

Meteorological modelling influence on regional and urban air pollution predictability

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ARPA Piemonte performs yearly air quality assessment (AQA) running a modelling system based on a chemical transport model. The model is capable to simulate air pollutant emission, transport, diffusion and chemical transformation, to provide concentration fields of the main atmospheric pollutants (CO, NO_x, SO₂, PM₁₀, PM_{2.5}, O₃, and benzene) on a hourly basis and to compute all the indicators required by EU legislation. Meteorological fields to drive air quality simulations are reconstructed assimilating ARPA Piemonte meteorological network observations within background fields obtained by ECMWF analyses. The reliability of mesoscale and urban scale meteorology is one of the key issues in determining an air quality modelling system effectiveness. Diagnostic meteorological analysis takes advantage of the wide local measurement network but cannot guarantee the dynamic and thermodynamic variables consistency provided e.g. by prognostic weather prediction models. Since July 2006 ARPA Piemonte operationally uses an air quality forecasting (AQF) system driven by the numerical weather prediction model COSMO 17. The simultaneous availability of the two systems results provides the possibility to compare different meteorological modelling techniques effects on air pollution predictability.

Modelling system characteristics and differences

The AQA and AQF modelling systems (Bande et al., 2007; Finardi et al., 2008) are built around the same Eulerian chemical transport model FARM (Gariazzo et al., 2007) and share the same emissions processing system EMMA (ARIANET, 2005) and interface module GAP/SurfPRO (Finardi et al., 2005) for the estimation of atmospheric turbulence and dispersion parameters. FARM, originally derived from STEM II (Carmichael et al., 1991), implements different gas-phase chemical mechanisms and two aerosol modules: the aero3 modal aerosol module (Binkowsky et al., 1999) and a simplified bulk aerosol module aero0 based on the EMEP Eulerian Unified model approach (EMEP, 2003). FARM implements two-way nesting techniques and can perform parallel computation using openMP approach. To limit computational time, the SAPRC90 (Carter, 1990) gas-phase chemical mechanism and the simplified aerosol scheme are adopted in the operational AQA and AQF system configuration.

