CHEMICAL ENGINEERING TRANSACTIONS, Volume 16, 2008
Guest Editor Eliseo Ranzi

The Influence Of Orography And Meteorology On The Spatial Distribution Of Pollutants In The Alpine City Of Sondrio (Northern Italy)

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A study on the spatial distribution of gaseous pollutants and PM2,5 was carried out in the city of Sondrio and its surroundings. Changes in the average concentrations of pollutants were associated with the season and the altitude. In the valley floor PM2,5 levels were higher in winter, while no significant differences between summer and winter was observed at intermediate altitudes. On the contrary, at high altitudes winter levels of PM2,5 resulted lower than summer ones. Winter concentrations of PM2,5 in the valley floor were above 50 $\mu g/m^3$ and there were no relevant differences in PM2,5 concentrations between rural, urban and kerbside sites. S was the most abundant element in the PM2,5 in summer while winter concentrations of K and Cl in PM2,5 rose between one and two orders of magnitude with respect to summer levels. An indicator of the atmospheric turbulence (z/L) was compared with the hourly means of PM10 in order to assess the influence of the vertical mixing on the dispersion of PM.

1. Introduction

Sondrio is a small alpine capital (22.000 inhab.) located in the Valtellina valley floor, an area of Lombardy where the principal economic activities are agriculture and tourism. The area (300 m a.s.l.; 46°11'N; 9°53'E) is partially protected from polluted air masses arriving from the Po plain by the prealpine barrier. Despite its size and the reduced number of industrial emissions, concentrations of particulate matter (PM10) overrun the European thresholds for daily and annual mean concentrations. In addition, levels of PAHs monitored since 2004 not only overrun the European target value (1 ng/m^3) but also are higher than those observed in more densely populated urban areas of Lombardy Region (Belis *et al.*, 2007).

Previous studies estimated that in this area a considerable fraction of the PM derives from primary biomass burning emissions (INEMAR 2007; Fermo *et al.* 2007).

2. Material and Methods

In order to study the influence of orographic and meteorological variables on the

Please cite this article as: Belis C., Gianelle V., De Stefani G., Colombi C. and Magnani T., (2008), The influence of orography and meteorology on the spatial distribution of pollutants in the alpine city of sondrio (northern italy), Chemical Engineering Transactions, 16, 153-160

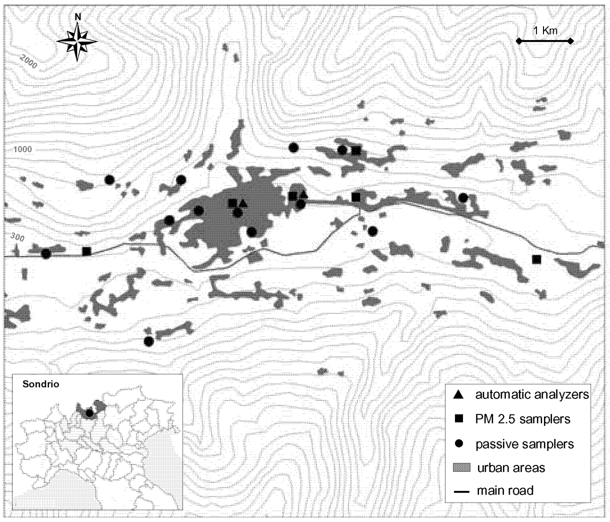

Figure 1. Map of Sondrio and neighbouring towns with indication of the sampling sites

