**COVID-19, Air Quality and Space Monitoring**

Yves M. Tourre1, Mireille Paulin2, Gilles Dhonneur3, David Attias4, Atul Pathak5

1 Yves M. Tourre : Former adjunct at Lamont Doherty Earth Observatory (LDEO of Columbia University, NYC), and Engineer Météo-France, Co-founder of Climate City, Toulouse, France

2 Mireille Paulin; Head of “Program Environment , Space and Public Health”, CNES, Toulouse

3 Gilles Dhonneur : Head of : Service Anesthésie Réanimation, Curie Institute*,* Paris, France

4 David Attias, Pneumology Department, Clinique Pasteur, Toulouse, France

5Atul Pathak, Head of Cardiology Department, Princess Grace Hospital, Monaco

Corresponding author: yvestourre@aol.com

**Abstract**

*COVID-19 can generate severe acute respiratory syndromes with serious pneumonia that may result in progressive respiratory failure and death. The acceleration and global diffusion of COVID-19 (i.e., pandemic) has been associated with changes of atmospheric chemistry and air pollution. For example, nitrous dioxide (NO2) and particulate matter (like PM10 and PM2.5) concentrations can be responsible for the over-expression of the angiotensin converting enzyme-2 (ACE-2) in human respiratory cells. Due to the COVID-19 pandemic in 2020 the world human mobility has slowed down considerably as well as economic activity, and thus the atmospheric chemistry. This is when space monitoring becomes a crucial tool for the spatio-temporal surveillance of the disease. For example, in places where the pandemic has struck very hard, it is found and where the socio-economic impacts are huge, air-pollution has diminished considerably through less nitrous dioxide for example (i.e., less industrial activity, less transport and circulation). Monitoring COVID-19 in real-time using proxies on air and chemical pollution in the atmospheric boundary layer, from space and from space agencies (i,e., CNES, ESA, NASA, JAXA, ASI, ASC, INPE among others) could be delivered deliver to Health Information Systems (HIS) for decision makers involved with Public Health.*

**Keywords:** COVID-19, Space monitoring, Atmospheric pollution

**I Introduction**

Atmospheric particles from primary (i.e. dust in Sahel) and secondary particulates (PM), may transport airborne pathogens, bacteria and viruses to large distance. Examples of measles and/or meningococcal meningitis outbreaks occurring during dry seasons in Niger (Ferrari et al., 2008). In any case moving from local cases of infected patients to pandemic like COVID-19 requires the airborne pathogens being transported by different means. Recent specific studies and laboratory experiments of Van Doremalen et al. (2020) indicated that airborne and transmission of SARS-C was plausible, since the virus remained alive and infectious for hours.

.

Two major transport mechanisms radically opposed can be considered. The first one and probably the most important one for diffusion of the disease relies on Human-to-Human transmission (H2H). Social interactions are obviously responsible for H2H and can generate an epidemic situation. Since viruses may survive in the air and travel over intermediate distances in the planetary boundary layer (PBL). The second transport mechanisms over longer distances can be through airborne PM and civil aviation flights which could all contribute to a global pandemic. There is enough evidence to consider the airborne route in the PBL, with a possible role of particulate matter (PM10 and PM2.5 , Copat et al., 2020, Wathore et al., 2020, **Fan et al., 2020**). as enhancing factors for COVID-19 outbreaks as observed in Northern Italy for example (Lancet, 2020).

The aim of this review is to describe potential mechanisms of Coronavirus diffusion, its impact on health issues and how spatial monitoring could give insights on COVID-19 diffusion mechanisms.

**II COVID-19, small particulates and air quality**

1. **Small particulates (PM) and impacts on humans**

Small particulates such as PM10, PM2.5 associated with air pollution is known to cause abnormal inflammatory and deleterious cardiovascular effects. Whilst their concentration is a function of seasonality (Hand et al, 2012) , these particulates could indirectly affect the cardiovascular system by: i) enhancing the release of proinflammatory and procoagulant by lung cells, ii) inducing autonomic dysfunction. But these particulates also directly affect the cardiovascular system by enhancing vascular inflammation and pro-atherosclerotic lesions. The latter has a direct effect on the arterial wall as measured by an increase in arterial rigidity and/or coronary calcification. Both direct and indirect effects may explain the increased risks of ischemic heart disease and stroke leading to poor cardiovascular outcome ( Zanobetti, and Schwartz, 2007; Adar et al, 2013; Kaufman et al, 2016; Kim et al, 2017). PM10, PM2.5 irritate human airways and causes respiratory diseases including bronchiolitis among( youngsters (Carugno et al., 2018; Mansbach et el., 2020) . It has been measured that Incidences of airway disease and the frequency of asthma or chronic obstructive pulmonary disease (COPD) are increasing (Stevanovic et al.,2016) . More over incidences of lung cancer are also expected to increase (Cui et al., 2015). The mechanisms on how airway reacts when inhaling PM is still not well understood, but the inflammation could facilitate COVID-19 impacts on humans (Choi et al., 2020).

