Selected COSMO-2 verification results over North-eastern Italian Veneto

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1 Introduction

The regional meteorological service of the north-eastern Italian region Veneto, the Centro Meteorologico di Teolo (CMT) is part of the Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV). The CMT run a dense network of automatic weather stations (AWS), counting some 200 over the entire territory, a good part of which are transmitted in near real time. Also, in 2005 a network of planetary boundary layer (PBL) profilers was installed, more precisely four passive microwave radiometers (MWR) and four SODARs [1]. These observations are used to verify the COSMO-2 over the Veneto territory, which can be thought of as a domain roughly split in four parts with distinct climatological characteristics, i.e. going from south to north (Fig. 1) there is the plain, the flat Po Valley portion of Veneto, which spans about two thirds of the area, the prealpine foothills and the prealpine chain, which is a significant barrier for southerly flows, the Val Belluna, a major Alpine valley just north of the prealpine chain, and finally the Dolomite mountains, a high and inner Alpine mountain area.

In this contribution selected verification results of the screen-level temperature, the temperature profiles and the PBL mixing height is given. The data set is described in section 2, the results in section 3, while some conclusions are summarized in the final section.

2 Data sets

Observations used for this analysis were acquired from the CMT AWS network, which totals roughly 200 stations, 109 of which have been used for verification of the screen-level temperature, and 22 for the ten-meter wind over the plain (Fig. 1). Verification of ten-meter wind is still in progress and will be presented in a contribution to follow, as for precipitation, for which the network consists of 161 real time tipping bucket gauges. Given the significantly differing climate zones in Veneto these stations have been grouped in the following sets:

- Dolomiti: 19 mountain stations located in the Dolomite mountains at altitudes between about 600 and 2200 m;
- Val Belluna: 8 stations located in the major Alpine valley Val Belluna just south of the Dolomite mountains and just north of the pre-alpine chain; the altitude of the stations varies between about 300 and 1400 m;
- Prealpi: 25 stations on the pre-alpine chain with altitudes between 100 and 1100 m;
- Plain: 57 stations on the Veneto plain with altitudes generally close to sea-level, occasionally up to about 100 m; for the screen-level wind verification 22 stations, equipped with anemometers at 10 m, i.e. excluding the stations with anemometers at 2 m for agrometeorological purposes;

