

Impact of meteorology and air pollution on Covid-19 pandemic transmission in Lombardy region, Northern Italy

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Abstract

Italy was the first, among all the European countries, to be strongly hit by the Covid-19 pandemic outbreak caused by the severe acute respiratory syndrome coronavirus 2 (Sars-CoV-2). The virus, proven to be very contagious, infected more than 9 million people worldwide (in June 2020). Nevertheless, it is not clear the role of air pollution and meteorological conditions on virus transmission. In this study, we quantitatively assessed how the meteorological and air quality parameters are correlated to the Covid-19 transmission in Lombardy (Northern Italy), the region epicenter of the virus outbreak. Our main findings highlight that temperature and humidity related variables are negatively correlated to the virus transmission, whereas air pollution (PM_{2.5}) shows a positive correlation. In other words, Covid-19 pandemic transmission prefers dry and cool environmental conditions, as well as polluted air. For these reasons, the virus might easier spread in unfiltered air-conditioned environments. Those results will be supporting decision makers to contain new possible outbreaks.

Introduction

First cases of pneumonia of unknown origin were reported in Wuhan, Hubei Province, China late December 2019. Researchers identified the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) as the responsible of this disease in January 2020. The novel coronavirus shows a 70% genomic sequence similarity with SARS-CoV-1 (Cohen and Normile, 2020). The first documented case is dated December, 31 2019, but the Chinese authorities track back cases up to November 2019. The disease is transmitted from human-to-human easily by close contact (in a radius of 1.5 m or more) through droplets, especially if an infected person is coughing, sneezing or just talking (at a lesser extent). It is still matter of debate if the virus can be transmitted by touching contaminated surfaces or its airborne permanence. A recent study (Wang et al, 2020) put in evidence the natural origin of the virus, which seems to initiate from bats and infected humans through an interspecies spillover process that involves an intermediate host, e.g. snakes. The zoonotic virus can penetrate the human cellule through the ACE 2 receptor, and similarly to SARS, the incubation period (median) is 5.1 days (95% Confidence Interval, 4.5 to 5.8 days; Lauer et al., 2020). Anecdotal incubation period of 28 days is also reported. The infection is causing a wide range of symptoms and shows different degrees of severity with different fatality rates that are country dependent. Most common symptoms include dry cough, loss sense of smell, fever, tiredness. More serious symptoms include difficulty of breathing, shortness of breath, chest pain or pressure and loss of speech or movement. Usually, mild symptoms are managed at home, but severe cases need weeks of hospitalization in Intensive or Sub-Intensive Care Unit (ICU) with pulmonary ventilation. There is no specific anti-viral treatment or vaccine (June 2020) and the only effective preventive measure to block the virus outbreak is social distancing, limiting public gathering, especially indoor.

It is well documented in literature, for other coronavirus outbreaks, how the meteorological conditions can affect the transmission, enhancing or suppressing it. Atmospheric variables, i.e., ambient temperature

and humidity, or the solar irradiation act differently with respect to the coronavirus survival, e.g., Casanova et al, 2010 and Lauc et al., 2020 shows that the coronavirus transmission is facilitated in cold and dry weather. Nevertheless, it is still not fully understood if and how SARS CoV-2 virus spread and if it is influenced by the meteorological parameters as other different flu seasonal viruses. Several studies were recently investigating the contribution of meteorological conditions on Covid-19 transmission around the world. As shown in Pani et al., 2020 studies from China (Shi et al., 2020; Liu et al., 2020b; Xie and Zhu, 2020; Ma et al., 2020; Qi et al., 2020), Iran (Ahmadi et al., 2020), Spain (Briz-Redón and Serrano-Aroca, 2020), the USA (Bashir et al., 2020; Gupta et al., 2020), Mexico (Méndez Arriaga, 2020), Turkey (Sahin, 2020), Brazil (Auler et al., 2020; Prata et al., 2020), Indonesia (Tosepu et al., 2020), Norway (Menebo, 2020) and also over the globe (Sobral et al., 2020; Wu et al., 2020a) are controversial and the World Health Organization (WHO) highlighted that new investigations are needed to quantitatively assess how the weather influence the virus spreading. On this topic, Pani et al. (2020) results found that water vapor temperature, dew point, absolute and relative humidity show positive significant correlation with SARS CoV-19 transmission in Singapore, one of the biggest densely-populated megacities in South-East Asia.

On other hand, it seems that the SARS CoV-2 is selectively spreading, i.e. some large metropolitan areas are devastated by the virus in term of infected people and fatalities, while in others the virus transmission is limited with consequent much lesser fatalities. Air pollution is another crucial factor that should be taken into account to investigate the Covid-19 transmission and its role in leading to a more severe form of the disease. It has been formerly proven for SARS CoV-1 in 2002 (Cui et al., 2003) that air pollution can facilitate the virus transmission and increase its persistence in the atmosphere. In the United States, a study put in evidence that long-term exposure to high-concentration of particulate matter with an aerodynamic diameter less than 2.5 micron ($PM_{2.5}$) increases the mortality (Wu et al., 2020). Liu et al. (2020) investigated the aerodynamic nature of SARS CoV-2 sampling aerosols from different indoor environments. The results put in evidence that high concentrations of viral RNA are found in submicron aerosols, especially in Wuhan Hospital ICU rooms. However, the study cannot assess if the airborne aerosols carry a sufficient viral loading to infect people.

