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Influence of climate change on the frequency of daytime temperature inversions and stagnation events in the Po Valley: historical trend and future projections

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ABSTRACT

This work analyzes the frequency of days characterized by daytime temperature inversion and air stagnation events in the Po valley area. The analysis is focused on both historical series and future projections under climate change. Historical sounding data from two different Italian stations are used as well as future projections data, provided by CMCC-CCLM 4-8-19 regional climate model (MED-CORDEX initiative). A new method to detect layers of temperature inversion is also presented. The developed method computes the occurrence of a temperature inversion layer for a given day at 12 UTC without a detailed knowledge of temperature vertical profile. This method was validated using sounding data and applied to the model projections, under two different emissions scenarios (RCP4.5 and RCP8.5). Under RCP4.5 intermediate emissions scenario, the occurrence of temperature inversions is projected to increase by 12 days/year (around + 10%) in the last decade of 21st century compared to 1986–2005 average. However, the increase in temperature inversions seems to be especially concentrated in the warm period. Under RCP8.5 extreme scenario, temperature inversions are still projected to increase, though to a lesser extent compared to RCP4.5 scenario (+6 days/year in the last decade of 21st century). A similar trend was found also for air stagnation events, which take into account the variation of precipitation pattern and wind strength. The expected increases are equal to +13 days/year and +11 days/year in the last decade of 21st century compared to 1986–2005 average, under RCP4.5 and RCP8.5 scenarios respectively.

1. Introduction

The Po Valley area is characterized by one of the highest population density in Europe as well as by one of the poorest air quality (EEA, 2014). Since the average emissions per capita are similar to other European urban areas (EEA, 2014), poor air quality is chiefly related to the adverse local climate (Carbone et al., 2010; Ferrero et al., 2011). As a matter of fact, the Po Valley basin is characterized by one of the lowest wind speed in Europe, on average between 2 and 2.5 m s^{-1}. During winter, the wind speed is even lower, around 1.5 m s^{-1} on average (Arpa Emilia-Romagna, 2013). Moreover, temperature inversions are very frequent, especially during the cold period when the height of Planetary Boundary Layer (PBL) rarely exceeds 450 m (Bigi et al., 2012). Temperature inversions reduce vertical dispersion ventilation into the free troposphere. Hence, primary pollutants tend to accumulate and secondary pollutants tend to form in a shallow layer near the surface (Perrino et al., 2014; Sandrini et al., 2014).

However, as climate is changing, a growing interest on the relationship between global warming and the diffusive properties of atmosphere has occurred over the last few years. According to Kirtman et al. (2013), the frequency of stagnation events will decrease on a global scale, although some increases are still possible in some regions. According to Horton et al. (2012), stagnation events are expected to increase by 12–25% by the end of 21st century in the Mediterranean area. Furthermore, climate change-induced variations of temperature and humidity can influence atmospheric chemical reactions and thus the formation of secondary pollutants (Stocker et al., 2013).

As regards Italy, some studies (Pasini and Cipolletti, 2007; Giulianelli et al., 2014) showed that global warming has already influenced atmospheric diffusive properties, although a clear trend cannot be detected due to the limited length of the assessment period. However, a 50% decrease of fog events, typically related to temperature inversions, has been observed in the Po Valley from the early 1990s (Giulianelli et al., 2014). This large decrease has been also found in other regions of the world, such as in California (Johnstone and Dawson, 2010). Potential causes of this trend might be the increasing temperature and the decline of available condensation nuclei due to the recent implementation of air quality policies focused on particulate matter emissions. However, since

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influence of climate change on atmospheric diffusive properties seems to be relevant to air quality issues, this work aims to analyze the historical trend and the projections for the frequency of diurnal temperature inversions and stagnation events in the Po Valley. Only daytime temperature inversions were considered in this work, because they usually correspond to particular conditions of atmospheric stability. Contrariwise, nighttime temperature inversions are typically due to the different solar radiation between day and night, and therefore they were not taken into account in this work.

2. Material and methods

2.1. Surface temperature

Data of surface temperature were acquired from 41 weather stations managed by four different Regional Environmental Protection Agency (ARPA) and from 7 weather stations managed by Aeronautica Militare (Fig. 1). Acquired data refer to the period 1985–2013.

These data show a statistically significant increase of surface temperature at a 5% significance level, in 90% of the considered stations. Averaging over the entire Po Valley basin, the estimated growth rate of surface temperature is equal to 0.55 K decade^{-1}.

2.2. Vertical profile of temperature

In order to compute the vertical profile of temperature, atmospheric temperature data were acquired from two weather stations, San Pietro Capofiume and Milano Linate. In the Po Valley basin, these two stations are the only ones where sounding data are collected. However, San Pietro Capofiume and Milano Linate can be considered representative of the so-called lower Po Valley and higher Po Valley respectively (Fig. 1).

