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PUBLIC INFORMATION UNDER THE NEW 50/2008/EC DIRECTIVE: AN EXAMPLE OF AIR QUALITY FORECAST INDEX

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Abstract: Since 2003 people living in the metropolitan area of Turin have been easily able to inquire about air pollution through the Air Quality Index (AQI), a number depending on the concentrations of the three most relevant pollutants (PM_{10}, NO_2, O_3) measured by some monitoring stations located inside the metropolitan area. The Air Quality Index however may be affected by local effects and it is computed using data measured one day before.
Since July 2006 ARPA Piemonte has operationally used an air quality forecasting system (AQF). The forecasting system, with a series of detailed input datasets (emission inventories, IREA for Piemonte region, geographic and physiographic data, large scale air quality from the continental transport model Chimere and meteorological forecasts from the limited area model COSMO-I7), is able to simulate air pollutant emission, transport, diffusion and chemical transformation to provide concentration fields of the main atmospheric pollutants (CO, NO_X, SO_2, PM_{10}, $PM_{2.5}$, O_3, and benzene) over the metropolitan area of Turin with 1 km horizontal resolution, up to 72 hours in advance.
In order to offer a more complete and useful information, Arpa Piemonte, Arianet Srl and the Province of Turin have been running an Air Quality Forecast Index using the AQF concentration fields. The AQFI, in analogy with the AQI, is computed as the mean of the indexes calculated for each grid point weighted on its land use type.
The analysis of AQFI values during critical air pollution episodes shows a good capability to simulate peak pollution episodes, even if weather forecast errors may cause the occurrence of overestimation and underestimation conditions.
Long-term comparison with the traditional AQI shows that the AQI forecast provides a good indicator of the present and future air quality, thus fulfilling all the requirements of the new 50/2008/EC Directive on Air Quality for what concerns public information.

***Key words:** Air Quality Index, Air Quality Forecast Index, air quality forecast.*

INTRODUCTION

Communication about air quality has always encountered some difficulties mainly because there are many pollutants monitored and for each of them a specific limit value is defined and because, in the same urban context, different concentrations for the same pollutant may be registered depending on the siting of the monitoring stations. The Air Quality Index (AQI) was first developed by EPA in 1976 in order to provide the local agencies with a standard capable to convey a clear and consistent message about air quality.

In 2002 the Province of Turin introduced an AQI, describing the air quality of metropolitan area of Turin. The index is calculated taking into account the concentrations of three main pollutants: PM_{10}, NO_2, O_3 and it is published every day, considering the values measured in the previous day in selected monitoring sites, as a number varying from 1 to 7. The highest values correspond to higher pollution levels and higher risks for population. Each value is associated to a risk evaluation and a cautionary message for the population in order to prevent health consequences in case of high pollution levels. The values 1, 2, 3 correspond to the air quality classes *very good*, *good* and *moderate* and describe a situation with a low risk for population health. The values 4 and 5 correspond to air quality classes *poor* and *unhealthy for sensitive groups*, characterized by pollutants concentrations slightly higher than the limit threshold which may have some consequences on sensitive groups of population. Finally the values 6 and 7 are linked to the classes *unhealthy* and *very unhealthy* characterized by very high pollutants concentrations which may pose a risk for health.

The simple algorithm for calculating the AQI needs the computation of three sub-indexes related to the main pollutants I_{PM10}, I_{NO2}, I_{O3}. For each pollutant a limit or a target value has been chosen to be compared with measurements: daily mean for PM_{10} (50 µg/m³), highest hourly mean for NO_2 (200 µg/m³), and maximum daily 8 hour mean for ozone (120 µg/m³).
The AQI is then obtained through a single index I_{AQI}, defined as the average between I_{PM10} and the larger sub-index between I_{NO2} and I_{O3}.

$$I_{AQI} = \frac{I_{PM10} + \max(I_{NO2}, I_{O3})}{2} \qquad (1)$$

In the case I_{PM10} is not available, the algorithm uses only the maximum sub-index between I_{NO2} and I_{O3}. If both I_{NO2} and I_{O3} are missing only I_{PM10} is taken into account. AQI is derived from I_{AQI} using Table 1.