geographical distribution of PM and other pollutants and their altitudinal variation, was carried out an intensive survey on an area of ca. 50 km^2 centred on the city of Sondrio. The survey consisted of two measuring periods: summer campaign (25/6/07 to 23/7/07) and winter campaign (19/11/07-20/01/08). The spatial distribution of NO_2, NO_X, O_3 and BTX concentrations was estimated using passive samplers in 12 sites while PM2,5 mass and chemical composition were determined in 6 sites. In addition, there were two monitoring stations (1 permanent and 1 temporary) within the study area with automatic analysers for PM10, CO, SO_2, NO_2, NO_X, O_3 and BTX. A complete set of meteorological parameters was collected in two sites within the study area (wind speed and direction, temperature, relative humidity, solar radiation, precipitation, etc...). Particulate matter was sampled using automatic sequential samplers and the mass was determined using a 1 μg precision scale. All the instruments were calibrated with reference standards on a regular basis. The concentrations of 22 elements in PM2.5 were determined by X-ray fluorescence (Ba, Br, Ca, Cl, Co, Cr, Cu, Fe, K, Mn, Ni, P, Pb, Rb, S, Sc, Si, Sn, Sr, Ti, V, Zn).

The atmospheric turbulence and the height of the mixing layer were estimated using the measurements of a sonic anemometer located in a rural meteorological station beside the study area. The Monin-Obukhov length (L) was calculated using the algorithm:

$$L = -\frac{\overline{T}}{k\,g}\,\frac{u*^{3}}{\overline{w'\theta'}} \quad \text{(Sozzi } et\ al.\text{, 2002)} \qquad (1)$$

where: $\overline{T}$ is the mean temperature of the surface layer, $\overline{w'\theta'}$ is the covariance between the perturbation scalar velocity and the potential virtual temperature, u* is the friction velocity, *g* is the gravity acceleration, and *k* is the Von Karman constant (k=0,4). L is plotted as the ratio z/L being z the height of the measuring point. The height of the mixing layer (h) was estimated setting $c = 2.4.10^3$ as follows :

$$h = c.u_*^{3/2} \quad \text{(Sozzi et al., 2002)} \qquad (2)$$

3. The meteorological context

The sampling campaigns have been subdivided in periods according to the dominant meteorological conditions. In the summer campaign (5 weeks) were identified two periods (Figure 2). The first period (25/6/07 - 11/7/07) was unstable and characterized by the alternation of atmospheric disturbances associated with precipitations and anticiclonic conditions with sunny weather. The second period (12/7/07 - 29/7/07) was dominated by the expansion of a vast African high which determined atmospheric stability, absence of precipitations, increase of temperatures and muggy weather.