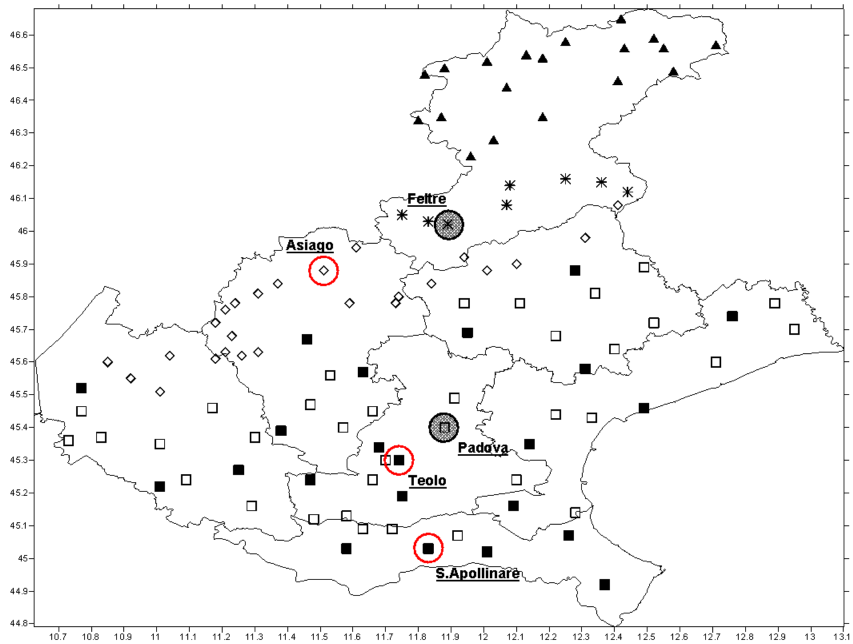

Figure 1: Layout of the ARPAV automatic surface station network desigend to cover the entire region Veneto (political contours). The stations were subdivided in four groups, i.e. high mountain stations (△), the major mountain valley Val Belluna (∗), the prealpine chain (⋄), and the plain (□). The filled squares denote surface stations in the plain with an anemometer at $10\,m$. Selected results for the three circled stations Asiago, Teolo, and S. Apollinare are shown in Fig.3. The two microwave radiometers used for this study are located in the plain in the city centre of Padova and in the Val Belluna in Feltre (shaded circles).

- vertical temperature profiles are verified for two sites, one in Padova, the other in the Val Belluna city of Feltre.

In addition, time series for a hot and cold multi-day period are analyzed for the stations Asiago, located on a high plateau, Teolo, located on the Euganean Hills emerging some $150\,m$ in the middle of the flat plain, and the plain station S. Apollinare.

The verification period comprises the two cold season months January and February 2010, and a the warm season spanning May to August 2011. The overall data availability for the verification period amounts to 97.4 %.

3 Results

Verification results of the screen-level temperature are shown in Fig. 2 for four groups of stations pertaining to the four distinctly different climatic zones of Veneto, i.e. the flat plain, the prealpine chain, the major Alpine valley Val Belluna, and the Alpine Dolomites (Fig. 1). The bias and standard deviation exhibit a clear diurnal cycle with the strongest warm bias during the night. Perhaps surprisingly, both statistical error measures are lowest for the Alpine Dolomites, a mixture of valley, slope and crest stations with bias values around $1.25\,K$ during the night and around or below $0.5\,K$ during the day, with two distinct minima mid morning and late afternoon. The corresponding values for the plain are about twice as high, in the early afternoon more than three times as high reaching $1.8\,K$, the maximum values attained during the night are as high as $3\,K$. For the night hours the two groups Prealpi and Val Belluna are in between the Dolomiti and the Plain groups, while during the daytime the Val Belluna stations show the largest bias reaching $2\,K$. This behaviour is reflected in