Italy is the first European and Western country heavily hit by the Covid-19 pandemic. As June 24th 2020, more than 239,000 cases are reported with about 34,000 fatalities. Almost 40% of documented cases and one third of fatalities are reported in Lombardy, the epicenter of the outbreak, a heavy industrialized and polluted region situated in the Po Valley (Figure 1), Northern Italy. The map in Figure 1 put in evidence how the Italian regions are differently affected by the Covid-19 outbreak with a strong meridional gradient. Population density cannot be taken as an explicit evidence to explain the different transmission because other metropolitan areas in the southern regions show similar or higher population density, e.g. Naples.

The main scope of this manuscript is to investigate a possible correlation between meteorological parameters, air pollution and Covid-19 pandemic transmission over 103 days (8 March – 19 June 2020) in Milan (Lombardy).

2. Data And Methodology

The proposed methodology tends to reproduce Pani et al. (2020) methodology to data obtained from the Lombardy region in Italy. However, differently, we add air pollution variables and take consideration on the latency period in response to those variables. Moreover, we consider as Covid-19 pandemic transmission outbreak variable, the ICU daily patients (critical conditions) because it is independent on tests and on delays in test results. Details are described in following sections.

2.1. Milan and Lombardy region

Milan (45.46N, 9.19E, 52 m a.s.l) is a large metropolitan area, Lombardy business center, with a population of about 5 million. The region is heavily-industrialized, with the highest Italian Gross Domestic Product (GDP). Located in the Po Valley and surrounded by mountains, Alps to the North and Apennines to the South that inhibit wind circulation from sea and northern Europe, is also one of the most polluted hotspots in Europe, where meteorology paired with aerosol emissions play a crucial role in deteriorating the air-pollution (Pernigotti et al., 2012). The region is subject to a continental climate, experiencing humid hot summers and cold winters, where, especially during anticyclonic episodes, accomplice the lower planetary boundary layer height (Milroy et al., 2012), the city experiences higher atmospheric aerosol concentrations and persistent fog and haze. Similar meteorological and air pollution conditions are found in Milan neighbor cities, e.g. Bergamo and Brescia, where also strongly hit by Covid-19 pandemic

2.2. Data and estimations

The first reported Covid-19 (not imported) case in Lombardy is reported on 24 February 2020, about 60 km south of Milan. Regional and urban daily new infections, total ICU patients, cumulative fatalities and recovery are reported and publicly available from the Italian civil protection department through github (<https://github.com/pcm-dpc/COVID-19>).

To block the Covid-19 pandemic transmission, Italy put in place progressive and regional dependent population lockdown. In this study, we analyzed data from 8 March 2020 to 19 June 2020 (103 days). With respect to the meteorological conditions, we considered the daily records of the most common meteorological parameters following the approach of Pani et al. (2020). The considered parameters with relative explanation are reported in Table 1.

Table 1 Basic Meteorological parameters obtained from Milano Linate airport observation site (<https://www.wunderground.com/>)

Parameters	Description (unit)
T_{\max}	Max temperature (°C)
T_{avg}	Daily Average Temperature (°C)
T_{\min}	Min Temperature (°C)
DP_{\max}	Max Dew Point (°C)
DP_{avg}	Daily Average Dew Point (°C)
DP_{\min}	Min Dew Point (°C)
RH_{\max}	Max Relative Humidity (%)
RH_{avg}	Daily Average Relative Humidity (%)
RH_{\min}	Min Relative Humidity (%)
WS_{\max}	Max Horizontal Wind Speed (m s ⁻¹)
WS_{avg}	Daily averaged Horizontal Wind Speed (m s ⁻¹)
WS_{\min}	Min Horizontal Wind Speed (m s ⁻¹)
P_{\max}	Max Atmospheric Pressure (hPa)
P_{avg}	Daily Average Atmospheric Pressure (hPa)
P_{\min}	Min Atmospheric Pressure (hPa)

The historical data are publicly available online (<https://www.wunderground.com/>). More information about data and data reliability can be found in Pani et al. (2020). Besides those variables, following Pani et al. (2020) methodology, we retrieved also the absolute humidity (AH, in g m⁻³) through Clausius-Clapeyron equation (Qi et al., 2020; Gupta et al., 2020; Pani et al., 2020)

$$AH = 2.1674 \times RH \times \frac{6.112 \times \exp\left(\frac{17.67 \times T}{243.5 + T}\right)}{273.15 + T} \quad (1)$$

where RH represents the relative humidity and T the temperature. Following Ou-Yang et al. (2014) and Pani et al. (2020), the water vapor (WV, in g kg⁻¹) is estimated:

$$WV = 6.22 \times RH \times \frac{6.112 \times \exp\left(\frac{17.67 \times T}{243.5 + T}\right)}{P} \quad (2)$$

where P is the atmospheric pressure.

