DOCUMENTATION OF THE DIURNAL CYCLE OF PM10 CONCENTRATION FOR THE URBAN SITE OF VENICE-MESTRE

Rossa Andrea, Pernigotti Denise, Ferrario Massimo E., Sansone Maria, and Benassi Alessandro
Istitution for all authors: ARPAV-CMT, Via Marconi 55, 35037 Teolo (PD), Italy.
Corresponding author: arossa@arpa.veneto.it

ABSTRACT

Stable boundary layer conditions are long known for causing increasing concentration of pollutant concentrations. In a recent study by the authors, emphasis was given to the documentation of the diurnal cycle of Particulate Matter with diameter < 10μm (PM10) in relation to the atmospheric stability for a high-concentration episode. In this contribution a four-year data set of two-hourly PM10 concentration values measured at the traffic site of Venice-Mestre is analyzed with a specific focus on the intra-diurnal variations. Also, atmospheric static stability observations observed with a radiometer are analyzed when available.

It was found that when daily variations of the PM10 concentration often are of the same magnitude, or larger, than the average daily values static stability does play role in the accumulation of PM10, but there seem not to be a linear relation neither with the absolute values nor with the increase of PM10 concentration; a relatively moderate static stability seems to be sufficient to allow significant accumulation, while marked decrease is observed also in strongly stable conditions. PM10 peak concentrations mostly occur in the late evening and early night hours, while the minimum values are more evenly distributed during the day, with preferred occurrence in the early morning and mid-afternoon. On a quantitative note, PM10 intra-diurnal variations between maxima and minima reach 100 $\mu g/m^3$ and obviously depend on the peak concentrations; hourly rates are estimated to reach 20 $\mu g/m^3$ and more.

INTRODUCTION

Inversions are tied to very stable conditions and therefore inhibit vertical mixing. They are, therefore, long known for causing increasing concentration of pollutant concentrations (e.g. MILIONIS and DAVIES, 1994 and references therein). Presence of a temperature inversion or stable stratification at ground level causes the response of PM10 concentrations to the morning traffic in a much more pronounced way (JANHÄLL et al., 2006), diurnal behaviour of PM10 and PM2.5 are influenced by temperature inversions on episodic basis. In response to the unfortunate climatology of the Po Valley in northern Italy, the Meteorological Centre of Teolo (CMT) of the regional agency of environmental protection of the region Veneto (ARPAV), has recently installed a boundary layer profiler network (Pernigotti et al. 2007), which consists of one HATPRO radiometer, three MTP5-HE radiometers and four PCS-2000 SODAR, mostly funded by the DOCUP 2000-2006 Project. The network is the first of its kind in Italy and its principal applications are in the field of environmental emergency management and regional air-quality short time forecasting.

In a recent study by Pernigotti et al. (2007, P07) the CMT profilers were applied to analyze the diurnal PM10 concentrations in a pollution episode that occurred in particularly stable conditions. In such regimes they found that the intra-diurnal PM10 concentration variations can be much stronger than day-to-day variations of daily averages reaching 100-150$\mu g/m^3$ in just 4 – 6 hours (see Fig. 4 of P07). They propose a schematic mechanism which depends on the daily emission cycle for the interpretation of the diurnal cycle of PM10 concentration in anticyclonic conditions. It accounts for the fundamentally different removal mechanisms of the particulate matter from the atmosphere in stable and unstable conditions, i.e. for the morning and evening emission peaks, respectively. In more detail:

- The peak concentration occurs at around midnight and subsequently decreases during the night when emissions are significantly reduced, and probably trough deposition and chemistry of this pollutant. This reduction takes place while the boundary layer stability is still increasing, which yields an anticorrelated behaviour.
- The morning emission peak occurs in stable conditions so that the PM10 concentration increases (JANHÄLL et al., 2006), but is counteracted by the destabilization of the boundary layer during the morning hours. Consequently, the resulting concentration signature, which does not always show as a distinct maximum, is much lower compared to the peak of the night and occurs before noon.
- The minimum concentration values are reached mid afternoon when the emissions are lower and stability is at its minimum.
- The main and sharp build-up of the PM10 concentration values comes about when the evening emissions due to traffic, including re-suspension, and other sources are coincident with the stabilization of the boundary layer and are not diluted through vertical mixing.

This mechanism does not account for aerosol chemistry, which plays an important role in the production of secondary PM. In this contribution the diurnal variability of PM10 concentration is further documented for the traffic station of Venice-Mestre analyzed in P07, which features two-hourly measurements since 2003. Particular attention is given to the time of the day when the maximum and minimum concentration values are attained. In section 2 the data set and the approach are described, results are presented in section 3, while a summary and an outlook on further work follows in the final section.

