APPLICATION OF A PBL PROFILING NETWORK TO AIR QUALITY IN THE PO VALLEY REGION VENETO -- ELEMENTS OF AN NWP MODEL VALIDATION

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INTRODUCTION

In response to the frequent air quality emergencies in the north-eastern Italian region Veneto, especially during the cold season, the Centro Meteorologico di Teolo (CMT) of the Regional Agency for Protection and Prevention of the Environment of the region Veneto (ARPAV) has recently installed a network of four passive radiometers and four SODAR for air quality monitoring purposes. The network, co-funded by the European Union, Italy, and the region of Veneto in the framework of the project DOCUP (DOCumento Unico di Programmazione), is the first of its kind in Italy. Compared to radio soundings these profiler data have a significantly higher temporal and vertical resolution, a feature which allows monitoring of key Planetary Boundary Layer (PBL) phenomena such as strong low-level static stability, temperature inversions and boundary layer jets.

In the context of mesoscale Numerical Weather Prediction (NWP) and meteorological modelling for air quality purposes such observations are ideal to validate a model’s potential to represent such structures. Also, assimilation these data is a unique way to improve the depiction of the PBL in the model’s initial conditions. For both these fields, a good data quality is most important. As reported in studies made in the framework of the FUMAPEX Project (S. Jongen and G. Bonafè 2006; B. Fay et al.2005) a good simulation of the thermal profile in the levels near the surface is very important for air quality assessment purposes.

In Ferrario et al. (2006, referred to as F06 hereafter) a first assessment of the quality of the MTP5-HE passive microwave radiometers has been performed. They found that there is a very good agreement between the MTP5-HE located in Rovigo with the radio sounding in Bologna, better at night than at midday, still very acceptable for the radiometer located in Padova, although featuring a distinct warm bias of the order of 1 K. The SODAR are two PCS2000-24 and two PCS2000-64 manufactured by Metek. SODAR is considered a well established technology (Antonious et al. 2003) and the manufacturer declared accuracy of the data is of 0.3m/s for wind intensity and 5-8° for wind direction. A critical aspect of these data concerns the vertical range, which is dependent on atmospheric stability yielding a strong decrease on the number of sampling with increasing altitude.

In this contribution, the second year of deployment of the CMT PBL profiler network is presented. In addition to F06 the RPG radiometer HATPRO amd 4 Sodars are evaluated. All the instruments are then compared to two mesoscale one global NWP models.

DATA SET

The 3 MTP5-HE passive microwave radiometers are manufactured by Attex in Russia and distributed by Kipp & Zonen. All instruments are set to have the first level at 50m. The HATPRO radiometer is manufactured by Radiometer Physics GmbH. It measures radiation emitted by the atmosphere in 14 channels (molecular oxygen and water vapour lines) and retrieves profiles of temperature and humidity (Rose et al. 2005). The instrument, installed in Legnago (RVR), performs also a vertical scan every 20’ to increase vertical resolution for temperature (50-75m up to 2000m) in the PBL; nominal accuracy is 1K. The measuring sites are flat and rural (Legnago), flat and urban (Padua, RPD and Rovigo, RRO), on smooth hills (Teolo) and in a closed valley with very very light winds and strong inversions (S. Giustina, Val Belluna). All Sodars are set to yield the first level at 40m and temporal resolution of 15'.

The present analysis spans two years of data split in two periods, i.e. 2005 (1 April 2005 – 31 March 2006) and 2006 (1 April 2006 – 31 March 2007). The Sodar data used for model verification are from 1 May 2006 – 31 March 2007. Table 1 reports fairly good data availability indicating the instrument's potential for operational deployment with an overall performance often larger than 75%.

Table 1. Information on instrument settings and data availability. The vertical range for SODAR is the altitude were data availability drops to 30% of the one at the first level (40m).

	SODAR				MTP5-HE			HATPRO
	Padova	S.Giustina	Legnago	Teolo	Padova	S.Giustina	Rovigo	Legnago
Vert. resol	20m	20m	20m	20m	50m	50m	50m	50-75m
Temp.resol	15'	15'	15'	15'	5'	5'	5'	20'
V. range	200m	220m	200m	440m	1000m	1000m	1000m	2000m
#data 2006	64%	72%	61%	83%	97%	75%	78%	54%
#data 2007	75%	73%	66%	85%	97%	60%	92%	63%

As none of the radiometers are collocated with a radio sounding, the times at which the soundings of Milano and Bologna are close in the lowermost kilometre, i.e. the temperature difference is smaller than 2K, were chosen for comparison. These are taken as conditions of homogeneity for which we can assume that the radiometers of Padua and Rovigo should be reasonably close to the radio soundings. All data have been interpolated on a vertical grid 50m spacing up to 1000m. For the HATPRO the grid was adapted to reach 10'000m, while for the Sodars the comparison with the model analyses was performed on a 20m grid with a vertical range of some 200m.

