ARPA FVG - Regional Agency for Environmental Protection of Friuli Venezia Giulia Region
CRMA - Regional Center for Environmental Modeling
Via Cairoli, 14 I-33057 Palmanova (UD) - ITALY

[1] Del Frate S., [1] Gallai I., [3] [4] Giacomini A., [1] Giaiotti D. B., [1] Gianesini E., [2] Goi D. [1] Montanari F., [1] Petrini A., [1] Piani L., [1] Pillon A., [1] Pinat T., [1] Stel F., [1] Tassan F., [2] [1] Turoldo F., (corresponding author: Giaiotti D. B dario.giaiotti@arpa.fvg.it)

[1] ARPA FVG - CRMA Regional Center for Environmental Modeling, [2] Dipartimento di Scienze e Tecnologie Chimiche - University of Udine - Italy, [3] School of Doctorate Environmental and Industrial Fluid Mechanics - University of Trieste - Italy, [4] Department of Physics - University of Udine - Italy

A case study of Ozone advection in the Northern Adriatic area

Introduction

Especially close to the ground, tropospheric ozone is considered a pollutant because its relevant irritant action to the human respiratory apparatus, its negative effects on natural ecosystems and its damaging action on some materials.

At the ground, high ozone concentrations usually occur during the sunny days in summer period, because of the photochemical actions of the solar radiation [1]. Anyway, the role of the transport in explaining peaks of concentrations has been already highlighted since more a decade ago and it is confirmed by recent studies [2], [3].

In this study we explain the rapid increase of ozone concentration in a rural area, on the top of a mountain, as the result of ozone transport across several hundred of kilometers. The explanation is bases on the computation of air flow trajectories by means of atmospheric limited area model simulations.

Measurements

In this work we have considered a significant anomaly in the hourly concentrations of ozone over a rural area, which is located on the top of a mountain. The mountain is placed in the easternmost Alpine ridge and it is a grass covered isolated top; its name is Mount Zoncolan (N46.503°, E12.927°, 1750 m msl, roughly 850 hPa). The measurement area hosts a complete weather station and a set of air quality devices operating continuously 24 hours a day, since year 2005, and recording concentrations of: Ozone, Sulfur dioxide, Nitrogen Oxides and fine particulate (PM10). Meteorological and air quality data have a hourly resolution.