The novel coronavirus disease (COVID-19) is a highly pathogenic, transmittable and invasive disease caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which emerged in December 2019 and January 2020 in Wuhan city, Hubei province, China and fast spread later on the middle of February 2020 in the Northern part of Italy and Europe (**Figure 1**).

Accelerated diffusion and lethality of COVID-19 and the PM10 (and PM2.5) surface air pollution in Milan metropolitan area, Italy were observed. From a collection of PM concentration in the planetary boundary layer Planetary Boundary Layer-PBL during 1 January–30 April 2020 were analyzed. Bedsides COVID-19 primarily transmitted by indoor bioaerosols droplets and infected surfaces, it seems like that high levels of urban air pollution, weather and specific climate conditions had a combined significant impact on confirmed cases of COVID-19, whilst lower levels of NO2 are associated with increase concentration of O3 through less titration by NO (Clark et al., 2015, Zoran et al., 2020).

**B. Monitoring PM from space**

Transmission dynamics of COVID-19 in specific environments are due to two mechanisms given by: air pollution-to-human transmission and human-to-human transmission. The mechanisms of air pollution-to-human transmission seems to play a critical role. It is suggested that to minimize future epidemic the maximum number of days per year in which cities can exceed the limits set for PM10, PM2.5 (or for ozone as a function of meteorological condition ) is less than 50 days. Passed that threshold, the combination between air pollution and meteorological conditions (with high humidity, low wind speed and fog) triggers the viral infection and epidemic diffusion. The latter will damage health of population, economy and society (Scatteia and Ravichandran 2020) as a whole.

Multispectral PM10 model can predict particulate matter concentrations with an acceptable level of accuracy. This is when monitoring from space the concentration of small particulates becomes of the surface reflectance bands (visible and infrared) from Landsat-7 ETM+, Landsat-8 OLI/TIRS, and Aqua-Terra/MODIS sensors. The data can be compared to estimate the PM10 concentration, using different predictive techniques(stepwise regression, partial least square regression, and artificial neuronal network (ANN). The model is able to estimate PM10 in regions where air data acquisition is limited. The best model selected allows the generation of PM10, PM2.5 concentration maps constituting a technique to estimate pollutants, especially when few air quality ground stations are available (Saraswat et al., 2017; Alvarez-Mendosa et al., 2019).

Another approach to monitor PM2.5 is through geo-intelligent deep learning model (fusion between satellite and station observations) to better represent the aerosol optical depth (AOD) and PM2.5 relationship ([Zhang](https://www.sciencedirect.com/science/article/abs/pii/S0034425715000516#!) and LI, 2015). The deep learning based AOD-PM2.5 modeling of China accurately estimated PM2.5 concentrations. It is predicted that over 80% of the Chinese population live in areas with an annual mean PM2.5 greater than the WHO IT-1standard (353/gmμ)in 2015. This is a promising approach for air pollution monitoring of large geographical regions (Li et al., 2017).

Finally, satellite-derived total-column optical depth or AOD, when combined with chemical transport models, provides estimates of global long-term average PM2.5 concentrations (Donkelaar et al, 2010)

**III COVID-19, atmospheric chemistry and air quality**

1. **Nitrogen dioxide (****NO2 ) and impacts on humans**

Nitrogen dioxide (NO2) is mainly man-made gas, and excess exposure to it will cause inflammation with lung damage and respiratory problems. This is amplified by the effect of NO2 on the endothelium (i.e., endothelial dysfunction, activation and injury through oxidative stress and inflammatory reactions) associated with autonomic dysfunctions. While endothelium damage could promote vasospasm, atherosclerosis and thrombosis, neural involvement triggers sympathetic activation and vagal withdrawal. These abnormalities could lead to coronary and cerebrovascular damage but also to arrhythmia and heart failure partly explaining NO2-related increase in short- and long-term mortality. It also plays an important role in atmospheric chemistry, because it leads to the production of ozone. Nitrogen oxides are produced by emissions from power plants, heavy industry and road transport, along with biomass burning. NO2 concentration in industrial areas can thus be monitored using remote sensing from space. In-situ ground-based data measuring networks are generally sparse the ground and do not allow a global view from satellites, and the assessment of local pollution versus advection.

One of an interesting observation is the increase of ozone through less titration by nitric oxide. Through GOME-2 (see following section B) short term variation of ozone tropospheric concentration can be evaluated. See also tropospheric O3 measurements from the Infrared Atmospheric Sounding Interferometer (IASI), which was launched on board of the MetOp-A European satellite in October 2006 (Clerbaux et al., 2009, Dufour, 2012). This kind of data is very important since ozone in the boundary layer also affects the respiratory system. Sentinel-4 should support this kind of research. Increase of ozone concentration was in deed measured in several cities (Nice, Roma, Valencia, Turin…) during COVID-19 pandemic (Sicard et al., 2020).

