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Modeling and Characterization of Air Pollution: Perspectives and Recent Developments with a focus on the Campania Region (Southern Italy)

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ABSTRACT: The wide availability of data on air pollutant emissions, the knowledge already achieved on the set of chemical and photochemical reactions in the troposphere, the ability to access real time weather conditions at the local scale that determine the transport and transformation of gases and aerosol, now make it possible to obtain credible and reliable predictions, retrospective analyses and/or future projections on air quality. Political institutions and the scientific community are strongly committed to achieve these objectives.During the last years, a sensible improvement has been achieved both because of the better analysis of physical/chemical phenomena, and software/hardware architecture advancements. Nowadays, it is not uncommon to provide, also in real-time, weather and chemical forecasts at very high resolutions (less than 1 km in the horizontal directions). Some of the achievements and future perspectives on the development scenarios are given, with focus on the results of the Campania region (Southern Italy).

Key words: Air pollution, Monitoring, Modeling, Forecast, Quality, Data analysis

INTRODUCTION

The alarm caused by climate change, the emergency situations occurring more and more often, and the increasing sensitivity to air pollution due to industrial activities, domestic heating and road traffic, has prompted the central authorities (EU and member countries governments) to formulate more stringent laws that force local authorities to periodically monitor the status of the environment and take countermeasures to limit the effects of detrimental actions to the environment and human health. As regards to air quality, the recent recommendations of the European Union (2008/50/EC) has been implemented in a unified manner through the D.Lgs. 155/2010 in Italy.

Currently the overall orientation, both of political and scientific community, is to integrate more and more satellite observations, surface observations, observations from the surface and model results. From several years, the EU supports the GMES (Global Monitoring for Environment and Security), the largest project ever launched for the observation of the Earth. The coordination and management of the GMES program are guaranteed by the European Commission, through the creation of a range of services for all areas involved. The creation of the initial versions of GMES services have been allocated to various projects, partly funded through the Seventh Framework Programme, while developments of the infrastructure are performed under the auspices of the European Space Agency for the spatial component (e.g. through the Sentinel projects) and the European Environment Agency and the Member States for the *in situ* components. Public authorities, the end users of GMES, will use this information to update the legislation and environmental policies; also GMES will support the most important decisions to be taken promptly during emergency conditions, such as during natural or manmade disasters and humanitarian crises.

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MATERIALS & METHODS

A service will be available on the so-called 'chemical weather' (COST Action ES0602) in a short time, similar to how services are now offered on the weather forecast, through the integration of the products offered by the observation of the earth with the modeling predictions.

This COST Action was recently completed. Interestingly, the action concerning the development of an ensemble system, and the construction of a European portal that includes links to most of the meteorological/chemical forecasting systems available in Europe, has been set. A number of monitoring stations in the European territory have been selected, and operational forecasts for these sites are constantly inter-compared and evaluated. Recently, the Campania Regional Board supported the CCMMMA (Campania Center for Monitoring and Modeling of Marine and Atmospheric Phenomena), giving a great opportunity to support the monitoring and modeling activities in this region.

In this paper we summarize the main achievements on atmospheric chemistry, with particular emphasis on the main results obtained from the analysis of pollution data and modeling results obtained for the region of Campania.

RESULTS & DISCUSSION

In the Campania region, the monitoring network is managed by the ARPA (Regional Agency for Environmental Protection), while nationwide the ISPRA (National Institute for the Protection and Environmental Research) and, at European level, the EEA (European Environmental Agency) and EMEP (European Monitoring and Evaluation Programme) maintain and store data relevant to the environment. These data are directly available on-line through a series of databases (AirBase; BRACE; EMEP).

It is interesting to highlight some of the phenomenological characteristics of such data. Fig. 1 shows the location of monitoring stations of the Airbase and EMEP networks; the EMEP network has been operating for over fifteen years for most of the stations, providing the most reliable data about the time series of atmospheric pollutants.

From the analysis of these data it is possible to deduce a number of important considerations on exposure to air pollutants of the human population (EEA Report, 2011). From the EEA Report it is claimed that, with regard to particulate matter, 20% of the population lives in urban areas where the EU has exceeded the limit value for PM10 in 2009. For the 32 member countries subject to monitoring actions by the EEA the estimate is 39%. However, the 80-90% of Europe's urban population is exposed to PM10 levels that exceed the guidelines, more stringent, the World Health Organization (WHO).

