-sky conditions are used.

For temperature, the 1D-Var outperforms the background up to 1km of altitude and the regression above 1km from the ground with respect to the truth. In particular the 1D-Var minus RS RMS differences are always below 0.7K except at the ground.

The convergence rate increases up to 100% if only observations at the V-band opaque channels (54-58 GHz) are used. Figure 4 shows biases, standard deviations and RMS T profiles of the background, the regression and the 1D-Var retrievals with respect to the RS profiles, using observations only at the 4 opaque channels. As in the previous case, the 1D-Var is able to reduce the RMS against the RS profile with respect to the background in first 1km from the ground and above 1km with respect to the regression.

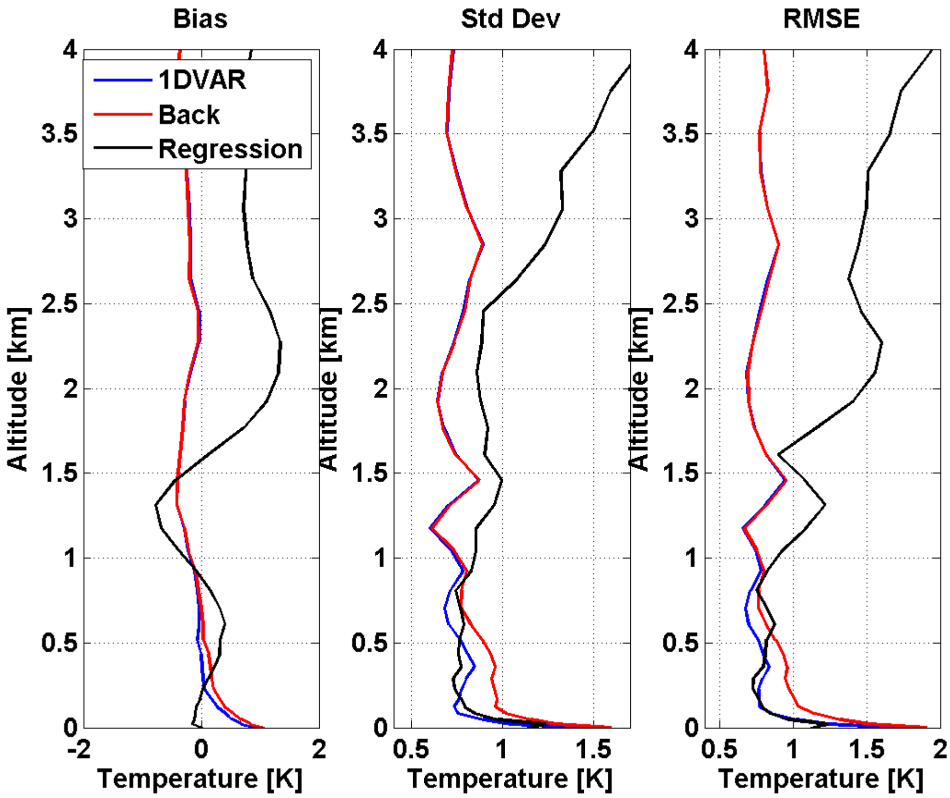

FIGURE 4 – Profiles of bias, standard deviation and RMSE temperature differences between RS and respectively the background (red line), the 1D-Var retrieval (blue line) and the regression (black line). Observations at the V-band opaque channels (54-58 GHz) and only at zenith in all-sky conditions are used.

Previously only observations at zenith angles were used but lower elevation angle observations in the V-band opaque channels (54-58 GHz) are useful to improve temperature retrievals in the PBL. A comparison of T retrievals obtained exploiting observations on three angles (90, 30, 19.2° elevation angles) and at the V-band opaque channels is shown in Figure 5 via bias, standard deviation and RMS profiles against the truth.