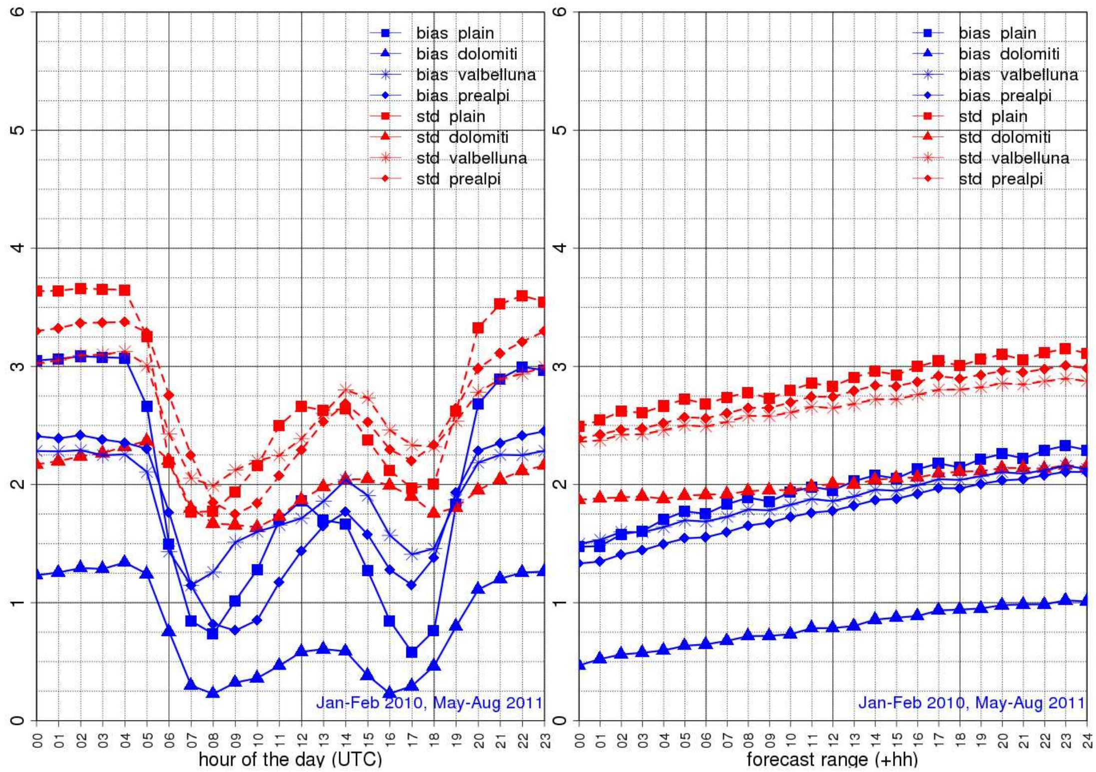

Figure 2: Bias (blue solid lines) and standard deviation (red dashed lines) for the four groups of ARPAV stations (Fig. 1), i.e. for the high mountain (△), the major mountain valley Val Belluna (∗), the prealpine chain (⋄), and the plain (□). The left panel shows the error in dependence on the hour of the day (UTC), while the right panel shows the dependence on the forecast range (+hh). The data set spans two cold and four warm season months.

the standard deviation. The structure of this diurnal cycle of the error is indicative for the model's underestimation of the diurnal temperature excursions, i.e. the warm bias in the minimum and maximum temperature, evidently larger for the night.

The dependence of the error from the forecast range shows a monotonour increase from $0.5\,K$ at $+01\,h$ to $1.0\,K$ at $+24\,h$ for the Dolomites and, again, significantly higher for the plain, where the bias ranges from $1.5\,K$ at $+01\,h$ to $2.3\,K$ at $+24\,h$. The prealpine and the Val Belluna stations have an error very similar to the plain.

Figure 3 illustrates one possible reason for the relatively large statistical forecast errors for three stations (see Fig. 1). Most notably, for the Asiago station (top panels), located on an elevated plain at around $1000\,masl$ on the prealpine chain, the COSMO-2 frequently severely underestimates the nocturnal cooling, sometimes by as much as $10\,K$, both for the heat wave and the cold period. This behaviour is even more pronounced for a nearby station (Marcesina), situated in a shallow basin, and for which the radiative cooling at night can be very significant (not shown). For the cold period the diurnal cycle is underestimated and the highs missed by several Kelvins, while for the heat wave these latter seem slightly overestimated. Note COSMO-2's different behaviour for 17 January, when the passage of an upper-level caused overcast skies over Veneto altered the conditions for the radiativ balance at the surface, the model underestimated the temperature during the night and for most of the day.

This same behaviour is found also for many of the Veneto plain stations as for example