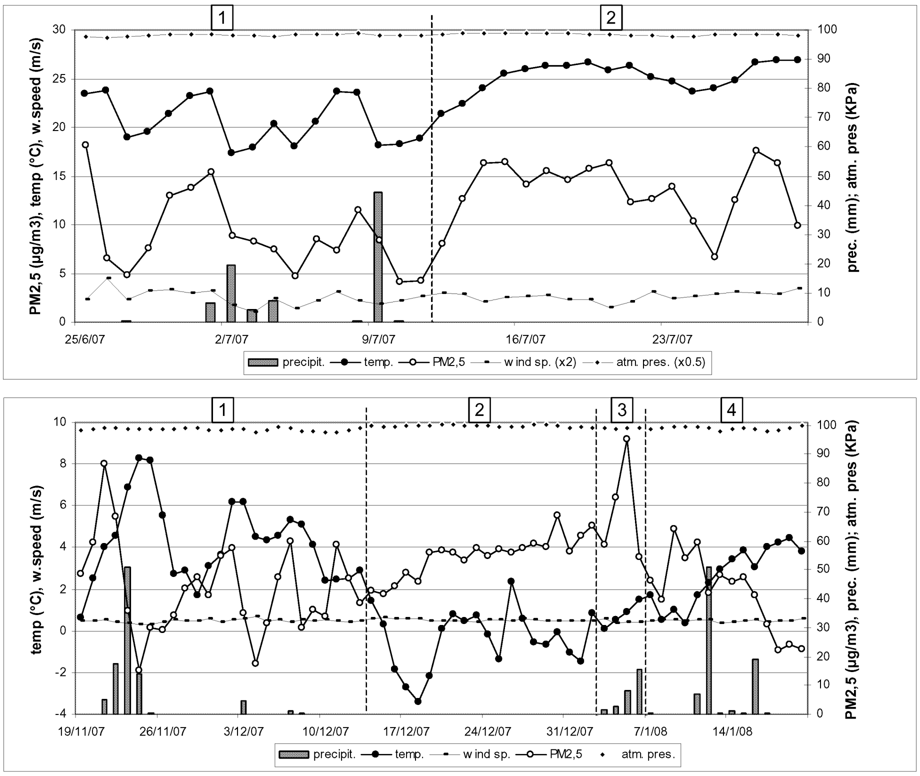

Figure 2. Trends of some meteorological parameters and PM2,5 in the city of Sondrio. On the top are indicated the periods in which were subdivided the campaigns.

The winter campaign (9 weeks) was subdivided in 4 periods. The first period (19/11/07 - 13/12/07) was characterized by variable conditions with the succession of three cycles of precipitation events associated with changes of air masses. The second period

(14/12/07 - 2/1/08) was dominated by stable conditions, absence of precipitations, high pressure and thermal inversion at the floor with a decrease in temperatures, in many cases constantly below zero. The third period (3/1/08-6/1/08) coincided with an episode of heavy snowfall caused by the circulation of an Atlantic low over the Mediterranean sea. The last period (7/1/08-20/1/08) was similar to the first one with variable conditions, associated with rainy weather and daily average temperatures above zero. During the periods with atmospheric instability the air pollutants presented a sawtooth trend with minima associated to changes of air masses or to events of heavy rain. The highest levels of pollutants that lasted for long periods coincided with anticiclonic conditions which were associated to the absence of precipitations and to atmospheric stability that favoured the accumulation of locally emitted pollutants.

4. The distribution of pollutants in space and time

According to the measurements carried out with passive samplers the levels of gaseous pollutants (with the exception of ozone) were significantly higher in winter than in summer only in the valley floor (Figure 3). The concentrations of these pollutants decreased with height. Sites in the valley floor were more polluted than those in the slopes (150 – 300 m a.g.l.) and these ones were in their turn more polluted than the elevated site (500 m a.g.l.). The kerbside site in the valley floor showed the highest NO_2 and NO_X levels (74 and 230 µg/m^3 respectively) however there were no significant differences in the levels of the other pollutants between this site and the urban background sites. On the other hand, mean ozone summer levels in the sites in the valley floor were 86 µg/m^3, while those in the slopes presented means between 103 and

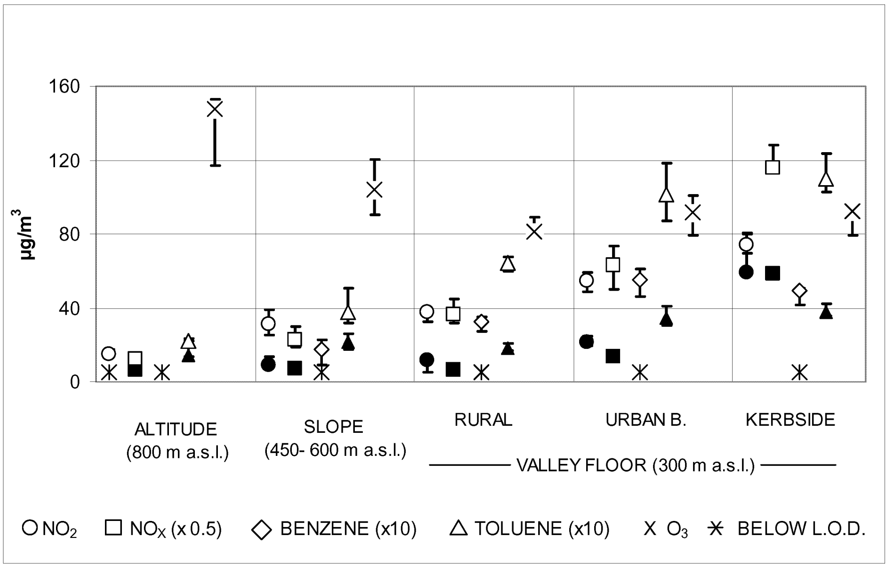

Figure 3. Median levels of pollutants measured with passive samplers in 12 sites (bars: 25° P and 75° P). Winter: empty symbols; Summer: solid symbols; O_3 *only in summer.*

