Characterization of PM10 accumulation periods in the Po valley by means of boundary layer profilers

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Abstract. Low wind and stable atmospheric conditions cause frequent PM10 episodes in the Po Valley. Such weather conditions are well characterized by temperature and wind profiles. Thermal inversion strength, height and duration, as well as wind profiles are set in relation to daily PM10 increments, and guidelines for forecasting air quality (AQ) in said conditions are derived.

1. Introduction

As laid out in the WHO air quality guidelines it is established that airborne particulate matter (PM) has an adverse impact on public health at exposures that are currently experienced by urban populations in both developed and developing countries. The range of health effects is broad, but are predominantly to the respiratory and cardiovascular systems, where all population is affected, but susceptibility to the pollution may vary with health or age [1].

Air pollution concentration, and that of PM10 (i.e. PM with diameters less than 10um) is strongly subject to meteorological action so that a region's burden not to exceed PM10 concentration limits depends on its climatology. The region of the Po Valley has a particularly unfortunate topographical conformation which favours low wind and strong inversion situations, conditions which can lead to extremely high PM concentrations, especially during the cold season [2]. This causes very frequent exceedance of the thresholds of PM10 concentrations set by the Council Directive 1999/30/EC (50 mg/m3 for single daily averages, 40 mg/m3 for yearly average).

In response to this particular situation of the Po Valley, the Centro Meteorologico di Teolo (CMT-DRST) of the Agenzia Regionale per la Prevenzione e la Protezione Ambientale del Veneto (ARPA Veneto) has recently installed a network of four passive radiometers (R or R*) and four SODAR (S) for air quality monitoring purposes [3] The instruments are all located in Veneto, a region in the northeastern Italy, as shown in figure 1, and were usual in a previous study related to a PM10 episode (Pernigotti [4]). While the network, in the framework of the project DOCUP (DOCumento Unico di Programmazione) Program 2 co-funded by the European Union, national Italian government, and the Veneto regional government, is the first of its kind in Italy, other Italian regional protection Agencies (e.g. Piemonte or Marche) have installed such instruments.

Temporal and spatial resolution of these profilers is significantly higher compared to radio soundings, whereas the vertical range is limited, allowing detailed observations and analyses of Planetary Boundary Layer (PBL). In this contribution the potential of having a network of PBL profilers is demonstrated.

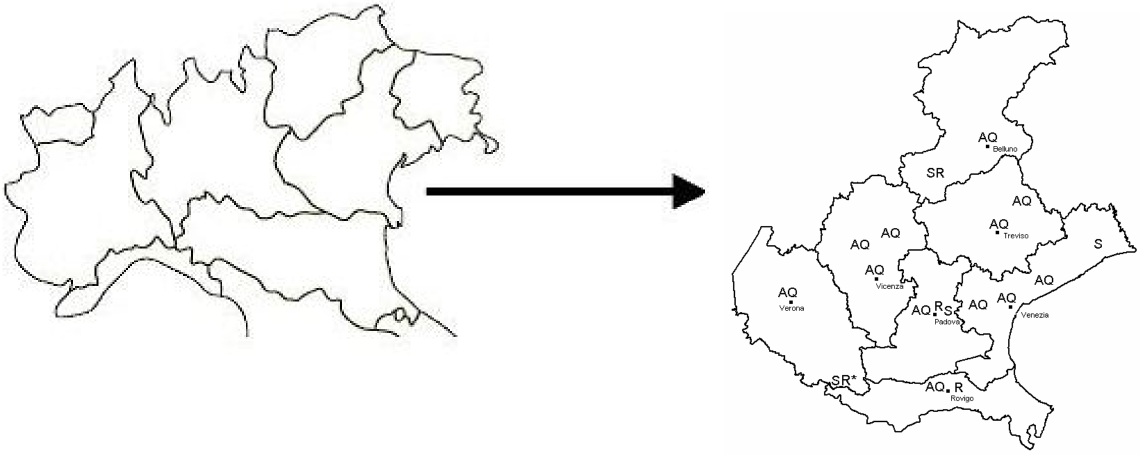

Figure 1. Temperature profilers (R or R*) and SODAR wind profilers (S) and Air Quality (AQ) surface station network of the north-eastern Italian region Veneto (right panel) operated by ARPA Veneto – CMT-DRST. Status is as of the end of 2007; left panel shows where Veneto is located in northern Italy.