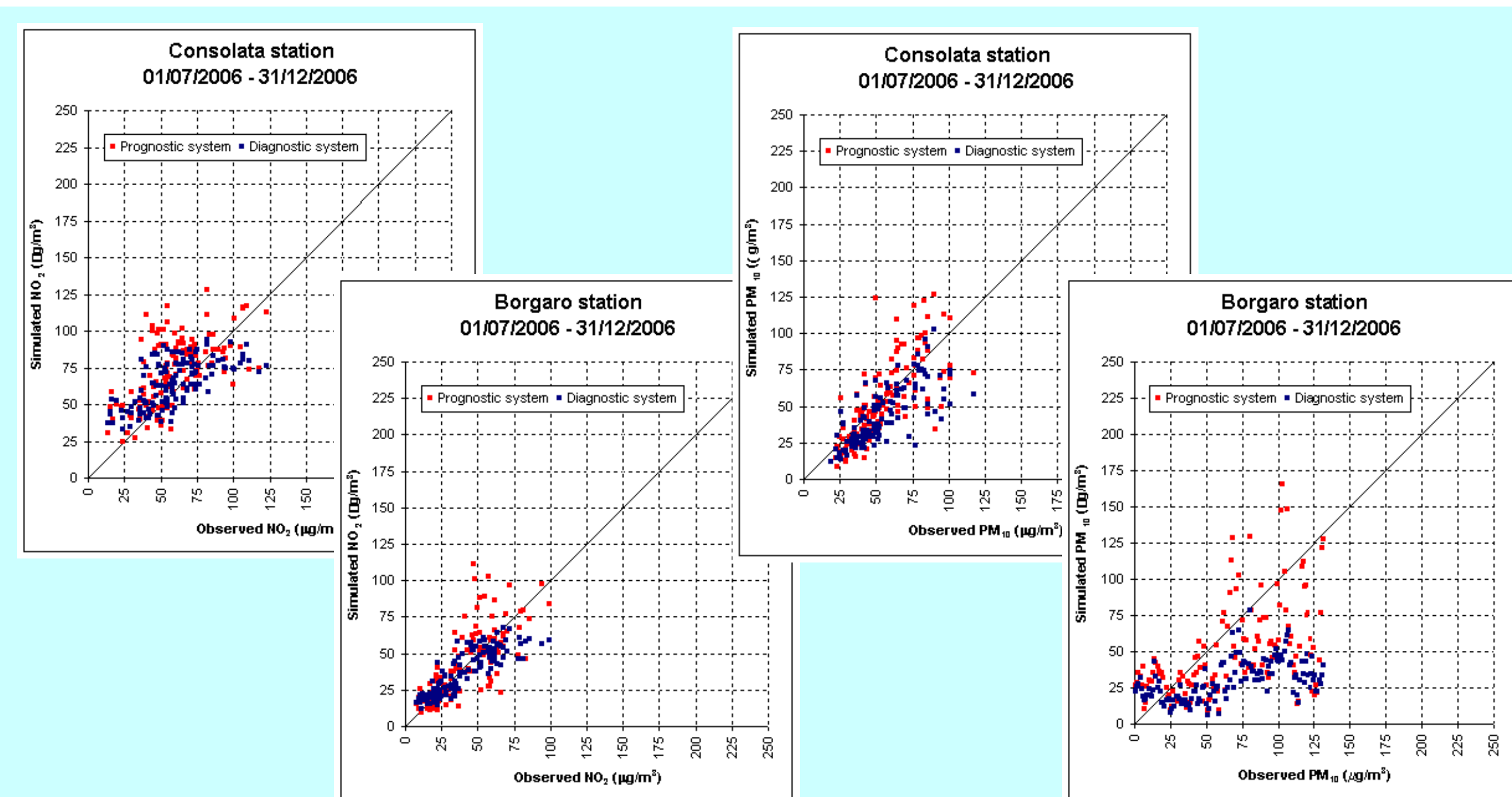


Fig. 3 Scatter plot of NO₂ (on the left) and PM₁₀ (on the right) daily mean concentrations simulated by diagnostic and prognostic systems in Torino Consolata and Borgaro stations.

Fig. 1 Air Quality Assessment and forecasting modelling systems computational domains.