1. **Monitoring NO2 from space**

Space-based sensors are the only way to carry out effective global monitoring of Nitrogen dioxides as demonstrated with the Global Ozone Monitoring Experiment (GOME) on ESA's ERS-2 a precursor of the German, Dutch and Belgian financed SCIAMACHY flying on Envisat.

From space, NASA’s Ozone Monitoring Instrument (OMI) aboard the Aura satellite (Bechle et al., 2013) and the European Space Agency (ESA) TROPOspheric Monitoring Instrument (TROPOMI) aboard the Sentinel-5P satellite have provided the data showing of [rapidly](https://www.nasa.gov/feature/goddard/2020/drop-in-air-pollution-over-northeast) [falling](https://earthobservatory.nasa.gov/images/146362/airborne-nitrogen-dioxide-plummets-over-china) [nitrogen dioxide](https://nasasport.wordpress.com/2020/04/04/new-generation-satellite-observations-monitor-air-pollution-during-covid-19-lockdown-measures-in-california/) (NO2) concentrations around the world due to people sheltering in place during lockdown), and lowering of industrial activities and transportation **(Figure 2**, for northern Italy). Another example is at the end of 2019, when medical professionals in the Wuhan Province (China), were treating dozens of pneumonia cases. The illnesses were caused by [COVID-19](https://www.cdc.gov/coronavirus/2019-ncov/index.html). Concentrations of nitrogen dioxide, emitted by motor vehicles, power plants, and industrial facilities, dropped down across China as monitored by [TROPOMI](http://www.tropomi.eu/) As of February 28, 2020, the virus [had spread not only over China but had been detected](https://www.nytimes.com/interactive/2020/world/asia/china-wuhan-coronavirus-maps.html) in at least 56 countries. The dramatic drop-off of NO2 concentrations over such wide areas was due to the economic recession associated with COVID-19 pandemic

Since 2004, OMI has been measuring total column NO2, an air pollutant associated with burning fossil fuels. In addition, ongoing observations from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band on the joint NASA/NOAA Suomi NPP mission, have provided insighst into [recent changes](https://earthobservatory.nasa.gov/images/146481/nighttime-images-capture-change-in-china) in global human activity.

The datasets are also being used to help shed light on our understanding of the spread of COVID-19. The Socioeconomic Data and Applications Center (SEDAC) has launched a [new interactive and freely available mapping tool](https://earthdata.nasa.gov/learn/articles/sedac-covid-19-viewer) which allows overlaying with data from the Johns Hopkins University of Medicine Coronavirus Resource Center on the spread of COVID-19.

The work which must be done is to determine whether any hydroclimatic observations, such as air-pollution, temperature and/or humidity, even seasonality may impact the spread of COVID-19.

NASA is exploring additional partnering opportunities beyond its current joint Earth-observing satellite operations with the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) to collaborate on Earth science research related to COVID-19. For example, economic, agricultural and environmental impacts are been studied from the COVID-19 pandemic.

Globally, indicators for air quality and atmospheric elements such asNO2 looks into factors that include tracking ships at ports, the number of new vehicles parked near automobile factories and agriculture production. In Germany, for instance, the COVID-19 lockdown affected the movement of seasonal agricultural workers, such as the harvesting of asparagus, a labor-intensive activity. A significant drop was found in the German federal state of Brandenburg (20% to 30% lower asparagus fields)

Satellite observations allowed for monitoring continuously the cultivated white asparagus fields documenting a 20 percent to 30 percent lower area in March and April during the lock down in Brandenburg (role of seasonality as mentioned earlier). In China and Singapore, using Copernicus Atmosphere Monitoring Service (CAMS), NO2 concentration dropped considerably (**Figure 3**) while fewer new vehicles were parked at an automobile factory near Beijing Airport in China and the density of new cars and containers had diminished at the port in Singapore. Initial studies suggest that COVID-19-related emission reductions will slow also the speed at which GHG accumulate in the atmosphere.

**IV Discussion and Conclusion**

In places where the pandemic has struck very hard, it is found the socio-economical impacts are huge, and as one of the consequences the air-pollution (i.e., particular matter and chemical compounds) has diminished considerably. For example, there is less Nitrous dioxide (NO2) concentration since less industrial activity, less transport and circulation. Thus following the argumentation of point made earlier , this should contribute to a lesser diffusion of the virus.

A correlation seems to exist between COVID-19 cases, virus diffusion and anthropogenic pollution involving small particulate matters (PM10, PM2.5 having sizes less than 10 and 2.5 microns) . So, on the one hand the virus could travel over longer distance as originally thought (e.g., greater than close contacts), whilst on the other hand the small particulates(PM) through inflammation of the respiratory system and pulmonary cells could favor human susceptibility (Comunian et al., 2020, Rodriguez-Urrego D and L, 2020). Also, when patients have breathing problems, the probability of PM2.5 entered into the lungs is higher, whilst particle deposition is distributed mainly over the upper respiratory tract which could lead to heart failure (Zhang et al., 2016).

