COVID-19, air quality and space monitoring

Yves M. Tourre,[1] Mireille Paulin,[2] Gilles Dhonneur,[3] David Attias,[4] Atul Pathak[5]

[1]Former senior scientist at Lamont Doherty Earth Observatory (LDEO of Columbia University, NYC), and Engineer (Météo-France), Toulouse, France; [2]Program Environment, Space and Public Health, CNES, Toulouse; [3]Department of Anaesthesia and Intensive Care, Curie Institute, Paris, France; [4]Department of Pneumology, Clinique Pasteur, Toulouse, France; [5]Department of Cardiology, Princess Grace Hospital, Monaco

Abstract

Due to the worldwide spread of the coronavirus disease 2019 (COVID-19), human mobility and economic activity have slowed down considerably since early 2020. A relatively high number of those infected develop serious pneumonia leading to progressive respiratory failure, system disease and often death. Apart from close human-to-human contact, the acceleration and global diffusion of this pandemic has been shown to be associated with changes in atmospheric chemistry and air pollution by microscopic particulate matter (PM). Breathing air with high concentrations of nitrogen dioxide and PM can result in over-expression of the angiotensin converting enzyme-2 (ACE-2) leading to stress of organs, such as heart and kidneys. Satellite monitoring can play a crucial role in spatio-temporal surveillance of the disease by producing data on pollution as proxy for industrial activity, transport and traffic circulation. Real-time monitoring of COVID-19 in air and chemical pollution of the atmospheric boundary layer available from Earth-observing satellites commuting with Health Information Systems (HIS) would be useful for decision makers involved with public health.

Correspondence: Yves M. Tourre, Former senior scientist at Lamont Doherty Earth Observatory (LDEO of Columbia University, NYC), and Engineer (Météo-France), Toulouse, France.
E-mail: yvestourre@aol.com

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Introduction

The novel, coronavirus disease 2019 (COVID-19) was discovered by medical professionals in Wuhan City, Hubei Province, China when treating patients with a new type of pneumonia in December 2019 (Ma, 2020). Described as a highly pathogenic, highly transmittable and commonly invasive disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the illnesses rapidly developed into a pandemic in the spring of 2020. Infection by this virus generates a respiratory syndrome that may result in systemic organ failures, such as cardiac impairment, vascular damages and inflammatory outbursts with a relatively high mortality (Nuovo *et al*., 1993).

The dissemination of COVID-19 is strongly associated with air pollution by nitrogen dioxide (NO_2) and microscopic particulate matter (PM) responsible for release of angiotensin-converting enzyme-2 (ACE-2) in the human respiratory cells (Paital and Agrawal, 2020). What increases the risk for systemic disease is the correlation that seems to exist between COVID-19 cases, virus dissemination and anthropogenic pollution involving PM. Pollution not only makes the virus travel over longer distance than originally thought, but particles of 10 microns (PM_{10}) or less ($PM_{2.5}$) increase human susceptibility through eliciting an inflammatory response in various parts of the respiratory system (Comunian *et al*., 2020). Adding to this injury, the risk for particles, especially $PM_{2.5}$, entering the lungs is higher in patients with breathing problems as it can lead to heart failure (Zhang *et al*., 2016).

The COVID-19 pandemic has led to diminished human activity with regional economies slowing down considerably in many places resulting in a change of the composition of the atmospheric chemistry as noted by Brunet *et al*. (2020). Although the socio-economic impact is huge in places where the pandemic has struck sufficiently hard to constrain industrial activity, the diminished air pollution is one of the many consequences that must be deemed positive. The industrial contraction also results in lower virus diffusion because of less transport needs and reduced general traffic.

Real-time spatial monitoring of PM and NO_2, available from the various national space agencies, can give insights on the mechanisms of COVID-19 transmission. The European Space Agency (ESA) already provides high-resolution air quality data, such as various greenhouse gases (GHG) and aerosols (*i.e.* fine PM), collected by its Sentinel-5P satellite (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P). Spatio-temporal information of this kind can contribute to mapping the global atmosphere providing key elements of health information systems (HIS) and early warning systems (EWS) thereby assisting public health decision makers. Applications are described using two examples for space monitoring of atmospheric chemistry involving the microscopic particles and nitrogen oxide.