Differently from Pani et al. (2020), to investigate a possible correlation with the air pollution, we also considered the PM_{2.5} and Nitrogen Dioxide (NO₂) daily averaged concentrations from all the different observational sites deployed over Milan metropolitan area. High concentrations of PM_{2.5} and NO₂ in the atmosphere have been already proven by previous study to be responsible of pulmonary diseases reducing life expectancy. PM_{2.5} and NO₂ data are publicly available upon request at Lombardy Environmental Protection Agency Website (https://www.arpalombardia.it/Pages/ARPA_Home_Page.aspx).

2.3. Statistical approaches

Correlations between Covid-19 pandemic, meteorological variables and air pollution were investigated using non-linear Spearman and Kendall rank correlation tests, which have also employed in Pani et al. (2020). The Spearman rank correlation non-parametric test is described as follows:

$$r_s = 1 - \frac{6 \times \sum_i d_i^2}{n(n^2 - 1)} \quad (3)$$

where d_i represents the difference between the ranks of two parameters, and n the number of alternatives. Equation 4 shows the Kendall rank correlation non-parametric test τ .

$$\tau = \frac{\text{concor} - \text{discor}}{0.5 \times n \times (n - 1)} \quad (4)$$

Here *concor* represents the number of concordant pairs, while *discor* represents the discordant pairs, and n is the number of pairs. A more detailed description of the statistical approaches can be found in Pani et al. (2020). Nevertheless, it is important to stress that values of r_s and τ equal to +1 and -1 implying a perfect positive and negative correlation, respectively.

3. Results And Discussion

3.1. Daily variation of Covid-19 cases, meteorological and air pollution variables

Different from the approach proposed by Pani et al. (2020), where the correlation analysis was built upon the basis of Covid-19 new daily infections, we employed ICU anomaly case as basis. Because we think that daily new positives variable is highly chaotic and it is also strictly correlated to the number of performed nasal test swabs, i.e. the more the test performed, the more positives are found. Moreover, delays in processing tests that introduce a bias in the analysis are not uncommon and are frequently reported.

We believe that the number of hospitalized patients in ICU unit is a much stronger indicator of Covid-19 pandemic transmission, independent on the previously described sampling methods. We also considered, differently from Pani et al., 2020, the latency and the incubation period of the patients admitted into the ICU unit in critical conditions. ICU patients are on average admitted three weeks after getting infected (Wang et al., 2020). For this reason, both meteorological and air-pollution data are 20 days back time-shifted. This means that the daily number of ICU patients from 8 March 2020 to 19 June 2020 are the result of infections that happened from 19 February 2020 to 31 May 2020.

The ICU daily cases follow the well-known bell-shaped model (Fanelli et al., 2020), with a phase where the ICU patients grow exponentially, followed by reaching a peak and an exponential drop. The curve

symmetry is strictly dependent, among other variables, on lockdown adopted measures. For this reason, the correlation analysis is strongly dependent on the considered time period, i.e. the results from Spearman and Kendall rank tests during the growing phase will be completely different with respect to the drop phase. To make the analysis independent on those issues, we consider instead the number of ICU anomaly cases with respect to a bi-gaussian model, extrapolated from the data trend. The model should account for the natural trend of viral epidemics and the effect of the lockdown on it. Thus, the residual analysis (i.e., the differences between the bi-gaussian model and the observed cases) should preserve from spurious correlations between the above-mentioned effects and the parameters under analysis. Indeed, the considered atmospheric parameters quickly change (sometimes day-to-day), thus representing a divergence factor (residue) with respect to the model and characterizing the existing anomaly about the classical behavior described by the model. Figure 2 represents the model and the number of ICU patients from 8 March 2020 to 19 June 2020.

Figure 3 shows the daily ICU patients anomaly with respect to the meteorological and air pollution variables. The daily variation of the meteorological and air-pollution parameters is shown in Figure 2, together with a statistical analysis. In Table 2 it can be noticed that the temperature shows a large variation over the period, ranging from $-1\text{ }^{\circ}\text{C}$ to $28\text{ }^{\circ}\text{C}$. The dew point (DP) is the temperature to which air must be cooled to become saturated with water vapor is ranging between $-16\text{ }^{\circ}\text{C}$ and $19\text{ }^{\circ}\text{C}$. Higher DP values ($>23\text{ }^{\circ}\text{C}$) are uncomfortable for humans and can induce heat stress (Pani et al., 2020). The relative humidity, absolute humidity, and water vapor content are dependent variables, and range from 6% to 100% for RH, 1 to 26 g m^{-3} for AH, and 0 to 22 g Kg^{-1} for WV. The wind speed also shows a large variability, ranging from 0 to 46 m s^{-1} . The air-pollution related parameters are affected by the lockdown restrictions. If considering the standard deviation, a temporal decrease is more evident in NO_2 concentrations than $\text{PM}_{2.5}$.