Spatial monitoring in real-time of PM and NO2  from the space agencies (CNES, ESA, NASA, JAXA, ASI, ASC, INPE among others) could give insights on COVID-19 diffusion mechanisms. Mapping the global atmosphere using data from the Sentinel-5P satellite already provides high-resolution data on several greenhouse gases (GHG) and aerosols (such as PM). All affecting climate variability and change as well as air quality and public health. Thus, the spatio-temporal analyses will provide key elements contributing to Early Warning Systems and Health Information Systems (EWS and HIS) for COVID-19. It should also bring material to decision makers involved with Public Health. Applications are described hereafter using two examples for space monitoring of small particulates (PM, section II) and atmospheric chemistry (NO2 , section III).

Thus, actions must be taken against varying ecosystems and anthropogenic activities (pollution) that might trigger new and unexpected threats to human health such as the COVID-19 pandemic. This is particularly important in a climate change context, when anticyclonic patterns (blocking ridges) may increase concentration of particulate matter and chemicals in the PBL (Ogen. 2020). The reservoirs of COVID-19 are of course humans and possible concentration from the ingested air is dependent upon the density of infected population in a specific area

Monitoring the variability of spatial distribution of small particles and gases from space should contribute to the development of precaution principles applied to public health. More studies are needed to strengthen scientific evidences and support firm conclusions. Significant statistical analysis and proven physical mechanisms from major findings must be consistent. This paper shows the important contribution of satellite surveillance of PM2.5 , NO2 (and potentially O3 ) triggering COVID-19 spread and lethality. In addition, and in order to identify all the possible sources/clusters it would be very interesting to test the hypothesis that scaled physical and chemical characteristics of the PBL including ground meteorological data such as local/altitude gradient of temperature and atmospheric pressure, hygrometry, wind speed, aloft; the presence and details (density and dimensions) of air transported particles in suspension (advection).

Today particle and chemical characteristics (PCC) dynamics through data (real-time monitoring) is available for most nations where the COVID-19 epidemic developed. Simultaneous, viral infection spread (VIS) kinetics in most large European cities are now known. VIS kinetics data would include the local density of human population and timed details such as the incidence rate of viral infection (based on testing strategy), the density of infected patients, the intensive care unit (ICU) bed occupation rate, the filling rate of hospital beds with infected patients.

A in a project using all the data describe above (from space and in-situ data) it would be very interesting to compare simultaneous timed PCC dynamic data with VIS kinetics. Standard statistics (logistic regression) may allow to identify specific correlations among them. Installing a machine learning superimposing PCC dynamics and VIS kinetics data would help to identify the impact of air bridges and corridors upon viral infection spread. Secondly, Artificial Intelligence may help to sort out which of PCC elements of the PBL might be involved in the transportation mechanisms.

The above knowledge would help models’ development and would make it possible to understand why a local infectious phenomenon concerning an airborne very contagious pathogen is evolving towards an epidemic and how to anticipate it and possibly block-off its progression by using drastic political decisions: imposing strict (intense and deep) containment of populations, the installation of a curfew, the systematic continuous wearing of facemask outside the private area; before a global pandemic situation occurs in the absence of vaccines.

This discussion and upcoming scientific projects are meant to contribute to Health Information Systems (HIS) in order to facilitate key actions and resolutions for policy and decision making.

**V Acknowledgments.**

The authors would like to thank unconditional support from CNES in general and Dr. C. Deniel in particular providing important feedback from “Effet du confinement du Printemps 2020 sur la composition atmosphèrique” report. Tourre would like to thank Dr. Maureen E. Raymo Interim Director of LDEO of Columbia University. This is LDEO contribution # XXXX.

**VI References**

Adar SD, Sheppard I, Vedal et al., 2013. Fine particulate air pollution and the progression of carotid intima-medial thickness: A prospective cohort study from the multi-ethnic study of atherosclerosi00s and air pollution. *PLoS Med*, 10:e1001430.

[Alvarez-Mendoza](https://sciprofiles.com/profile/219635)CI,  [Teodoro](https://sciprofiles.com/profile/263275) AC, [Torres](https://sciprofiles.com/profile/author/cDJTNnFvRWx2WU5wMk12ckRtVG9aeFlaTEZDWHVURTVjbnphOGhWMzIwZz0=) N, [Vivanco](https://sciprofiles.com/profile/author/OTZtbUNTQUp6bG1yTXBCWVV6Q0tUSmdlODd4RVJEUXhaZkZXY1BCR1B6WT0=) V,2019. Assessment of Remote Sensing Data to Model PM10 Estimation in Cities with a Low Number of Air Quality Stations: A Case of Study in Quito, Ecuador. *Environments,* *6*(7), 85. <https://doi.org/10.3390/environments6070085>

Bechle MJ, Miller DB. Julian M, Marshall D, 2013. Remote sensing of exposure to NO2: Satellite versus ground-based measurement in a large urban area. *Atmos. Environ*. Vol. 69, 345-353.

