A data assimilation experiment of temperature and humidity profiles from an international network of ground-based microwave radiometers

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***Abstract*—Temperature and humidity retrievals from an international network of ground-based microwave radiometers (MWR) have been collected to exploit the potential for data assimilation into Numerical Weather Prediction (NWP) modeling. This activity is carried on in the framework of the Hydrological cycle in the Mediterranean Experiment (HyMeX). The domain under analysis is the HyMeX West Mediterranean (WMed) target area, using data assimilation tools developed for the Météo-France Arome-WMed NWP system. In this paper we introduce the data set, discuss results concerning the observation-background statistics, and present preliminary results on the impact of MWR data assimilation into NWP.**

Keywords— ground-based microwave radiometer; data assimilation; numerical weather prediction.

I. Introduction

Nowadays, ground-based microwave radiometers (MWR) are robust instruments providing continuous unattended operations and real time accurate atmospheric observations under nearly all-weather conditions [1, 2]. However, the use of MWR data for assimilation into Numerical Weather Prediction (NWP) models has been limited to a few sporadic cases. For example, 4-Dimensional Variational Assimilation (4DVAR) of data from a single ground-based MWR has been attempted for a winter fog event [3]. More recently, an Observing System Simulation Experiment (OSSE) considering a simulated instrument network, including some 200 MWR, has been carried out for a winter storm case [4,5]. These studies all showed a tangible impact of MWR data into NWP, though results are limited to one case study each.

To our knowledge, the assimilation of data from a real network of ground-based MWR has never been attempted before. Thus, in the framework of the international Hydrological cycle in the Mediterranean Experiment (HyMeX) [6], temperature and humidity retrievals from an international continental-scale network of ground-based microwave radiometers (MWR) have been collected and synchronized to exploit the potential for data assimilation into Numerical Weather Prediction (NWP) modeling. This activity was carried on in preparation to the HyMeX Special Observing Period, held from September to November 2012 [7]. The domain under analysis is the HyMeX West Mediterranean (WMed) target area, using data assimilation tools developed for the Météo-France Arome-WMed NWP system.

II. DATA SET

A. Ground-based MWR observations

The recently established International Network of Ground-based Microwave Radiometers (MWRnet, http://cetemps.aquila.infn.it/mwrnet/) aims at defining the best practice for obtaining good quality MWR observations and retrievals, ultimately increasing the use of MWR data for NWP and other applications. A collaboration between Météo-France and MWRnet started in the context of HyMeX to investigate the potential for assimilating data from a real MWR network into NWP modeling. The observation data set exploited in this study includes temperature and humidity profiles from 13 MWR unit members of MWRnet. The period under analysis span from 15 October to 25 November 2011. The details on MWR location, operating institution, height above mean sea level (MSL), as well as the available retrieved products are reported in Table I. Temperature and/or humidity profiles data were collected from the 13 MWR units for more than one month.

B. NWP model

The NWP system used for this study is Arome-WMed, a particular version of the Arome system [8] covering the western part of the Mediterranean Sea. The domain of Arome-WMed together with the location of the MWR stations used here are displayed in Figure 1. Arome-WMed has a horizontal resolution of 2.5 km, a non-hydrostatic dynamical core, detailed physics inherited from a research model, and is coupled with the global Arpege NWP system. It employs a three-dimensional variational (3DVar) data assimilation (DA) system [9] with background covariances specially computed for the WMed domain. 3DVar analyses are performed every three hours and provide new initial states for subsequent forecasts. Data assimilated by the Arome DA system already include a comprehensive set of observations, such as radiosondes, wind profilers, aircrafts, ships, buoys, automatic weather stations, satellite radiometers, weather radars, ground-based GPS, satellite GPS radio-occultation. In this study, the period from 15 October to 25 November 2011 has been simulated with Arome-WMed, including several heavy precipitation events in Spain, France, and Italy.