Although the anthropogenic emissions of ozone precursors (nitrogen oxides and organic compounds) have been reduced, the level of this pollutant has not declined significantly between 1999 and 2009. In 2009 about 17% of Europeans live in areas where the EU target for the concentration of ozone was exceeded. If levels of ozone are compared with the more stringent guidelines of the WHO, over 95% of urban population has been exposed to ozone levels exceeding these criteria. Approximately one third of the total area cultivated in the thirty-two countries monitored by the EEA has been exposed to ozone levels above the target values.

From 1999 to 2009, the levels of SO_2 in Europe fell by about 50%, leading to significant reductions of acid rain and acidification. Only a small part of the urban population is exposed to SO_2 levels above the limit

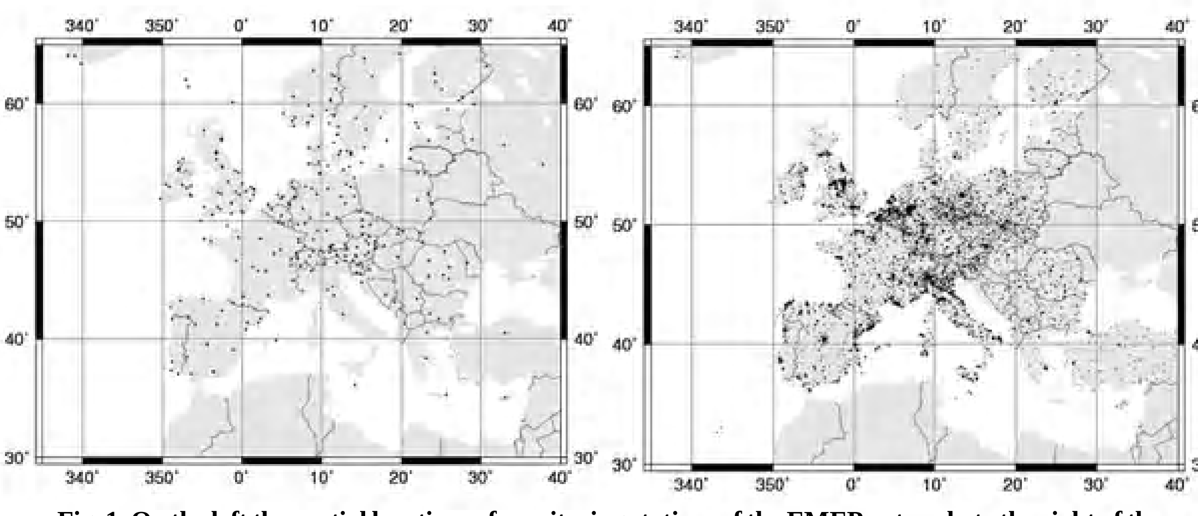

Fig. 1. On the left the spatial locations of monitoring stations of the EMEP network, to the right of the monitoring networks of the countries for which data are available through Airbase

value, although 68-85% is potentially exposed to levels above the WHO guidelines.

The concentrations of NO_2 have decreased slightly in recent years. Exceedances occur generally in the form of hot spots, such as along main roads. 12% of Europe's urban population lives in areas where concentrations of NO_2 are above the limit values recommended by the EU and WHO.

Atmospheric levels of arsenic, cadmium, lead and nickel are generally low in Europe. However, heavy metals can accumulate in soils, sediments and organisms. Despite considerable reductions in emissions of heavy metals in the EU since 1990, a significant percentage of the ecosystems are still at risk of contamination.

To show the phenomenology of the concentrations of the major air pollutants, in Fig. 2 the diurnal cycle of ozone is shown. These values are the average over all monitoring stations of the EMEP network in 2010, the most recent year for which data are available; the vertical bars indicate the range of variability, extended between 25° and 75° percentile of the concentration values of all the available stations. Note the maximum value, typically reached in the early afternoon, is correlated to the greater availability of solar ultraviolet radiation.

Figs 3 and 4, instead, show the trends of annual concentrations of major air pollutants: ozone, carbon monoxide, nitrogen dioxide, PM10, PM2.5 and sulfur dioxide, for 2010.