Table 2 Descriptive statistical analyses of meteorological and air-pollution variables (Feb. 19 - May 31, 2020; N = 103) in Milan, Lombardy.

Parameters	Min	Max	Mean	SD	Median	Mode	Kurtosis	Asymmetry
T _{max} (°C)	7	28	19	6	20	25	2.0	-0.3
T _{avg} (°C)	5	23	14	5	15	16	1.8	-0.1
T _{min} (°C)	-1	19	8	5	8	15	1.7	0.1
DP _{max} (°C)	-3	19	9	5	9	5	2.4	-0.1
DP _{avg} (°C)	-9	16	6	6	6	6	2.5	-0.2
DP _{min} (°C)	-16	15	3	7	3	4	3.2	-0.5
P _{max} (hPa)	991	1020	1006	6	1006	1004	2.5	-0.2
P _{avg} (hPa)	967	1018	1003	8	1004	1005	6.7	-1.2
P _{min} (hPa)	977	1015	1001	7	1002	999	3.4	-0.5
RH _{max} (%)	58	100	87	11	93	100	2.5	-0.6
RH _{avg} (%)	29	97	62	14	61	57	2.6	0.1
RH _{min} (%)	6	87	40	16	37	37	3.3	0.6
AH _{max} (g m ⁻³)	6	26	15	5	15	9	2.4	0.2
AH _{avg} (g m ⁻³)	3	14	8	3	7	3	2.4	0.4
AH _{min} (g m ⁻³)	1	9	4	2	3	2	2.7	0.7
WV _{max} (g kg ⁻¹)	5	22	12	4	12	11	2.4	0.2
WV _{avg} (g kg ⁻¹)	2	11	6	2	6	2	2.4	0.5
WV _{min} (g kg ⁻¹)	0	8	3	2	3	0	2.7	0.7
WS _{max} (m s ⁻¹)	7.0	43.0	16.0	6.2	15.0	13.0	5.8	1.4
WS _{avg} (m s ⁻¹)	3.6	19.6	7.9	3.1	7.0	5.8	4.9	1.4
WS _{min} (m s ⁻¹)	0.0	7.0	2.0	1.6	2.0	2.0	4.8	1.1
PM _{2.5} (µg m ⁻³)	4.0	52.0	18.9	10.8	17.0	8.0	3.6	1.0
NO ₂ (ppb)	13.1	68.3	31.3	12.6	29.3	13.1	2.9	0.7

Table 3 shows the monthly variations of the basic meteorological variables and air pollution concentrations. As expected, the transition between winter to spring season shows an increase of both temperature and DP. Instead the RH remains constant within the standard deviation, AH shows a sharp increase during May, as the WV. The atmospheric pressure does not show a particular monthly variability

like the horizontal wind speed. $PM_{2.5}$ and NO_2 concentrations, due to the block of human activity, show a substantial drop, more evident in NO_2 . We can speculate that the drop in NO_2 is stronger because nitrogen dioxide is mainly produced by road traffic, while $PM_{2.5}$ sources are road traffic, cooking and residence heating. After 40 days, NO_2 is halved.

Table 3 Meteorological parameters (mean \pm SD) monthly variations in Milan, Italy for 2020.

	February (N = 11)	March (N = 31)	April (N = 30)	May (N = 31)
T_{avg} ($^{\circ}C$)	9 \pm 2	9 \pm 3	15 \pm 3	20 \pm 2
DP_{avg} ($^{\circ}C$)	1 \pm 5	3 \pm 4	5 \pm 4	12 \pm 3
P_{avg} (hPa)	1004 \pm 9	1003 \pm 10	1004 \pm 6	1003 \pm 6
RH_{avg} (%)	61 \pm 16	69 \pm 11	55 \pm 13	63 \pm 14
AH_{avg} ($g\ m^{-3}$)	5 \pm 2	6 \pm 1	7 \pm 2	11 \pm 2
WV_{avg} ($g\ kg^{-1}$)	4 \pm 1	5 \pm 1	6 \pm 2	9 \pm 2
WS_{avg} ($m\ s^{-1}$)	8.5 \pm 4.1	7.7 \pm 3.5	7.4 \pm 3.1	8.5 \pm 2.3
$PM_{2.5}$ ($\mu g\ m^{-3}$)	33.5 \pm 15.5	23.4 \pm 8	17.4 \pm 8.4	10.6 \pm 3.9
NO_2 (ppb)	52.8 \pm 9.7	35.8 \pm 11.7	25.1 \pm 8.2	25 \pm 6.3

3.2. Correlation between COVID-19 and meteorological parameters

We investigated the correlation between the basic meteorological and air-pollution variables and Covid-19 pandemic transmission using the non-parametric Spearman and Kendall rank tests. As described in Section 3.1, the correlation is investigated against the residual ICU hospitalized patients with a time-shift of 20 days, i.e., met and air quality data from 19 February 2020 to 31 May 2020 and ICU patients from 09 March 2020 to 19 June 2020 to take into consideration the incubation period and hospitalization. We assume that hospital system did not collapse during the peak (hypothesis confirmed by the Italian health authorities). The results of non-linear correlations between Covid-19 pandemic and meteorological and air-pollution variables are summarized in Table 4.