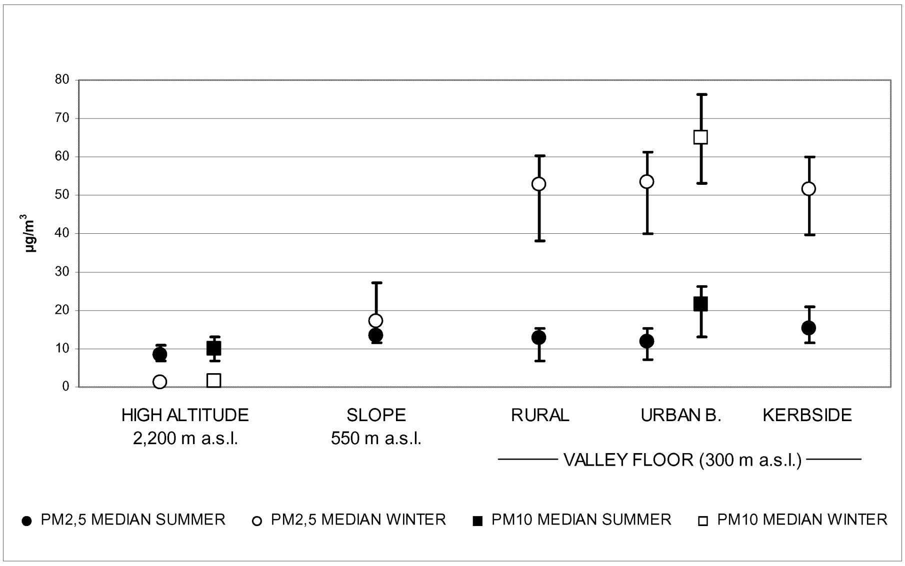

*Figure 4 Median winter/summer levels of PM measured with automatic analysers in 7 sites. *urban background represents the average of 3 sites. (bars =25°P and 75° P).*

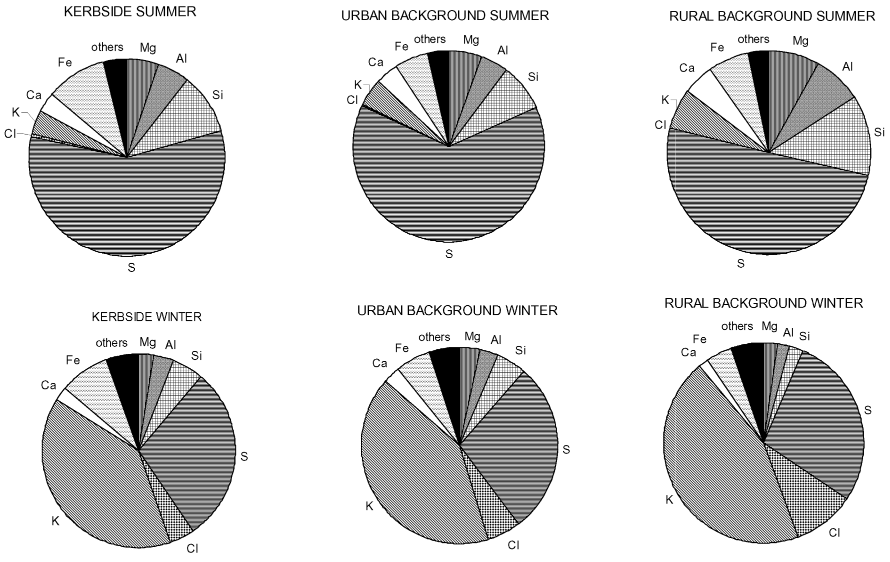

Figure 5 Winter/summer composition of 22 elements in PM2,5 in three kind of sites.