Among the main qualitative features that can be deduced from these data the annual cycle of ozone is clearly pronounced, with a peak in the summer months, when the solar ultraviolet radiation is maximally available, and the absence of an annual cycle for PM, for both the 10 and 2.5 dimensional cut-offs; the considerable number of exceedances that occur for particulate matter (for PM2.5 the threshold limit of 25 μg/m3 is definitely overcome for many monitoring stations); the low values (in the majority number of cases) for SO_2.

The analytical methods are suitable for collection of data localized in space and time and can be used as a basis for formulating policies for the governance of the territory. However, they do not arrive not at a complete understanding of the phenomena in progress, or to easily predict the events of pollution from new developments or changes within the energy, transport or due to new regulations.

One of the way to approach the problem of reconstruction of atmospheric concentration fields is by means of an Eulerian modeling chain. This kink of modeling requires the definition of meteorological and chemical boundary conditions, a process that is generally implemented for subsequent nesting. The meteorological data to apply this process are distributed by different centers, for example the NCEP (National Center for Environmental Prediction) of the United States or the ECMWF (European Centre for Medium Range Weather Forecasting). These data can be used by software, such as the WRF (Weather Research and Forecasting model), for simulations at

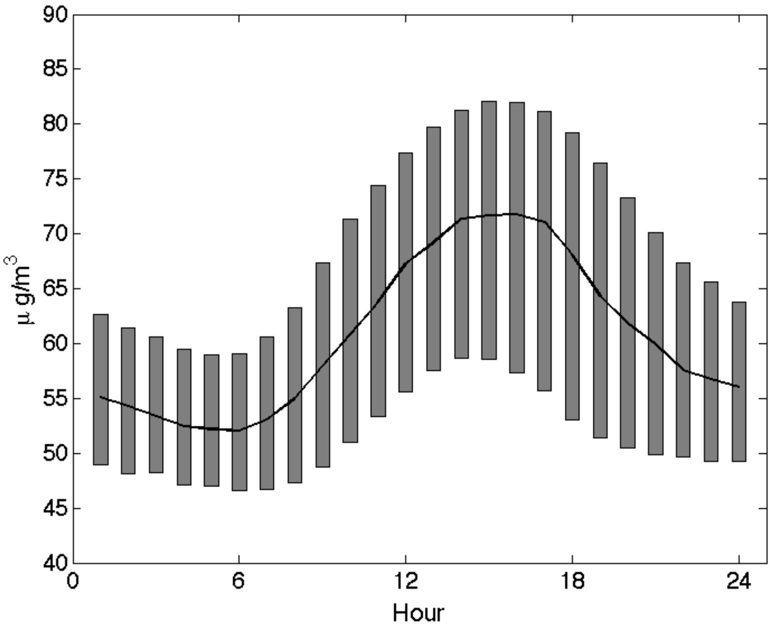

Fig. 2 . Diurnal cycle of ozone (black line), calculated as the median value of all the stations of the EMEP 2010. Vertical bars indicate the inter-quartile range

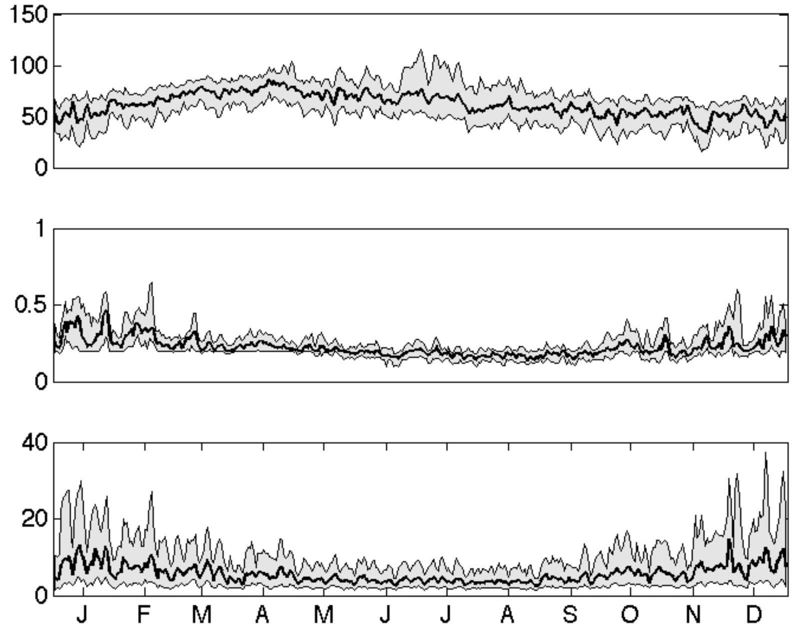

Fig. 3. Annual pattern of ozone concentrations (top), carbon monoxide (center) and nitrogen dioxide (bottom) for the year 2010. The concentrations are expressed in mg/m3 for CO and in μg/m3 for the other compounds; the black line indicates the median value among all the EMEP stations, while the shaded area the inter-quartile range