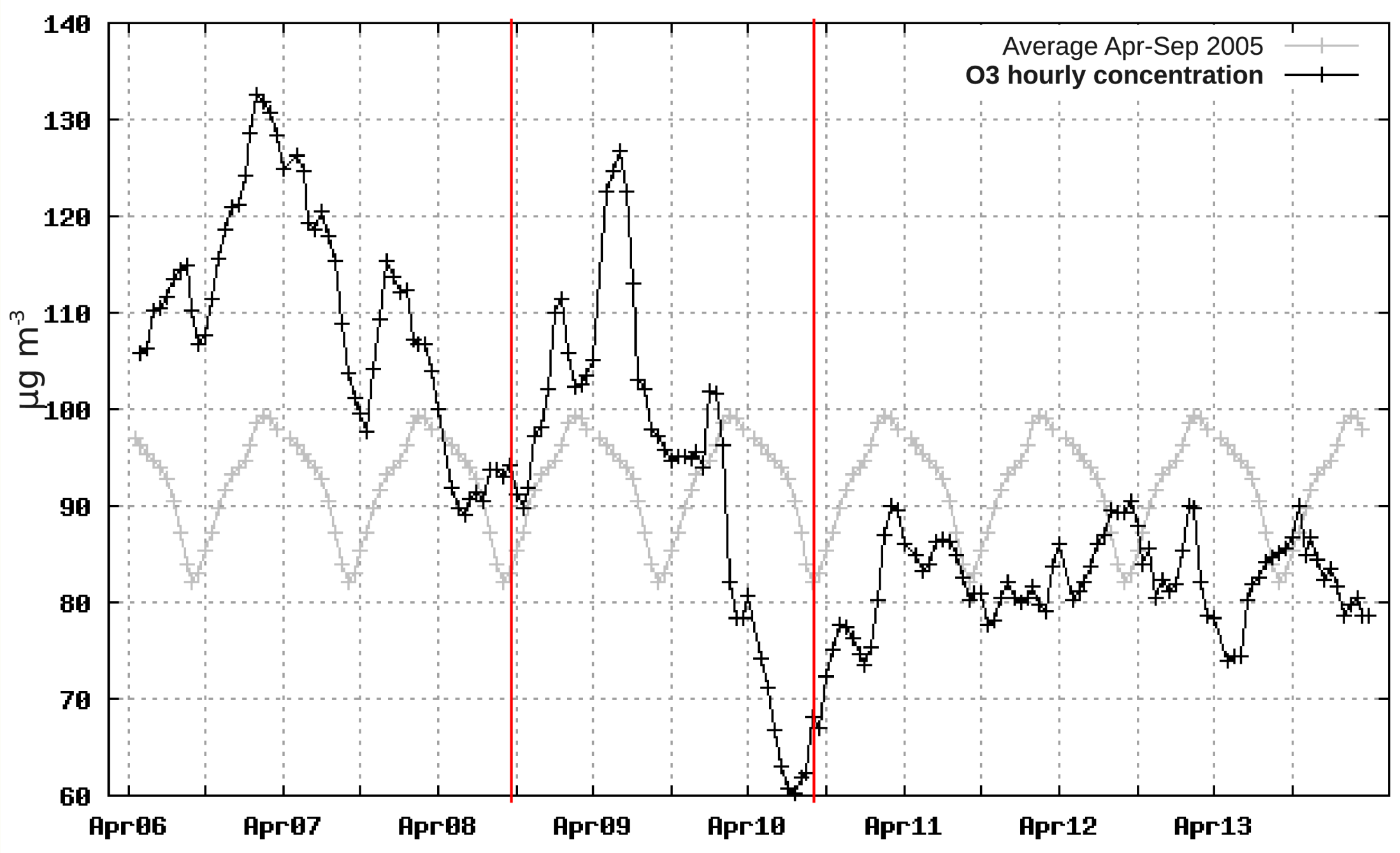


Figure 1
Time series of ozone concentration measured in April 2005 at Mount Zoncolan station. Solid black line with crosses reports hourly measurements, while gray line shows the average hourly modulation computed as hourly average over the period April – September 2005. The two vertical red lines limit the time window of interest.

During the summer period, the hourly average ozone concentration is modulated with a daily period. Daily variation spans from about 80 ug m^{-3} (50 ppb) to 100 ug m^{-3} (60 ppb); see figure 1. Anyway, there are large displacements from the average behavior, mainly depending on solar radiation flux, but in some cases the large and rapid increase in the ozone concentration is not explainable according to local effects. One example is considered in this study.

From 08 to 10 April 2005, ozone concentration has moved from the usual average value to a peak of about 130 ug m^{-3} in 12 hours, then it dropped to a minimum of 60 ug m^{-3}. In particular the concentration rise was very steep at the beginning of the 09 April, with a ratio of 20 ug $m^{-3}h^{-1}$. See figure 1. Southern wind has blown since the beginning of 08 April and it intensified up to midday of 09 April, reaching 6 ms^{-1}, then, late in the afternoon, it turned from northeast and it further increased in magnitude, up to 15 ms^{-1} which were reached in the evening of 10 April. Days 08 and 09 were characterized by weak solar radiation, due to cloud coverage an light precipitation, while the radiation flux increased on 10 April, thanks to a scattered sky.

Hypothesis

The absence of regular daily solar flux and the rapid inversion of ozone concentration trend, which is associated with the change in wind direction, stimulates the interpretation of air advection for such large concentration displacements from the average daily cycle.