Winter 2007-08	Verona 1	Verona 2	Vicenza 1	Vicenza 2	Padova 1	Padova 2	Venezia 1	Venezia 2	Venezia 3	Venezia 4	Treviso 1	Rovigo 1	Belluno 1	Belluno 2
Verona 1	1,00	0,97	0,88	0,91	0,84	0,82	0,78	0,84	0,86	0,87	0,86	0,74	0,73	0,82
Verona 2		1,00	0,86	0,89	0,80	0,76	0,76	0,82	0,81	0,86	0,84	0,65	0,76	0,83
Vicenza 1			1,00	0,98	0,84	0,83	0,86	0,87	0,88	0,96	0,88	0,85	0,74	0,75
Vicenza 2				1,00	0,86	0,85	0,82	0,85	0,86	0,91	0,86	0,86	0,77	0,73
Padova 1					1,00	0,96	0,90	0,94	0,94	0,93	0,91	0,88	0,61	0,69
Padova 2						1,00	0,86	0,89	0,90	0,93	0,89	0,87	0,50	0,59
Venezia 1							1,00	0,95	0,93	0,96	0,88	0,80	0,64	0,67
Venezia 2								1,00	0,98	0,97	0,92	0,81	0,65	0,71
Venezia 3									1,00	0,96	0,91	0,82	0,59	0,66
Venezia 4										1,00	0,84	0,92	0,75	0,82
Treviso 1											1,00	0,76	0,68	0,73
Rovigo 1												1,00	0,48	0,57
Belluno 1													1,00	0,96
Belluno 2														1,00

Figure 2. Correlation in last winter 2007-08 between the AQ stations in Veneto Region. Note the low correlation of Belluno city with the other AQ site, excellent correlation between all the cities that lay in Po valley (figure 1), and a good correlation between Padova and Rovigo (0.87-0.88).

Table 1. Some parameters on instruments settings and data availability, Vertical range for SODAR is the altitude for which data availability drops to 30% of the one of the first level (40m). Data availability doesn't include periods in which the instrument was stopped for software/hardware up-grades.

Profilers	SODAR PCS2000-24		SODAR PCS2000-64		MTP5-HE			HATPRO
Area operation	Belluna Valley	Padova	Legnago	Loncon	Padova	Belluna Valley	Rovigo	Legnago
ID number	17	18	19	20	25	26	27	1
Hight resol.	20m	20m	20m	20m	50m	50m	50m	50-75m
Time resol	15’	15’	15’	15’	5’	5’	5’	20’
Vertical range	~ 500m	~ 500m	~ 700m	~ 700m	1000m	1000m	1000m	2000m
Data 2005	79 %	72 %	78 %	84 %	95 %	76 %	84 %	68 %
Data 2006	83 %	85 %	87 %	87 %	100 %	97 %	83 %	94 %
Data 2007	68 %	80 %	82 %	86 %	94 %	100 %	96 %	93 %

2. Data set

The 3 MTP5-HE Radiometers (R, in figure 1) are manufactured by Attex, Moscow (RUS), and distributed by Kipp & Zonen, Delft (NL). As shown in Kadygrov [5] this instrument reports a good agreement within 0.5-0.8K with a co-located radio sounding found in Payerne, Switzerland, on 63 profiles. Ferrario [6] confirmed this data for the ARPAV MTP5-HE radiometers. All instruments are set to have the first level at 50m.

