Towards the comparability of microwave observations: Results from a temporary profiler network during the WMO campaign LUAMI in November 2008

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ABSTRACT

The field campaign LUAMI was organized in November 2008 at the Lindenberg observatory focussed on improvements of radiosounding and on intercomparisons of both, up-to-date active and passive ground-based sensors. Additionally, a temporary network of passive microwave profilers at 8 stations in Europe was established to demonstrate the capabilities of these systems when deployed in operational meteorological networks.

The comparability of observations provided by different instruments operating at different sites is an essential precondition for any applications in climatology and numerical weather forecast. Independent data are needed to evaluate the profiler network. In the paper, calculations from the DWD forecast models COSMO-EU as well as GPS-derived Integrated Water Vapor (IWV) data are used to validate measurements from all participating sites. Results of the intercomparisons are presented and examples are shown, how systematic differences can be reduced.

1. INTRODUCTION

In the period of 3-30 November 2008 the Lindenberg upper-air method intercomparison (LUAMI) was organised by the Richard-Aßmann Observatory to improve our understanding of remote sensing and methods of measuring the basic atmospheric variables. The campaign had its emphasis on in-situ system intercomparisons using a number of operational as well as research radiosonde systems and was directed on essential contribution to the improvement and correction of water-vapor soundings from surface up to the middle stratosphere. Besides this main goal another major issue was embedded to examine a specific practical application. By means of a test network of microwave profilers supplying quality-proven data in real-time to a network hub at Lindenberg, investigations about the capabilities of passive microwave profiler systems for their use in operational meteorological networks were planned.

There has been increasing interest in continuous monitoring of the boundary layer structure. Microwave radiation emitted by the atmosphere contains information on meteorological parameters and therefore ground-based radiometric sounding is useful to derive temperature, water vapor and cloud liquid. Multichannel microwave radiometer enable profiling of these atmospheric parameters. Over the past decade a growing quantity of microwave profilers (MWP) has been introduced for a variety of meteorological applications, including numerical weather prediction (NWP) and climate research. The capability to provide observations in an unattended mode in nearly all-weather conditions stimulates an increasing interest for further practical use. Comparisons with numerical weather forecasts, routinely performed and presented at the Lindenberg observatory (www.dwd.de/mol -> ground-based remote sensing -> ground-based microwave radiometry -> actual results) show that significant short term temperature and moisture field variations are detected. Technical progress and decreasing costs enhance chances of the implementation of an operational network of microwave radiometers in future. However, comparability of provided data is a precondition necessary for further application. Forecasts from NWP models seem to be appropriate to test the homogeneity of the samples as they are calculated by means of a uniform procedure for all included locations.

2. EXPERIMENT DESCRIPTION AND INTERCOMPARISONS

In order to demonstrate the capabilities of passive MWP systems for their use in operational meteorological networks, scientific institutions and services which are ready to operate a MWP were invited to participate in LUAMI. In Table 1 stations are summarised which have been supplied their data to a network hub at Lindenberg. The variety of possible applications is reflected by the major tasks of the MWP's at their original location. Profilers are operated mainly at the stations to use it together with other ground-based sounding instruments as lidar, radar and windprofiler to characterise the atmospheric state in order to take part in WMO programs, satellite validation projects or other coordinated research activities.

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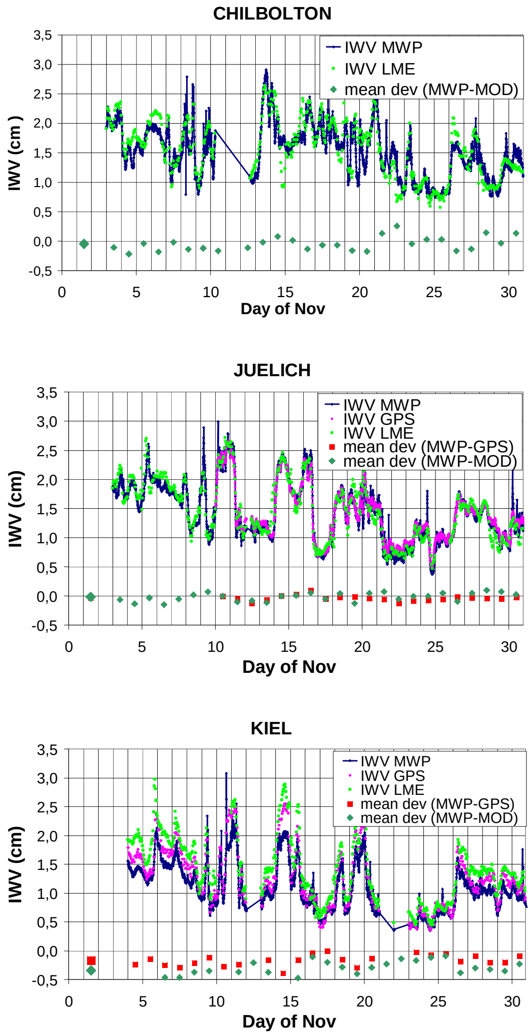
Table 1: *Site specifications of the MWP network*

