A model-based approach to adjust microwave observations for operational applications: Results of a campaign at Munich airport in winter 2011/2012

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ABSTRACT

In the frame of the project "LuFo iPort VIS" which focuses on the implementation of a site specific visibility forecast, a field campaign was organised to offer detailed information to a numerical fog model. As part of additional observing activities a 22-channel microwave radiometer profiler (MWRP) was operating at the Munich airport site in Germany from October 2011 to February 2012 in order to provide vertical temperature and humidity profiles as well as cloud liquid water information. Independently from the model-related aims of the campaign, the MWRP observations were used to study their capabilities to work in operational meteorological networks. Over the past decade a growing quantity of MWRP has been introduced and a user community (MWRnet) was established to encourage activities directed at the set up of an operational network. On that account, the comparability of observations from different network sites plays a fundamental role for any applications in climatology and numerical weather forecast.

In practice, however, systematic temperature and humidity differences (bias) between MWRP retrievals and co-located radiosonde profiles were observed and reported by several authors. This bias can be caused by instrumental offsets as well as by the absorption model used in the retrieval algorithms. At the Lindenberg observatory besides a neural network provided by the manufacturer, a measurement-based regression method was developed to reduce the bias. These regression operators are calculated on the basis of coincident radiosonde observations and MWRP brightness temperature measurements. However, MWRP applications in a network require comparable results at just any site, even if no radiosondes are available.

The motivation of this work is to study the suitability of the DWD numerical forecast model COSMO-EU for the calculation of model-based regression operators in order to provide unbiased vertical profiles during the campaign at the Munich airport. The results of this algorithm as well as the retrievals of a neural network, specially developed for the site, are compared with radiosondes from Oberschleißheim located about 10 km from the MWRP site. The bias of the retrievals could be considerably reduced and the accuracies which have been assessed for the airport site is quite similar to those of the operational radiometer at Lindenberg above 1 km height. Additional investigations are made to determine the lenght of the training period necessary for generating best estimates. Thereby three months have proven to be adequate. The results of the study show, that on the basis of NWF model data, available everywhere at any time, the model-based regression method is capable to provide comparable results at a multitude of sites. Furthermore, the approach offers auspicious conditions for automation and continuous updating.

1. INTRODUCTION

The campaign of the project LuFo iPort (innovative airport) was organised from October 2011 to February 2012 and had its focus on forecast techniques of poor visibility, one among various weather related phenomena affecting airport management and traffic. DWD in cooperation with University Bonn was implementing a site specific fog forecasting system for Munich International Airport [1]. Therefore the fog forecasting model PAFOG [2] was upgraded in order to integrate local observations from instruments installed close to the runways. Among them a 22-channel microwave radiometer profiler from Radiometrics (MP- 3000A) [3] was operating at the airport site during the campaign to provide additional observations. Independently from the visibility forecasting studies, the MWRP observations can be used to investigate the capabilities of microwave radiometers for applications in operational networks.

Over the past decade MWR technology has reached a level mandatory for starting efforts towards the establishment of permanent networks. Due to their capability to operate autonomously during all weather conditions several activities are directed to describe the potential. For example, a user community MWRnet (http://cetemps.aquila.ifn.it/mwrnet) was established to support ambitions of people working with ground-based radiometers. Furthermore, within the European COST action EG-CLIMET (European Ground-Based Observations of Essential Variables for Climate and Operational Meteorology) efforts have been initiated, e.g. to establish "best practice" for making MWR observations/retrievals and to develop common retrieval algorithms with error analysis. However, good calibrations and accurate knowledge about radiative transfer are fundamentally for progress in network applications. Comparable results at just any site of a network are indispensible for any operational use.

2. EXPERIMENT DESCRIPTION AND DATA SETS

Retrieval algorithms developed for deriving vertical profiles expect unbiased measurements. Experiences obtained during a decade of microwave profiling at the Lindenberg observatory indicate that, in practice, systematic differences in observations and retrievals are not uncommon. Biases can be caused by calibration and/or uncertainties in the absorption model [4, 5]. In Lindenberg an observation-based regression methods have been succesfully applied using MWRP and radiosonde measurements from the past to calculate regression operators. The method removes systematic errors and produces weak-biased retrievals with respect to radiosondes [6]. This technique is quite mature and performed operationally at the GRUAN (GCOS Upper-Air Network) Lead Centre Lindenberg. However, for MWRP applications within a network, comparable results are required at any possible location. On this account, the appropriateness of NWP model data was shown in a study during the LUAMI campaign (Nov 2008) applying microwave data from eight stations in Europe [7].