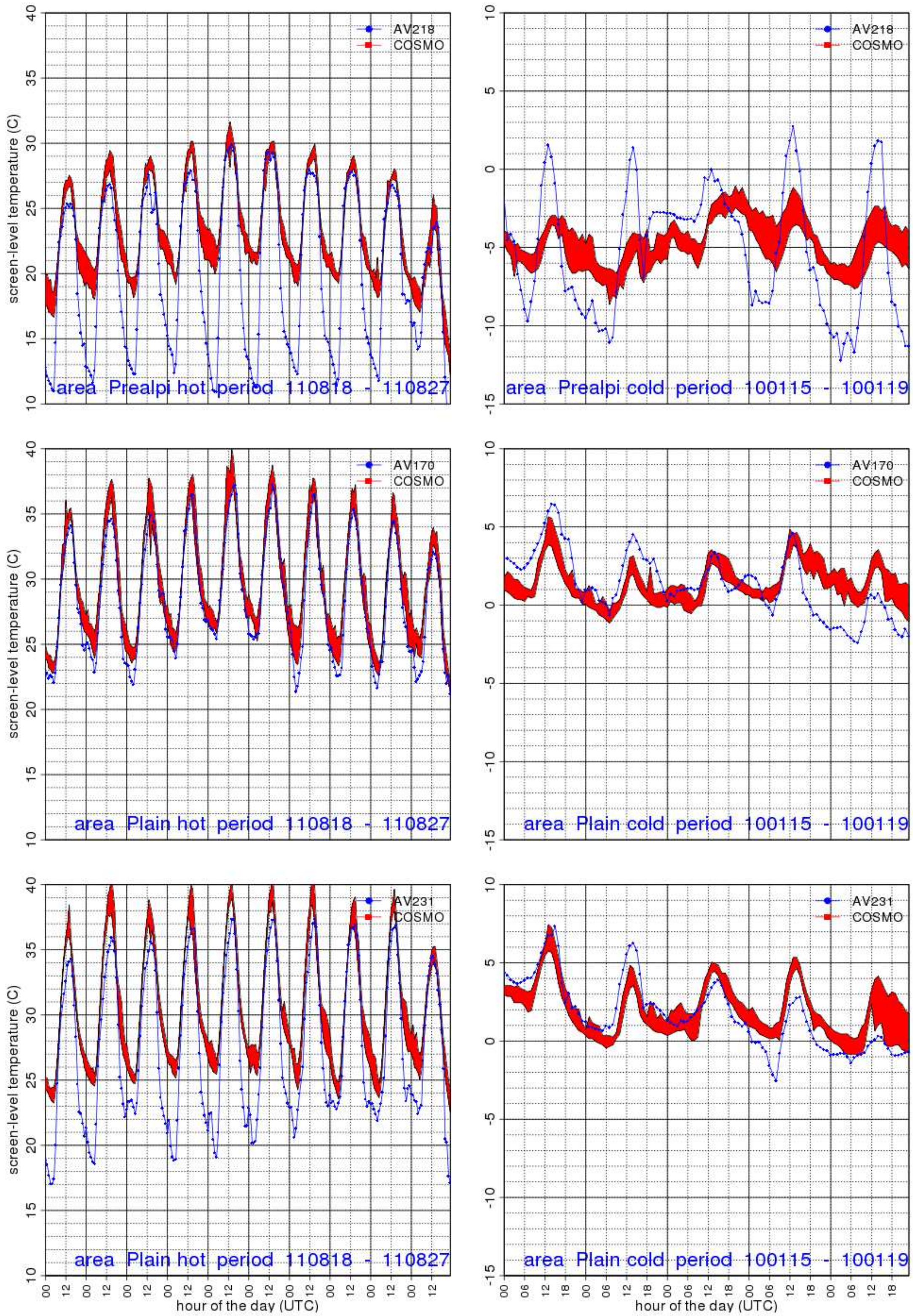

Figure 3: Time series of screen-level temperature observations (blue solid line) and COSMO-2 forecasts (red shading) for the three selected ARPA Veneto stations Asiago (AV218, top panels), Teolo (AV170, mid panels), and S. Apollinare (AV231 bottom panels, see Fig. 1). The left column panel are for the 18-28 August 2011 heatwave, while the right column panels for a period of cold and stable weather 15-19 January 2010. The red shaded area denotes the forecast range for each hour as spanned by the COSMO-2 time-lagged ensemble.