DATA SET AND APPROACH

In this study we focus on the relation between static stability and PM10 concentration evolution at the Venice-Mestre site. The closest thermal profile is measured in Padua, a city some 25km west of Venice, with an MTP5-HE radiometer, manufactured by Attex (Russia) and distributed by Kipp & Zonen (NL). It is a well proven and robust instrument that measures temperature up to 1000m with a vertical resolution of 50m and a time resolution of 5'. Data availability in the first year of deployment is quite high for the Padua site with 97% with a nominal accuracy of 0.3-0.4K for adiabatic and 0.8-1.2K for inversion conditions (FERRARIO et al., 2006). The particulate matter with diameter lower than 10 µm (PM10) are measured every two hours with an ENVIRONNEMENT MP101M, using the method of beta-ray attenuation; the daily average are validated trough comparison with a near by gravimetric instrument. The MP101M is located in the centre of Venice-Mestre, a city close to Venice. For this study a four-year time series of two-hourly measurements are available, as well as temperature profiles for a full year starting 1 Apr 2005.

RESULTS

A high-concentration episode, the strongest of the analyzed data set, occurred in Venice-Mestre in the Christmas week 2005 when a stable high pressure system persisted for several days (see P07 for more details). Figure 1 shows the PM10 concentration evolution for this period with values below 50 $\mu g/m^3$ at the 19th that increased over the next days to 150 $\mu g/m^3$ around noon, and peaks over 200 $\mu g/m^3$ during the night. Eventually, on the 26th the synoptic conditions changed and brought the episode to an end. One very obvious feature of this evolution is the pronounced diurnal cycle, both of the PM10 concentration and the PBL stability.

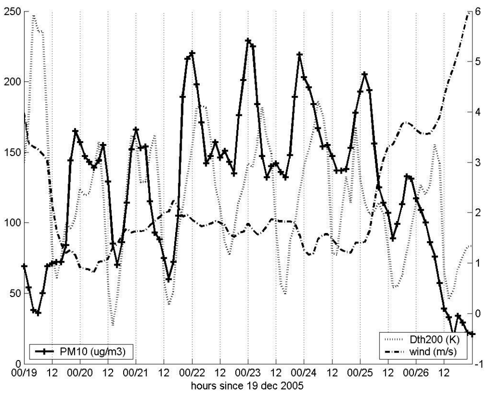

Figure 1 :19-26 dec 2006, 2h-ly data, left axis for PM10, right axis for difference of potential temperature between 200m and ground level in K, and wind at 100m above ground in m/s.

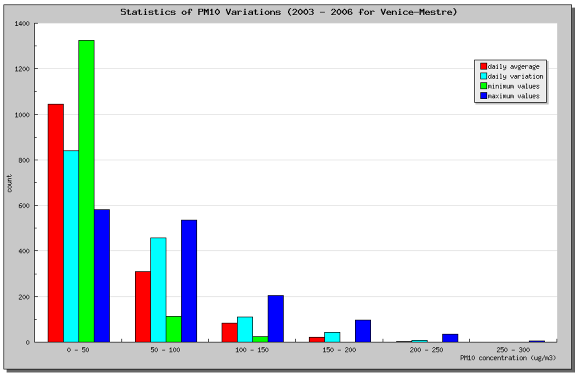

Figure 2 Daily average, maximum daily variation, minimum, and maximum values of PM10 concentration measured at the traffic station Venice-Mestre for the period 1 Jan 2003 – 31 Dec 2006. The measurements are made for two-hourly intervals**.**

Figure 2 summarizes a more systematic documentation of the two-hourly PM10 concentration values of the traffic station Venice-Mestre by looking at an intensity histogram for the period 1 Jan 2003 – 31 Dec 2006 (Fig. 1). The daily average values (red, leftmost bar) peak for the lowest class of concentration values between 0 and 50 $\mu g/m^3$ feature a count of over 1000 of a total of 1460, leaving a significant number of days with average values above 50 $\mu g/m^3$ (about 300), above 100 $\mu g/m^3$ (still about 80), and episodes with concentrations above 150 $\mu g/m^3$. The minimum (green, second from the right bar) and maximum (blue, rightmost bar) show that for about one third of the time the concentration does not relax below 50 $\mu g/m^3$, while for about one forth of the days maximum daily values are well over 100 $\mu g/m^3$. It is noteworthy that the significant daily variations found in the 2005 Christmas episode seem not to be exceptional, in that a substantial number of days are found in which daily variations are of similar magnitude, or larger, that the daily average concentration values. This seems to be especially true for concentrations above 50 $\mu g/m^3$.
The timing of the peak and minimum values in the Christmas episode is another salient aspect of the diurnal PM10 concentration that is found in the entire in the entire data set (Fig. 3). As a matter of fact the largest part of the peak values with an amplitude of at least 30 are attained in the evening and night hours between 20 and 02 (local time). There is a minimum of the peaks at 06 stability is largest, and in the afternoon, when