The Radiometer (R*, in figure 1), is manufactured by Radiometer Physics GmbH, Meckheim (D). It receives radiation emitted by the atmosphere in 14 channels (molecular oxygen and water vapour lines) and converts this data to profiles for temperature and humidity (Rose [7])via a neural algorithm optimized for the measuring site. In addition, the instrument installed in Legnago performs a vertical scan every 20 minutes for temperature with variable vertical resolution (50m up to 2000m) in the PBL, where the declared accuracy is 1K. The measuring sites are flat and rural (Legnago and Loncon), flat and urban (Padova and Rovigo) and in a closed valley with very light winds and strong thermal inversions (Belluna Valley).

The SODAR (S, in figure 1), are two PCS2000-24 and two PCS2000-64 manufactured by Metek, Elmshorn (D). This is well known technology and the manufacturer declared accuracy of the data is of 0.3m/s for wind intensity and 5-8° for wind direction. The vertical range of SODARs is strongly dependent upon the state of atmospheric turbulence which in stable conditions frequently features a strong decrease with increasing altitude with a corresponding decrease in data availability. All the CMT SODARs are set with first level at 40m and temporal resolution of 15 minutes.

In table 1 type and mode of operation of profilers are shown. Moreover real percentage of work are listed (we don't consider the data holes when the instrument was stopped for regular maintenance). Radiometer MTP5-HE are very reliable thermal profilers and when their efficiency drops it is often due to problems with the power supply. The Metek SODARs operated by ARPAV run quite reliably, but quite often can exhibit problems with the plausibility of data in low wind conditions. The HATPRO radiometer, when working, is a powerful thermal profiler but has had many up-grades in software and hardware in the measuring period that has reduced the availability.

3. PM10 Episodes in northern Italy

Episodes of pollutions by particulate matter with diameter less than 10μm (PM10) are quite frequent in the Po Valley, figure 4 (Rossa [8]). From 1980-ies the Regional Agencies for Environment in northern Italy began to check and try to quantify the problem. First type of measurement was TSP (Total Suspended Particulates) variables. TSP decreased significantly during the 1990-ies (figure 3) probably due to improved technology deployed in power plants, engine for transports, and discontinuation of some heavy industry. PM10 is monitored in Veneto only since 2001 and the corresponding air quality monitoring network became stable only in 2007 thanks to the DOCUP project.

We made an attempt to characterize in manner the PM10 episodes by evaluating the whole historical series isolating only periods that exhibited PM10 concentration above the 95th percentile (Figure 5). We catalogued the episodes with a number (the year) and a Letter (A,B,C for early months, X,Y,Z for last months in the year). Results are shown in table 2. Episodes are present from late autumn to spring, but take place especially in the winter season. The evolution of the PM10 concentration in acute winter episodes shows a regular build up as well as spin down phase, whereas episodes in Autumn or Spring tend to end abruptly, say with a major precipitation event linked to a frontal passage. In figure 6 the average temperature profile in different months is shown, i.e. that from the April to September atmosphere with frequent unstable to neutral conditions that establish the end of Acute Episode. Typically 3 to 4 episodes lasting in the order of 10 days take place per cold season, table 2. In 2007 windy conditions above normal gave rise to only 1 episode. Our network of PBL profilers was installed and operates since 2005 Spring.