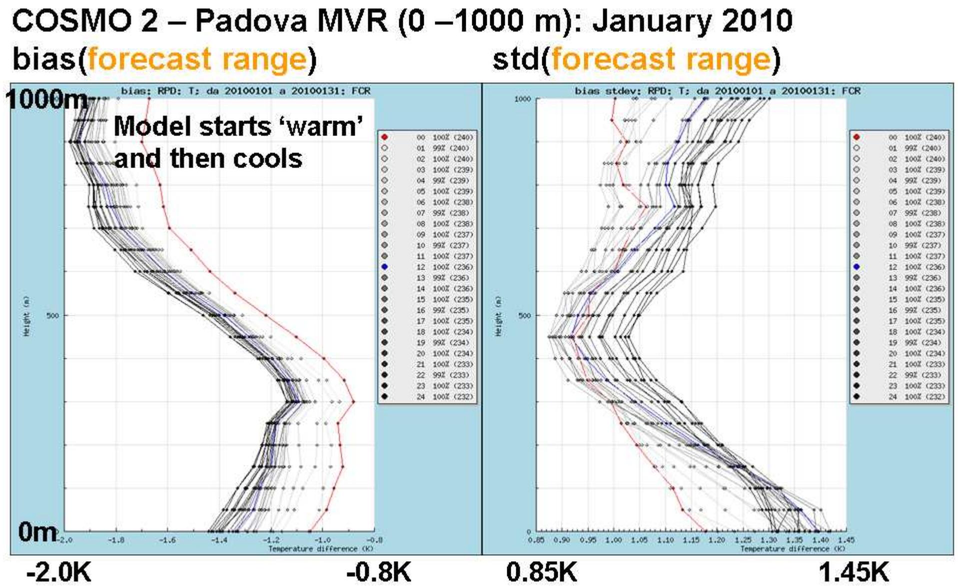

Figure 4: Bias and standard deviation of the COSMO-2 temperature profile against the MWR retrieval for the site Padova as a function of forecast range for the month of January 2010. The vertical axes denote the height above ground, the horizontal axes temperature. The darker the lines the longer the forecast range, while the +00 h line is in red and the +12 h line is in blue. The number in the legend denote percent of nominally available data and number of data pairs.

S. Apollinare (bottom panels), for many plain stations COSMO-2 exhibits a very similar behaviour, i.e. the a clear warm bias in the maximum temperature and an even larger one for the minimum temperature. It is interesting to note that the observed nocturnal cooling is not constant, in that it is more pronounced, for instance, for the nights of 21-24 August, while much less pronounced for the nights of 25-27 August 2011, where the sort of exponential decrease in the observed the temperature after sun down is interrupted. Closer inspection reveals that elevated values of the wind are likely to have induced mixing of the surface layer with the warmer residual layer and thus counteracted the radiative cooling. This process seems not to be reproduced in the model.

For the Teolo station (middle panels), located on the Euganean Hills at about 150 $masl$, COSMO-2 performs very well for the heat wave and decently during the cold period. There are a few stations in the Veneto plain which are located at about 100 $masl$ or a bit more, for which COSMO-2 performs similarly. Apparently, the these stations are not completely immersed in the nocturnal planetary boundary layer of the flat Po Valley, but are rather often part of a mixed or residual layer, which seems to be more adequately represented in the model.

For the station Venice, situated right at the coast in the historical city center, COSMO-2 clearly underestimates the diurnal temperature excursion, which is much smaller on the coast than in the inlands (not shown). Unlike for the other stations examined, for this location the the warm bias is larger for the maximum temperatures than for the minimum temperatures, probably because the for the latter the nocturnal cooling is mitigated by a combined effect of the urban heat island and the Venice Lagoon surrounding the city. The model performed better during the cold and stable period.

Figure 4 shows the verification result of the COSMO-2 temperature profile against the temperature profiles retrieved from the microwave radiometer (MWR) located in the city centre of Padova (Fig. 1) as a function of forecast range. The bias is negative on all levels ranging