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TABLE I. LOCATION, OPERATING INSTITUTION, HEIGHT ABOVE MEAN SEA LEVEL (MSL), AND AVAILABLE PRODUCTS (PROD.) FOR THE 13 MWR PARTICIPATING TO THIS STUDY. H AND T STAND FOR HUMIDITY AND TEMPERATURE PROFILES, RESPECTIVELY.

Station	**Institution**	**Lat**	**Lon**	**MSL**	**Prod.**
Bern	IAP	46.88	7.46	905	H
Cagliari	INAF/OAC	39.5	9.24	623	T, H
Granada	CEAMA-UGR	37.16	-3.6	683	T, H
Kloten	MeteoSwiss	47.48	8.53	436	T
Lampedusa	ENEA	35.51	12.34	50	T, H
Madrid	UniLeon	40.49	-3.46	620	T, H
Padova	ARPAV	45.4	11.89	30	T
Payerne	MeteoSwiss	46.82	6.95	491	T, H
Potenza	IMAA/CNR	40.6	15.72	760	T, H
Rovigo	ARPAV	45.07	11.78	23	T
Schaffhausen	MeteoSwiss	47.68	6.62	437	T
Schneefernerhaus	UniCologne	47.42	10.98	2650	T, H
Toulouse	ONERA	43.38	1.29	144	T, H

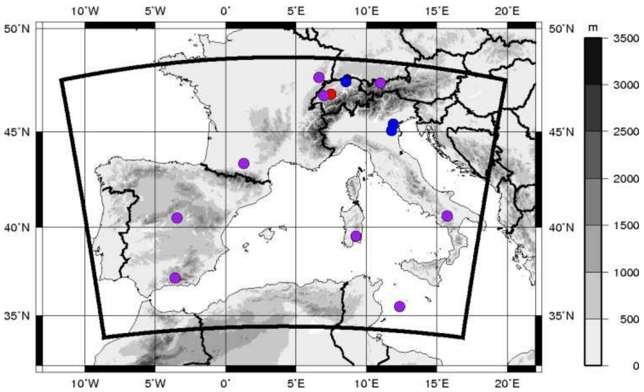

Fig. 1. Domain of Arome WMed (black bold line) and locations of MWR sites (red: humidity only, blue: temperature only, purple: humidity and temperature).

In order to check the consistency between MWR products and 3-h model forecasts, observation-minus-background (O-B) differences and statistics have been computed for temperature and relative humidity profiles at each site. An example of O-B temperature differences for one site and the whole period is shown in Figure 2. The daily cycle as well as the longer scale modulation measured by the MWR are well captured by the model. Differences seem well centered and usually are within 2 K, though can exceptionally exceed 5 K. O-B statistics are computed from O-B differences at each site. Results are shown in Figure 3, in terms of bias and standard deviation for both temperature and relative humidity. Results show that the standard deviations of MWR retrievals are comparable with those of radiosondes (not shown), while biases are generally larger. The larger biases are due to a combination of model bias, instrument bias, and retrieval bias. Methods to produce weakly biased MWR retrievals are already available [2,10], though were not used operationally at the sites considered here, except for Payerne.

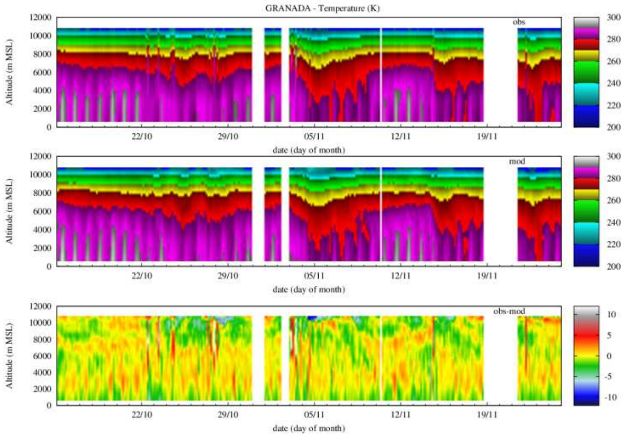

Fig. 2. Example of colocated temperature profile observations from MWR (top) and background simulations from Arome-WMed (middle). Observation-background (O-B) differences are shown in the bottom panel (Granada, Spain).