Table 1. AQI and I_{AQI} correspondence table.

I_{AQI}	AQI	AIR QUALITY CLASSES
0-50	**1**	***Very good***
51-75	**2**	***Good***
76-100	**3**	***Moderate***
101-125	**4**	***Poor***
125-150	**5**	***Unhealthy for sensitive groups***
151-175	**6**	***Unhealthy***
>175	**7**	***Very unhealthy***

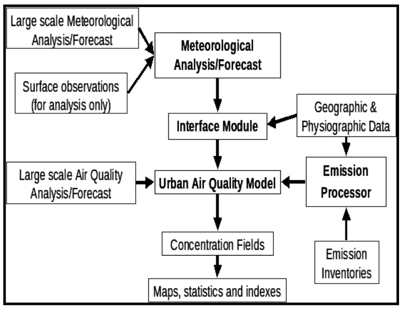
The directive 2008/50/CE enforces the need for clear and reliable information, since it requires that actual or predicted exceedances of alert or information thresholds are provided promptly to the public. A valid instrument to fulfil this requirement is an air quality forecasting system, capable of predicting pollutants concentrations in the following days on the basis of estimated emissions and weather forecast.

When an air quality forecasting system is operative, a forecast AQI can be readily calculated and the population can thus be warned in advance about the expected air pollution. An example of such a system has been running for almost three years over the Turin metropolitan area and its main features and results are described in this paper. In 2006, in fact, within the EU funded project Fumapex, the Environmental Protection Agency of Piemonte Region (ARPA) has implemented - in cooperation with ARIANET Consulting - an air quality forecasting (AQF) system over Piemonte region and Turin city (Finardi *et al.*, 2008). The following year ARPA, the Province of Turin and ARIANET started a project to work out a forecast AQI (AQFI) based on pollutants concentration estimated by the air quality forecasting system.

THE AIR QUALITY FORECASTING SYSTEM

The AQF modelling systems, built around the Eulerian chemical transport model FARM (Gariazzo *et al.*, 2007), needs a series of detailed input datasets: emission inventories, geographic and physiographic data (to describe topography, surface land cover and urban details), large scale air quality and meteorological forecasts. Some specific modules are needed to process these data in order to produce emissions, meteorological and boundary conditions necessary as input to the air quality model.

Emission data coming from different resolution inventories available over the area (high resolution regional inventories for Piemonte, Lombardia and Valle d'Aosta regions, national CORINAIR inventory for the remaining Italian regions and EMEP for foreign countries) are processed to compute gridded emissions. This data processing involves space and time disaggregation - according to cartographic thematic layers and specific time modulation profiles (yearly, weekly and daily) - and non-methanic hydrocarbon speciation, to produce gridded hourly emission rates for the all the chemical species considered by the air quality model over all computational domains.



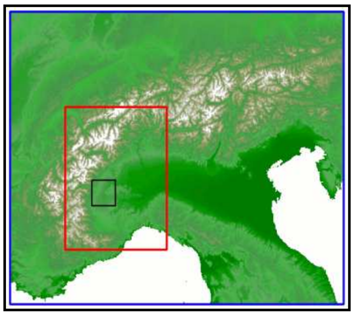


Figure 1. Air Quality Model forecasting system: general system architecture (left) and domains (right).