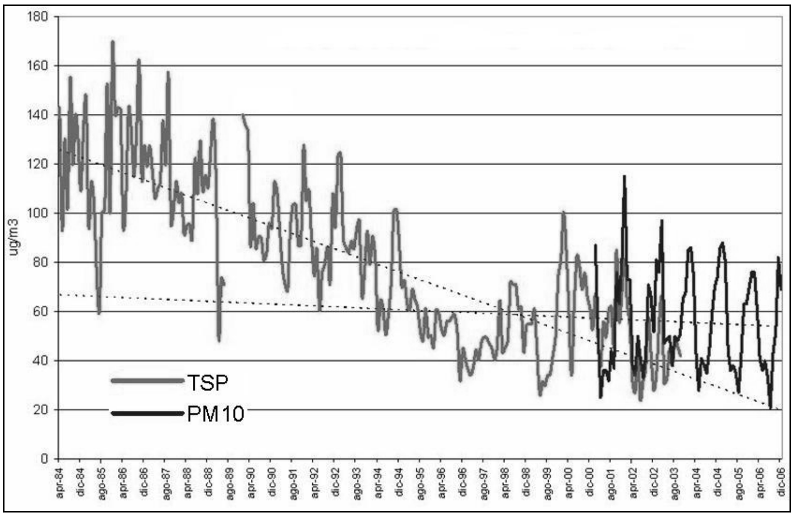

Figure 3. City of Padova, monthly average of TSP (light grey, μg/m^3) and PM10 (dark grey, μg/m^3), dashed line are linear trends, a similar behavior was detected in the other cities of Veneto. Data source DAP of Padova ARPA Veneto (on the x-axis every 8th month is shown starting April 1984, ending December 2006).

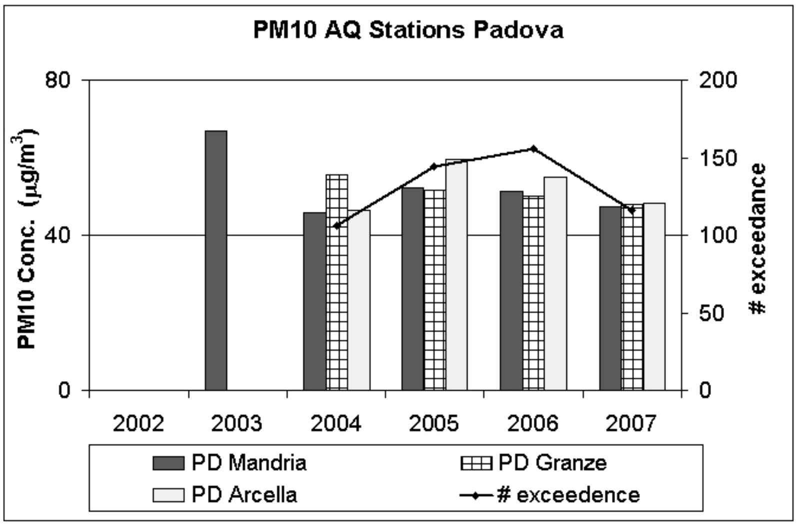

Figure 4. Annual average of PM10 in 3 air quality stations in Padova (always over 40 μg/m^3!) and the number of days for which the 50 μg/m^3 threshold was exceeded (always significantly (over 100 times) more than the 35 allowed) [9].

Table 2. Episodes of PM10 pollution in Veneto region since 2002.

Year	# Ep.	Periods			
2002	1	A 07 Mar.-22 Mar.			
2003	3	A 12 Jan.-24 Jan	B 24 Feb.-13 Mar.	X 13 Nov.-25 Nov.	
2004	4	A 04 Jan.-14 Jan.	B 24 Jan.-12 Feb.	C 13 Mar.-22 Mar.	X 08 Dec. -19 Dec.
2005	5	A 01 Jan.-18 Jan.	B 06 Feb.-14 Feb.	X 22 Oct.-5 Nov.	Y 18 Dec.-27 Dec.
2006	4	A 09 Jan.-22 Jan.	B 06 Feb.-16 Feb.	C 15 Mar-18 Mar.	Y 04 Nov.-22 Nov.
2007	1	A 01 Jan.-22 Jan.			
2008	1	A 10 Feb.-23 Feb.			