RESULTS

Analysis of the radiometer-derived temperature profiles

In Ferrario et al. (2006) very good agreement between radiometer RRO and the Bologna radio sounding (16144) was found, especially at 00UTC. One peculiarity worth mentioning is that the night-time profile of the radiometer has a cold bias while the daytime profile features a warm bias. For RPD a warm bias is present both at 00 and 12UTC, probably due to the urban site. The biases and standard deviations for the periods 2005 and 2006 are reported in Table 2. One unfortunate feature is that the correspondence of the radiometer profiles with the radio soundings is less good when the conditions of a horizontally homogeneous atmosphere would suggest agreement. E.g. the average warm bias of RPD profile w.r.t. the Bologna radio sounding degraded from 1K at 00UTC and 1.5K at 12 UTC to roughly 1.5K and 3K respectively, where the disagreement is larger above 500m than closer to the ground.

On a more positive note, the HATPRO radiometer, not included in F06, features excellent agreement (within 1K) with the Bologna sounding for almost the entire profile up to 10'000m (Fig.1). Largest disagreement (< 2K) is found below, say, 2000m. HATPRO tends to exhibit a cold bias below 4000m, while above this level a slight warm bias is present. Note that the sample size here is only 16 for 00UTC and 14 for 12UTC, as agreement within 2K was required for the Milano and Bologna soundings to meet the homogeneity criterion.

Table 2. Comparison of bias and standard deviation for the periods 2005 and 2006 for the radiometer-derived temperature profiles, and bias and RMSE for the period of the NWP model verification (below =).

	Padova (RPD)	Legnago (RVR)	Rovigo (RRO)
BIAS 2006 (K)	< 1 at 12UTC > 1.5 at 00UTC	- 0.9 - 0.2	1
STD 2006 (K)	1.5K	2 below 500m 1.5 above	1/1.5 at 00/12UTC, 1-1.5 above 500m
BIAS 2007 (K)	0.4 - 2.2	-1.6 : -0.8	0.5/~1.5 at 00/12UTC > 2 above 500m
Distance Km	97	81	62
# data	117	74	110
BIAS (K)	1.72	-0.54	1.08
RMSE (K)	2.31	1.69	1.81
R	0.98	0.98	0.99

Temperature inversions

Compilation of the temperature inversions for period 2006 (Fig. 2) confirms the large number of stable situation in the Po Valley, and reveals that about ¾ of these inversions are confined within first 200m. Note that the frequency of inversions depends on location, e.g. for the urban site of Padova (RPD) exhibits significantly more inversions at higher levels.

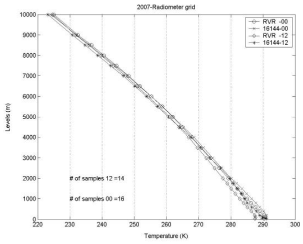

Fig. 1; Comparison between the HATPRO radiometer in Legnago and Radio sounding in Bologna (distance 74 km).

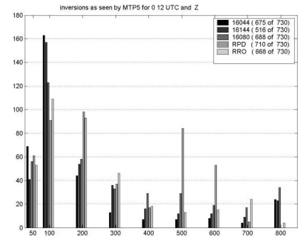

Fig. 2; Histogram of the height of temperature inversions (m). The legend includes the number of available profiles.with a maximum of 730.

NWP verification of PBL temperature

The results of the comparison between two limited area (COSMO model Italy (CI) and Switzerland (CCH)) and one global (ECMWF IFS) NWP model with the CMT radiometers of 1 year of data starting 1 May 2005 are summarized in Tab.3. The model analyses are well correlated in Padua, Legnago and Rovigo, not for S. Giustina. The bias is well below 1K for Legnago and Rovigo (both rural sites in the plain) and in the order of 2K for Padova (urban site) and S. Giustina. Overall, CCH seems to have the smallest bias. The RMSE is in the order of 2K for the sites in the plain, whereas for the valley station S. Giustina it is about 10K! This seems to indicate the models' inability to correctly portray the PBL in complex topography.

These values should be analysed in the light of the radiometer errors, bearing in mind that the model analyses are expected to be quite close to the radio soundings. Indeed, the comparison between radiometers and radio soundings (Tab. 2) show that both bias and RMSE are of the same order as the model analysis error for RPD, and less than 1K larger for RVR and RRO.

The opposite sign in the bias is due to the fact that the reference for the model verification is the set of profilers while for the profiler evaluation is against the radio soundings.

Table 3. Average of statistical parameter from 50m to 1000m above ground, 'Distance' is the distance from model point to the radiometer site.