Station	MWP type/ retrieval method	Lat	Lon	Height MWP (m)	Height Mode (m)l	Hght GPS (m)
Chilbolton	MP 1500A/ NN	51.14	1.44 W	84	75	/
Jülich	HATPRO/ NN	50.91	6.41 E	108	118	156
Kiel	HATPRO/ NN	54.33	10.15 E	35	34	34
Legnago	HATPRO/ NN	45.09	11.25 E	10	21	/
Lindenberg	MP 3000/ NN+REGobs	52.21	14.12 E	126	78	112
Payerne	HATPRO/ NN	46.81	6.94 E	491	507	612
Potenza	MP 3000/ NN	40.60	15.72 E	760	889	/
Potsdam	MP 3000A/ NN	52.38	13.05 E	76	78	174



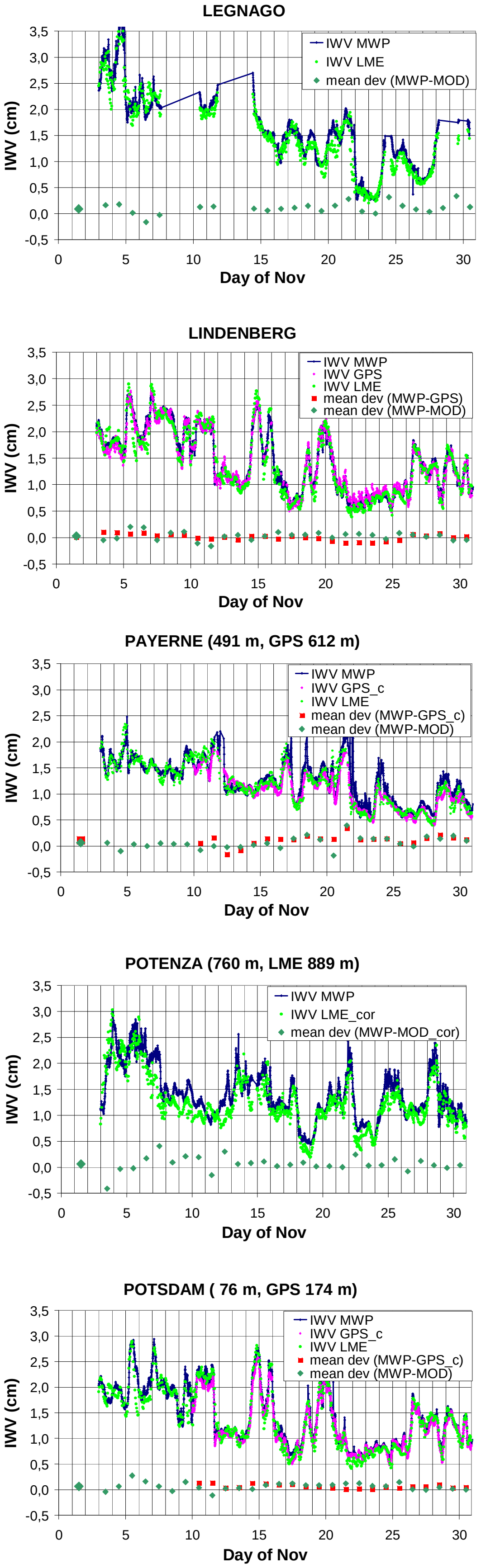


Figure 1: *Course of IWV of 8 participating sites during LUAMI observed by MWP (blue), LME (Local Model, green) and GPS (magenta). The daily mean deviation between MWP and Model, respectively GPS, is plotted as boxes. The mean deviation of the whole period is assigned to the 1*[st] *November.*

But even other objectives are in the focus of MWP applications as in Payerne (Switzerland) where three instruments are used as part of a measurement network for the operational meteorological surveillance of the Swiss nuclear power plants. The MWP which was mounted in Kiel during LUAMI is operating most of the time on board of the German research ship “Polarstern” to support the project OCEANET aimed at monitoring of material and energy exchange between ocean and atmosphere.