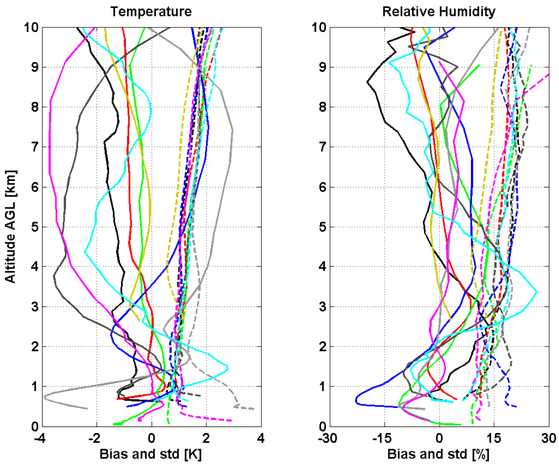

Fig. 3. Observation-minus-background bias (solid) and standard deviation (dashed) for temperature (left) and relative humidity (right). Different colors indicate different sites.

III. DATA ASSIMILATION IMPACT: PRELIMINARY RESULTS

In order to investigate the impact of MWR data assimilation, we run four versions of the Arome-WMed model for the period under analysis (15 October to 25 November). The control (CTRL) run uses 3DVAR to assimilate all the operational data described above, but not the MWR products. The other three experimental runs assimilate, in addition to operational data, MWR products: temperature profiles only (DA_T), humidity profiles only (DA_U), and both temperature and humidity profiles (DA_TU).

The assimilation set-up is such that every 3 hours the model starts from new initial conditions that include operational observations plus possibly MWR data. At 00 UTC, the forecast lasts 30 hours, while at other times (03, 06, 09, 12, 15, 18, 21 UTC) only 3-h forecasts are produced. For istance, when computing initial conditions at 12 UTC, operational observations and MWR products (temperature, humidity or temperature and humidity, depending upon experimental run) are merged with a 3-h forecast that started at 09 UTC from an analysis that took into account operational and MWR observations. Thus, the information brought by MWR observations at a given time is indirectly propagated throughout the experiment through the 3-h forecasts. An estimate of the observation error is needed to run variational data assimilation. In this experiment, we set the observation error to 12 % for relative humidity, while for temperature it depends on altitude.

To get a qualitative and quantitative measure of the impact of MWR data assimilation, the output of the four model runs need to be compared against independent reference data. This was done using 24-h accumulated precipitation measured by a dense rain gauge network deployed in Europe. Validation against other data sources (such as surface and upper air temperature and humidity measurements) are in progress. A qualitative example is pictured in Figure 4 for the case study of 3-4 November 2011 over Cévennes, France. Figure 4 shows that the CTRL and DA_TU runs provide significantly different precipitation patterns. This demonstrates that, despite the fact that 3DVAR already assimilates a comprehensive set of observations (from ground, radiosonde, and satellite) in the control run, it is still sensitive to MWR data. For the case study in Figure 4, we can say that DA_TU run, which also assimilates MWR temperature and humidity profiles, provides a 24-h accumulated precipitation field that better matches the rain gauge measurements. For example, it's evident that the MWR data assimilation helps predicting some of the heaviest precipitation, which was completely missed by the CTRL run (e.g. at 44°N; 3.5°E).

For a quantitative analysis, we computed statistical scores from the measured vs. simulated 24-h accumulated precipitation for the entire period under analysis. These results are summarized in Table II. With respect to the CTRL run, the MWR data assimilation shows only slightly better bias and correlation coefficient. Other skill scores such as equitable threat score and frequency bias, and other accumulation periods (1 h, 3 h, 6 h, and 12 h) yield similar trends (not shown). Thus, from this analysis, we can conclude that the MWR data assimilation shows neutral-to-positive impact. This result is quite encouraging, as from one side it demonstrates that MWR data have already enough quality to be safely assimilated into NWP, and from the other it leaves room for improvement. To confirm the above results, a similar analysis is undergoing using other source of comparison, such as surface and upper air temperature and humidity measurements.