Table 4. Spearman and Kendall non-linear rank correlation test between meteorological and air-pollution variables and ICU number patient's residual. Variables with a significant statistic at 99% are indicated in green, significant at 95% in orange. No correlation in red.

Parameters	Spearman rank correlation		Kendall rank correlation	
	r_s	p	τ	p
T_{\max}	-0.30	<0.01	-0.21	<0.01
T_{avg}	-0.31	<0.01	-0.19	<0.01
T_{\min}	-0.27	<0.01	-0.19	<0.01
DP_{\max}	-0.27	<0.01	-0.19	<0.01
DP_{avg}	-0.31	<0.01	-0.21	<0.01
DP_{\min}	-0.32	<0.01	-0.22	<0.01
P_{\max}	-0.18	0.07	-0.12	0.07
P_{avg}	-0.22	<0.05	-0.16	<0.05
P_{\min}	-0.27	<0.01	-0.20	<0.01
RH_{\max}	-0.12	0.22	-0.08	0.23
RH_{avg}	-0.06	0.54	-0.04	0.57
RH_{\min}	-0.05	0.61	-0.03	0.68
AH_{\max}	-0.37	<0.01	-0.25	<0.01
AH_{avg}	-0.33	<0.01	-0.23	<0.01
AH_{\min}	-0.20	<0.05	-0.14	<0.05
WV_{\max}	-0.36	<0.01	-0.24	<0.01
WV_{avg}	-0.33	<0.01	-0.22	<0.01
WV_{\min}	-0.20 [#]	<0.05	-0.14	<0.05
WS_{\max}	0.08	0.43	0.06	0.40
WS_{avg}	0.05	0.59	0.04	0.56
WS_{\min}	0.07	0.48	0.06	0.47
$PM_{2.5}$	0.20	<0.05	0.14	<0.05
NO_2	0.16	0.11	0.11	0.09

The analysis, working on ICU anomalies, is then independent on lockdown and epidemiology phases. Temperature, DP, AH, VW show significant negative correlation ($p < 0.01$; 99% C.I.) with Covid-19 pandemic transmission. These results confirm previous findings (e.g., Casanova et al., 2010; Lauc et al., 2020; Liu et al., 2020b) that virus transmission is enhanced by cold and dry climates. The wind speed does not present significant correlation. Also, the daily minimum atmospheric pressure shows a negative significant correlation, as found in Pani et al. (2020). On the opposite, Pani et al. (2020) show a positive correlation with the temperature, DP and AH. The main findings of other studies are reported in Table 5. Furthermore, it is important to highlight that lower temperatures at mid-latitudes promote indoor activities and people aggregation, facilitating the virus transmission.

Table 5 Main research findings on Covid-19 pandemic transmission and basic meteorological parameters.

Study	T	DP, AH, WV	Region
Pani et al., 2020	Positive	Positive	Singapore
Xie and Zu, 2020	Positive	N/A	China
Liu et al., 2020b	Negative	Negative	China
Yao et al., 2020b	No Correlation	N/A	China
Mendez-Arriaga 2020	Negative	N/A	Mexico
Tobias and Molina 2020	Negative	N/A	Catalunya (Spain)
Shi et al., 2020	Negative	N/A	China
Biktasheva, 2020	Positive	Negative	Germany
Bashir et al., 2020	Positive	Negative	NY City, USA

Regarding the air-pollution, there is a positive correlation with $PM_{2.5}$ atmospheric concentration ($p < 0.05$; 95% Confidence Interval), while for NO_2 the positive correlation is not significant ($p = 0.11$). The results from this study confirms that air-pollution has a role in Covid-19 pandemic, but still is not clear. More studies are needed to be performed if higher aerosol concentrations are able to carry the virus or just turn mild cases into severe requiring ICU hospitalization. Those results however confirm previous studies in literature that put in evidence the role of aerosol in aggravating or transmitting the SARS CoV-2 virus (Frontera et al., 2020; Setti et al., 2020, Wu et al., 2020)

This study, for the first time, investigates the correlation between basic meteorological and air-pollution variables and Covid-19 pandemic transmission on anomaly with respect to ICU hospitalized patients. Using the ICU patient anomaly number instead of the daily new positive cases variable. This approach makes the correlation independent on eventual lockdown policies and on the natural trend of viral epidemics as reported in the previous section. More research and studies are needed to assess why the Covid-19 pandemic outbreak hit stronger (also in terms of fatalities) the northern regions (Figure 1, inset) compared to center, southern and insular regions. In contrast to Pani et al. (2020), this study shows limitations as the meteorological data are taken from a single observation site. Also, the founded correlations are specific for this temperature and humidity ranges. More studies are needed for averaged lower and higher temperatures to corroborate the outcomes provided in this paper.