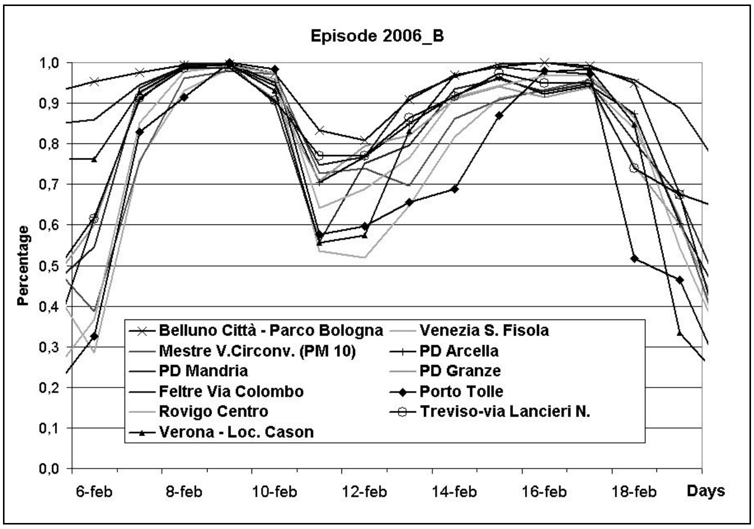

Figure 5. Episode 2006_B note the very high correlation in all the AQ station.

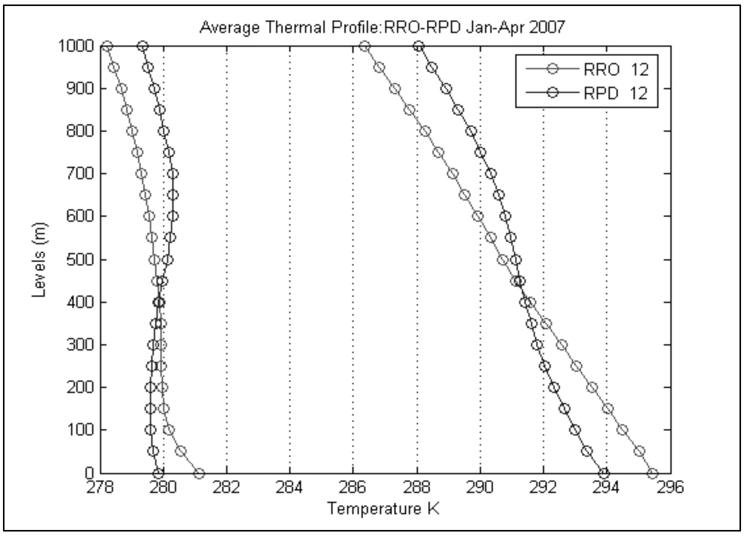

Figure 6. From Winter (January left graph) to Spring (April right graph) the thermal profile became more unstable that establish the end of Acute Episode. (RRO Rovigo MTP5-HE Radiometer, MTP5-HE RPD Padova Radiometer).

most AQ stations were placed in the main cities of Veneto and the profilers were confined by the DOCUP project to stay in a specific list of municipalities, it was not straight forward to have AQ station and profiler collocated. Moreover, because of their very nature SODARs need to stay away from town centre, where a lot of AQ stations are placed. In order to justify the analysis of PM10 and the PBL profiler it is important to note that in all the major cities (except Belluno which is located behind the pre-alpine chain in the Belluna Valley) are located in the Po Valley. In addition, the DOCUP project prescribed the siting of instrumentation in less developed areas of the political region Veneto, thus basically excluding city centers. Placing SODARs on flat, high roof-tops has not yet been explored. In anticylonic conditions in winter this translated into relatively uniform PBL structure (e.g. during a long stable period with high pressure, with no precipitation and only weak winds); PM10 concentrations even from distant AQ station exhibit a high correlation of about 0.9 if the cities are closer (like 30km apart). We therefore think that in episodic conditions the PBL profilers give representative observations for the cities which are ‘not too far away’, figure 2.

4. Profiler and Acute Episodes

As is well known, for northern Italy most episodes happen during the cold season when there are stable anticyclonic synoptic conditions characterized by absence of precipitation and significant winds like Bora or Sirocco. The important atmospheric phenomena which then govern the accumulation mechanisms for PM10 are mechanically and thermally induced turbulence, both of which can be estimated in a qualitative way by SODARs and radiometers respectively. Figure 7 shows the periodic build up of temperature inversions after sunset and the break up some time after sun rise. During some days the winter sun is not able to disrupt the thermal inversion. Height and strength of the inversion are two important parameters which both can be retrieved from the MTP5-HE.