Simulations

To test the advection hypothesis, dedicated numerical model runs have been performed by means of the Weather Research and Forecasting model (WRF) [4]. The mesoscale air flow over the interested area was reproduced for 60 hours largely covering the period of interest, avoiding the initial transients. Three domains have been considered using the nesting technique, getting the higher spatial resolution of 2 km in the inner domain, see figure 2; 31 vertical levels characterize the run. ECMWF boundary conditions have driven the simulation, but no local data assimilation has been done.

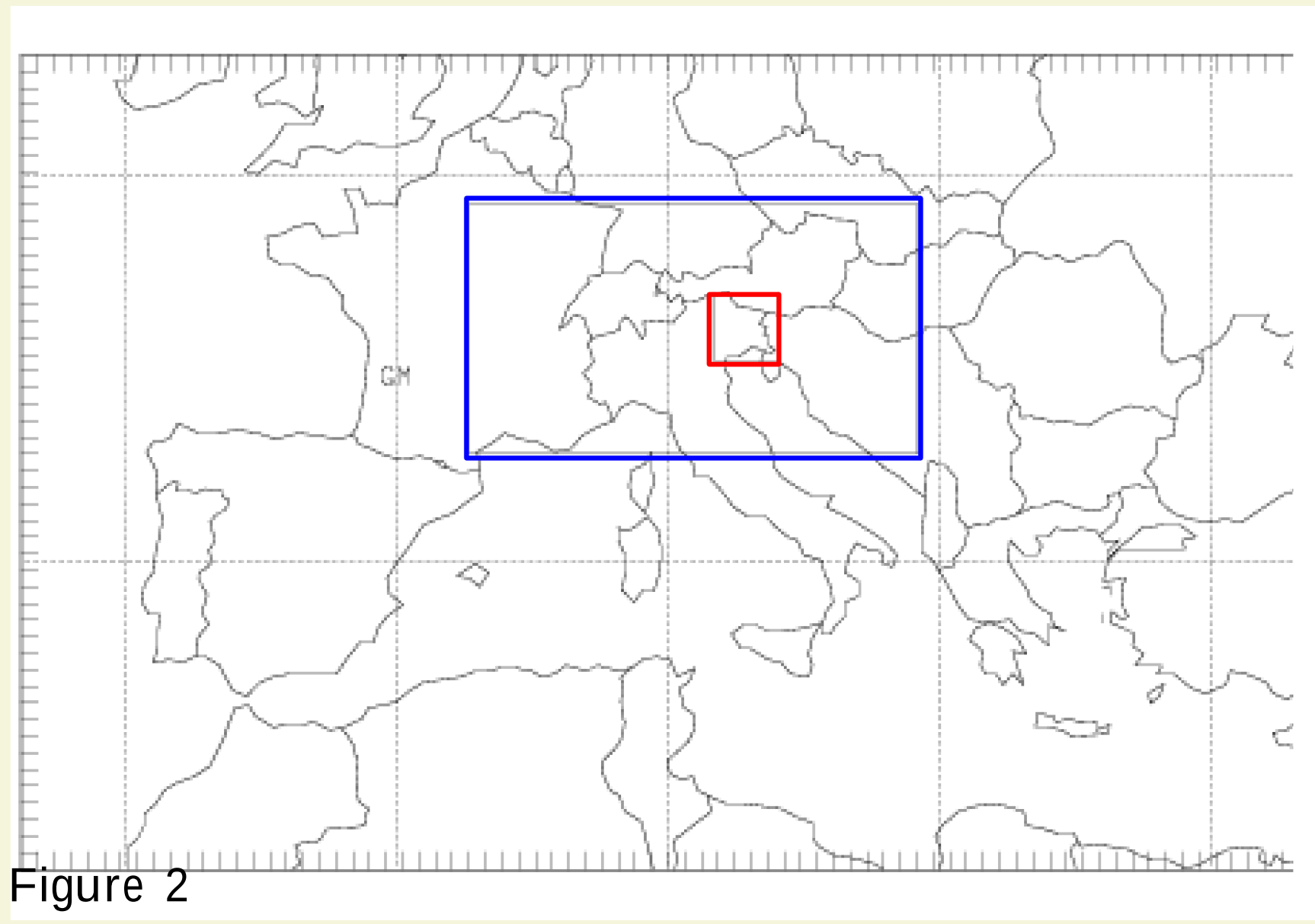
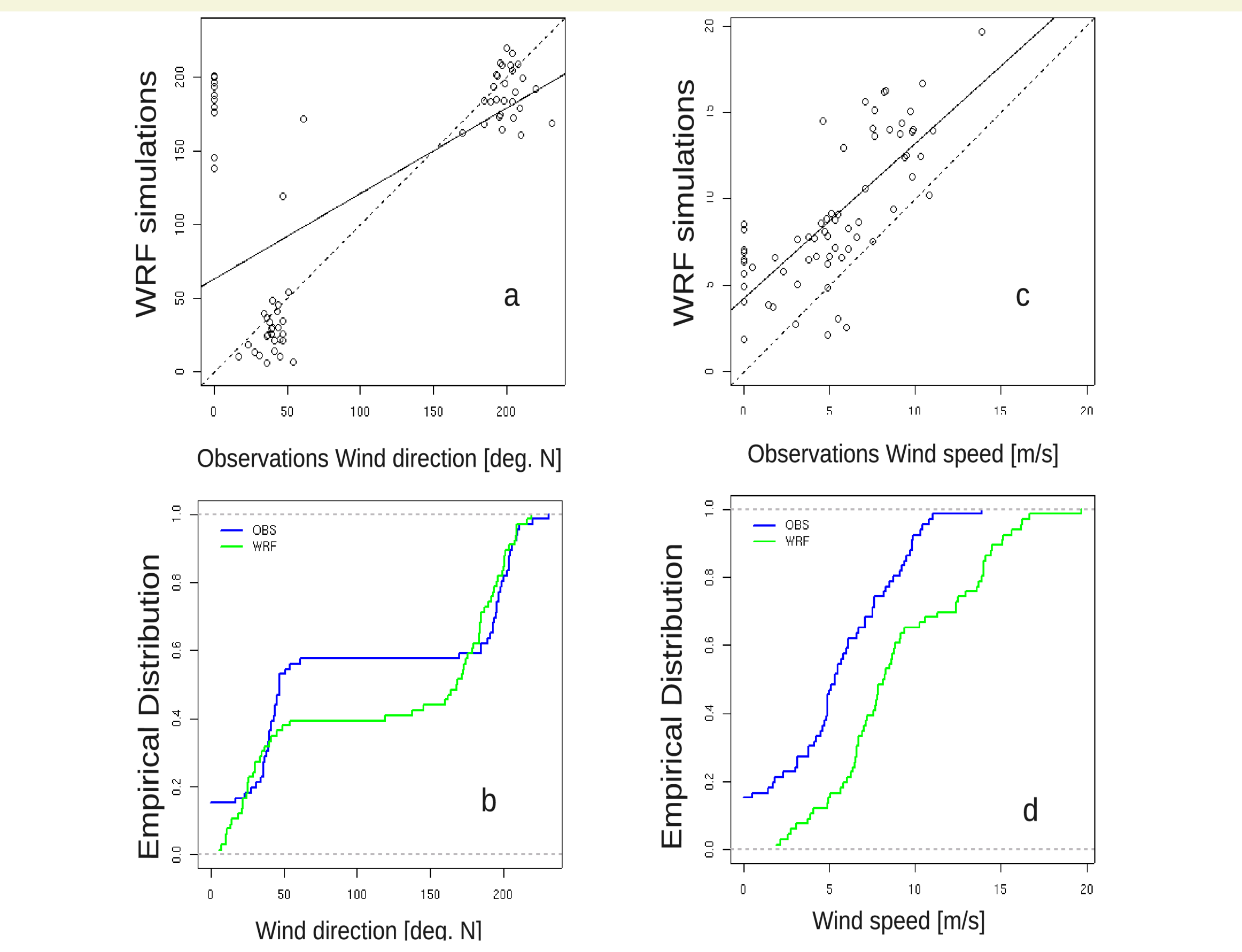


Figure 2
The three domains considered in WRF simulations by means of nesting technique. The largest domain at continental level contains the mid level domain (blue). In the inner domain (red), the spatial resolution is 2 km x 2 km.