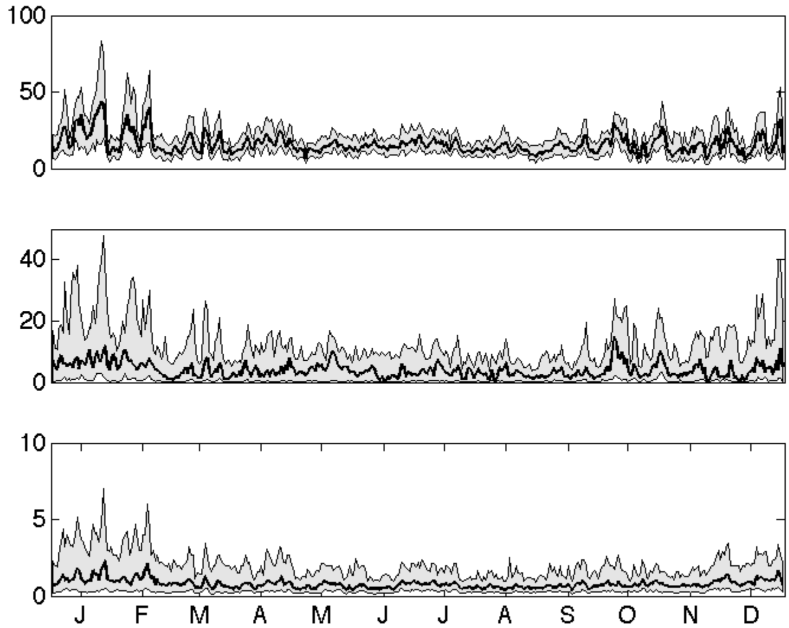

Fig. 4. Annual trend in the concentrations of PM10 (top), PM2.5 (center) and sulfur dioxide (bottom) for the year 2010. The concentrations are expressed in μg/m^3, the black line indicates the median value among all EMEP stations, while the shaded area in the inter-quartile range

regional scale. High spatial resolutions are then used, together with data on the emission flows, in software, such as the CHIMERE, for predictions of chemical concentrations.

We already worked in the past on the modeling of transport processes and chemical reactivity of atmospheric pollutants (Barone *et al.*, 1999; 2000; Chianese, 2012; Ferrero, 2010; 2011; Giunta *et al.*, 2007; Riccio, 2005; Riccio *et al.*, 2006; 2007) and such a system is now used at the CCMMMA at several spatial scales (from Europe up to the Campania region). Examples of the results that can be obtained from this system are shown in Figs 5 and 6, where it is intended to highlight its predictive ability. In these figures the retrospective analysis of trends in ozone and PM10 concentrations is represented (averaged over all EMEP stations for the period from June to September in the year 2010). As can be seen, the time series of ozone and particulate matter concentrations is satisfactorily reproduced, the daily cycle of ozone is in phase, even if sometimes the model tends to overestimate the peaks, also the time trend is correctly reproduced. For PM10