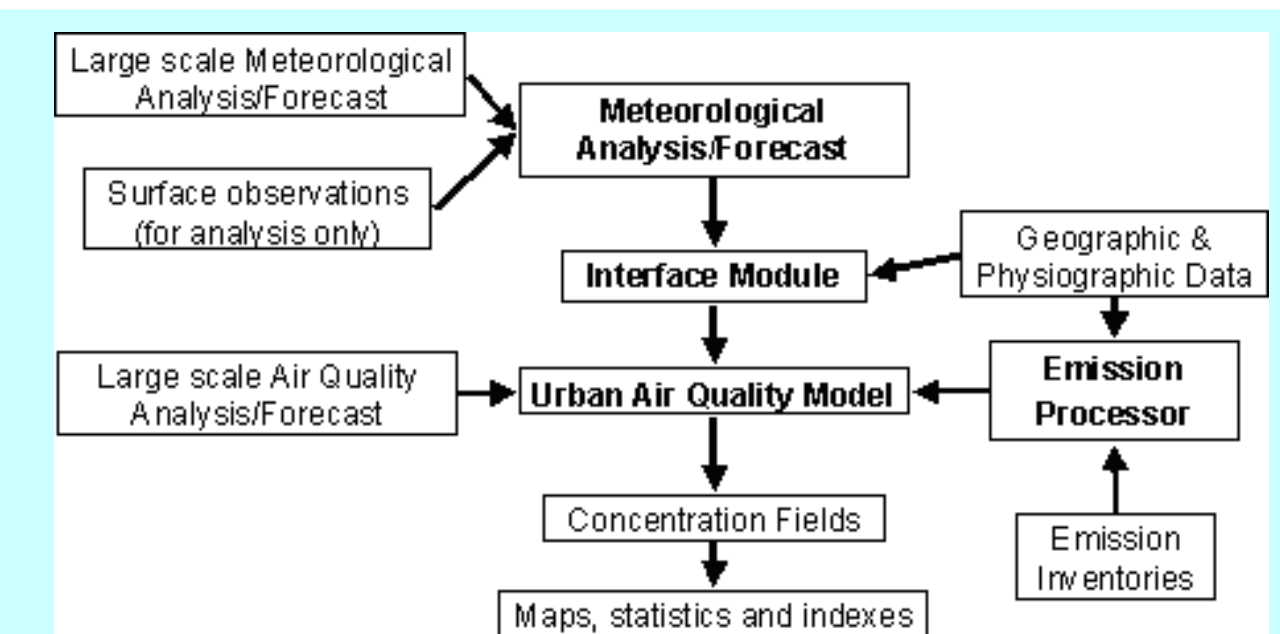
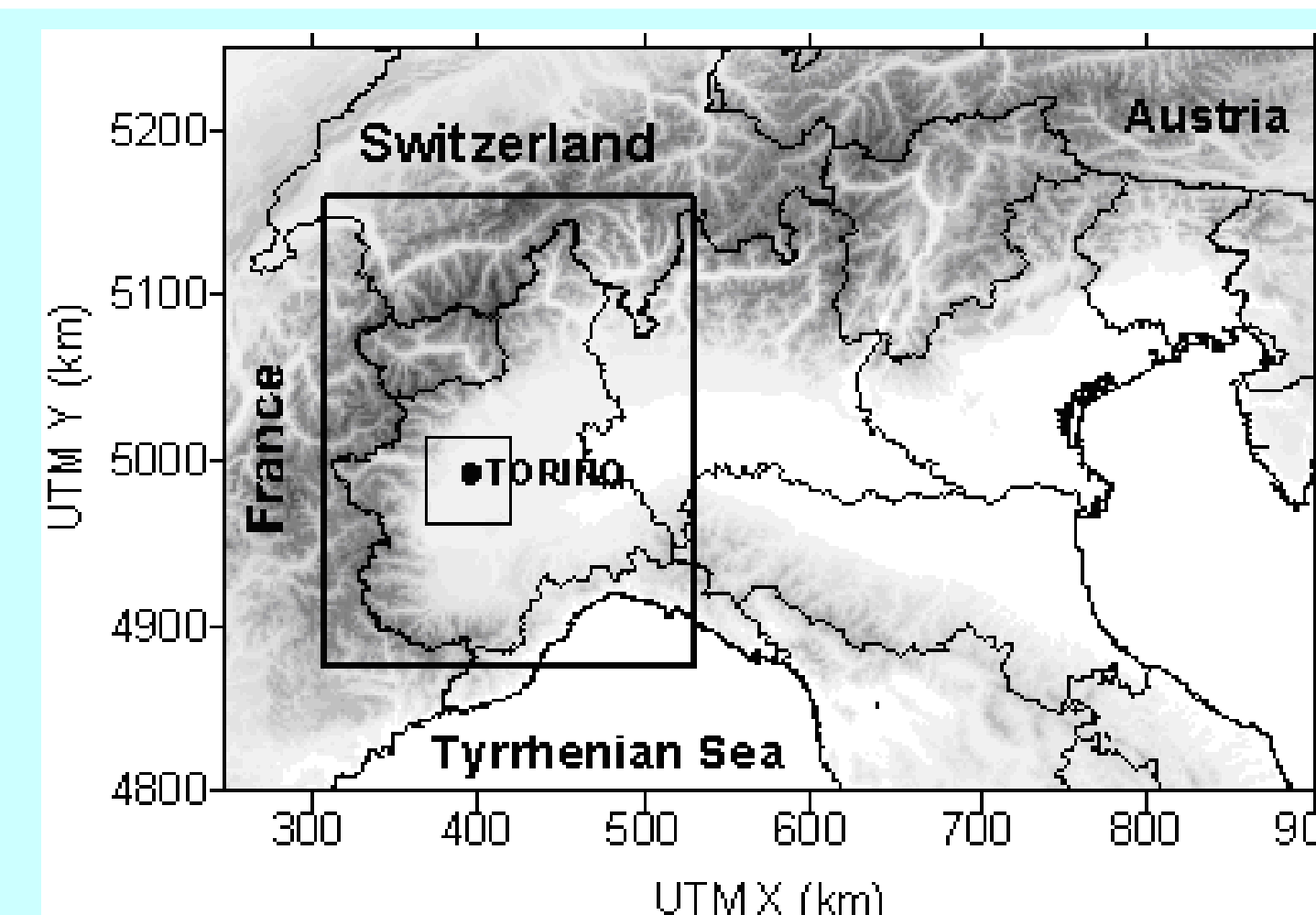


Fig. 2 Air Quality Modelling system general architecture.