Brunet Y, Chevallier F, Colette A, Deniel C, Doussin JF, Dubreuil V, Hanoune B, Lac C, Loubet B , Loustau D, Uzu G, Villenave E, 2020. Agence Nationale de recherche pour l’environnement, ALLEnvi,. https://www.allenvi.fr/content/download/4979/37501/version/1/file/Effet\_confinement\_GT\_Atmosph%C3%A8re\_oct\_2020.pdf

[Carugno](https://pubmed.ncbi.nlm.nih.gov/?term=Carugno+M&cauthor_id=29940478) M, [Dentali](https://pubmed.ncbi.nlm.nih.gov/?term=Dentali+F&cauthor_id=29940478)F, [Mathieu](https://pubmed.ncbi.nlm.nih.gov/?term=Mathieu+G&cauthor_id=29940478) G, [Fontanella](https://pubmed.ncbi.nlm.nih.gov/?term=Fontanella+A&cauthor_id=29940478) A,  [Mariani](https://pubmed.ncbi.nlm.nih.gov/?term=Mariani+J&cauthor_id=29940478) J, [Bordini](https://pubmed.ncbi.nlm.nih.gov/?term=Bordini+L&cauthor_id=29940478) L, [Milani](https://pubmed.ncbi.nlm.nih.gov/?term=Milani+GP&cauthor_id=29940478) GP, [Consonni](https://pubmed.ncbi.nlm.nih.gov/?term=Consonni+D&cauthor_id=29940478)D,  [Bonzini](https://pubmed.ncbi.nlm.nih.gov/?term=Bonzini+M&cauthor_id=29940478) M, [Bollati](https://pubmed.ncbi.nlm.nih.gov/?term=Bollati+V&cauthor_id=29940478) V,  [Pesatori](https://pubmed.ncbi.nlm.nih.gov/?term=Pesatori+AC&cauthor_id=29940478) AC , 2018. PM10 exposure is associated with increased hospitalizations for respiratory syncytial virus bronchiolitis among infants in Lombardy, Italy”. *Environ Res.* Vol.166, pp 452-457. doi: 10.1016/j.envres.2018.06.016. PMID: 29940478 .

# Choi J, Sim K, Oh JY, Lee YS , Hur GY, Lee SY, Shim JJ, Moon J, Min, KH 2020. Relationship between Particulate Matter (PM10) and Airway Inflammation Measured with Exhaled Nitric Oxide Test in Seoul, Korea, *Canadian Respiratory Journal*, vol. 2020, Article ID: 1823405, <https://doi.org/10.1155/2020/1823405>

[Comunian](https://sciprofiles.com/profile/author/Rk9mM3FPMXh6WFBYazAxa3diM3ZvUFYvV2FBa3VNKzZjRFdNOUFlc1hKUT0=) S, Dongo D, Milani C, Palestini S, 2020. Air Pollution and COVID-19: The Role of Particulate Matter in the Spread and Increase of COVID-19’s Morbidity and Mortality. *Int. J. Environ. Res. Public Health* , *17*(12), 4487; <https://doi.org/10.3390/ijerph17124487>

Clark H, Sauvage B, Thouret V, Nédélec P , Blot R, Wang KY, Smit H, Neis P, Petzold A, Athier G , Boulanger D, Cousin JM, Beswick K, Gallagher M , Baumgardner D, Kaiser J , Jean- Flaud JM, Wahne A, Volz-Thomas A, Cammas JP, 2015 The first regular measurements of ozone, carbon monoxide and water vapour in the Pacific UTLS by IAGOS, *Tellus B: Chemical and Physical Meteorology*, Vol. 67:1, doi: [10.3402/tellusb.v67.28385](https://doi.org/10.3402/tellusb.v67.28385)

Clerbaux C, Boynard A, Clarisse L, George M, Hadji-Lazaro J, et al., 2009. Monitoring of atmospheric composition using the thermal infrared IASI/MetOp sounder. *Atmos. Chem. and Phys*., European Geosciences Union (EGU), Vol. 9 (16), .6041-6054.