114 µg/m^3. The highest values were those observed in the elevated site (135 µg/m^3). Concerning PM2,5, summer median values ranged from 9 to 15 µg/m^3 while winter medians values were between 53 and 57 µg/m^3 (Figure 4). During summer, the average of the sites in the valley floor and in the slopes were quite homogenous, only the kerbside site presented PM2,5 concentrations slightly higher than the others. Pearson

coefficients between sites were ≥ 0.9 both in summer and winter campaigns. Worth to mention that in a high altitude site located outside the study area (Bormio S. C. 2,200 m a.s.l.; further details in Belis *et al.*, 2006) PM2,5 median summer values were 8 μg/m^3, which is relatively close to the values observed at lower altitudes. In winter, PM2,5 levels in the valley floor were still quite homogeneous and were three times higher than those observed in summer. Unlike the valley floor, PM2,5 levels in the slope site (ca. 250 m above the valley floor) rose very little with respect to the summer values (median 17 μg/m^3). On the contrary, during this part of the year the concentrations of PM2,5 in the site at high altitude fell to extremely low levels, 1 μg/m^3. In the urban background site also PM10 rose three times in winter, from 22 μg/m^3 in summer to 65 μg/m^3, while in the high altitude site levels fell from 10 μg/m^3 in summer to 2 μg/m^3.

The PM2,5/PM10 ratio presented a slight seasonal trend in the urban site with winter mean (0.7 ±0.1) slightly higher than the summer one (0.6±0.1).

In summer the total mass concentration of the 22 analyzed elements in the PM2,5 ranged from 1.0 to 1.1 μg/m^3 with S representing more than the half of the mass of the elements (Figure 5). In this season the rural site presented higher levels of Si and Al than the urban and the kerbside sites, what may indicate a higher contribution of soil particles in this site. In winter the mass of the elements rose to 2.5-2.6 μg/m^3 mainly due to the dramatic increase of K which became the most abundant element in all the sites. Also Cl presented a marked increase in winter in particular in the rural site. High levels of both K and Cl are reported in the emissions of PM2.5 from open burning of agricultural biomass (Hays *et al.,* 2005) hence the dramatic increase in these elements in winter in may be interpreted as a contribution from this source. However, a contribution of Cl from road salting cannot be excluded. On the other hand, the kerbside site showed the highest values of Fe which likely derives from the wearing of brake-linings.

4. PM and atmospheric turbulence

Since the concentration of pollutants depends on both the emissions and on the capacity of the atmosphere to dilute them (Stull, 1997) special attention was paid to the atmospheric turbulence and its relationship with the concentration of PM. The height of the night-time mixing layer (*h*) in summer was on average 160 m a.g.l. while diurnal heights rose to 960 m a.g.l.. In winter *h* oscillated on average from a daily minimum of 115 m a.g.l to a maximum equal to 230 m a.g.l.. In summer, during the night were present adiabatic conditions (Figure 7). Soon after the sunrise the atmosphere shifted to the maximum daily convective conditions (minimum values of z/L) that lasted between 8.00 and 11.00. From 11.00 to 18.00 there was a gradual return to neutral or slightly stable conditions which persisted until the following day. The average daily trend of PM10 measured in the permanent station of Sondrio in the summer campaign was similar to the one of z/L indicating that the diurnal cycle of the atmospheric turbulence influenced the dynamics of PM during this part of the year.