4. Conclusions

In this study, we investigate the correlation between the basic meteorological, air-pollution variables, and SarS CoV-2 virus transmission over 103 days from 09 March 2020 to 19 June 2020 in Milan, the business

center of Lombardy, the Italian region epicenter of Covid-19 pandemic outbreak, with the first documented local transmission case dated back to 24 February 2020. Differently from other studies, we considered as a reliable variable the anomaly of the daily number of Intensive Care Unit (ICU) hospitalized patients. This variable, with respect to others, i.e. daily new positive cases, is not linked to the number of performed test. Moreover, working on the anomaly, makes this study independent on the analyzed time period. To take into consideration the incubation period and latency for admission in ICU unit, both the meteorological and air-pollution variables are 20 days back time-shifted (19 February 2020 – 31 May 2020). The results put in evidence that temperature, absolute humidity, water vapor are negatively correlated with the virus transmission. Those findings confirm other studies for mid-latitude regions. Wind speed shows an insignificant correlation, while the daily minimum atmospheric pressure shows a significant negative correlation. The PM_{2.5} concentration positively correlates with SARS CoV-2 transmission. From those results, it is possible to speculate that air-conditioned environments not using sub-micron filters for organic particulate might help the virus transmission.

Further studies will investigate if the differences in meteorological and air-pollution variables played a role in inhibiting the virus transmission in different Italian metropolitan areas like Rome and Naples, that show higher population density than Milan.

Declarations

Credit authorship contribution statement

Simone Lolli: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft. **Ying-Chieh Chen:** Software, Data curation, Validation. **Gemine Vivone:** Conceptualization, Supervision, Writing - review & editing. **Sheng-Hsiang Wang:** Supervision, Writing - review & editing.

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Declaration of competing interest