Monitoring the variability of the spatial distribution of PM_{10}, $PM_{2.5}$ and GHG from space should contribute to the development of precaution principles applied to public health. More studies are needed to strengthen scientific evidence 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 $PM_{2.5}$, NO_2 (potentially also ozone) triggering COVID-19 spread and lethality. 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 atmospheric planetary boundary layer (PBL) including ground meteorological data such as local/altitude gradient of temperature and atmospheric pressure, hygrometry, wind speed and the presence density and dimensions of air-transported particles in suspension (advection).

PM concentration and dynamics using primary combustion chamber (real-time monitoring) is available for most nations. As simultaneous, viral infection spread (VIS) in large cities is now common, it is important for surveys to include data on 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 and the rate of general hospital bed use for infected patients.

COVID-19, particulate matter and air quality

A large part of the general air pollution consists of PM_{10} and $PM_{2.5}$ and their concentration in the air is a function of seasonality (Hand *et al*., 2012) resulting in higher contamination over the northern half of the globe during winter. PM is known to irritate human airways and causes respiratory diseases including bronchiolitis among youngsters (Carugno *et al*., 2018; Mansbach *et al*., 2020). In addition, the frequency of respiratory diseases, such as asthma and chronic obstructive pulmonary disease (COPD), is increasing (Stevanovic *et al*., 2016). Importantly, PM can also cause inflammatory effects leading to systemic, deleterious cardiovascular injury, either by affecting the release of proinflammatory and procoagulant lymphokines from lung cells or by accelerating vascular inflammation, arterial rigidity and pro-atherosclerotic lesions (Guan *et al*., 2017; Yang *et al*., 2020), effects that explain the increased risk of ischemic heart disease and stroke in polluted areas (Zanobetti and Schwartz, 2007; Adar *et al*., 2013; Kaufman *et al*., 2016; Kim *et al*., 2017). Moreover, the incidence of lung cancer, that is already high, is also expected to increase further in areas with poor air quality (Cui *et al*., 2015). The exact mechanisms on how the airways react to inhaled PM are still not well understood, but it is obvious that inflammation amplifies the impact of COVID-19 (Choi *et al*., 2020).

The accelerated dissemination and lethality of COVID-19 were first recorded in China and Italy (Bergquist and Rinaldi, 2020). As shown in Figure 1, the areas with major occurrences of this infection coincided with the heavily populated and highly polluted areas in the industrial, low-lying regions of eastern China and the Italian Po Valley (Donkelaar *et al*., 2010).

An analysis by Zoran *et al*. (2020) of ground level PM concentrations in Milan, Italy during the January-April 2020 period and the number of COVID-19 cases demonstrate a positive association with surface air temperature, while a negative one with humidity. Although COVID-19 seems to be primarily transmitted by indoor exhaled, airborne droplets (bio-aerosols) and infected surfaces, it seems likely that high levels of urban air pollution, weather and specific climate conditions have an additional, significant impact, while lower levels of NO_2 are associated with increased concentration of ozone (Clark *et al*., 2015). Naturally, all these weather conditions are negative for confirmed cases of COVID-19.

Although COVID-19 transmission dynamics boil down to human-to-human transmission, the mechanism is strongly dependent on air pollution and convection, which in turn are governed by the various parameters of each specific environment in question. Humans need not to be in close quarters for the infection to easily be transmitted from one to the other, while air pollution seems to play a critical role in contributing transfer over large distances. It has been suggested that the maximum number of days per year in which cities can exceed the limits set for PM_{10} and $PM_{2.5}$ or ozone must be less than 50 days to minimize future epidemics (Coccia, 2020). When that threshold is passed, the combination of air pollution and meteorological conditions, such as high humidity, low wind speed and fog, can trigger increased viral dissemination (Scatteia and Ravichandran, 2020).