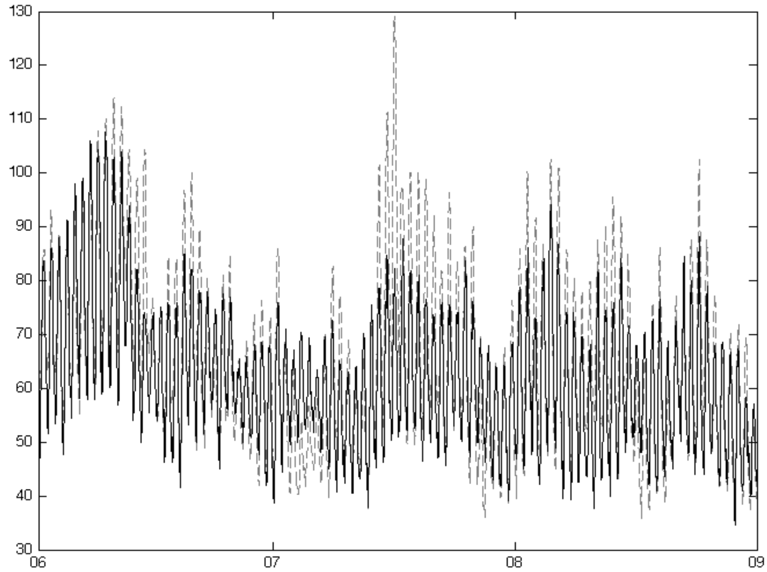

Fig. 5. Hour concentration of ozone between June and September 2010. The data refer to the median among all EMEP stations. The black line indicates the experimental data, while the grey dashed line corresponds to the value simulated by CHIMERE. The concentrations are expressed in μg/m^3

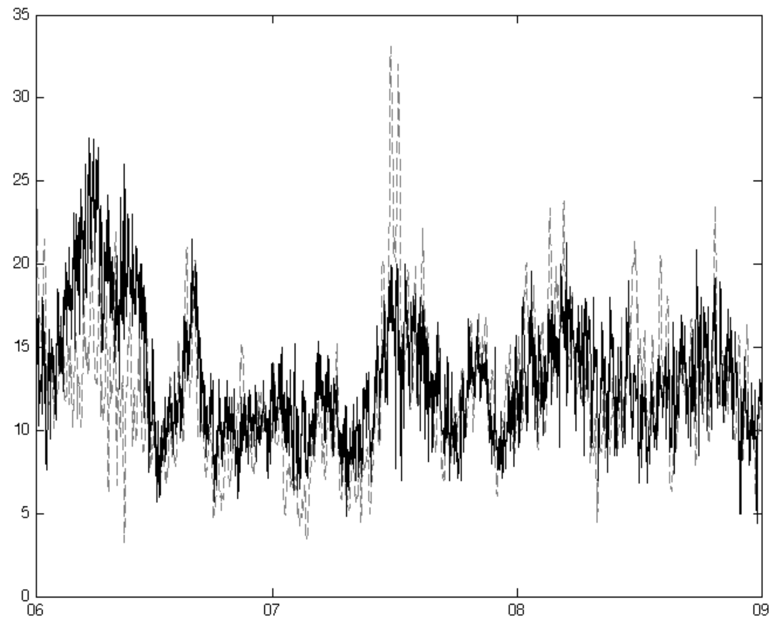

Fig. 6 . Hour concentration of PM10 between June and September 2010. The data refer to the median among all EMEP stations. The black line indicates the experimental data, while the grey dashed line corresponds to the value simulated by CHIMERE. The concentrations are expressed in μg/m^3