Long term modelling system comparison

The different modelling system results have been compared with observations from the regional air quality monitoring network. The comparison has been limited to the time period July-December 2006 that was covered by simulations of both air quality modelling systems. For the AQF system a concentration time series has been built selecting for each daily air quality forecast the second day of the simulation (from +24 to +48); actually, from previous verifications the second day showed a lower influence of initial concentrations and was considered more suitable for comparison with the AQA system results.

The two simulations overall performance is quite similar (figure 3) showing a weak influence of the meteorological modelling technique over global results statistics (reported in the extended abstract). This outcome was not totally expected because a better reliability of the simulation based on diagnostic meteorological reconstruction could be foreseen due to the large number of local meteorological observations employed. It has to be noticed that both simulations results can be considered reasonably good for a long term performance evaluation.

Short term episodes chemical analysis

The statistical evaluation of results can be considered satisfactory for long term applications finalised to air quality assessment. The main request for those simulations is therefore to reproduce concentration distribution, providing a reliable evaluation of average and peak values through the estimation of indicators prescribed by EU directives. The requests become more stringent for air quality forecast, when concentration variations should be described with the correct space and time correlation.

Figure 4 shows the time series of computed and observed concentrations for two monitoring stations located within Torino urban area during two air pollution episodes. During the first analysed episode, since November 26th till December 03rd (figure 4, above), a "false alarm" condition is detected during the last days of November, when the air quality forecast produced a quick growth of concentrations, while NO₂ observations showed a slight decrease. Lower errors and a better description of concentrations variation is obtained, especially in Borgaro station, by the simulation driven by diagnostic meteorology.

On the contrary, from December 10th to December 18th (figure 4, below), when observed PM₁₀ daily average concentration reached values larger than 100 µg/m³, the AQF obtained a better performance than the diagnostic AQA system. This is particularly evident for December 13th in Consolata station and for the whole period in Borgaro station. During both episodes it has been observed that prognostic meteorology used by the AQF system exerts a more intense forcing causing larger short time variations of modelled concentrations than diagnostic meteorology.

Fig. 4 Comparison of observed NO₂ (above) and PM₁₀ (below) concentrations with simulation results driven by diagnostic and prognostic meteorological fields from November 26th to December 03rd (above) and from December 10th to 18th (below) in Consolata (left) and Borgaro (right) stations.