[Comunian](https://www.ncbi.nlm.nih.gov/pubmed/?term=Comunian%20S%5BAuthor%5D&cauthor=true&cauthor_uid=32580440) S, [Dongo](https://www.ncbi.nlm.nih.gov/pubmed/?term=Dongo%20D%5BAuthor%5D&cauthor=true&cauthor_uid=32580440) D,[Milani](https://www.ncbi.nlm.nih.gov/pubmed/?term=Milani%20C%5BAuthor%5D&cauthor=true&cauthor_uid=32580440) C,  [Palestini](https://www.ncbi.nlm.nih.gov/pubmed/?term=Palestini%20P%5BAuthor%5D&cauthor=true&cauthor_uid=32580440) P, 2020. Air Pollution and COVID-19: The Role of Particulate Matter in the Spread and Increase of COVID-19’s Morbidity and Mortality.. [*Int J. Environ. Res. Public Health*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7345938/). Vol. 17(12): 4487. doi: [10.3390/ijerph17124487](https://dx.doi.org/10.3390%2Fijerph17124487)

Copat C,  [Cristaldi](https://www.ncbi.nlm.nih.gov/pubmed/?term=Cristaldi%20A%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) A,[Fiore](https://www.ncbi.nlm.nih.gov/pubmed/?term=Fiore%20M%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) M, [Grasso](https://www.ncbi.nlm.nih.gov/pubmed/?term=Grasso%20A%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) A,  [Zuccarello](https://www.ncbi.nlm.nih.gov/pubmed/?term=Zuccarello%20P%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) P ,[Santo Signorelli](https://www.ncbi.nlm.nih.gov/pubmed/?term=Signorelli%20SS%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) S, [Conti](https://www.ncbi.nlm.nih.gov/pubmed/?term=Conti%20GO%5BAuthor%5D&cauthor=true&cauthor_uid=32853663) GO,[Ferrante](https://www.ncbi.nlm.nih.gov/pubmed/?term=Ferrante%20M%5BAuthor%5D&cauthor=true&cauthor_uid=32853663), M, 2020. The role of air pollution (PM and NO2) in COVID-19 spread and lethality: A systematic review. [*Environ Res*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7444490/)*.* 2020 Vol. 191: 110129. doi: [10.1016/j.envres.2020.110129](https://dx.doi.org/10.1016%2Fj.envres.2020.110129)

Cui P, Huang Y, Han J, Song F, Chen K, 2015. Ambient particulate matter and lung cancer incidence and mortality: a meta-analysis of prospective studies,” *European Journal of Public Health*, Vol. 25, 2, 324–32.

Dufour G, Eremenko M, Griesfeller A, Barret B, Leflochmoën E, 2012. Validation of three different scientific ozone products retrieved from IASI spectra using ozone sondes. *Atmospheric Measurement Techniques*, European Geosciences Union, 2012, 5 (3), .611-630.

Fan Z, Zhan Q, Yang C, Liu M, Zhan M, 2020. How Did Distribution Patterns of Particulate Matter Air Pollution (PM2.5 and PM10) Change in China during the COVID-19 Outbreak: A Spatiotemporal Investigation at Chinese City-Leve. *Int. J. Environ. Res. Public Health*, *17*(17), 6274; <https://doi.org/10.3390/ijerph17176274>.

Ferrari MJ, Grais RF, Braiti N , Conlan AJ, Wolfson IJ, Guerin PJ, Djibo A, Grenfell BT, Bjornstad ON, 2008. The dynamic of measles in sub-Saharan Africa. *Nature.* 451, 679-684 .

Hand JL, Schichtel BA, Pitchford M, Malm WC, N. H,Frank NH , 2012. Seasonal composition of remote and urban fine particulate matter in the United States. *J. Geophys. Res., Atmospheres,* Vol. 117, D5, <https://doi.org/10.1029/2011JD017122>

Kim H , Kim J, Kim S et al., 2017. Cardiovascular effects of long-term exposure to air pollution: a population-based study with 900 845 person-years of follow-up. *J Am Heart Assoc*. doi: 10.1161/JAHA.117.007170.

Kaufman JD , Adar SD, Barr RG et al., 2016. Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. *Lancet*,388, 696–704.

Lancet, 2020. https://www.thelancet.com/action/showPdf?pii=S2213-2600%2820%2930514-2

Mansbach JM, Hasegawa K, Piedra PA, Sullivan AF, Camargo CA, 2020. Severe Coronavirus Bronchiolitis in the Pre–COVID-19 Era. *J. American. Academy of Pediatrics*. Vol. 146 (3) e20201267; doi: <https://doi.org/10.1542/peds.2020-1267>

Ogen Y, 2020. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. [*Science of The Total Environment*](https://www.sciencedirect.com/science/journal/00489697), Vol 726, 138605. <https://doi.org/10.1016/j.scitotenv.2020.138605>

Paital B, Agrawal PK , 2020. Air pollution by NO2 and PM2.5 explains COV ID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: a review. *Environ. Chem. Lett.* <https://doi.org/10.1007/s10311-020-01091-w>

Rodriguez-Urrego D, Rodrigues-Urrego L, 202 Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. *Environ. Pollut*. 266, 115042, doi: [10.1016/j.envpol.2020.115042](https://dx.doi.org/10.1016%2Fj.envpol.2020.115042)

ID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: a review. *Environ. Chem. Lett.* <https://doi.org/10.1007/s10311-020-01091-w>

Saraswat I, Kumar Mishra R, A. Kumar A, 2017. Estimation of PM10 concentration from Landsat 8 OLI satellite imagery over Delhi, India*.* [*Remote Sensing Applications: Society and Environment*](https://www.sciencedirect.com/science/journal/23529385). [Vol. 8](file:///C:\Users\user\AppData\Local\Temp\Vol.%20%208), 251-257, <https://doi.org/10.1016/j.rsase.2017.10.006>

Scatteia I,Ravichandran A, 2020. Insights from Space: Assessing Impacts of the Covid-19 Crisis The role of space data in assessing the industrial and environmental impacts of the Covid-19 crisis. Prepared by *PricewaterhouseCoopers* ( PwC). 1-13.