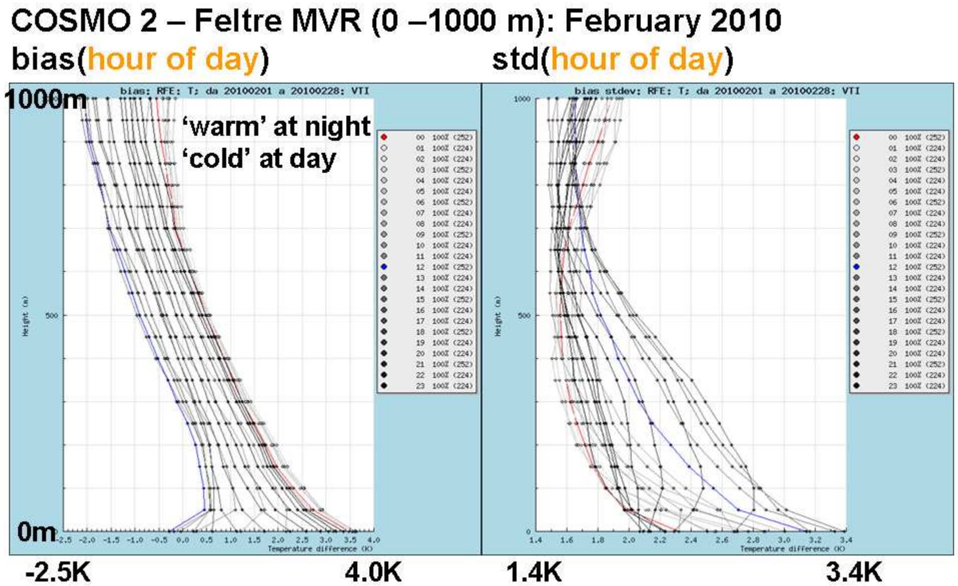

Figure 5: Bias and standard deviation of the COSMO-2 temperature profile against the MWR retrieval for the site Padova as a function of forecast range for the month of January 2010. The vertical axes denote the height above ground, the horizontal axes temperature. The darker the lines the later the hour, while the 00 UTC line is in red and the 12 UTC line is in blue. The number in the legend denote percent of nominally available data and number of data pairs.

from -0.9 to $-2\,K$ and might be related to the urban environment not represented in the model. One can appreciate that the bias is smallest at analysis time and tends to become more negative with increasing forecast range. Also, this progressive cooling of the lowermost part of the profile appears to be particularly rapid in the first few hours of the forecast. The standard deviation exhibits values between 0.9 and $1.4\,K$ where at analysis time larger values are found for levels between 250 and $900\,m$. Also, unlike the bias the standard deviation does not seem to increase monotonically with forecast range, an effect for which an explanation is yet to be found. The same behaviour can be seen for the prealpine valley station Feltre (not shown), except for the fact that the lowermost $250\,m$ of the profile shows a warm bias, at analysis time (red line) up to $350\,m$.

The behaviour of the COSMO-2 temperature profiles as a function of the hour of the day is shown in Fig.5 with values for the bias ranging from $+3.5$ to $-0.3\,K$ and values for the standard deviation ranging from 3.4 to $2.1\,K$ for the lower levels. At higher levels the bias decreases quite steadily and evenly for all hours by $3\,K$ at $1000\,m$ above ground. The standard deviation decreases with height and seems to be smallest for the morning hours. In summary, the model appears to have a tendency to be colder during the day and warmer during the night, visible also for the urban station Padova (not shown).

The mixing height verification is a more subtle issue as this variable is not directly measured, but needs to be estimated, or retrieved. There are several methods on how to do this [see 3, for a comprehensive review], the one used to retrieve the the mixing height from the observations is based on the PBL temperature and wind, and the surface energy balance [2]. The one used for the COSMO-2 is based on evaluating the Bulk Richardson number [5, 4].

Figure 6 shows the results of the COSMO-2 mixing height comparison against the estimats retrieved from observations as a function of the forecast range (left panel) and the hour of the day (right panel) for the month of January 2010. During the night the COSMO-2 tends to have a higher PBL than what is retrieved, i.e. a bias between 40 and $100\,m$, largest

