INVESTIGATION OF THE WINTERTIME LOCAL-SCALE METEOROLOGY IN AN ALPINE URBAN AREA

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Abstract:

Preliminary results from a recent measurement campaign performed during the early Winter season 2006-2007 in the urban area of the city of Trento (Eastern Italian Alps) are presented. Aim of the investigation is to deepen the knowledge of the local-scale meteorological processes occurring close to this urban area located within a quite narrow valley in the Alps and accounting for approximately 100'000 inhabitants. The reason for this interest is the relevance of the weather-factors in determining the pollutant concentrations levels, which often exceed the limits set by the European Union and Italian regulations.

Keywords: *Alpine valley, Urban Heat Island, Winter, air pollution*

1. INTRODUCTION

One of the peculiar aspects of the urban environment is the frequent occurrence of a local temperature anomaly, in the literature usually referred to as *Urban Heat Island* (UHI: cf. Geiger et al., 2003). The latter consists in the fact that large urban areas often display air temperature values higher than in the surrounding suburban or countryside areas, this difference being in some cases quite strong, especially during Winter, under fair weather conditions and calm wind. In the diurnal temperature cycle the difference is more evident some hours after sunset, when rural environments cool down more rapidly than the interior urban area. As already pointed out by Oke (1987) and more recently by Christen and Vogt (2004), the formation of an UHI is due to following processes: a) reduced radiative cooling due to the reduced sky view factor inside the street canyons; b) enhanced absorption of solar radiation due to a low albedo typical of urban areas, along with multiple reflections inside street canyons; c) high energy storage inside buildings during the day with a slow nocturnal release; d) high values of the Bowen ratio between latent and sensible heat fluxes due to the limited presence of vegetation; e) strong dumping of turbulent exchanges inside the urban canopy induced by the reduced ventilation caused by a dense urbanization. These phenomena, which induce a horizontal temperature gradient across urban boundaries, are also responsible for the modification of the vertical structure of the Atmospheric Boundary Layer (Barry, 1992; Stull, 2000), which is itself an interesting process to study within a complex orographic environment, such as the Adige Valley close to the city of Trento (cf. Rampanelli and Zardi, 2002), which is the subject of the present work. Moreover, the interaction between atmospheric processes, typical of a valley environment, with those induced by the urban area, is of particular interest when dealing with air-quality issues and especially during Winter.

2. THE STUDY AREA AND THE EXPERIMENTAL SETUP

The Adige Valley connects the Po Plain (with an inlet close to the city of Verona) to the basin of the city of Bolzano (where it bifurcates in three upper valleys) and displays a well defined layout along the South-North direction. The city of Trento is located approximately at half this way, where the valley is flanked westward by the massif of Mount Bondone (whose top reaches a height of 1537 m a.m.s.l.) and eastward by Mount Marzola (1738 m a.m.s.l.).

The area is known in the literature for peculiar local valley winds occurring in Spring and Summer (Wiener, 1929; Schaller, 1936; Wagner, 1938; de Franceschi et al., 2002), whereas during Winter phenomena more typical of urban meteorology occur. Their investigation motivated the measurement campaign, whose rationale and planning are described below.