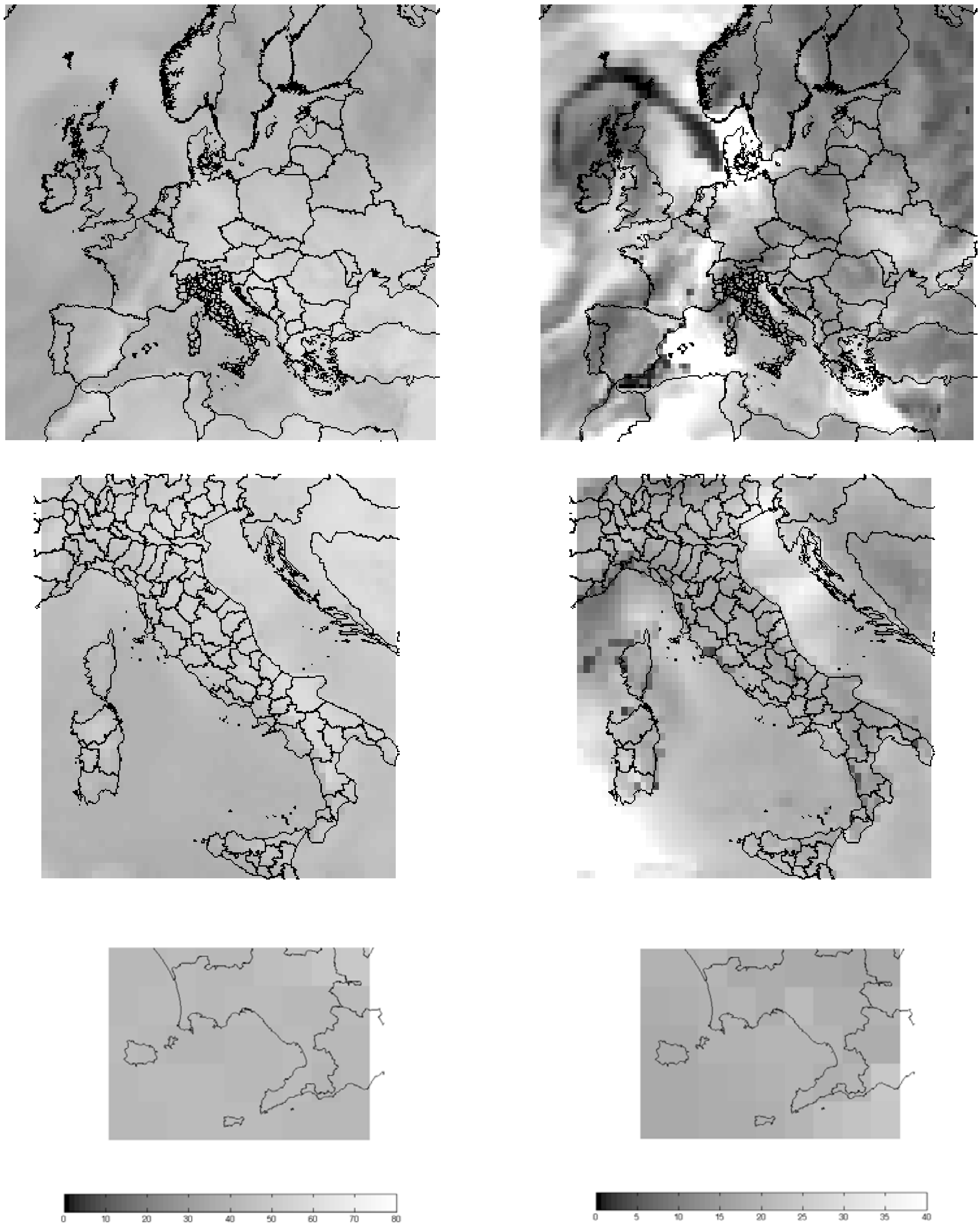

Fig. 7. Ozone (left panel) and PM10 (right panel) concentration for the day June 29, 2012 at Z12 at different spatial scales, obtained from the modeling system WRF/EMEP/CHIMERE. The concentrations are expressed in μg/m3

(Fig. 6) the trend is satisfactory, with an average bias of only -1.7 $\mu g/m^3$. It might show that similar results are obtained for other classes of pollutants.

The advantage of models, however, is not just the ability to simulate the time series of concentrations at the monitoring stations, but also to have an overview on different scales and to provide real-time data. Fig. 7 shows examples of simulations of ozone and PM10 concentrations at different scales, for June 29, 2012, obtained by the model chain WRF/EMEP/CHIMERE used at CCMMMA. Each domain refers to simulated 'nested' domains at increasing resolutions, up from the European to the local scale. In the simulated conditions we see an episode of dust, also confirmed by other observations not reported here, from the north-western Africa to the center of the Mediterranean, and that, at the given time, touch on the shores of Sardinia. Obviously, this result would not be directly deduced from the mere analysis of the concentration values of particulate measured by the monitoring stations.

We can affirm that the information provided by modeling chains, such as that used in these examples, are the natural complement to experimental observations. The support of the Campania Region to the CCMMMA provided the framework for studying air pollution phenomena in this region in much more detail, overcoming some of the limits inherently associated to the monitoring network based on fixed stations.

CONCLUSION

In recent years there has been a major effort by the political authorities and the scientific community to provide reliable tools for monitoring and forecasting of natural and/or anthropogenic events. As part of the European and local air quality monitoring plans, an almost complete coverage has been achieved by instrumentation, and this allows to have under control, even in real-time, the conditions on physico-chemical state of the atmosphere at different spatial and temporal scales. Concurrently, the evolution of models has been impressive; today, with relative ease, it is possible to obtain realistic simulations of atmospheric conditions, which allow a retrospective analysis and projections of future scenarios. The integration between monitoring and forecasting will soon delivers information on the conditions of air pollution similar to those that are now common on daily weather conditions; models still remain the natural tool to support plans for the improvement of air quality, both because they provide essential information on the characteristics of pollution on a synoptic scale, and because it fills the 'holes' of observations in remote areas.

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