COVID-19, atmospheric chemistry and air quality

Nitrogen dioxide and nitric oxide are mainly emissions from power plants, heavy industry and road transport as well as the result of burning various forms of biomass. They also play an important role in atmospheric chemistry due to their role in ozone production. Excess exposure to NO_2 causes respiratory inflammation injury through oxidative stress and inflammatory reactions associated with autonomic, endothelial dysfunction resulting in lung damage and breathing obstruction (Polverino *et al*., 2018). While endothelium damage can lead to vasospasm, atherosclerosis and thrombosis, neural involvement triggers sympathetic activation and vagal withdrawal (Rea and Thames, 1993). Coronary and cerebrovascular impacts are possible outcomes that can lead to arrhythmia and heart failure, which may partly explain the role of NO_2-related increase in short- and long-term mortality. Short-term exposures to ozone irritate the respiratory system and damage lung tissues, thus reducing lung function, and increasing airway inflammation. Persons especially sensitive to ozone exposure are the elderly, infants, children and persons with existing respiratory issues such as diabetes, asthma/ allergies or with co-morbidities and/or a compromised immune system (Fillipidou and Koukouliata, 2011).

Monitoring PM and atmospheric chemistry constituents from space

Multispectral PM_{10} models can predict particulate matter concentrations with an acceptable level of accuracy when monitored from space. The concentration of these particles can be demonstrated by the surface reflectance bands (visible and infrared) by MODIS sensors onboard the Aqua and Terra satellites since 1999/2002 (https://terra.nasa.gov/about/terra-instruments/modis), by Landsat-7's ETM+ sensor since 2003 (https://www.usgs.gov/landsat-missions/landsat-7), by Landsat-8 OLI/TIRS instruments since 2013 (https://www.usgs.gov /centers/eros/science/usgs-eros-archive-landsat-archives-landsat-8-oli-operational-land-imager-and) and with even higher quality by sensors onboard the Landsat-9 satellite launched in 2021 (https://www.usgs.gov/landsat-missions/landsat-9). The data collected can be used to estimate the PM_{10} concentration, using different predictive techniques (stepwise regression, partial least square regression and artificial neuronal network (ANN). The advantage of modelling is that it allows

PM_{10} estimations also in regions where air data acquisition is limited, *e.g*., as shown by recently generated concentration maps of pollutants (Saraswat *et al*., 2017; Alvarez-Mendosa *et al*., 2019).

Aerosol optical depth (AOD), when combined with chemical transport models, can provide estimates of global long-term average $PM_{2.5}$ concentrations (Donkelaar *et al*, 2010). Another approach to monitor $PM_{2.5}$ is through geo-intelligent 'deep-learning' using a fusion between satellite observations and datasets from land-based stations to better represent AOD and $PM_{2.5}$ relationships (Zhang and Li, 2015). This approach accurately estimated $PM_{2.5}$