In the actual experiment, the model-based regression method (REGmod) will be analysed to get more representative conclusions enabled by the longer time period of the campaign. In addition, intercomparisons with radiosondes of Oberschleißheim, located about 10 km away, can be performed to assess the accuracy of the REGmod method. For the entire period from October 2011 to February 2012, NWP data of the airport site were extracted from the operational local forecast model (COSMO-EU) of the Deutscher Wetterdienst (DWD). The temperature and humidity profiles are available with a temporal resolution of one hour for the model runs started at 00 and 12 UTC, respectively. Furthermore, MWRP observations and neural network (NN) retrievals were summed up to 10 minute means.

3. RESULTS

For this study the complete dataset, described above, was divided into two groups. One part, containing observations on odd-numbered days, was used for training of regression operators. The other independent dataset was applied for validation. REGmod is a specific approach to the inversion of the radiative tranfer equation [6]. Estimated profiles $\hat{\mathbf{x}}$ are calculated using the equation:

$$\hat{\mathbf{x}} = x_o + C_{xy}\, C_{yy}^{-1}\, (y - y_o) \qquad (1)$$

$\mathbf{C_{xy}}$ represents the covariance matrix of the profiles $\mathbf{x}$, extracted from the forecast model, and the simultaneous MWRP measurements $\mathbf{y}$. $\mathbf{C_{yy}}$ is the autocovariance matrix of $\mathbf{y}$.

Based on this approach various regression operators REGmod were calculated. The radiosondes are launched about 10 km away and the NWP model data at 00 and 12 UTC are the result of a numerical analysis.

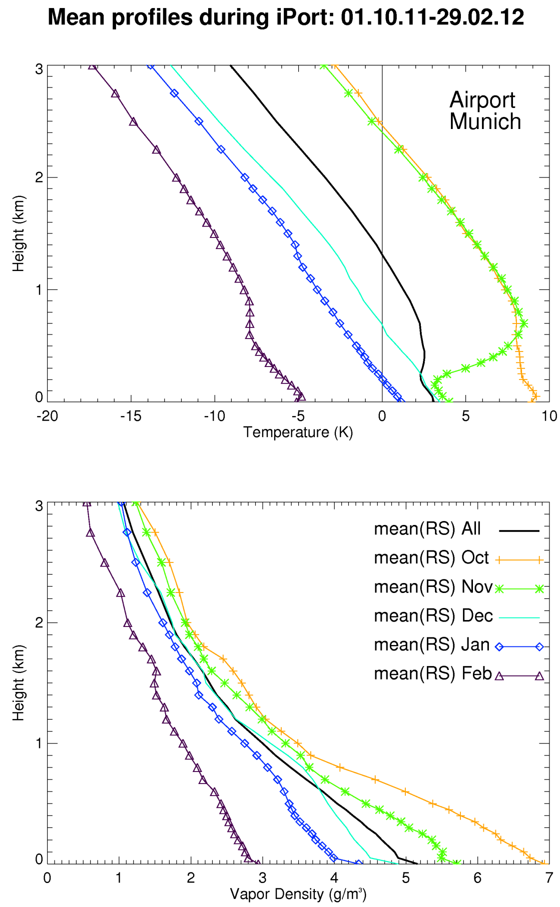

Figure1. Monthly mean temperature (upper panel) and vapor density profiles during the campaign 2011/2012.

Therefore the vertical profiles at 00 and 12 UTC are strongly influenced by the RAOB data. However, the investigation is directed on the minimization of systematic errors at any site of a potential MWR network. For this reason, only the NWP forecast model data calculated for 11 hours later on were taken into account assuming that the mean profiles of temperature and humidity (vapour density) are in the order of the real atmospheric state. Nevertheless, errors in the forecast are contained in the training data set and will have an impact on the REGmod matrices.