The experiment is not only a continuation of previous campaigns focused on intercomparisons performed at one location, but goes beyond this. The ambition of this work is to assess observations of a network as a whole. Measurements and vertical profiles of different radiometer types [1, 2] were used for validation of the temporary network. The IWV as well as temperature and humidity profiles, retrieved by a neural network, are included for comparisons with corresponding GPS-derived IWV, respectively NWP data extracted from the operational local forecast model (COSMO-EU) of the Deutscher Wetterdienst (DWD). In this study forecasts for 0, 1 ... 23 UTC of each day from the model initialized at 0 UTC are taken into account. Data of the NWP model are used for the analysis if the grid-points are as close as possible to the radiometer position. The mean height of the surface level model or the GPS-site can differ in mountainous terrain (Potenza, Payerne) as listed in Table 1. Corrections of IWV have been made if height differences are more than 100 m. At first efforts were undertaken for a pragmatic reduction of the dataset to 10-minute values. Therefore just one value of IWV and one profile was extracted for each interval. Averaged values are used if they are provided by the operators as for the station at Jülich. Data are not taken into account if they are flagged. Furthermore, an additional empirical screening was applied to eliminate outliers caused by rain or any other reason. The IWV of the model is calculated on the basis of the forecasted humidity profiles and have a temporal resolution of one hour. GPS-derived IWV is mainly provided for 15-minute periods and assigned to the corresponding 10-minute value of the MWP. The comparison of the integrated water vapor is shown In Figure 1. Plotted is the course of IWV during the campaign, derived from MWP, GPS and NWP model. Additionally, the mean deviation for each day at each station was calculated as well as the bias of the whole four-week period.

Table 2: Mean deviation of IWV during Nov 2008

Station	IWV BIAS (cm) (MWP-Model)	IWV BIAS (cm) (MWP-GPS)
Chilbolton	-0.045	
Jülich	0.017	-0.036
Kiel	-0.340	-0.165
Legnago	0.092	
Lindenberg	0.030	0.008
Payerne	0.061	0.111
Potenza	0.150	
Potsdam	0.065	0.064

The variability of water vapor is well reproduced at all sites. The mean deviation vs. GPS and NWP model is within the realms of current possibilities. The results are presented in Table 2. Only for Kiel higher discrepancies were found although the retrieved humidity profiles have only a small bias there as shown later.

MWP provides temperature and humidity profiles and therefore an additional validation is required extending the assessment of integrated values. For the study the same dataset is used, but this time we look at the vertical distribution of systematic deviations. Therefore retrievals at 0m, 500m, 1000m and 2500m were extracted and compared with forecasts at these levels. As an example, MWP retrievals and forecasts of water vapor at 500m are shown in Figure 2.

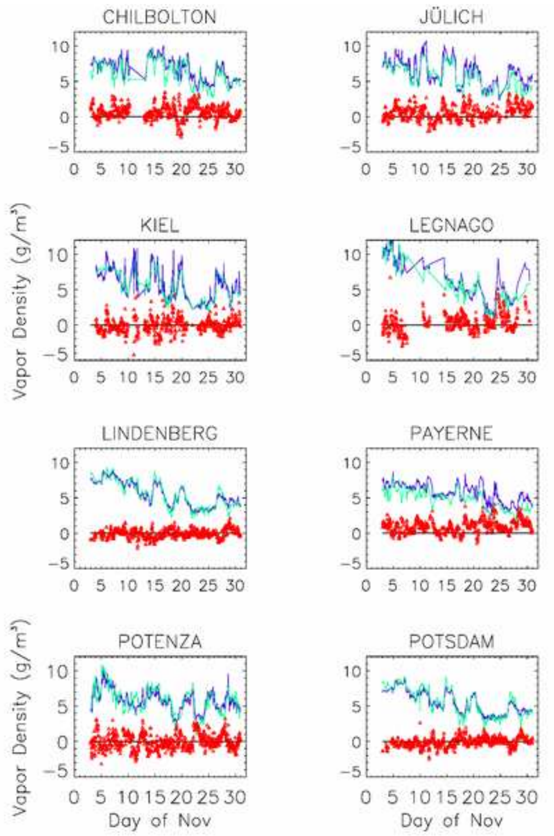


Figure 2: *Water vapor from MWP / Model and their difference (red) during LUAMI at 500 m.*

The differences of MWP and model data run along the axis for all stations. There are not any obvious time- or humidity-dependent trends recognisable. In contrary, there are evident distinctions in the variability of the differences between MWP and model. As at Lindenberg and Potsdam the standard deviation is rather low, the variability of the difference is higher at the other sites. Table 3 contains results of the comparison for the selected heights. Listed are the mean deviations between MWP retrieval and forecast model taking into account all unmarked data observed during LUAMI. Accordingly, a maximum of 628 data sets (28 days X 24 hours) are available at each station. The percentage really used for comparisons is registered in the last column. The table has two entries for Lindenberg, NN and REGobs. The reason for that results retrieved by different methods are available operationally.