In winter average values of z/L were close to zero indicating that the air column was substantially in equilibrium, i.e. without any predominant forces inducing mixing nor stability. Despite the daily trend looks more stable than summer one the latter is more

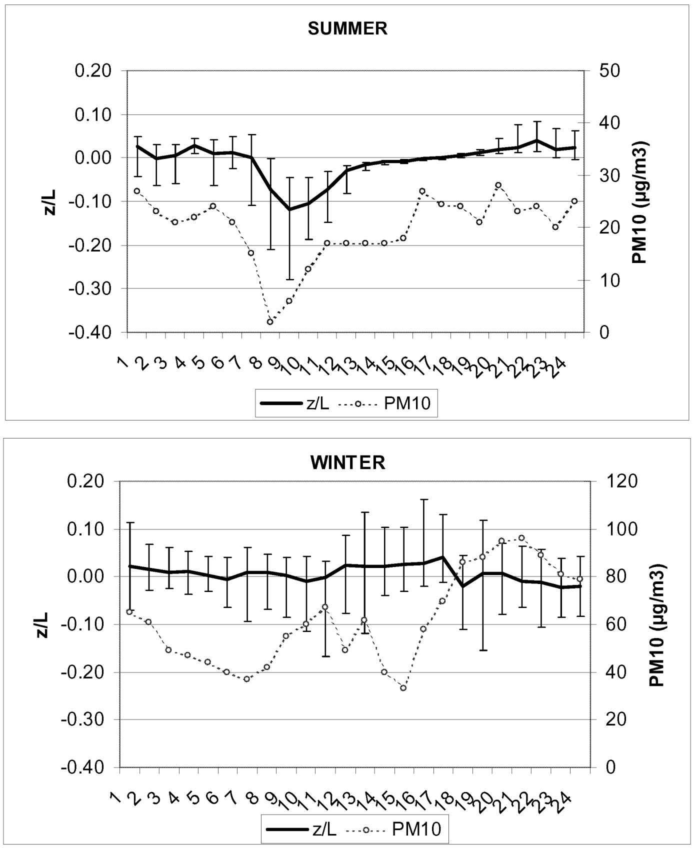

Figure 6 Daily trends of atmospheric turbulence (z/L) in summer and winter campaigns (median, 25°P and 75°P). PM10 daily trend is also reported.

variable from one day to the another, as indicated by the percentile bars.
Since the daily trend of the turbulence in winter is relatively flat the daily trend of PM10 is probably more influenced by the diurnal fluctuations in the PM10 sources (heating, traffic) which present one maximum in the morning and one in the evening.

5. Concluding remarks

The study area is located in the central part of the valley delimitated by two E-W oriented ranges, without passes, which constrain the main circulation of the air masses near the ground along the longitudinal axis of the valley. During summer the emissions of primary PM are low, the height of the PBL is maximum and the presence of along valley and slope breezes contribute to the dispersion of pollutants. The main critical condition in this part of the year is determined by the higher temperatures that favour the development of photochemical secondary PM. In this area episodes of secondary PM occur in July- August, the warmest months, and levels may overcome the daily limit value for PM10 (50 $\mu g/m^3$). However, the most critical phase of the year for PM in this Alpine area lasts from November to February. In this time window the lowest temperatures determine both the maximum emissions of the heating systems, and the minimum height of the mixing layer. These two factors cause the accumulation day after day of the PM, in particular the finer fractions with higher resident times in the atmosphere, as indicated by the higher PM2.5/PM10 ratio in this season. The results of this study indicate that during winter there are relatively high background levels of PM and other pollutants in the rural and urban areas in the valley floor.

In winter, high PM levels were associated to conditions of atmospheric stability suggesting that local emissions are the prevalent sources of PM in this area. The mass and the chemical composition of PM2,5 along the different sites of the valley floor are quite homogeneous indicating that pollutant sources are diffuse and/or that the air masses near the ground are relatively well mixed. In addition to the local sources, the circulation of air masses at low altitude over the Po plain transporting high concentrations of PM may occasionally determine episodes of high PM levels.

6. Acknoledgements

The authors thank Cristian Lussana and Marco Negri for their support. Part of this study was carried out within the framework of a project financed by Lombardia Region, Province of Sondrio and Municipality of Sondrio in partnership with the F.L.E.

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