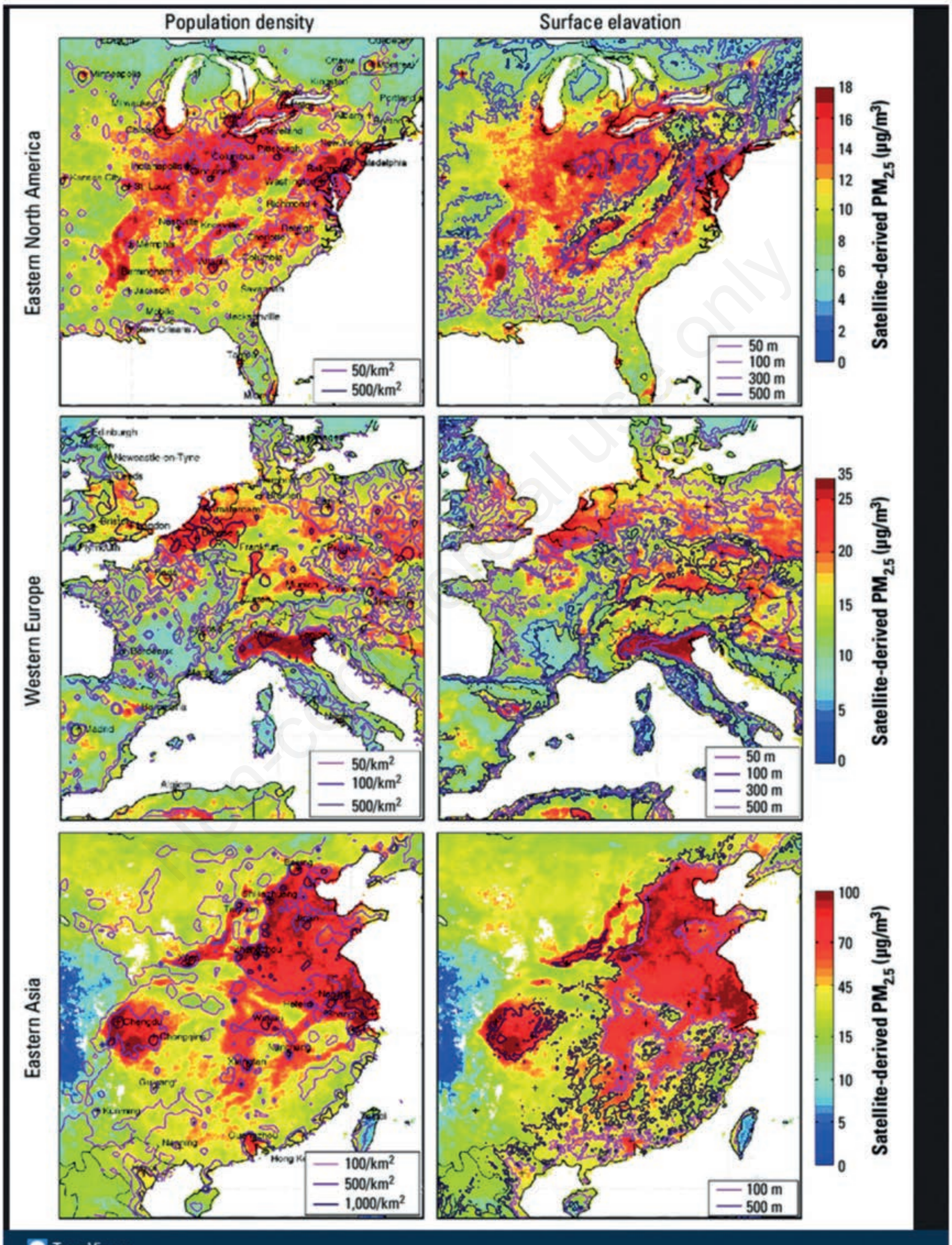

Figure 1. Regional satellite-derived averaged $PM_{2.5}$ concentrations (µg/m^3) for 2001-2006 with population density per km^2 (left) and surface elevation in m (right) (after v. Donkelaar *et al*., 2010). From Dankelaar *et al*., 2010.

concentrations over China showing that over 80% of the population live in areas with an annual mean $PM_{2.5}$ greater than the international tolerance (IT)-1 standard (353/gmm) issued by the World Health Organization (WHO) (Li *et al*., 2017). This is a promising approach for air pollution monitoring of large geographical regions.

Data emanating from *in-situ* ground-based networks for GHG are available but the stations are generally sparsely located and do neither allow a global view nor assessment of local pollution *versus* advection. Therefore, nitrogen dioxide concentration in industrial areas is best monitored using remote sensing from space. With regard to ozone, an interesting observation is its increase through less titration by NO. Even if this dynamic is still not fully understood, it is suggested that decreasing NO in rural areas and plumes contribute to longer ozone duration allowing it to be transported over greater distances than a decade ago (see also Clarke *et al*., 2015). Indeed, increased ozone concentrations have been measured in several European cities during the COVID-19 pandemic (Sicard *et al*., 2020).