Shen TH, Yuan Q, Zhang X, L. Zhang L , 2017. Estimating Ground‐Level PM2.5 by Fusing Satellite and Station Observations: A Geo‐Intelligent Deep Learning Approach. *Geophys. Res. Lett.* [Vol. 44 (23](https://agupubs.onlinelibrary.wiley.com/toc/19448007/2017/44/23)), 11.985-11,993 <https://doi.org/10.1002/2017GL075710>

Sicard P, [De Marco](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!) A,Agathokleous E,  [Feng](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!)Z **,** [Xu](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!) X, [Paoletti](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!) E,  [Diéguez Rodriguez](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!) JJ, [Calatayud](https://www.sciencedirect.com/science/article/pii/S004896972033059X#!) V, 2020. Amplified ozone pollution in cities during the COVID-19 lockdown. [*Science of The Total Environment*](https://www.sciencedirect.com/science/journal/00489697)***.*** [Vol. 735](https://www.sciencedirect.com/science/journal/00489697/735/supp/C), 139542 <https://doi.org/10.1016/j.scitotenv.2020.139542>

# Stevanovic I, Jovasevic-Stojanovic M, Stosic J, 2016.Association between ambient air pollution, meteorological conditions and exacerbations of asthma and chronic obstructive pulmonary disease in adult citizens of the town of Smederevo. *Vojnosanitetski Pregled*, vol. 73, no. 2, 152–158

# Toscano D, Morena F, 2020.The Effect on Air Quality of Lockdown Directives to Prevent the Spread of SARS-CoV-2 Pandemic in Campania Region—Italy: Indications for a Sustainable Development **.** *Sustainability*, *12*(14), 5558; <https://doi.org/10.3390/su12145558>

van Donkelaar A, Martin RV, Brauer M, Kahn R, Levy ,Verduzco C, Villeneuve PJ, 2010. Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application. *Environ. Health Perspect.* Vol.118, 847–855 . doi:10.1289/ehp.0901623

van Doremalen N, Morris DH, Holbrook MG, Gamble A, Williamson BN, Tamin A, . Harcourt JL, Thornburg NJ, Gerber SI , Lloyd-Smith JO, de Wit E, Munster VJ, 2020. Aerosol and surface stability of SARS-Cov-2 as compared with SARS-Cov-1. *The New England Journal of Medicine .* <https://doi.org/10.1056/NEJMc2004973>

Wathore R, Gupta A, Bherwani H. Labbasetwar N, 2020. Understanding air and water borne transmission and survival of coronavirus: Insights and way forward for SARS-CoV-2. [Sci Total Environ](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7402210/). Vol. 749, 141486. doi: [10.1016/j.scitotenv.2020.141486](https://dx.doi.org/10.1016%2Fj.scitotenv.2020.141486)

Zanobetti A, Schwartz J , 2007.Particulate air pollution, progression, and survival after myocardial infarction. *Environ Health Perspect*, 115,.769–75.

Zhang Y, Z. Li, 2015. Remote sensing of atmospheric fine particulate matter (PM2.5) mass concentration near the ground from satellite observation. *Remote Sensing of Environment*. Vol. 160, 252-262.

[Zhang](https://www.ncbi.nlm.nih.gov/pubmed/?term=Zhang%20T%5BAuthor%5D&cauthor=true&cauthor_uid=28155704) T, [Gao](https://www.ncbi.nlm.nih.gov/pubmed/?term=Gao%20B%5BAuthor%5D&cauthor=true&cauthor_uid=28155704) B,[Zhou](https://www.ncbi.nlm.nih.gov/pubmed/?term=Zhou%20Z%5BAuthor%5D&cauthor=true&cauthor_uid=28155704) Z,, 2016. The movement and deposition of PM2.5 in the upper respiratory tract for the patients with heart failure: an elementary CFD study. *Biomed. Eng. Online.* Vol. 15, pp138. doi: [10.1186/s12938-016-0281-z](https://dx.doi.org/10.1186%2Fs12938-016-0281-z)