The meteorological fields are provided by the numerical weather forecast model COSMO-I7, the Italian version of COSMO-MODEL (Consortium for small Scale Modelling), running at ARPA Emilia-Romagna Meteorological Service and available at ARPA Piemonte as member of COSMO. COSMO-I7 provides two daily forecasts (12 and 00 UTC) lasting 72 hours, with three hours time frequency, over a geographic coordinates grid covering the whole Italian territory with about 7 km horizontal resolution. The meteorological fields on model levels produced by the 12 UTC run are adapted to all computational domains through the interface module GAP/TINT (Finardi *et al.*, 2005), carrying out space and time interpolation. Eddy diffusivities and deposition velocities are evaluated using parameterisations based on the surface energy balance and similarity theory, by the interface module SurfPRO (Figure 1). Air quality boundary values are defined from continental runs of the chemical transport model CHIMERE, from the INERIS Prev'Air service (http://www.prevair.org).

The AQF modelling system performs simulations on three nested domains (Figure 2): a background domain, covering Po valley basin and the Alps, with a horizontal resolution of 8 km, a regional domain, covering the whole Piemonte and Valle d'Aosta Regions, part of Liguria, the eastern part Lombardia (including Milan urban area) and portions of France and Switzerland, with a horizontal resolution of 4 km and an inner domain, with 1 km horizontal resolution, centred over Turin metropolitan area.

The forecasting system runs on a daily basis in order to produce air quality forecasts for current day and the two days after. At the end of each system runs, post-processing tools compute and provide to the Regional authorities all the indicators required by EU air quality legislation.

THE AIR QUALITY FORECASTING INDEX

Availability of AQF simulations makes it possible to calculate an Air Quality Forecasting Index (AQFI) for Turin metropolitan area and to increase its spatial representativeness. The forecasted AQI is calculated using gridded concentrations produced by the forecasting system over the Turin target domain and high-resolution land use data, adapting the original algorithm developed for observed concentrations at monitoring station.

The new algorithm works in three different steps. In the first step the grid points inside the defined urban area are classified according to the corresponding land use class (Figure 2).

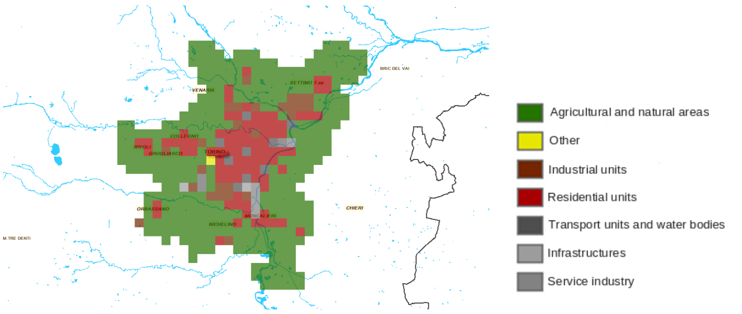


Figure 2. The land use classification of Turin metropolitan area.

Afterwards a specific weight is assigned to each grid point according to the relative classification and each grid point concentration is normalised with the corresponding pollutant limit value. In the second step a sub-index for each pollutant is calculated as weighed average of grid point concentrations:

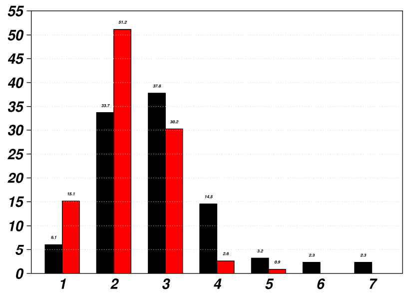
$$I = \frac{\sum_{i=1,n} p_i V_{IND}}{\sum_{i=1,n} p_i V_{ref}} x100 \qquad (2)$$

where I is the generic sub-index, p_i the weight assigned to the i^{th} grid point according to its land use, V_{IND} the indicator of the pollutant concentration at the i^{th} grid point (daily mean for PM_{10}, daily maximum for NO_2, daily maximum of 8 hours mean for O_3), V_{ref} the reference value for the pollutant (50 μgm^{-3} for PM_{10}, 200 μgm^{-3} for NO_2 and 120 μgm^{-3} for O_3). I_{AQFI} is calculated as the average between the PM_{10} sub-index and the higher between NO_2 and O_3 sub-indexes (see equation 1) and finally AQFI value is derived using Table 1.