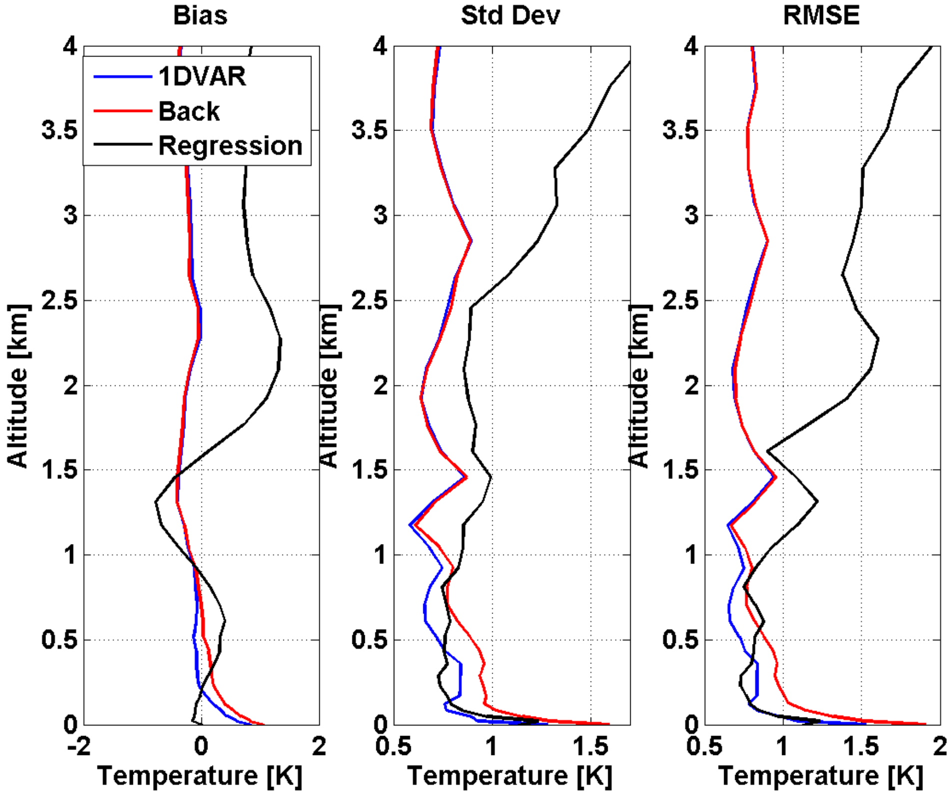

FIGURE 5 – Profiles of bias, standard deviation and RMSE temperature differences between RS and respectively the background (red line), the 1D-Var retrieval (blue line) and the regression (black line). Observations at the V-band opaque channels (54-58 GHz) and at elevation angles 90, 30 and 19.2° in all-sky conditions are used.

In the three-angles case the 1D-Var further slightly reduces the RMS in the first 1.3km of altitude, especially close to the ground. However this improvement should be more visible in the PBL and this aspect highlights the need of further modifications in RTTOV-gb when simulates observations at low elevation angles.

Figure 6 shows the statistics (bias, standard deviation and RMS) of the differences between the RS T profile and respectively 1D-Var retrievals, background and regression in clear sky conditions. In this case, although the 1D-Var outperforms the background and the regression, the improvement is less visible because the AROME 3h-forecasts are closer to the truth in clear-sky conditions with respect to the all-sky cases (AROME-RS RMS differences less than 0.7 K except at the ground).

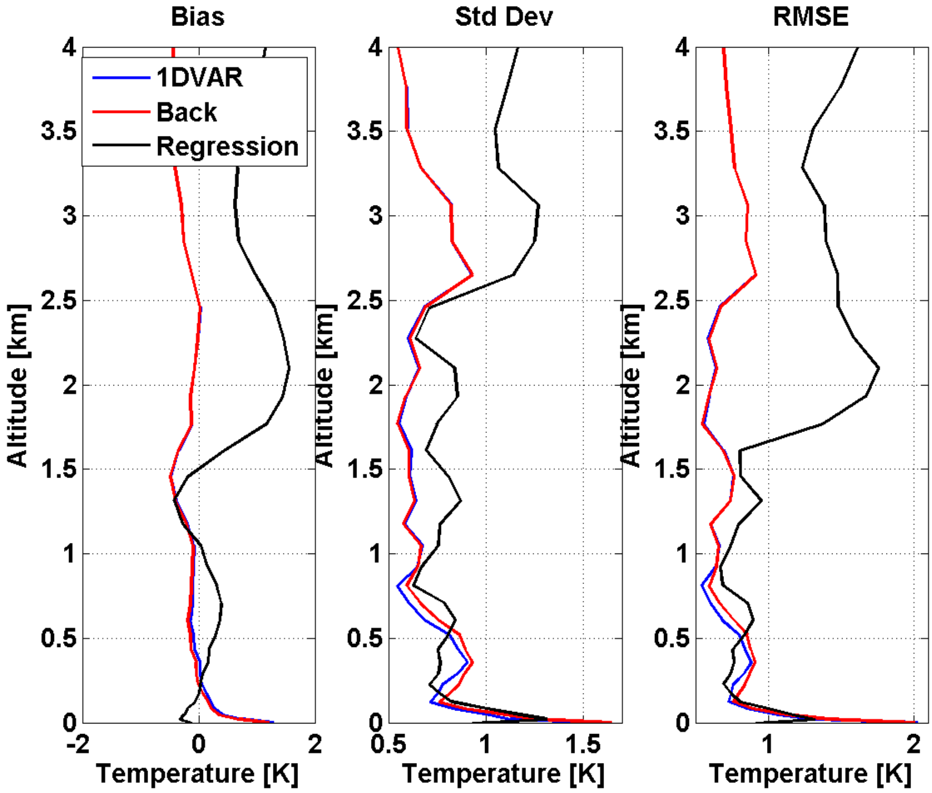

FIGURE 6 – Profiles of bias, standard deviation and RMSE temperature differences between RS and respectively the background (red line), the 1D-Var retrieval (blue line) and the regression (black line). Observations at the V-band opaque channels (54-58 GHz) and only at zenith in clear-sky conditions are used.