atmospheric mixing is largest. The minimum values, on the other hand, have a less distinct diurnal distribution, but tend to cluster in the early morning and mid-afternoon hour hours.

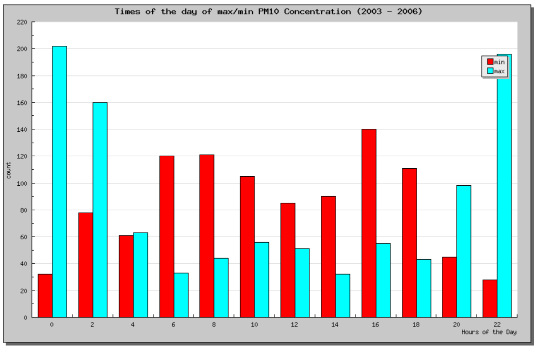

Figure 3 Histogram of time of the day of relative minimum (red, left bars) and maximum (cyan, right bars) values of PM10 concentration (counted extrema>30 µg/m^3

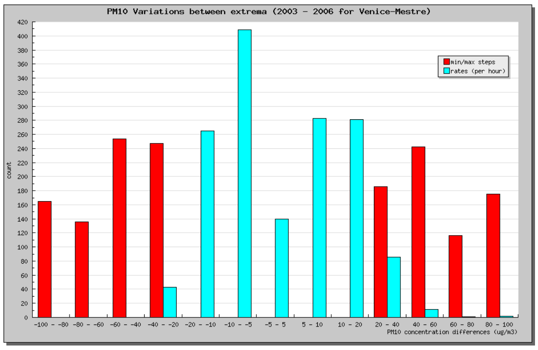

Figure 4 PM10 variation between adjacent minima and maxima (> 30 µg/m^3). Red bars (left) denote the absolute variation, while the cyan bars (right) denote the rate of change per hour of the same variations.

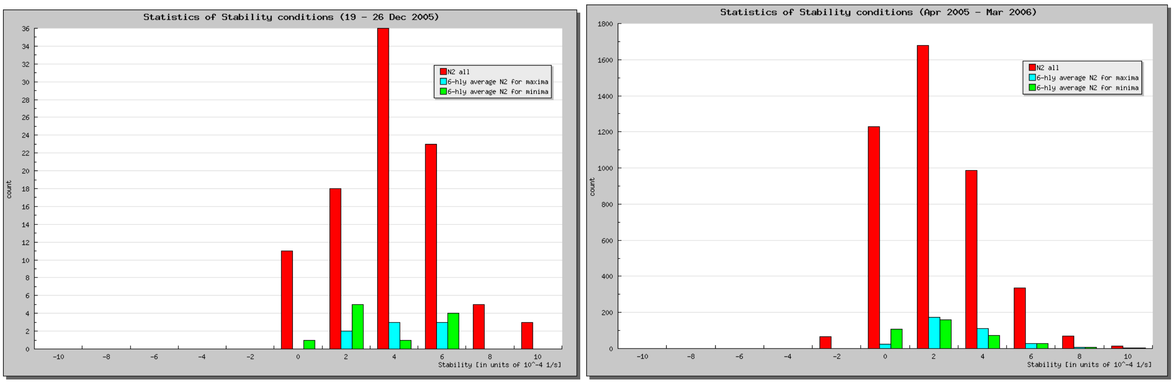

Figure 5 Atmospheric static stability in terms of the Brunt-Vaisala frequency N^2 in 10^4/s for the Christmas 2005 episode and the year 1 Apr 2005 – 31 Mar 2006. The red and leftmost bars denotes all stability values, while the cyan/middle and the green/rightmost bars denote static stability at the time of minimum and maximum PM10 concentration, respectively.