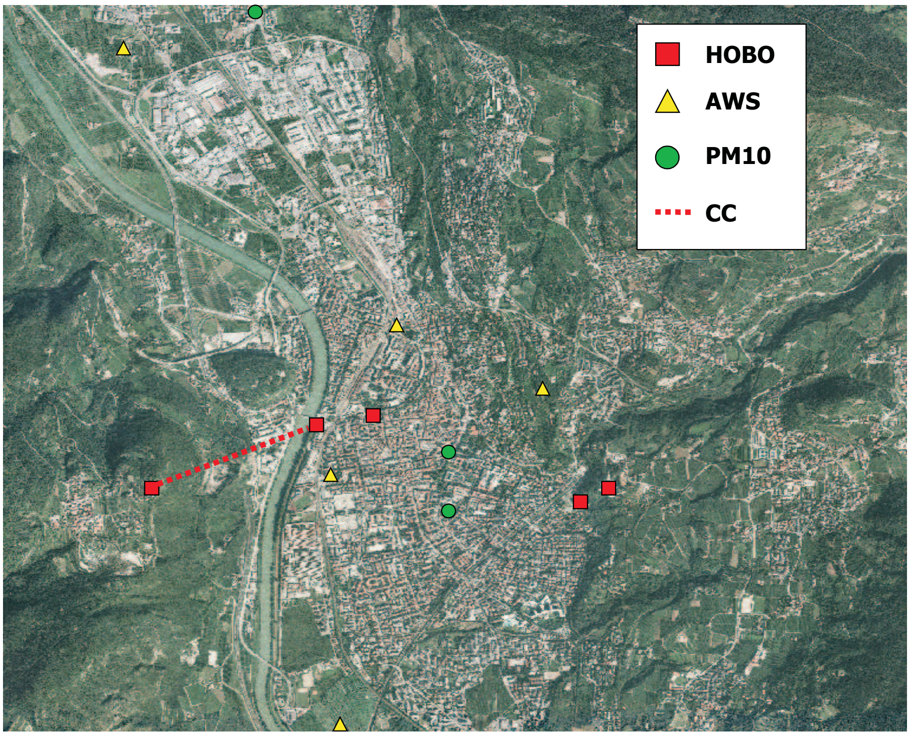

Figure 1: Schematic representation of the layout of the instrument network, including HoBo air temperature and humidity sensors (red squares), automated weather stations (AWS, yellow triangles), air-quality stations (green circles) and a measurement system based on a cable car (dotted red line).

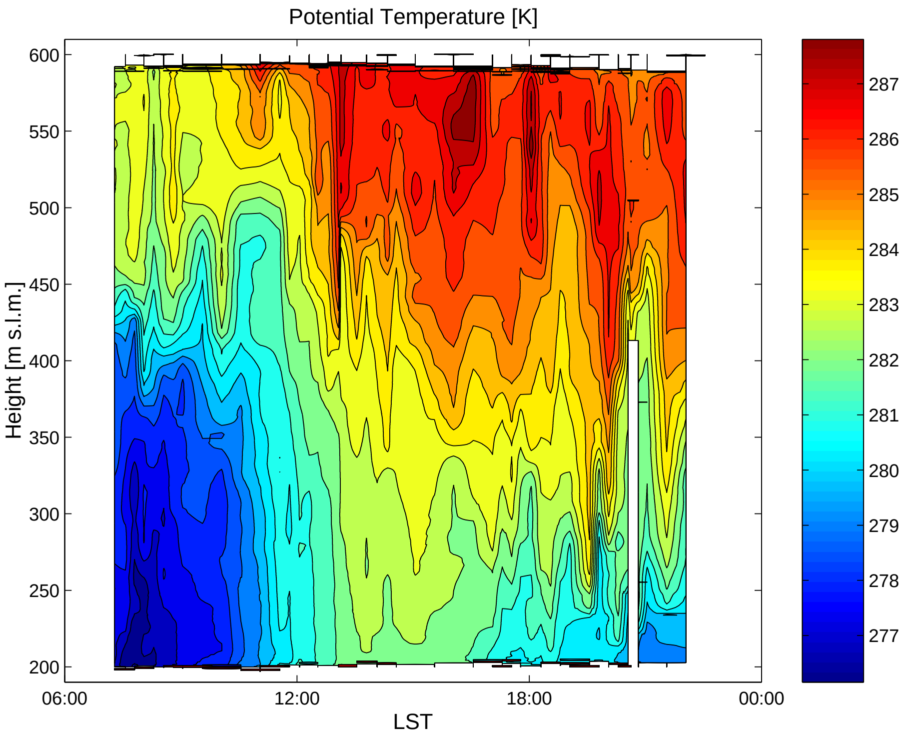

Figure 2: Time-height representation of the diurnal evolution of the vertical structure of potential temperature measured from cable car runs on 6 November 2006.

The experimental setup included 4 automated weather stations, permanently operated by various Institutions and located close to the city centre, North and South to the central urban area and on the Eastern sidewall of the valley respectively.

As it is well known that the boundary layer vertical structure within valleys can be significantly different from flat uniform terrain (Rampanelli and Zardi, 2002, 2004; Rampanelli et al., 2004), in order to investigate in detail not only the horizontal but also the vertical thermal structure, the above observing network - approximately North-South oriented (i.e. along-valley) and laying at the same height on the valley floor - was integrated with one further network composed of 5 air temperature and humidity dataloggers (HoBo), placed in a cross-valley direction along two facing slopes on opposite valley sidewalls, the upper extremes being Mesiano, on the Eastern sidewall (at approximately 300 m a.m.s.l.) and Sardagna, on the Western sidewall (600 m a.m.s.l.), close to the upper station of the cable car line, which was used as a mobile platform for further soundings.