Successful Modifications have been made in the 1D-Var tool to include a new MWR instrument (from HATPRO to MP3000A). After these modification the 1D-Var has been tested using the dataset collected in Lindenberg with TB measured with the MP3000A.
Figure 7 shows biases, standard deviations and RMS profiles of the background and the 1D-Var retrievals with respect to the RS profiles in all sky conditions, using observations from the MP3000A in Lindenberg only at the opaque channels.
In this case 1D-Var is able to reduce the RMS against the RS profile with respect to the background in first 1.2km from the ground, especially in the first few hundred meters where the MWR information mostly resides. In particular the 1D-Var minus RS RMS differences are always below 1K and even the surface temperature has been improved with the 1D-Var. As for the dataset collected in Payerne, the improvement of the 1D-Var decreases if only clear-sky cases are taken into account.

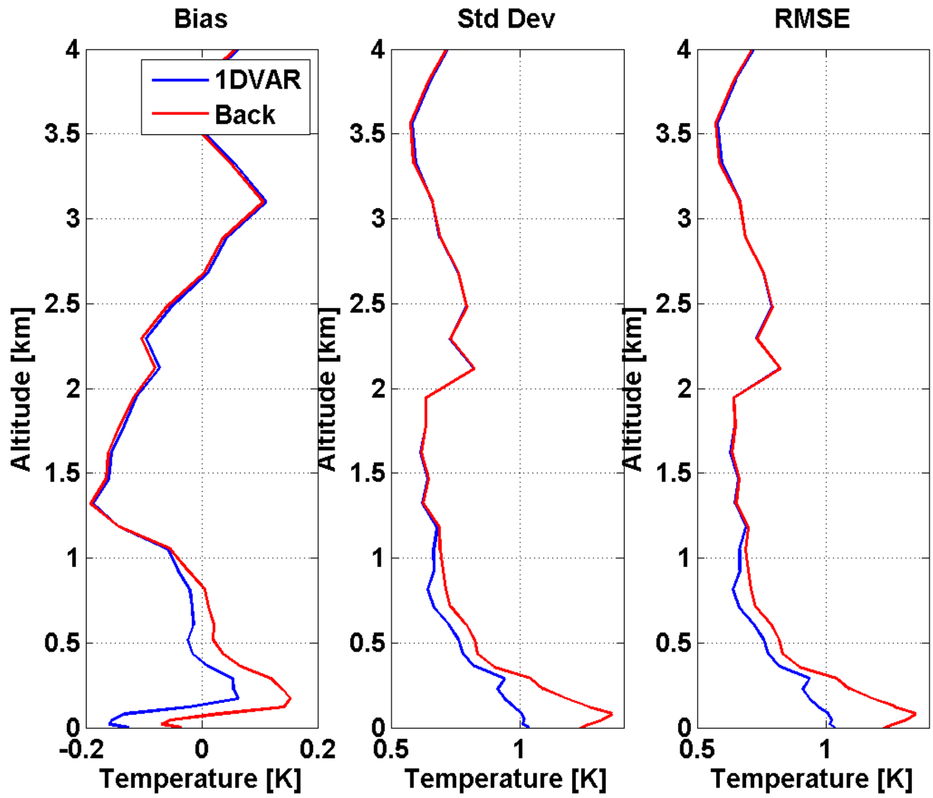

FIGURE 4 – Profiles of bias, standard deviation and RMSE temperature differences between RS and respectively the background (red line) and the 1D-Var retrieval (blue line). Observations at the V-band opaque channels (54-58 GHz) and only at zenith in all-sky conditions from the dataset collected in Lindenberg are used.

Conclusions

In summary, the STSM was successful in achieving its objectives:

1) The 1D-Var tool interfaced with RTTOV-gb was tested for the assimilation of real MWR observations for the retrieval of temperature profiles. It works well with observations only at zenith. In this case the expected accuracy is:
   - For temperature: RMSE < 0.7 K except at the ground;
2) 1D-Var improves the retrieval of Temperature profile with observations at lower elevation angles up to 19.2°, but the improvement should be more visible in the PBL;
3) The convergence rate for the retrieval of Temperature is larger if only opaque channels are used.
4) 1D-Var contributes more for the retrieval of Temperature in all-sky conditions with respect to only clear-sky cases.
5) 1D-Var has been successfully modified to handle a new MWR instrument (from HATPRO to MP3000A).

Therefore, the remaining work towards a trustworthy and usable version of 1-DVAR tool package can be summarized as follows:

1) Further modifications in RTTOV-gb for the simulation at low elevation angles, useful to improve the 1D-Var T retrievals in the PBL;
2) Evaluation of the 1D-Var tool interfaced with RTTOV-gb for the retrieval of Humidity profiles in clear- and all-sky conditions.
3) Evaluation of the 1D-Var tool for the retrieval of Liquid Water Path in cloudy-sky conditions;
4) O – B monitoring in radiance space on 6 available sites and with a dataset of 1 year.
5) Complete evaluation of the 1D-Var tool for the retrieval of Temperature and Humidity profiles and Liquid Water Path with a dataset of 1 year.

The scientific report will be posted on the TOPROF website: www.toprof.eu [7].

References

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Confirmation by the host institution of the successful execution

Dr. Pauline Martinet who received Francesco De Angelis at Météo-France during this STSM confirms that all the objectives of this mission were fully completed by Francesco.