Table 3: *BIAS between MWP retrieval and NWP forecast at selected height levels*

Station	Mean Dev. of Temperature (MWP-Model) (K)				
	0 m	500 m	1000 m	2500 m	Used %
Chilbolton	-	-	-	-	
Jülich	0.71	0.59	0.87	0.90	76
Kiel	-0.23	-0.04	0.37	0.91	81
Legnago	1.13	1.30	2.12	4.03	70
Lindenberg (NN)	0.09	-0.80	-1.36	-2.95	100
Lindenberg (REGobs)	0.17	0.18	-0.45	0.01	78
Payerne	0.60	0.38	0.10	-0.13	94
Potenza	0.83	-0.63	-0.71	-2.17	99
Potsdam	0.45	-0.35	-1.73	-2.21	91
	Mean Dev. of Vapor Density (VD) (g m^{-3})				
Chilbolton	0.86	0.69	0.40	-0.40	90
Jülich	0.80	0.64	0.49	-0.38	76
Kiel	0.08	0.02	-0.15	0.00	81
Legnago	0.18	0.46	0.49	0.07	70
Lindenberg (NN)	0.14	-0.04	-0.10	0.45	100
Lindenberg (REGobs)	-0.06	-0.06	-0.10	-0.22	78
Payerne	1.58	1.34	1.08	-0.02	94
Potenza	0.30	0.02	0.42	0.71	99
Potsdam	-0.13	-0.09	0.12	0.36	91

Additionally to the NN profiles an observation based regression method is applied for profiling. Simultaneous observations (Brightness Temperature) of the MWP and radiosondes from the past are used to calculate a regression operator. As the REGobs operator is not affected by errors in the absorption model or instrumental bias, systematic deviations are considerably reduced [3]. With respect to temperature a noticeable bias was found for Legnago and at higher levels >1000 m for Lindenberg (NN), Potsdam and Potenza. On the other hand, at Chilbolton, Jülich and Payerne an increased moist bias was detected.

3. HARMONISATION OF OBSERVATIONS

In addition to the analysis of observations in a network, the development of techniques to harmonise data was formulated as primary task of this study. Comparable results are the prerequisite for practical application in NWP and climatology. Radiosondes are available only at selected sites and the calculation of REGobs operators, successfully applied at the Lindenberg observatory, can't be performed to harmonise a multitude of network data. On this account, the suitability of forecast data is considered for reconciling MWP measurements. For this purpose data from Chilbolton, Jülich and Potsdam were selected to test the model-based regression method (REGmod). These stations were chosen because different radiometer types had been operated there inducing increased deviations in certain cases. For the experiment the remaining dataset was divided into two groups. One set, containing observations on odd-numbered days, was used for training of regression operators for each station. The other independent part was applied for validation. REGmod is a specific approach to the inversion of the radiative tranfer equation [3]. Profiles are calculated given by the solution:

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

where $\mathbf{C_{xy}}$ and $\mathbf{C_{yy}}$ represent respectively the covariance matrix of the profiles $\mathbf{x}$, extracted from the forecast model, and the simultaneous MWP measurements $\mathbf{y}$, and the autocovariance matrix of $\mathbf{y}$.

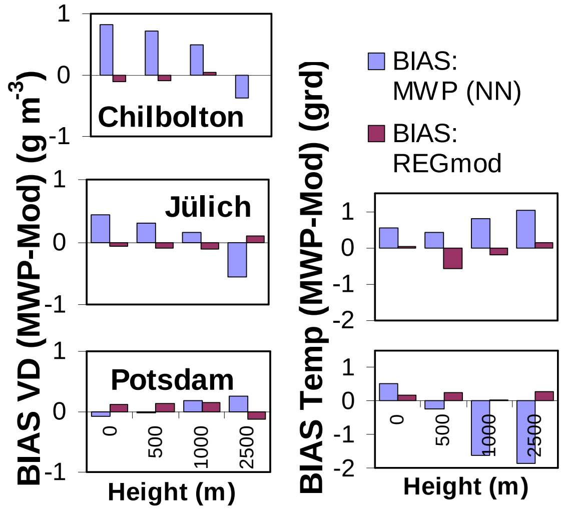


Figure 3: *Comparison of mean deviations before and after the harmonisation by a model-based regression.*

The results of the adjustments for the independent dataset are shown in Figure 3. The bias resulting from the NN-retrievals has been considerably improved by applying REGmod operators.

4. CONCLUSIONS

By means of a temporary network of 8 stations established during LUAMI in Nov 2008 it could be shown that microwave profilers are capable to provide reliable information of the atmospheric state continuously. In order to meet user requirements a method was proposed to produce comparable results at different observation sites. The usefulness of a model-based regression method has been successfully demonstrated.

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