Space-based sensors are the only way to carry out effective global monitoring of NO_2 as demonstrated by the Global Ozone Monitoring Experiment (GOME) utilizing ESA's second European Remote Sensing satellite (ERS-2) that was launched in 1995 (https://www.esa.int/Applications/Observing_the_Earth/ERS_at_a_glance), a mission followed by the Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) onboard the ENVIronmental SATellite ENVISAT put in orbit in 2002 (https://www.esa.int/ Applications/Observing_the_ Earth/ Envisat/Mission_overview). The follow-up GOME-2 mission focused on the short term variation of ozone tropospheric concentration, while tropospheric ozone measurements are collected by the Infrared Atmospheric Sounding Interferometer (IASI) onboard the MetOp-A European satellite launched in 2006 (Clerbaux *et al*., 2009, Dufour, 2012). Sentinel-4 (https://www.eumetsat.int/sentinel-4) is supporting this kind of research. Figure 2 depicts the evolution of NO_2 concentration (µmoles/m^2) in the tropospheric column measured over the Padana Plain in northern Italy by the ESA's Copernicus Sentinel-5P satellite before, during and after lockdown in the spring of 2020**.** The drop in NO_2 levels is particularly visible in the April 2020 map.

NASA's Ozone Monitoring Instrument (OMI) aboard the Aura satellite (Bechle *et al*., 2013) and ESA's TROPOspheric Monitoring Instrument (TROPOMI) onboard its Sentinel-5P satellite (https://sentinel.esa.int/web/sentinel/missions/sentinel-5p) have provided data showing rapidly falling NO_2 concentrations around the world, which are due to widespread lockdowns and diminished industrial activities and transportation. These satellite data also show that NO_2 concentrations, emitted by motor vehicles, power plants and industrial facilities, dropped across China. As of 28 February 2020, COVID-19 had not only spread in China, but rapidly appeared in a large number of countries with the *Omicron* variant reported from 89 countries less than two years later (https://q107.com/news/8461031/covid-19-omicron-countries-who/). The dramatic fall in NO_2 concentrations over such wide