The latter were aimed at obtaining a more detailed picture (both in space and in time) of the vertical temperature structure with special emphasis on the occurrence and strength of possible inversion layers. The whole setup included an air temperature and humidity sensor (Rotronic MP101A), a barometer (Vaisala PTB101B) and a datalogger (DataTaker D600) for the acquisition and storage of the data at 1 Hz rate.

After a series of test runs, which demonstrated the reliability of the method, measurements have been performed for several days and some preliminary results are presented here, briefly focusing on the effects of local scale processes on the diurnal evolution of the temperature field.

3. RESULTS

The analysis of the temperature data measured at the various locations allows an immediate characterization of the area into urban or rural environment: the first one displays a common behaviour with values between 1°C and 4°C higher with respect to the second one. This is particularly evident for the nocturnal values, whereas during the morning (i.e. between 09:00 and 14:00 LST) the heating effect induced by the increasing solar radiation is uniform over the whole area considered in this study.

The time series of wind speed and direction also allow to distinguish the position of the measuring stations respectively inside, above or outside the urban area: as a matter of fact, considering that the cold seasons are mostly characterized by low speed conditions, the highest intensities (of order 3–5 m s^{-1}) are recorded by the weather station operated by the Atmospheric Physics Group of the Department of Civil and Environmental Engineering of the University of Trento and located on the rooftop of an old tower well inside the central urban area (*http://prometeo.unitn.it/*). On the contrary, the stations located at street-level inside the city, as well as the stations in the surrounding open areas, display lower wind speeds, often close to calm conditions. These differences can partly explain the different patterns in pollutant concentrations typically measured during the winter seasons: the very low wind speed inside the Urban Canopy Layer (in this case mainly characterized by quite narrow streets, displaying a depth-to-width ratio around 2) is responsible for pollutant stagnation within the street canyons. Only when the weak local-scale circulations are replaced by stronger flows at larger scale, such winds can be detected at all sites inside and outside the urban area, even through with small differences. Unfortunately no information were available at the time of this study on the vertical structure of the wind field close to the investigation area: such data would be important in coupling the dynamical structure of the boundary layer to its thermal structure.

Considering the vertical thermal structure of the atmosphere in the first few hundred meters close to the ground, explored by means of the system installed on the cable car, other interesting considerations can be added to the discussion. The time-height 2D plot of the potential temperature measured during the opening hours of the cable car on 6 November 2006 (Fig. 2) clearly shows the transition from a nocturnal ground based inversion toward a diurnal well mixed boundary layer. This pattern can be considered as typical for fair weather conditions during the cold season, the only differences being the strength and duration of both stable and unstable conditions due to the different evolution along the season. For what concernes the effects on the pollutant concentrations, considered in terms of PM_{10}, which is one of the main indicators usually adopted by the environmental agencies to decide the gravity of the situation, the whole dataset collected and analyzed for the winter 2006-2007, clearly shows that the hourly concentrations are higher during the night (especially close to sunrise, when the inversion is strongest) and lower during the early afternoon, when the mixing height reaches its maximum. This effect may be related to the orography of the investigated area, which, under weak or absent valley circulations, acts as a closed system where the daily cycle of ground concentrations is mostly controlled by the occurrence, strength and height of a topping inversion layer. In this context, the continuous emissions by the traffic and house heating sources (accounting for most of the emissions in the area) may possibly modulate the diurnal cycle of concentrations, but appear to be more responsible of the rather continuous increase in the daily average values.

In conclusion, the following considerations can be drawn from the measurement campaign briefly discussed in this work:

- the horizontal thermal structure highlighted by means of a network of automated weather stations and small temperature data loggers clearly shows the presence and strength of an UHI during Winter;
- the average daily concentration of the various pollutants is strongly influenced by the presence and intensity of winds, with special emphasis on the gradients between urban and rural stations, where the stagnation and ventilation characteristics are of great relevance even in such a rather small area;
- as for the air temperature, even for the pollutant concentrations the position of the measuring stations inside the urban canopy plays an important role in highlighting the spatial inhomogeneities;
- in the absence of relevant mesoscale and synoptic phenomena, the diurnal cycles of the pollutant concentrations are modulated by the duration and extension of the ground-based inversion as well as of the mixing layer height above the city.

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