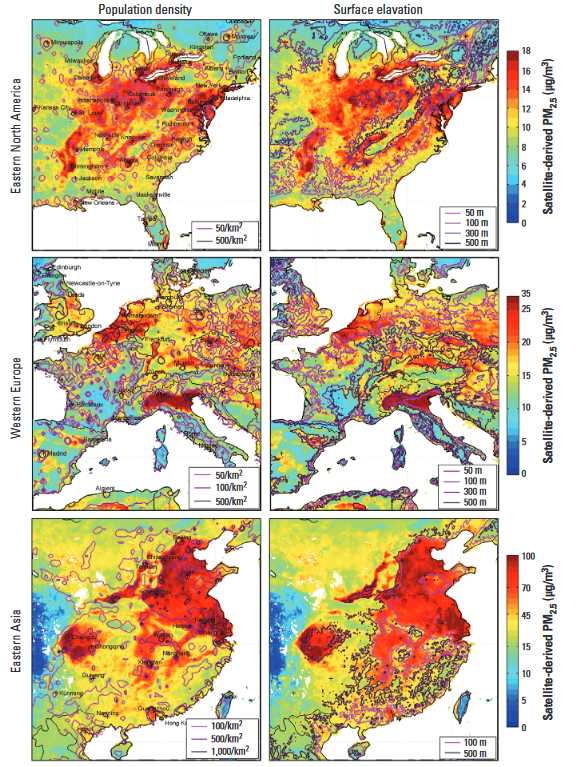
Zoran M, [Savastru](https://www.sciencedirect.com/science/article/pii/S0048969720333453#!) RS, [D. Savastru](https://www.sciencedirect.com/science/article/pii/S0048969720333453#!) DM, [Tautan](https://www.sciencedirect.com/science/article/pii/S0048969720333453#!) MN, 2020.Assessing the relationship between surface levels of PM2.5 and PM10 particulate matter impact on COVID-19 in Milan, Italy. [*Science of The Total Environment*](https://www.sciencedirect.com/science/journal/00489697)*.* [Vol. 738](https://www.sciencedirect.com/science/journal/00489697/738/supp/C), <https://doi.org/10.1016/j.scitotenv.2020.139825>

**Figures Captions**

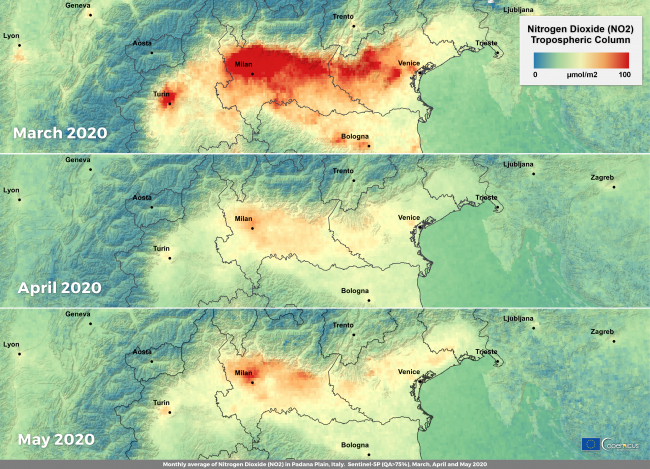
**Figure 1:** Regional satellite-derived averaged PM2.5 concentrations (µg/m3 ) for 2001–2006 with population density per km2 (left) and surface elevation in meters (right) (from Dankelaar et al., 2010). Heavily populated and highly polluted, along with low-lying regions of eastern China and the Pô Valley of northern Italy are easily identified.

**Figure 2:** Evolution of NO2 concentration in Northern Italy**.** Imagery of monthly average of NO2 concentration levels (µmole/m2) in the tropospheric column, measured by the Copernicus Sentinel-5P satellite before, during and after the lockdown period over the Padana Plain. As the lockdown began in March 2020, the drop of NO2 levels is particularly visible in the map of April 2020. (Credit **:** European Union , Copernicus Sentinel-5P, July2020).

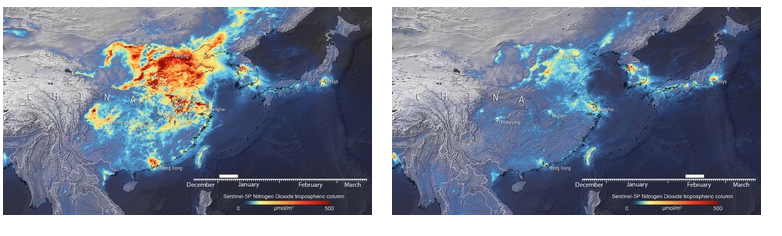
**Figure 3:** Over China, the Copernicus Atmosphere Monitoring Service (CAMS) observed a major drop in NO2 emissions (µmole/m2) during February 2020 as factories were closed and streets and highways were cleared from traffic (Courtesy of Eurisy, 2020). <https://www.eurisy.eu/what-we-can-learn-from-the-corona-crisis-with-satellite-data_46/>

******

**FIGURE 1**



**FIGURE 2**



**FIGURE 3**