San Pietro Capofiume station is managed by ARPA Emilia-Romagna. The main meteorological variables, namely atmospheric temperature, pressure, humidity and wind speed, have been monitored via radio-soundings since 1985. However, only measurements from 1987 to 2006 were analyzed in this work, because the number of valid data is >90% only during this period. Generally, observations are collected twice a day, at 00 UTC and 12 UTC (Universal Time Coordinated). For each observation, six paired measurements of pressure and temperature are available in the atmospheric layer between the surface and geopotential height at 850 hPa (on average).

Milano Linate station is managed by Aeronautica Militare. Sounding data at 12 UTC are available with a daily frequency during the period 1985–2012. On average, during the period 1985–1999, five paired measurements of pressure and temperature are available in the atmospheric layer between surface and geopotential height at 850 hPa (5.5 during winter). However, during the period from 1999 to 2012, the mean number of paired measurements increases to seven (eight during winter period), and therefore the estimated vertical profile of temperature becomes more accurate.

2.3. CMCC-CCLM4-8-19 model (MED-CORDEX initiative)

A regional climate model (CMCC-CCLM4-8-19) was used in order to assess the impact of climate change on the frequency of temperature inversions and stagnation events. This model, denominated just CMCC hereinafter, was developed by the Euro-Mediterranean Center on Climate Change within the MED-CORDEX initiative (www.medcordex.eu). The domain of this model is the entire Mediterranean area, partitioned into 6174 grid cells. Resolution of every cell is 0.44° × 0.44°, covering approximately a 50 × 50 km^2 surface (Ruti et al., 2011). The Po Valley area is situated within 17 cells, as shown in Fig. 2.

This model provides data both for the historical series (1950–2005) and for future projections (2006–2100), under different scenarios. It should be noted that the model runs on the past (1950–2005) have been performed without a specific initialization from a reanalysis. In this work, the 11 variables summarized in Table 1 have been considered.

Furthermore, two different RCP (Representative Concentration Pathways) scenarios were considered, namely RCP4.5 scenario and RCP8.5 scenario (Stocker et al., 2013; Van Oldenborgh et al., 2013). Every dataset has been downloaded from MED-CORDEX database (www.medcordex.eu).

2.4. Air stagnation index

The so-called stagnation events have been analyzed in this work as well as temperature inversions. A stagnation event is characterized by meteorological conditions that lack contaminant-scavenging capabilities and minimize the horizontal dispersion and vertical dispersion escape of pollutants (Wang and Angell, 1999). In the United States, air stagnation is monitored by the National Climatic Data Center (NCDC) via the air stagnation index (ASI). In the NCDC metric, stagnation events

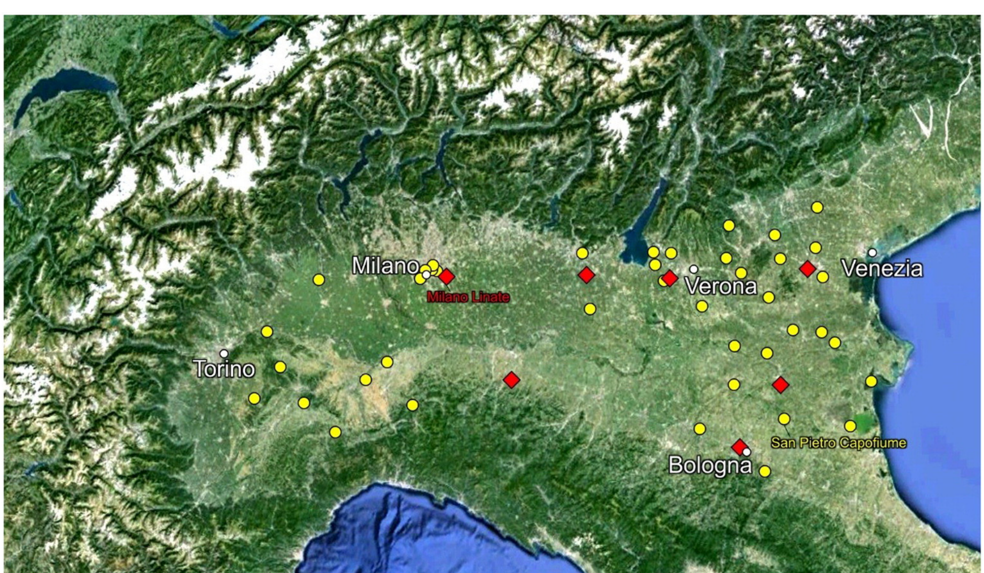

Fig. 1. Locations of ARPA weather stations (yellow circles) and Aeronautica Militare stations (red diamonds). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)