For a general charcterisation of the campaign period, monthly mean profiles of radiosondes were calculated and displayed in Fig.1. Basically, a decrease of temperature and humidity from October to February is apparent. In November 2011 even the mean temperature profile shows a strong inversion. A multitude of fog situation was recorded and with regard to the main aim of campaign, a site specific visibility forecast, it was the golden month.

At first a screening was performed to reject faulty data. Therefore the rain sensor installed on the radiometer was used. Additionally, the brightness temperatures were cross-checked by eye to avoid defective calculations by using the training dataset or misinterpretations with regard to the validation profiles. For the following periods REGmod operators were calculated:

T1mMO: 1 month (Oct) NWP Model used for training

T3mMO: Three months (Oct - Dec 2011) used

T5mMO: Five months (Oct - Feb 2012) used

The even-numbered days of the entire five months period were generally used as validation dataset. Fig.2 shows the result of this intercomparison calculated on the basis of 104 cases. Plotted are the mean values (MV) of regression minus radiosonde profiles and the corresponding standard deviations (STD) separated according to the different training periods. Furthermore the STD of the radiosondes and the results of the NN algorithm are shown. All calculations were done for temperature and vapor density. Consequently, the major differences occur if only one month was used for the calculation of REGmod operators (T1mMO, red lines). Obviously, the absolute bias is significantly higher and the STD shows greater values above 2 km height for temperature and up to 2 km for water vapor compared to all other retrieval algorithms. Additionally to the small size of the sample it can be caused by the fact that October was the warmest as well as the most humid month of the campaign and therefore not adequately representative. On the other hand, the results are quite similar when matrices derived from three months (T3mMO, yellow) or five months (T5mMO, green) training periods are applied. It indicates that data of 3 three months could be sufficient for using site-specific REGmod operators within a microwave profiler network to redraw systematic errors, provided that the operators are continuously updated. Furthermore an accuracy assessment of the NN algorithm provided by the manufacturer was performed and is displayed in Fig.2. The retrievals show a large temperature bias increasing steadily with height above 1 km.

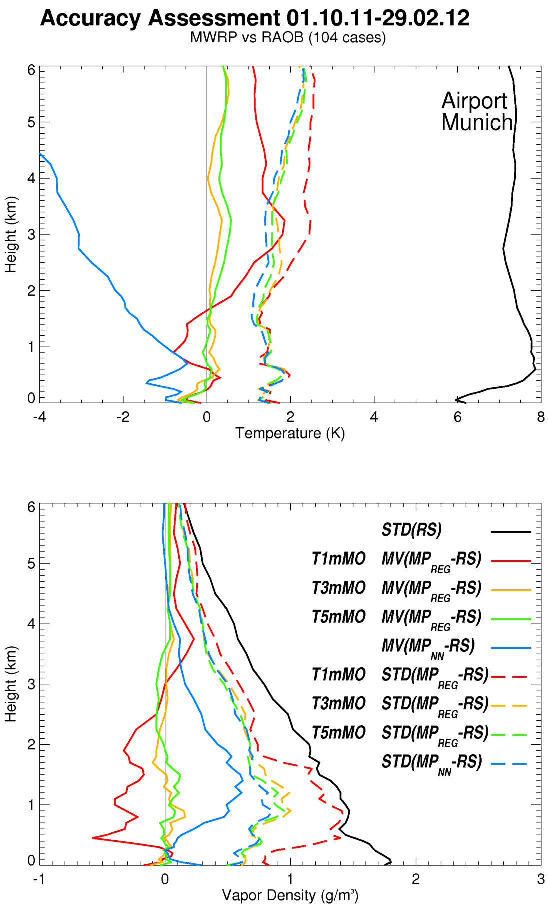

Figure2. Mean value (MV; solid line) and standard deviation (STD; dashed line) of retrieval minus radiosonde profiles for various retrieval methods in respect to temperature (top) and vapor density (bottom) during the campaign at Munich Airport from Oct 2011 - Feb 2012.