AIR QUALITY FORECASTING INDEX PERFORMANCES

The annual comparison of the AQFI and AQI enables to see the distinctive features of the two index: the AQI gives information about air quality using some measurement stations (including hot spot stations) sited in the Turin metropolitan area, while the AQFI is an index representative of the simulation domain including Turin metropolitan area. Local peak values, typical of the hot spot monitoring stations, exert therefore more influence on AQI than on AQFI.

Considering AQI and AQFI frequency distribution diagrams and related contingency table (Figure 3) it's possible to see that AQFI tends to fill first and second classes more than AQI and the higher classes are underestimated by AQFI: this behaviour is due to difficulties in correctly reproducing peak PM_{10} concentrations.



Predicted

Observed	c1	c2	c3	c4	c5	c6	c7
c1	15	5	1	0	0	0	0
c2	26	64	25	1	0	0	0
c3	8	72	44	5	1	0	0
c4	2	18	26	2	2	0	0
c5	0	8	2	1	0	0	0
c6	1	5	2	0	0	0	0
c7	0	4	4	0	0	0	0

Figure 3. Observed (black) and predicted (red) AQFI (for the second day of simulation, from +24 to +48) frequency distribution for the year 2009 (left) and contingency table for the same year.

The main request for AQFI is therefore to provide an information representative of air quality over the metropolitan area and to help the public to easily understand air pollution forecast; so AQFI should describe pollutant concentrations with the correct time correlation.

For a better insight on AQFI, the time series of predicted and observed daily concentrations have been analysed with particular attention to air pollution episodes characterised by relevant time variation of measured concentrations. 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).

Figure 4 and 5 compare model results for two monitoring stations sited inside Turin metropolitan area. During a winter episode (Figure 4, on top) an urban background station has been chosen to check if high NO_2 and PM_{10} concentrations were accurately simulated. During the summer critical air pollution episode (Figure 5, on top) a sub-urban station has been chosen to verify if high ozone concentrations were detected. In both winter and summer episodes the AQFI (Figure 4 and Figure 5, below) should give information consistent with observed concentrations.

During the winter episode, AQFI (Figure 4, below), computed using PM_{10} and NO_2 sub-indexes, describes accurately the time modulation of daily average concentrations. The time variation of observed concentrations is especially well described for PM_{10}.

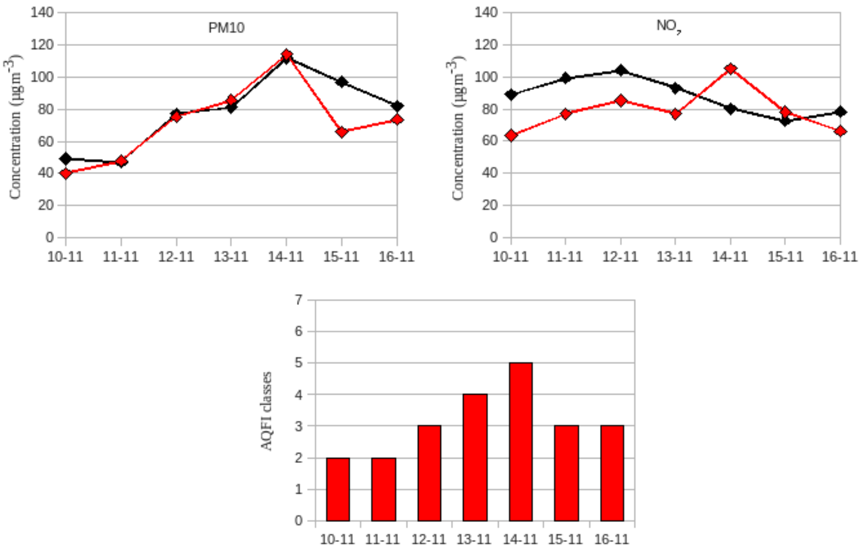


Figure 4. Predicted (red line) and observed (black line) PM_{10} and NO_2 (on top) daily concentrations in two urban stations inside Turin metropolitan area and AQFI classes from 11th November to 16th November (below).