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Figures

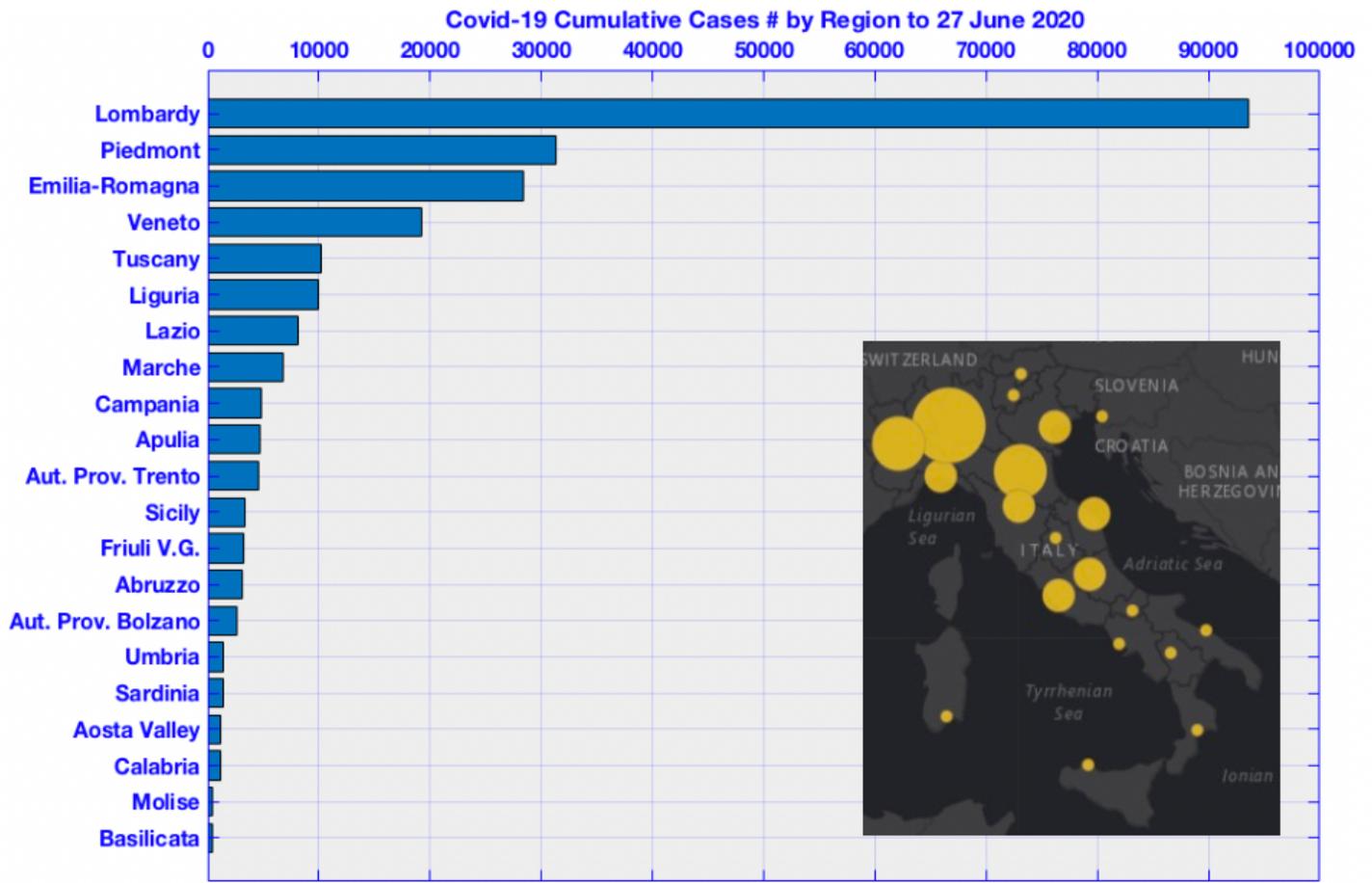


Figure 1

Covid-19 cumulative infected cases by region: Covid-19 pandemic transmission shows a transmission gradient between Northern and Southern regions. Lombardy (outbreak epicenter), Veneto, Piedmont and Emilia-Romagna account for 60% of cases and 70% of deaths (as in June 2020). Inset: North-South gradient in Covid-19 pandemic transmission