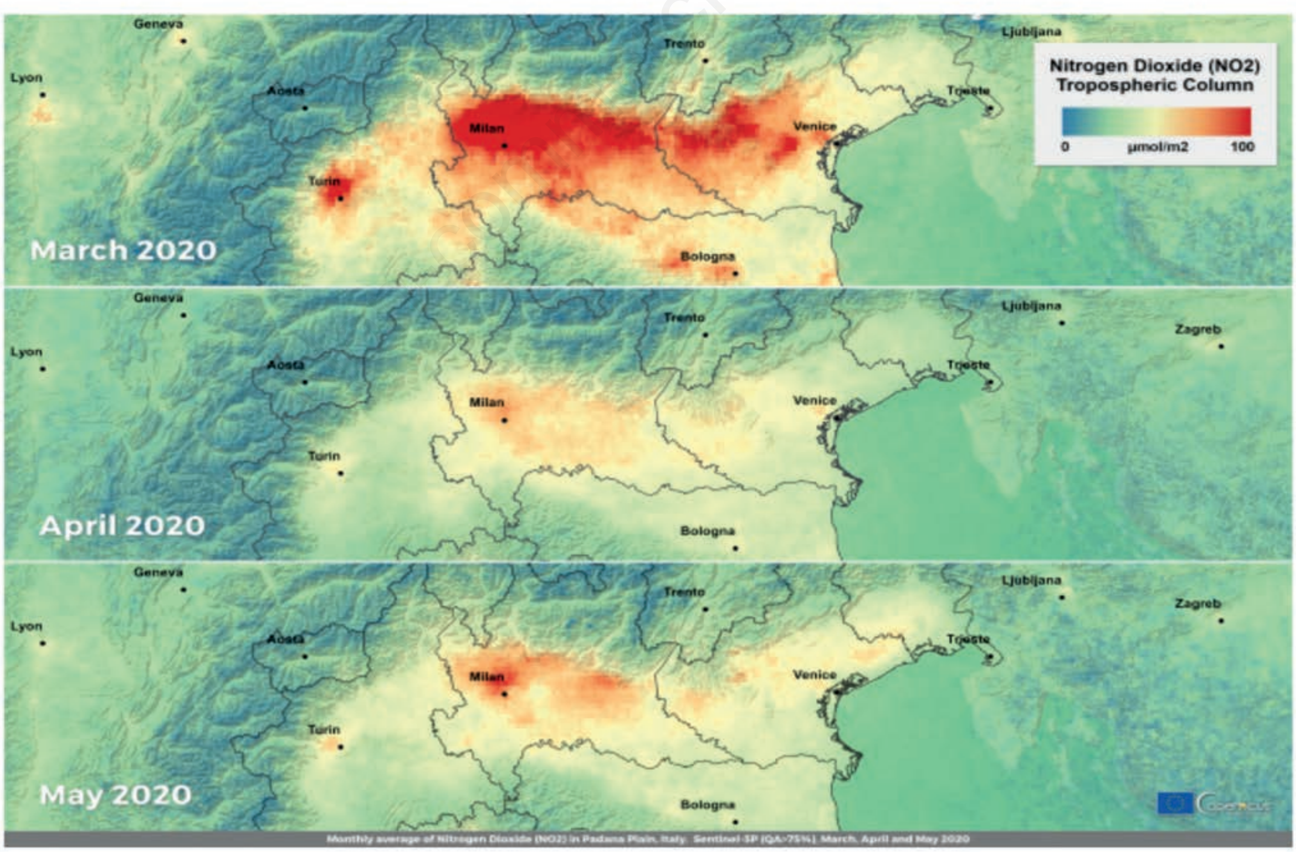

Figure 2. The reduced NO_2 levels over northern Italy during spring 2020. Imagery source: Copernicus Sentinel-5P, European Union.

areas can only be explained by to the economic recession associated with COVID-19 pandemic.

Indicators for air quality and atmospheric elements include global tracking of ships at ports, the number of new vehicles parked near automobile factories and agriculture production. For example, the COVID-19 lockdown affected the movement of seasonal agricultural workers in Germany, such as the labour-intensive asparagus harvesting in Brandenburg fields, where a 20-30% drop was noted last year (https://www.wsws.org/en/ articles/2021/11/10/coro-n10.html). According to EURISY, a non-profit association of European space agencies, governmental offices and international organisations in charge of space affairs (https://www.eurisy.eu/what-we-can-learn-from-the-corona-crisis-with-satellite-data_46/), the Copernicus Atmosphere Monitoring Service (CAMS) observed a major drop in NO_2 emissions (μmole/m^2) during the beginning of 2020 (Figure 3) as factories were closed and streets and highways were cleared from traffic.

The total NO_2 column in the world has been measured by OMI, while ongoing observations from the visible infrared imaging radiometer suite (VIIRS) day/night bands, have provided insights into recent changes in global human activity. The VIIRS is part of the Suomi National Polar-orbiting Partnership (NPP) mission, a joint American operation by NASA and the National Oceanic and Atmospheric Administration (NOAA). As NO_2 is an indicator of the use of fossil burning, these activities are shedding light on our understanding of the spread of COVID-19. However, work must be done to also determine whether any other observations on air-pollution as well as temperature and/or humidity measurements, average and seasonal, may impact the spread of the virus.

The Socioeconomic Data and Applications Center (SEDAC), a searchable NASA database of all identified publications that cite this kind of data, has launched an (https://earthdata.nasa.gov/eosdis/daacs/sedac), which accepts overlays from the Johns Hopkins University of Medicine Coronavirus Resource Center outlining the spread of COVID-19. This is of great help as is also the fact that NASA is exploring additional partnering opportunities beyond its current joint Earth-observing satellite operations with 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 being studied with respect to the pandemic (Nicola *et al*., 2020).