TABLE II. SKILL SCORES FOR 24-H ACCUMULATED PRECIPITATION FOR THE ENTIRE PERIOD UNDER ANALYSIS (> 1-MONTH)

	Bias (mm)	**Rmse (mm)**	**CorrCoef**
CTRL	-0.23	6.58	0.62
DA_T	-0.22	6.71	0.64
DA_U	-0.24	6.61	0.64
DA_TU	-0.22	6.62	0.64

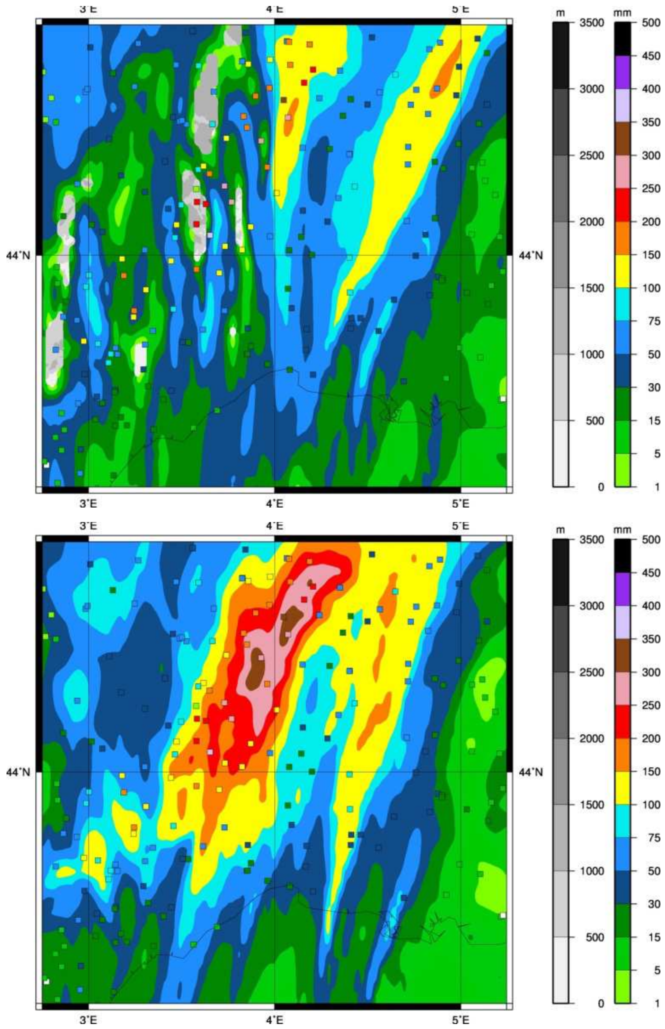

Fig. 4. 24-h accumulated precipitation measured by raingauges (squares) and simulated by the Arome WMed control run (top) and with MWR data assimilation DA_TU (bottom). Case of 3-4 November 2011, Cévennes, France.

IV. SUMMARY AND OUTLOOK

A comprehensive set of ground-based MWR products and model runs has been collected and analyzed to demonstrate the feasibility and impact of MWR data assimilation into NWP model. Results from the first data assimilation experiment of products generated by a continental scale ground-based MWR network demonstrated that (i) MWR data can be safely assimilated into NWP and (ii) the MWR data assimilation shows neutral-to-positive impact on forecasts skills. While these results are still under investigation, possible reasons for low impact include the retrieval biases and the relatively low amount of data with respect to other operationally assimilated data. In this regard, activities have been started within the EU COST Action TOPROF (TOwards operational ground based PROFiling with ceilometers, doppler lidars and microwave radiometers for improving weather forecasts), towards the optimization of MWR data assimilation into NWP models and the evaluation of their impact on analyses and forecasts.

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