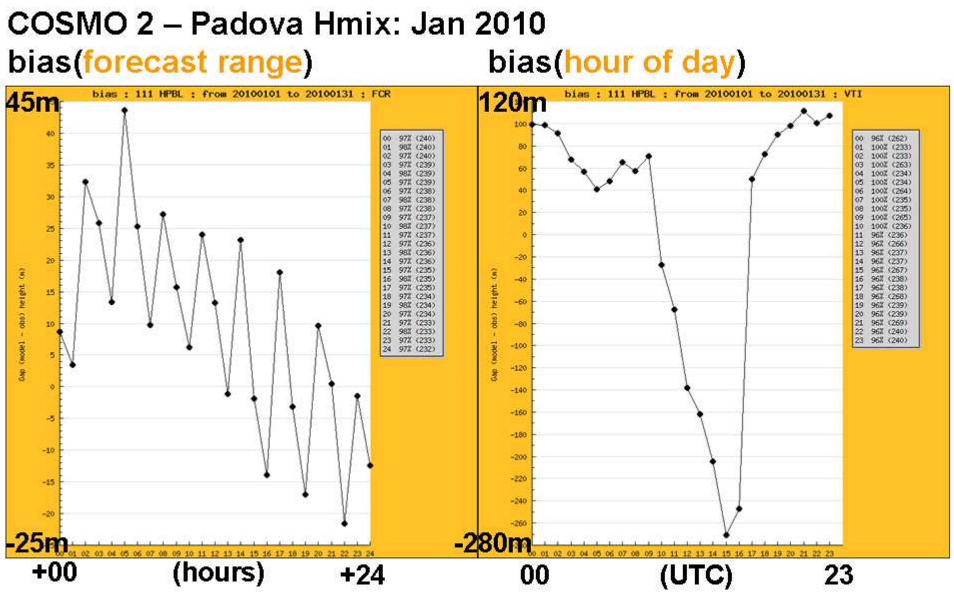

Figure 6: Bias of the COSMO-2 PBL mixing height against the retrieval for the site Padova as a function of the forecast range (left panel) and the hour of the day (right panel) for the month of January 2010. The vertical axes is in meter, the horizontal axis forecast range (+hh) and hour of the day (UTC), respectively. The number in the legend denote percent of nominally available data and number of data pairs.

around mid-night. This may be due to the fact that there is a minimum PBL height in the retrieval algorithm applied on the observations, which is set to $40\,m$ in the absence of mechanical turbulence. This happens in low wind conditions, which are very frequent in the Po Valley. On the other hand, there is a significant underestimation of the PBL height during the day, when starting at sun rise the positive bias changes to negative and peaks at almost $-300\,m$ mid to late afternoon. Results for February 2010 (not shown) show an even larger underestimation up to $-500\,m$.

4 Summary and Outlook

First verification results for the COSMO-2, run at MeteoSwiss, over the north-eastern Italian region Veneto are presented in terms of screen-level temperature, boundary layer temperature profiles and boundary layer mixing heights. The verification period spans two cold and four warm season months for the screen-level temperature, while the boundary layer verification was done for the two cold season months. The main results can be summarized as follows:

- COSMO-2 screen-level forecasts are affected by a clear warm bias for all station groups, with a pronounced diurnal cycle and maximum biases during the night, pinpointing insufficient nocturnal cooling;
- the overall error seems to be smaller for the Alpine stations and is largest for the plain stations, but also for stations on the high plateau of Asiago, where the nocturnal overestimation is most systematic, an effect that might be linked to the boundary layer evolution;
- bias and standard deviation increase monotonously with forecast range by about half a Kelvin;

- the dependence of the COSMO-2 cold season boundary layer temperature profile forecasts on the hour of the day shows a higher bias during the night and a lower bias during the day, i.e. relatively speaking too warm during the night and too cold during the day;
- the COSMO-2 cold season boundary layer temperature profile forecasts show a decreasing bias with forecast range, as if the model cools to quickly; this seems to contradict the screen-level temperature results and no explanation is proposed;
- comparison of COSMO-2 boundary layer mixing height with estimates retrieved from observations indicate a positive bias during the night and a significant negativ bias during the day, i.e. the COSMO-2 boundary layer seems to be too thick during the night and to shallow during the day.

Future verification work should include a more systematic verification of the boundary layer parameters, as well as ten-meter wind and precipitation over the Veneto. Also, more detailed studies of the COSMO-2 boundary layer over the plain portions of the domain would be helpful to understand the significant nocturnal warm bias of the model.

Acknowledgements The following individuals are thankfully acknowledged, i.e. M. E. Ferrario for providing the profiler data, M. Sansone for providing the mixing height estimates, and A. Della Valle for helping with the data processing.

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