Conclusions

It would be of interest to compare simultaneous timed ozone concentration dynamics with VIS kinetics based on all the data described above (from space and *in-situ* data). Standard statistics should allow identification of specific correlations among them. Installing a machine learning superimposing primary combustion chambers for determination of PM concentrations and dynamics would help to identify the impact of air bridges and corridors for viral infection spread. Secondly, artificial intelligence (AI) may help to sort out which of elements of the PBL might be involved in the transportation mechanisms. This would assist model development and making it possible to understand why and how a local infectious phenomenon concerning an airborne very contagious pathogen can evolve towards a pandemic. This would contribute to anticipate and possibly block-off its progression before drastic needs for political decision, *e.g*., consisting of imposing strict (intense and deep) containment of populations, installation of a curfew, systematic continuous wearing of facemask outside private areas. This presentation is a proposal for discussion and upcoming scientific projects that could contribute to Health Information Systems (HIS) in order to facilitate key actions and resolutions for policy and decision making.

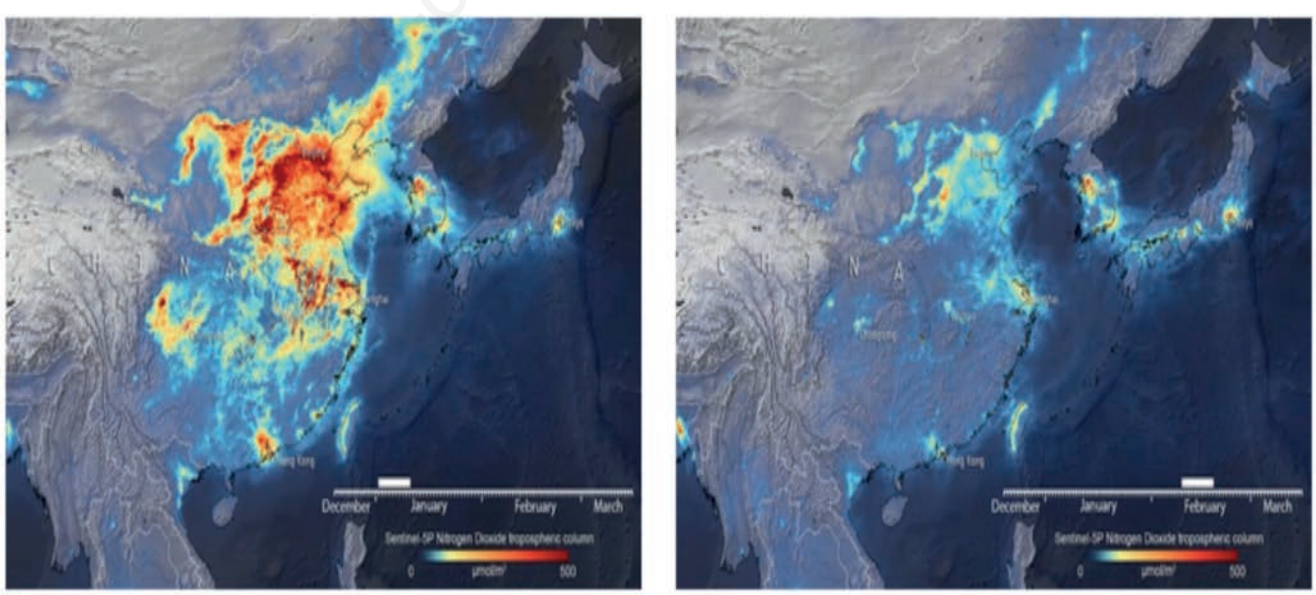

Figure 3. The major drop in NO_2 emissions from the beginning of January 2020 to mid-February 2020 as factories were closed and streets and highways were cleared from traffic. Imagery source: Eurisy, 2020.

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