Figure 5 summarizes the static stability conditions for the Christmas 2005 episode as well as for the year 1 Apr 2005 – 31 Mar 2006 evaluated between the ground and 200m height from the temperature profiles measured by the radiometer of Padua. First it can be seen, that there seem to be relatively few conditions which are statically unstable, while the most populated stability classes are between 0 and 4 times 10^{-4} and even very stable situation very rarely reach 10 times 10^{-4}. The static stability values for the times of peak concentrations are very similar to those found for minimum concentration, except for the weakly stable class 0, when very few maxima occur. Most PM10 peaks, however, occur in moderately stable condition, while minimum concentration values can be found even in strongly stable conditions. This is in agreement with the conclusions of P07 who claim that the diurnal PM10 cycle cannot be explained with atmospheric parameters alone but need to take into account the emission cycle which, in the case of a traffic station features a distinct morning-evening-peak behaviour. As a last part of the documentation of the diurnal cycle we look the intensity of the PM10 accumulation and dilution between extrema. Figure 5 shows that in absolute values variations between 40 and 100 are almost equally frequent, while the PM10 rate of change per hour are confined by 20 in both directions, which occasionally larger values.

The mean daily average PM10 concentration (all in µg/m^3) for the entire four-year period is 42 with a variance of 34. The mean daily minimum 19 with a variance of 25, while the mean peak concentration is 71 with a variance of 52 with a fair correlation of 0.66 between the two series. The mean daily variation of PM10 amounts to 52 with a variance of 40 and correlates very well with the peak concentrations featuring a coefficient of 0.88. Looking for a relation between PM10 concentration and static stability seems not to be straight forward. For the Christmas 2005 episode the correlation between the PM10 increase that leads to the peak values and the six-hourly average of the static stability preceding the peak yields a correlation coefficient of 0.88. The PM10 drops that lead to the minimum values with the same stability measure yields

0.64. Analysis for the year 1 Apr 2005 -- 31 Mar 2006, on the other hand, gives moderate correlation coefficients of 0.26 and 0.09 for the static stability and the peak and minimum values, respectively.

SUMMARY AND OUTLOOK

In the present paper a documentation of the two-hourly PM10 concentration for the traffic station Venice-Mestre was presented with a particular focus on the diurnal cycle. Features found in Pernigotti et al (2007) in an episode could be recognised in the four years worth of data. In particular:

- there are a significant number of days with PM10 concentrations above 50 μg/m^3;
- daily variations of the PM10 concentration often is of the same magnitude, or larger, than the average daily values;
- static stability does play role in the accumulation of PM10, but there seem not to be a linear relation neither with the absolute values nor with the increase of PM10 concentration; a relatively moderate static stability seems to be sufficient to allow significant accumulation, while marked decrease is observed also in strongly stable conditions;
- PM10 peak concentrations mostly occur in the late evening and early night hours, while the minimum values are more evenly distributed during the day, with preferred occurrence in the early morning and mid-afternoon;
- PM10 variations between maxima and minima reach 100 μg/m^3 and obviously depend on the peak concentrations; hourly rates are estimated to reach 20 μg/m^3 and more.

From this perspective it becomes evident that explaining the diurnal variations of PM10 concentration is more complex that trying to relate day-to-day variations. The emission cycle as well as aerosol chemistry are likely to play a fundamental role in governing the significant variability of the intra-diurnal PM10 concentration variability.

ACKNOWLEDGMENTS

This work was supported by the European Community, Italian Government and Padua Municipality trough the DOCUP Project and the ‘Air pollution in the city of Padua’ Project. Particular thanks are due to Massimo Bressan of the ARPAV-Padua Department for the data of radiometer and SODAR and to the ARPAV-Venice Department for the data of PM10 concentrations.

REFERENCES

FERRARIO, M.E., A. M. ROSSA, D. PERNIGOTTI, M. SANSONE, A. BENASSI, 2006: Presentation and first assessment of a radiometer network in the Italian region Veneto -- Proc. of the Int. Conf. on Urban Climate, Goteborg, 10-16 June 2006.

JANHÄLL, S., K. F. G. OLOFSON, P. U. ANDERSSON, J. B.C. PETTERSSON, M. HALLQUIST, 2006: Evolution of the urban aerosol during winter temperature inversion episodes.-- Atmospheric Environment. **40**, 5355-5366.

MILIONIS, A.E., T. D. DAVIES, 1994: Regression and stochastic models for air pollution—II. Application of stochastic models to examine the links between ground-level smoke concentrations and temperature inversions **--** Atm. Env. **28**, 2811-.2822.

PERNIGOTTI, D., A. ROSSA, M. FERRARIO, M. SANSONE, A. BENASSI, 2007: Influence of PBL stability on the diurnal cycle of PM10 concentration. Submitted to Meteorologische Zeitschrift.