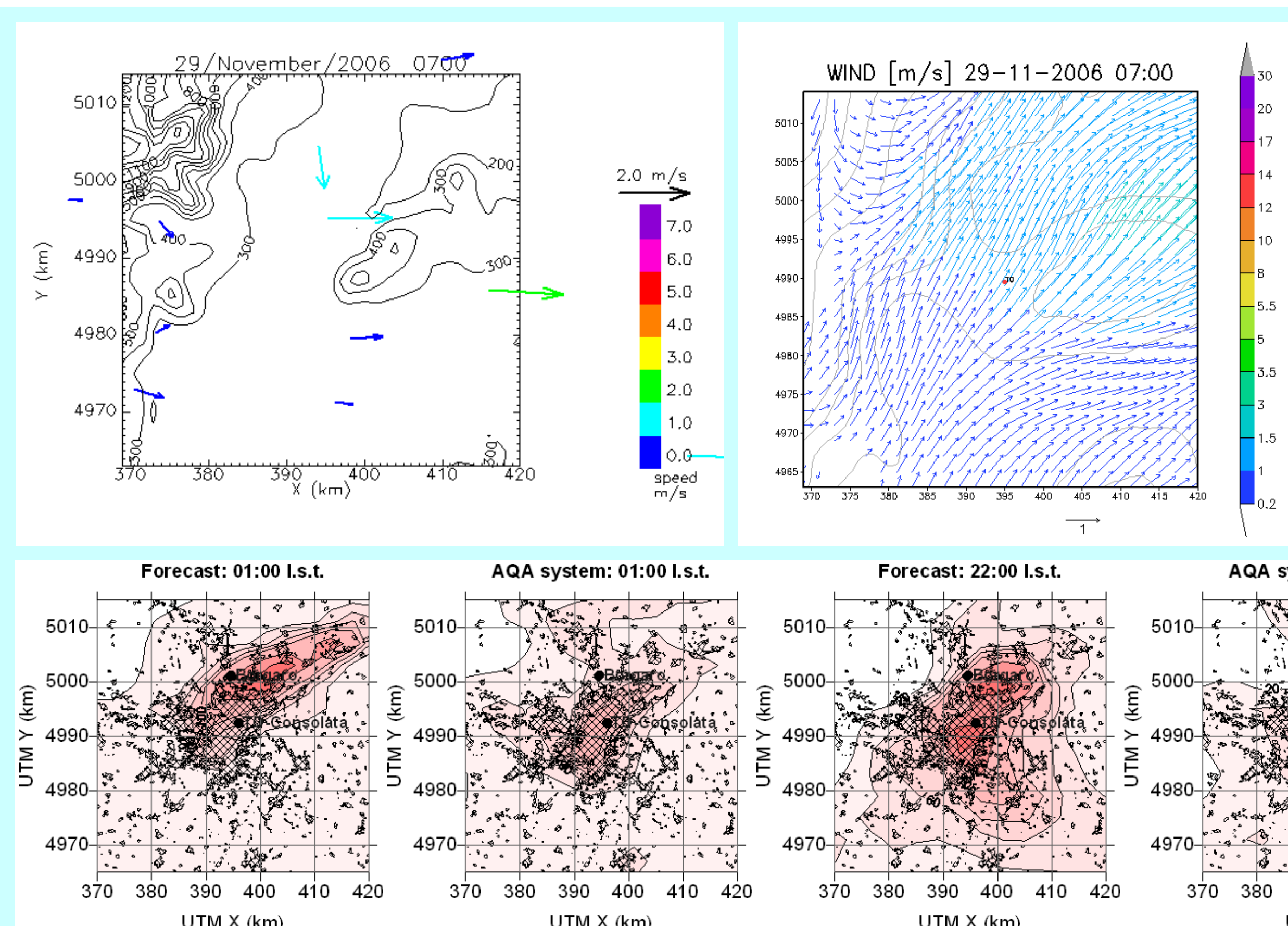
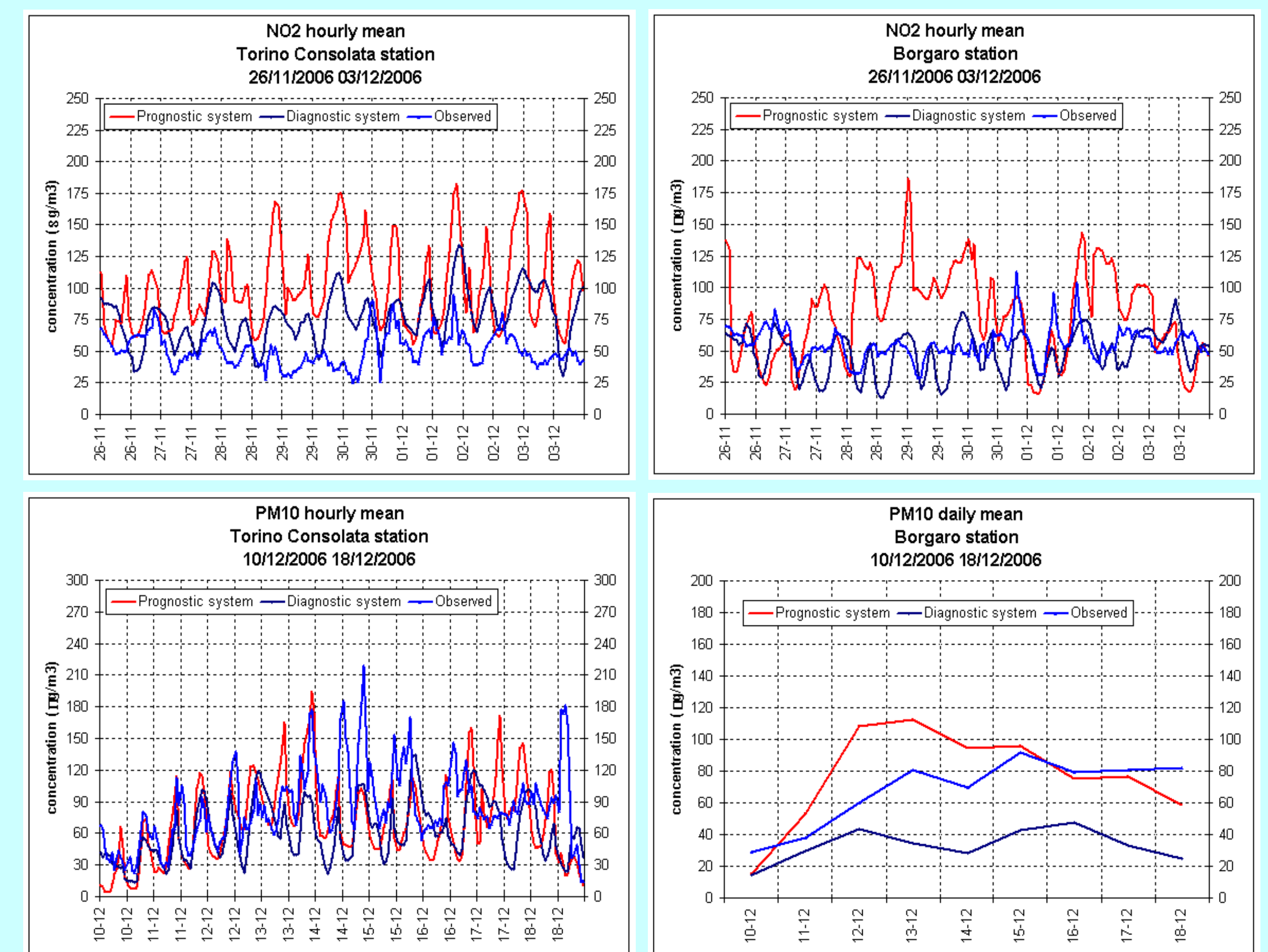