The goodness of the simulated wind field was tested comparing model outputs with mesonetwork measurements and synoptic WMO 16044 radiosounding data. The quality of the wind field generated by WRF is considered sufficiently reliable to describe the wind behavior, which was measured at stations, inside the time window selected in this study; see vertical red lines in figure 1.

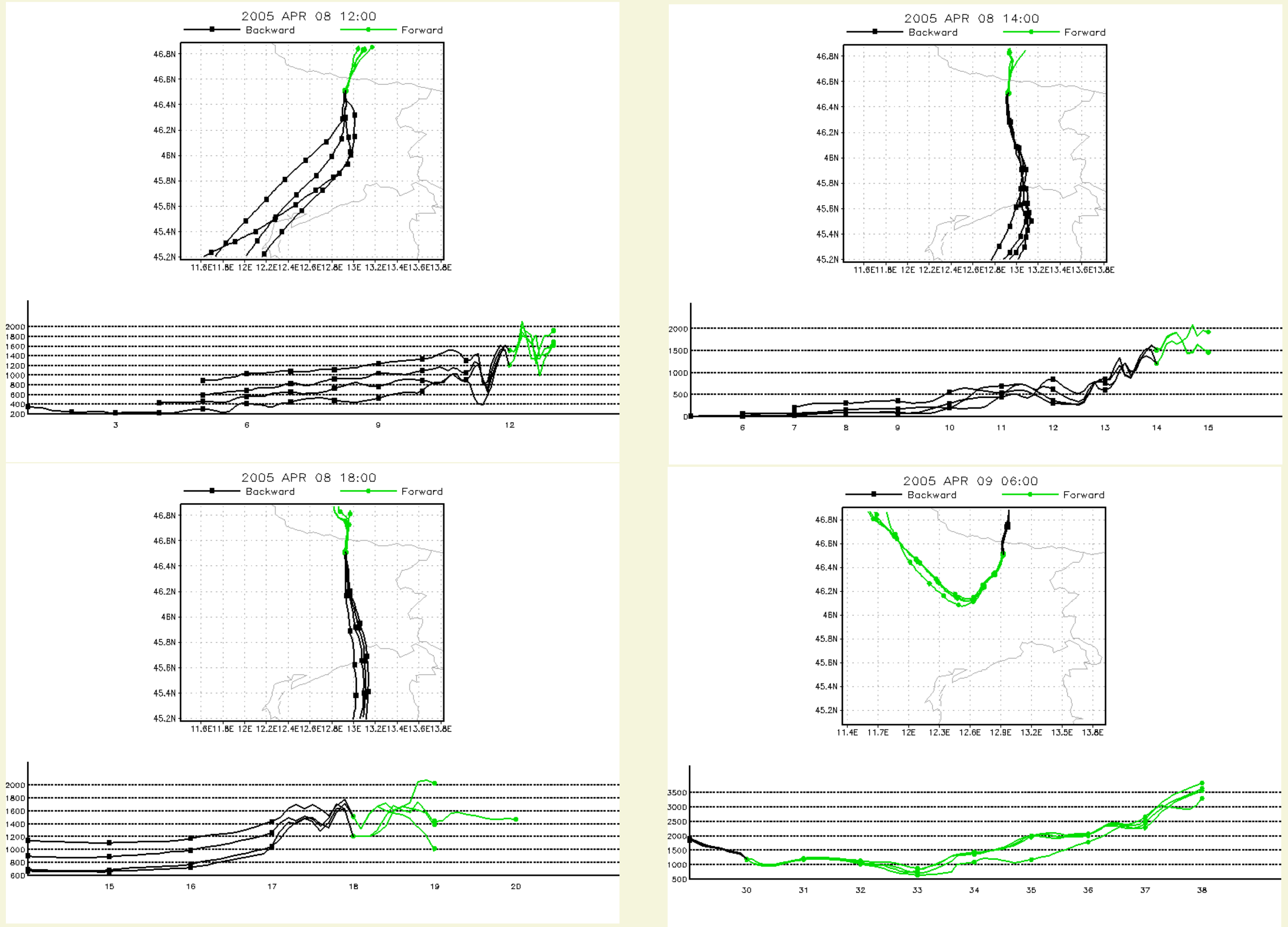
Wind direction is in good agreement with measurements, while wind speed is overestimated by the model on the top of the mountains. As an example, figures 3 report the comparison between wind speeds at Mount Zoncolan location.