A typical example is shown in figure 8 for the Padova AQ station from 10-23 February 2008 (2008_A). In the presence of thermal inversions during nighttime there is a successive build up of PM10 which reaches a first peak concentration around the 14th. In the weekend of the 16-17th the stability of the boundary layer completely changed from very stable to almost neutral. The moderate winds (not shown) were efficient in dispersing the particulate matter. Subsequently stability of the boundary layer was re-established leading to some of the highest concentrations since the monitoring started in 2001. Starting from the 21st humidity increased and led to fog and low clouds, a factor which further influences the deposition of PM10.

It is interesting to note that the inversion height seems to play a role in the accumulation process. When the inversion height is lower, i.e. around 200-400m the PM10 concentration often is lower than for situations in which the inversion height is above 600m. However, a systematic study needs to be done in order to understand to what extent PM10 dispersion is taking place for very confined thermal inversion situations. Also, the role of the direction of the typically very weak winds during pollution episodes needs more investigation, as for the Veneto AQ stations westerly flow can imply import of pollution from the industrialized neighboring region Lombardia, whereas easterly flow brings clean air from the northern Adriatic Sea.

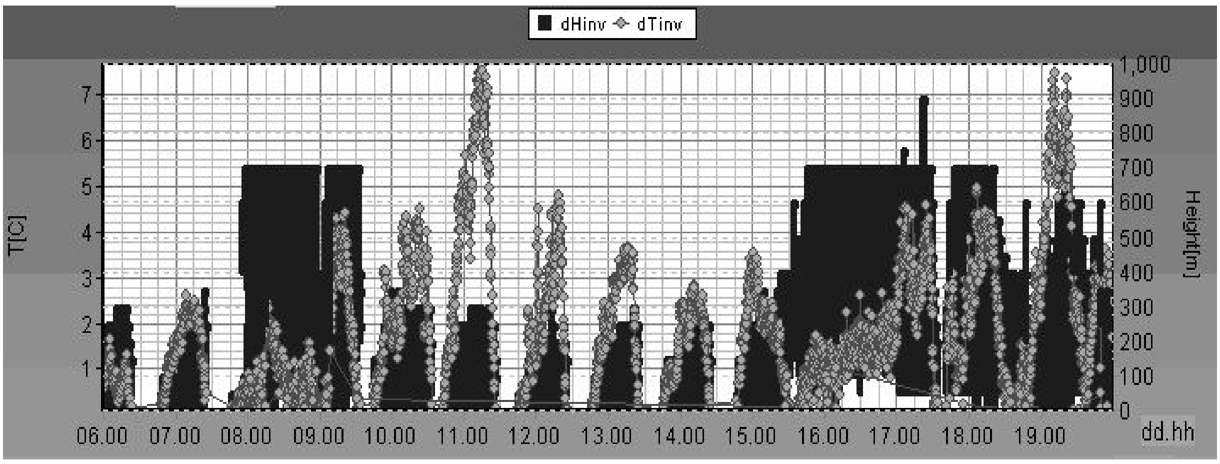

Figure 7. Time series of the temperature inversion as retrieved from the MTP5-HE located in Padova for the period 6-19 February 2006 (2006_B). Light grey dots denotes the inversion strength (C, left axis), while dark grey line denote the portion of the atmosphere in which there is a temperature inversion. The upper border of the blue lines denote the height of the thermal inversion (m, right axis).