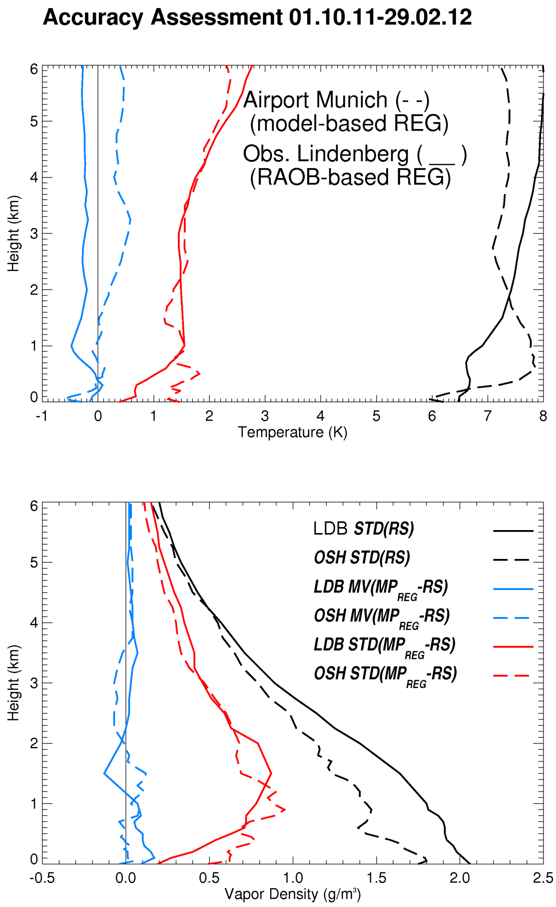

Figure3.Comparison of retrieval minus radiosonde profiles at two different sites in Lindenberg and Munich/Oberschleißheim.

In respect to water vapor maximum biases were found between 0.5 and 2.5 km. Nevertheless, the STD (retrieval - radiosonde) of temperature as well as for vapor density is slightly better than those of the REGmod methods. It shows the potential of this nonlinear method in case systematic deviations can be avoided. The relative development of profiles interrelated with boundary layer processes were reproduced adequately.

Finally a statistic is created, which compares retrievals calculated by the REGmod operator (T5mMO) for the temporary site in Munich with profiles from the reference site at Lindenberg observatory. These temperature and humidity profiles are derived by a retrieval approach basing on radiosonde and in situ MWRP measurements from the past. This method (REGobs) has been successfully applied for more than ten years. During the campaign the 12-channel MWRP (TP/WVP 3000) was running in Lindenberg, continuing the operational profiling required for the reference site. The airport site is located at 11.48°E longitude, 48.21°N latitude, height 446 m m.s.l. and the Lindenberg site at 14.12°E, 52.21° N, 125 m m.s.l..

Fig.3 shows mean values and standard deviations for both sites as performed in Fig.2. The absolute temperature bias is less then 0.5 K up to 6 km a.s.l. and quite similar in scale for both locations. The mean differences of vapor density are almost all less than 0.1 g/m^3. With regard to STD comparable values are achieved for heights above 700 m. For the levels near to the surface Lindenberg retrievals are significantly better if compared with the assigned radiosondes. This result is comprehendible if it is taken into account that for the airport site the validation is done with RAOBs launched about 10 km away. Especially in the lowest layers pronounced deviation can occur. Furthermore, for the training of the REGmod matrices forecast values were processed with their specific inherent errors. Given these preconditions, the REGmod method works amazingly well and offers an opportunity to produce comparable results within a network of microwave profilers.

4. CONCLUSIONS

The operation of MWRP was embedded in a campaign at Munich Airport site. The radiometer had been worked reliably and the data were used to test MWRP capabilities to operate within networks. In particular, NWP model data were used to produce weak-biased temperature and humidity profiles. In order to provide comparable retrievals, regression operators were calculated on the basis of various training data sets using forecasted profiles and MWRP measurements. The results of the model-based regression at the temporary site Munich and the regression at the permanent site Lindenberg were compared. The accuracy of retrievals are comparable for both methods above 700 m a.s.l.. The differences below 700 m are mainly caused by the use of forecast data instead of in situ observations. The usefulness of a model-based regression method to redraw systematic errors and to provide comparable results within a network has been demonstrated. Additionally, model data as well as radiometer measurements are always available in operational weather services, if required. That offers good prospects for a continuous and partially autonomuous updating of REGmod operators at a multitude of radiometer sites.

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