Figures 3
Comparison between WRF simulations and measurements at Mount Zoncolan weather station for wind speed and direction. Hourly data for the time window selected in this case study have been used. Sections a and c present the scatter plots of measurements vs simulations; regression line and the bisector are plotted. Sections b and d compare the empirical distributions.

Back trajectory [5] have been computed to retrieve origin and time of fly of the air masses crossing over the Mount Zoncolan during the anomalous fluctuations.

From back trajectories it is evident that, from midday of 08 April up to early morning or 09 April, air masses crossing the Zoncolan peak were from south, in particular the air advected had a marine origin, coming from the Adriatic sea. Later the trajectories are coming from north matching the in situ measurement, so it is assumed the air mass origin changed rapidly. See figures 4.



Figures 4
Back trajectories (black) and forward trajectories (green) computed from simulated wind fields, for different hours on days 08 and 09 April, starting from Zoncolan peak. Four trajectories for each time of the day have been computed to evaluate the uncertainty. Each trajectory starts in a different point of the mountain peak; these points are about 1 km apart.

The ozone concentrations along the shore were on average high before the afternoon of day 09 April. Figure 5 shows the time series of the pollutant concentration at Lignano station which is located on the shore line facing the Adriatic sea. The trajectories computed for 14 UTC show air masses coming from offshore, passing trough Lignano, and then reaching Zoncolan peak. The time of fly is consistent with the advection hypotesis.