	Padova (RPD)			Legnago (RVR)			Rovigo (RRO)			S. Giustina (RSG)		
	IFS	CI	CCH	IFS	CI	CCH	IFS	CI	CCH	IFS	CI	CCH
distance	13.9	2.9	2.9	22.3	3.8	3.8	18.7	4.3	4.3	9.9	2.2	6.4
# data	1409	8315	8455	918	5405	5539	1031	5972	6145	1156	6810	6913
BIAS	-2.0	-1.2	-1.5	1.4	0.7	0.5	0.1	-0.2	-0.5	-2.5	-2.2	-0.9
RMSE	2.5	1.8	2.1	2.6	2.3	2.2	2.6	2.7	2.7	10.3	10.0	9.9
R	0.99	0.99	0.98	0.94	0.95	0.94	0.94	0.95	0.95	0.70	0.71	0.69

Modelled temperature inversions

To further study the NWP model's ability to represent the PBL number and strength of nocturnal temperature inversions, particularly important for pollutant dispersion in the Po Valley (S. Jongen and G. Bonafè 2006), are investigated. The radiometers' data report 37% of total time with inversions in Padua, 49% in Rovigo and 60% in Legnago. This spatial variability in not well represented in the limited area model analysis which give inversions always around 45% of the time for CI and 35% for CCH. The global IFS is doing better giving frequencies of 37% for Padua, 44% for Rovigo, and 51% for Legnago. Figure 3 reports the histograms for the inversion strength, showing quite reasonable agreement for the weaker cases, whereas an underestimation for the strongest cases is evident (more frequent in S. Giustina and Legnago). Surprisingly the IFS seems to outperform CI and, especially CCH, which exhibits a systematic deficit of inversions. Figure 4 confirms that CCH tends to have the weakest vertical temperature gradients for all sites with no average inversion at midnight in S. Giustina, whereas IFS even seems to even exaggerate the inversions.

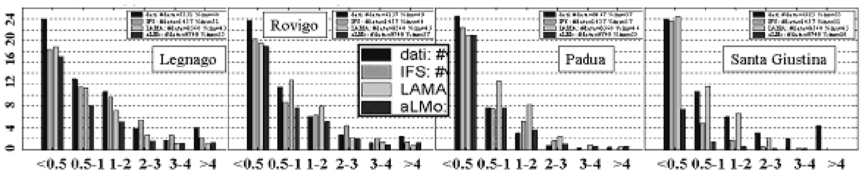

Fig. 3; Histogram of temperature inversion strength (max T in profile - T50 in K) in % on the total data.

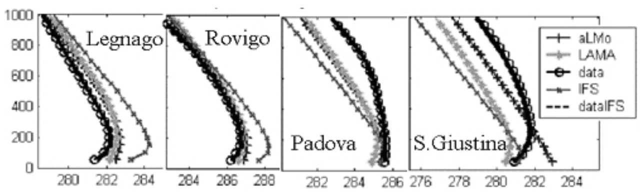

Fig. 4; Average temperature profile in K for 00UTC for various stations and models.

NWP verification of PBL winds

A first evaluation of the model performances versus the Sodar measurements has been done in Pernigotti et al. (2007). The results include biases in the range of 0.2-0.4 m/s with RMSE in the order of 2.5 m/s, values that become significantly worse for the valley station S. Giustina. As to wind direction, percentage of success within 30° is around 50%, within 60° is abound 75% for the stations in the plain, again with significantly worse values for the valley station.

Compared to surface wind verification (Pernigotti et al. 2005) the RMSE seems to be larger for the profiles (about 1.5m/s for surface stations, around 2.5 m/s here).

CONCLUSIONS

In this contribution an analysis of two years of boundary layer temperature and wind profiles, as well as a one-year model verification was performed. The main findings are as follows:

- the MTP5-HE radiometers work very efficiently and reached levels of data availability larger than 90% (cf. also F06);
- comparison of radiometer profiles with radio soundings in homogeneous atmospheric conditions (MI - BO < 2K) generally yield average biases in the order of 0.5-1.5K and standard deviations of about 1.5K);
- compilation of the temperature inversions for the period 2006, confirms the large number of stable situation in the Po Valley, and reveals that the larger part of these inversions are confined within first 200m (75%);
- the agreement is better for 2005 than for 2006 (reasons still unknown);
- comparison of three NWP models with the CMT PBL profilers exhibit differences which are slightly larger that the differences between radiometer and radio sounding, reflecting the fact that the model analysis are quite close to the radio soundings;
- results for the wind verification indicate that the limited area models CI and CCH are not significantly better than the global IFS, neither in the plain nor in a mountain valley. This will have to be revisited when next-generation high-resolution models will have mesh sizes in the order of 1km, as will be in the near future for the COSMO model.
- results for temperature profile and inversion analysis are quite surprising, in that IFS seems to be cope better with the PBL variability over the Po Valley.

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