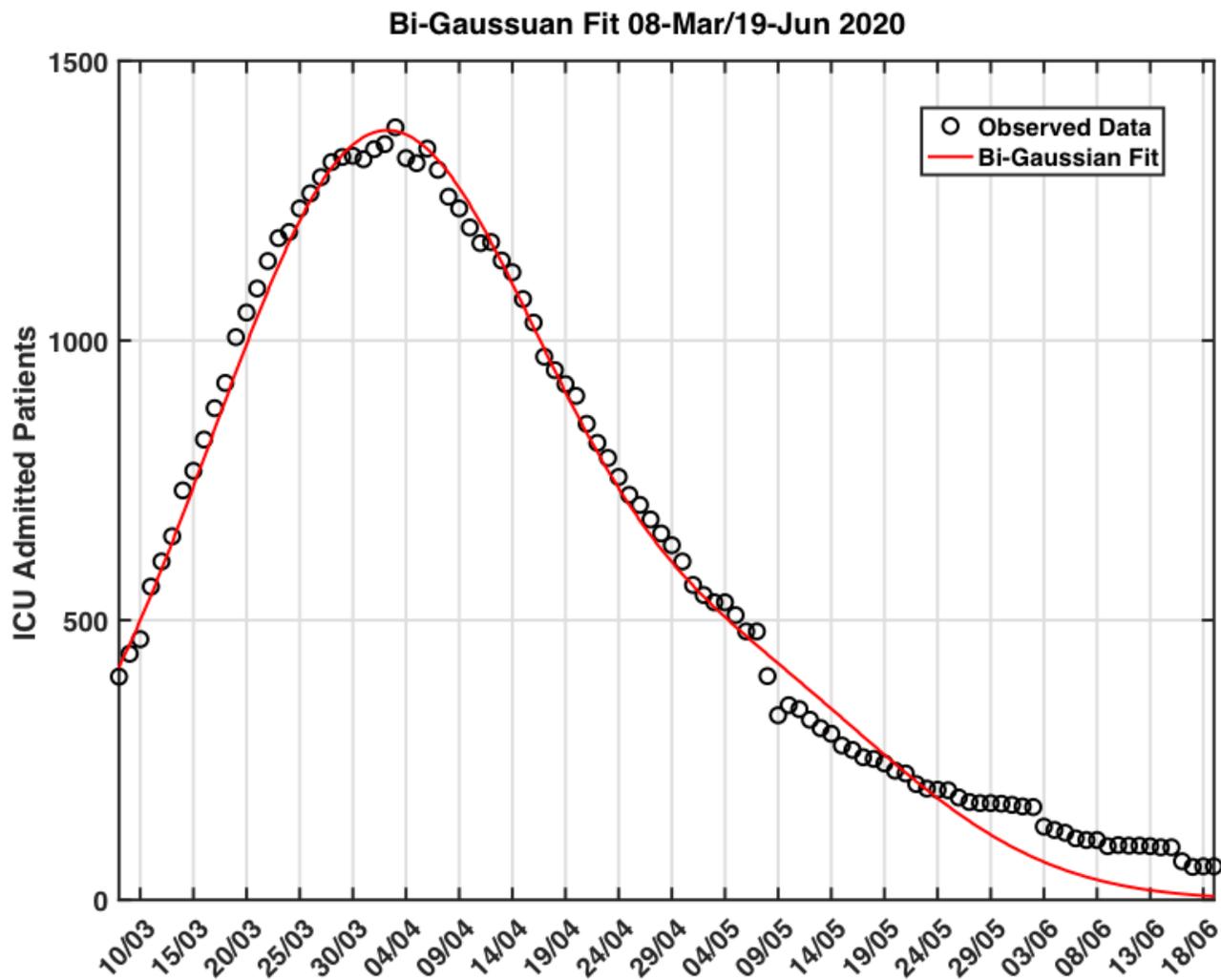


Figure 2

ICU Admitted patients fitted by a Bi-Gaussian function extrapolated from the observed data. The residuals are used to investigate the correlation with the meteorological and air-pollution variables

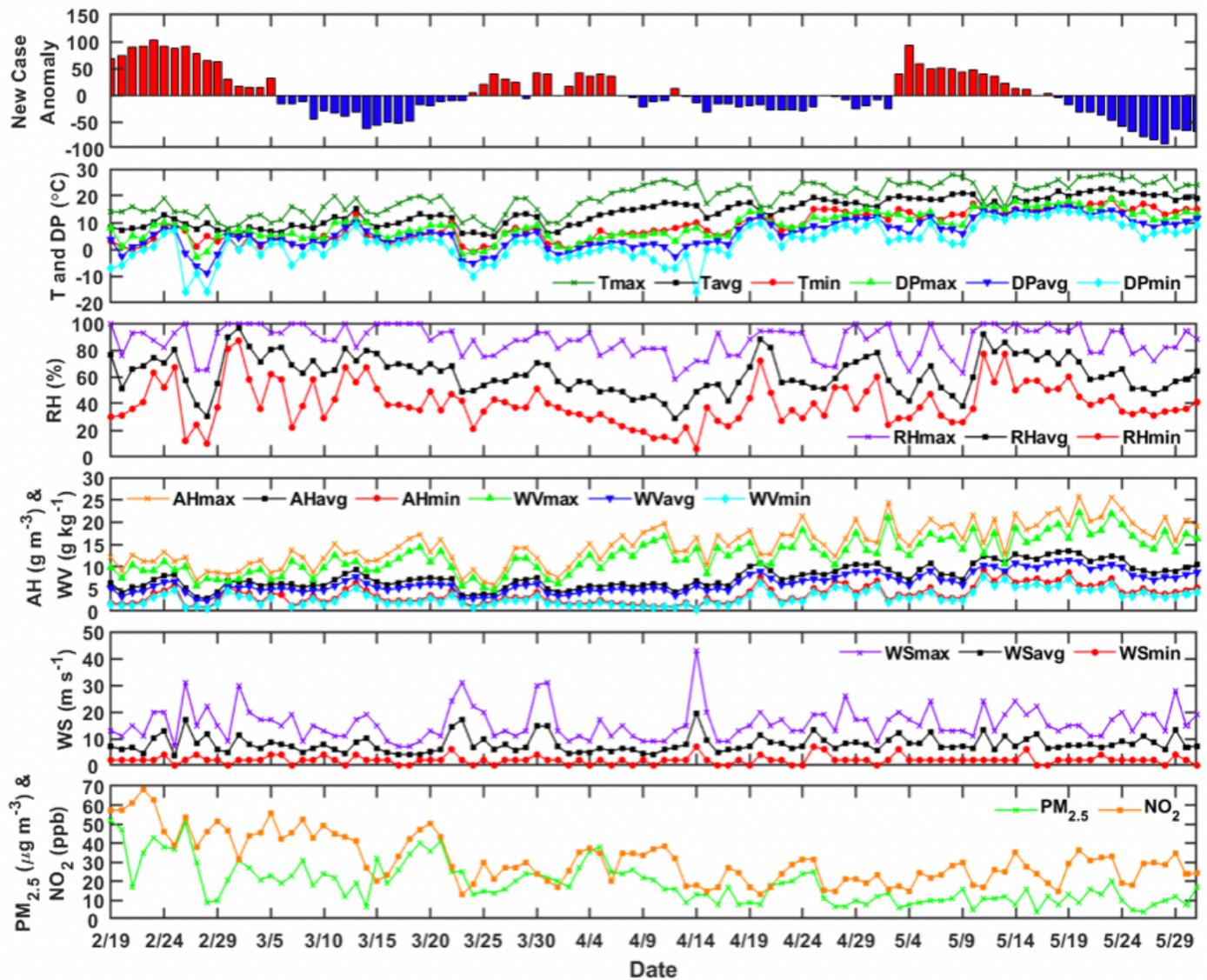


Figure 3

ICU patients daily case anomaly and meteorological and air pollution variables back time-shifted 20 days to take into consideration incubation and latency.