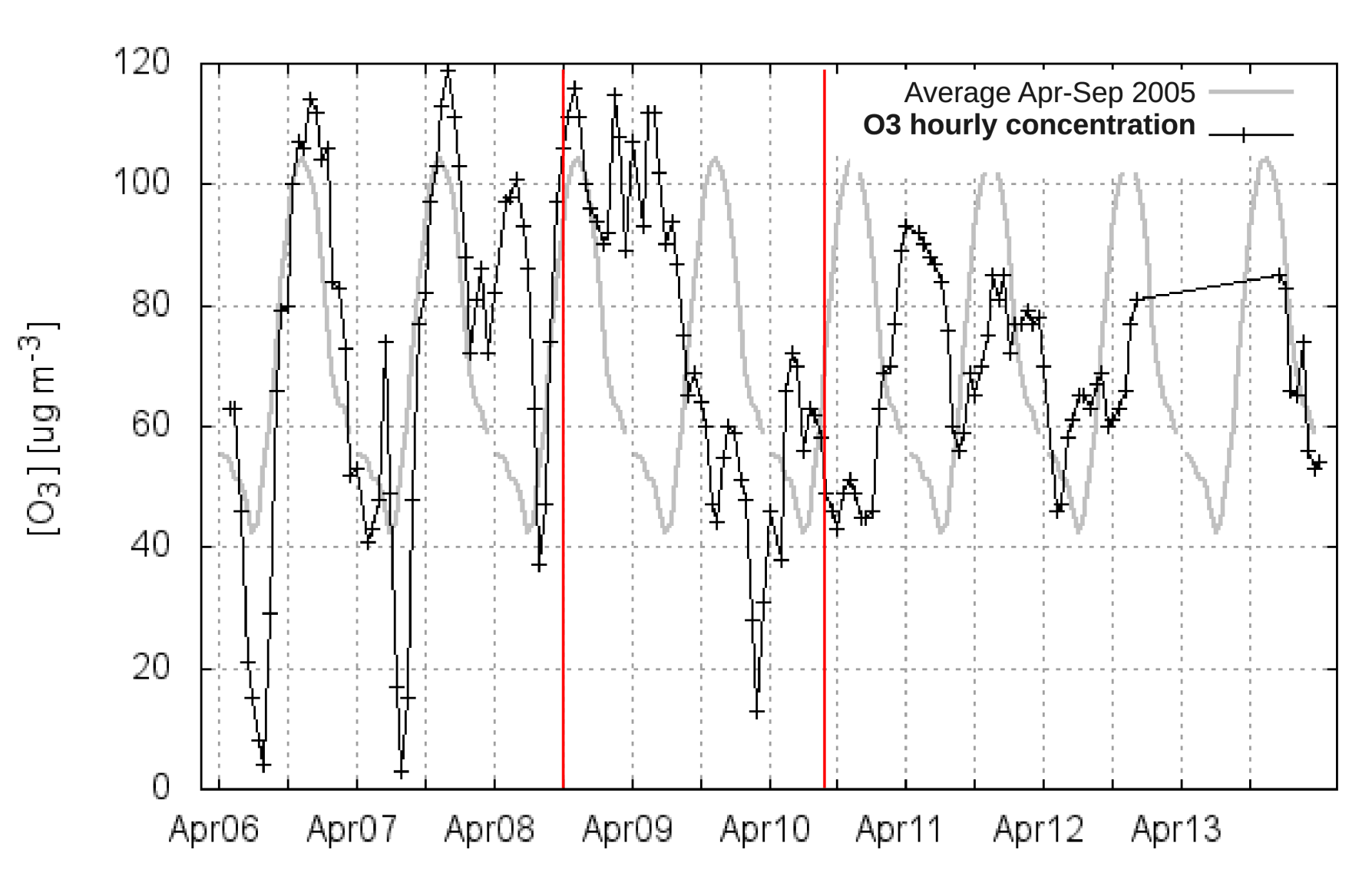


Figure 5
Time series of ozone concentration measured in April 2005 at Lignano station. Solid black line with crosses reports hourly measurements, while gray line shows the average hourly modulation computed as hourly average over the period April – September 2005. The two vertical red lines limit the time window of interest.

Conclusions

The hypothesis of sudden increase and subsequent decrease of ozone concentration in a mountainous rural area has been tested. The weak insulation and the relevant wind speed support the idea that the ozone has been transported from other polluted areas. Back trajectories are consistent with the advection interpretation. Rapid increase and maximum of concentration correspond to air masses coming from offshore, while rapid inversion in hourly concentration trend is related to the change of flow direction and the minimum is measured when trajectories indicate intense flow of air coming from north.

References

[1] Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, 2006, Seinfeld J. H. and Pandis S. N., John Wiley & sons Inc.,

[2] Effect of regional precursor emission controls on long-range ozone transport – Part 1: Short-term changes in ozone air quality, 2009, West J. J., Naik V., Horowitz L. W. and Fiore A. M., Atmos. Chem. Phys., 9, 6077-6093.

[3] Effect of regional precursor emission controls on long-range ozone transport – Part 2: Steady-state changes in ozone air quality and impacts on human mortality, 2009, West J. J., Naik V., Horowitz L. W. and Fiore A. M., Atmos. Chem. Phys.,Atmos. 9, 6095-6107.

[4] Weather Research and Forecasting model http://www.wrf-model.org/

[5] Application of back-trajectory techniques to the delimitation of urban clean air zones, 2002 Sturman A, Zawar-Reza P., Atmospheric Environment 36 3339–3350