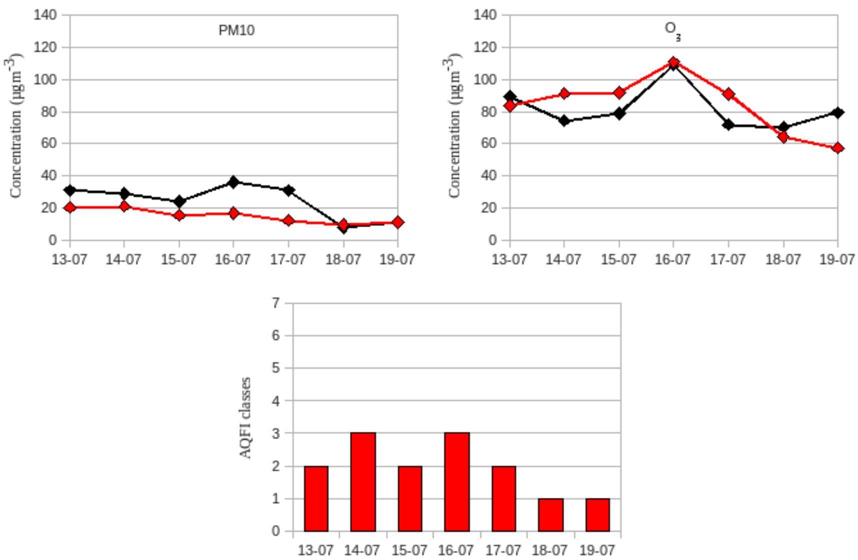


Figure 5.Predicted (red line) and observed (black line) PM_{10} and O_3 (on top) daily concentrations in two urban stations inside Turin metropolitan area and AQFI classes from 13th July to 19th July (below).

During the summer episode AQFI (Figure 5, below), computed using PM_{10} and O_3 sub-indexes, seems to be forced more by low PM_{10} concentrations than by high ozone concentrations, with index values less than moderate: AQFI domain is characterized by a high number of urban grid points in which there are summer low ozone concentrations; anyway index values give a good time modulation.

CONCLUSIONS

In this paper we have described an example of AQFI, fully operational for almost three years. Both long and short term comparison with the traditional AQI shows that the AQFI provides a good indicator of the present and future air quality, even if weather forecast errors may cause the occurrence of overestimation and underestimation conditions.

Being based on modelled fields and depending on many grid points values, the AQFI is more representative of the air quality in the whole metropolitan area than the original AQI. For the same reason, though, the AQFI is less sensitive to local effects which may affect the values measured in a monitoring site. As a consequence, the AQFI rarely takes values 6 or 7, corresponding to the *unhealthy* and *very unhealthy* definition for the air quality status. This suggests the need for an improvement in the AQFI definition, aiming at reporting the worst conditions occurring in the whole area. Under the current EU legislation on air quality, in fact, the presence of a single exceedance of air quality standard is sufficient to require additional measures (air quality plans) for reducing emissions and obtaining cleaner air.

A permanent activity of updating, improvement and harmonization of emission inventories is also a key factor for the reliability of this informative tool.

The analysis of AQFI values during critical air pollution episodes shows a good capability to simulate peak pollution episodes. This feature, coupled with the directness of its message, makes the AQFI a useful tool for establishing an effective communication to the public on air quality.

The Province of Turin will soon start to employ the AQFI instead of the older AQI. This service will be launched in June 2010 with a dedicated web page. The same forecast will be sent to newspapers and to the network of variable message street signs already present in town for traffic purposes in order to reach a wider audience.

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