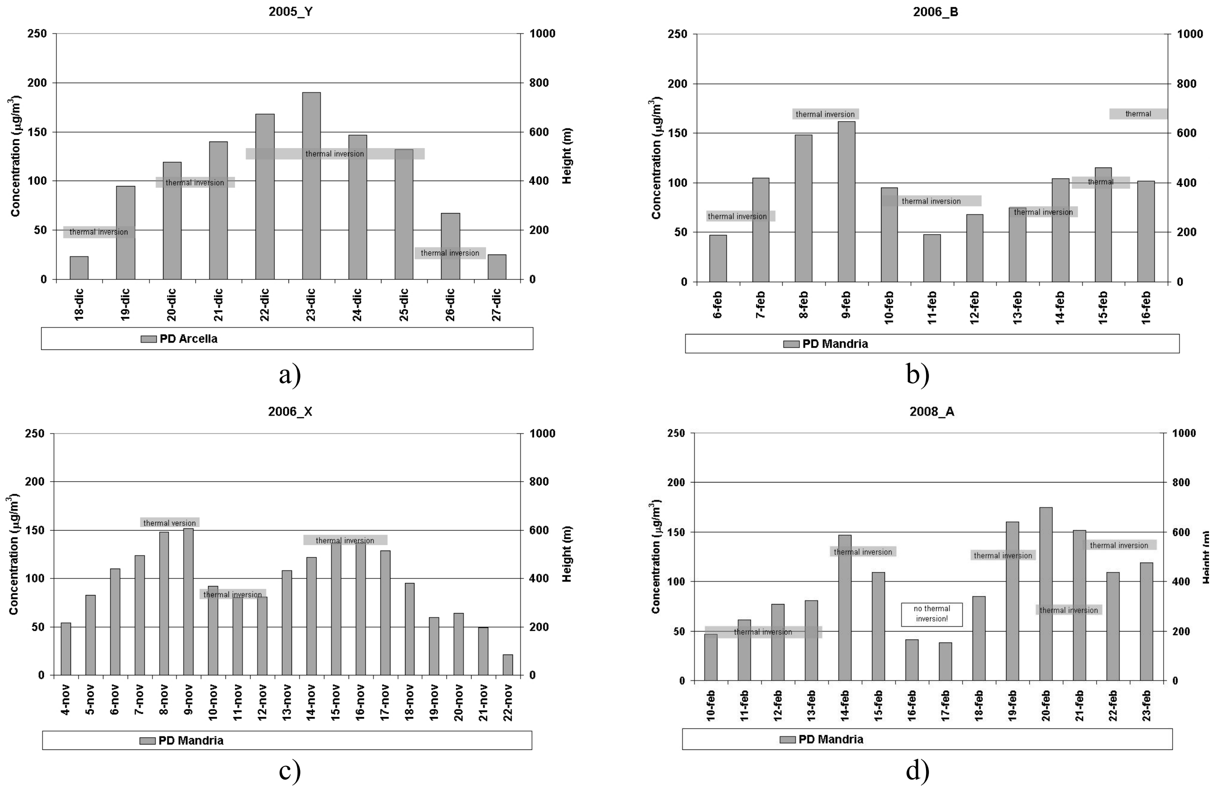

Figure 8. Time series of PM10 concentration (μg/m^3) as measured at the Padova AQ station, The horizontal shaded bars denote a representative height of the top of the thermal inversion at the given days; where there is no bar a thermal inversion was absent. Panel a) For episode 18-27 December 2005 (2005_Y). Panel b) episode 6-16 February 2006 (2006_B). Panel c) For episode 4-22 November 2006 (2006_X). Panel d) for episode 10-23 February 2008 (2008_A).

5. Conclusions

An overview of PM10 episodes in the Po Valley was given and related to the observations obtained from the recently installed PBL profiler network of the Centro Meteorologico di Teolo. For meteorological conditions without precipitation, significant winds, and a very moist boundary layer, there seems to be no appreciable accumulation in the absence of a thermal inversion. Moreover, higher reaching inversions appear to be more efficient for the PM10 accumulation than shallow inversions.

From this preliminary analysis it appears that the details of the temperature profile could be important to understand the potential of accumulation of PM10. Therefore, having a network of temperature profilers could unveil regional differences. Either way, the temperature profiles are a valuable piece of information for the AQ forecaster in estimating the evolution of the PM10 concentration.

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