Fig. 5 Wind measured by Torino urban area stations used inside diagnostic system (left) and prognostic wind field (right) on November 29th at 07:00.

Fig. 6 PM₁₀ surface concentration (µg/m³) of the prognostic (AQF) and diagnostic (AQA) systems on December 13th at 01:00 (left) and 22:00 (right), local solar time.

Short term episodes meteorological analysis

The overestimation provided by the prognostic system from November 27th to December 2nd 2006 was not caused by different dispersion conditions: the vertical diffusion coefficient (K_z) and the mixing height fields had no considerable differences, although during this period the vertical temperature profiles predicted by COSMO-17 model showed a weak near-surface temperature inversion while measurements from a radiometer located inside Torino monitored a nearly adiabatic profile. The disagreement between the two modelling systems is mainly caused by different circulation fields. The wind direction measured by the stations used in the diagnostic system show prevailing westerly flow (figure 5 left), while the wind field predicted by COSMO-17 model (figure 5 right) has south-westerly direction: since pollutant emissions are stronger over Torino city core and the stations of Torino Consolata and Borgaro are located in the northern part of the urban area, the prognostic system predicted higher concentration caused by pollutant transport downwind of the main source areas.

The second episode (figure 4 and 6) was characterized by a rising trend in concentrations caused by pollutants accumulation due to stagnation conditions affecting the Po valley under the influence of a persisting high pressure system. From December 10th to 13th both the prognostic and the diagnostic systems accurately simulated the growth of PM concentration and its daily modulation. On December 13th-14th only the prognostic system was able to reproduce the observations, while the concentration calculated by the diagnostic system decreased. During the following days the two systems showed similar errors for the Torino Consolata station, while the forecast system continued to provide good performances for the Borgaro station. The cause of these different behaviours is that Torino city plume moved northward in the AQF simulation during December 12th, while it remained centred over the city, with lower maxima, in the AQA simulation. The following day a slight south-eastward transport was observed, causing the AQF system to carry back higher concentrations within the city giving rise to higher maxima during late morning and late evening, while the AQA system simulated a lower background pollution (figure 6).

Conclusions

The analysis of model results over a six months period, performed by means of model evaluation statistical indexes, showed very similar performances suggesting the possibility to use the air quality forecast system results for air quality assessment without significant performance decay. The analysis of modelling system performances during critical air pollution episodes showed that prognostic meteorological fields can provide a better capability to simulate meteorological forcing that can cause peak pollution episodes, even if weather forecast errors cause the occurrence of "false alarm" conditions due to concentration overestimation. The diagnostic meteorological fields induce a "smoother" time variation of predicted concentrations that sometimes causes underestimation of peak episodes. The short term episodes analysed showed a major role of local circulation in determining actual PM and NO₂ concentrations. High resolution meteorological modelling is therefore one of the main aspects to be improved for a better air quality forecast. The performances of the air quality assessment system could probably be enhanced by the implementation of meteorological data assimilation techniques to take advantage of both physical consistency of meteorological fields produced by meteorological models and reliability of local measurements.

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