

“Novel 2019 Coronavirus Outbreak” through the Eyes of GNSS Signal

Bhaskar Kundu*, Dibyashakti Panda, Naresh Krishna Vissa and Bhishma Tyagi

Department of Earth and Atmospheric Sciences, NIT Rourkela, Rourkela - 769 008, India

*E-mail: rilbhaskar@gmail.com

Received: 28 June 2021 / Revised form Accepted: 7 November 2021

© 2022 Geological Society of India, Bengaluru, India

ABSTRACT

Besides the global crisis of the novel COVID-19 outbreak, we have presented the other side towards an environmental perspective. Due to the economic shutdown of major cities, the novel COVID-19 outbreak has significantly influenced air quality in the atmosphere and also affected the tropospheric refraction on Global Navigation Satellite System GNSS signal propagation in the horizontally stratified column. We suggest that GNSS signal propagation and variation in Zenith Tropospheric Delay (ZTD) in the tropospheric column can be used as a proxy for the pollution-monitoring tool in the future. Although we have presented a case study from mainland China, the hypothesis can be tested globally.

INTRODUCTION

“You must keep looking on the bright side, because you won't find anything in the dark” – Zack W. Van

On 31 December 2019, a novel coronavirus (COVID-19) caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) outbreaks. COVID-19 arguably originated in the Hubei province of the Wuhan city of mainland China, and eventually, it has spread across the entire globe within a few days (Paules et al., 2020). On 24 March 2020, the World Health Organization (WHO) reported more than ~398,000 confirmed cases globally, along with more than ~17,000 reported deaths in which Italy, China, Spain, and Iran leading in the front row; of which ~81% deaths have been reported outside the mainland China (@WHO report, 2020). However, it was just the beginning. After the second wave of devastation in 2021, the COVID-19 outbreak has become a focal point in terms of global health, economic, scientific, and socio-political crisis. In fact, in the 21st century, the recent COVID-19 outbreak represents probably the third novel coronavirus emergence, after the 2003 Severe Acute Respiratory Syndrome (SARS) and the 2013 Middle East respiratory syndrome (MERS). Due to this pandemic outbreak, the lockdown of major worldwide cities and states, travel restrictions, and border control measures have been imposed globally (Wells et al., 2020), including mainland China to restrict the spread of this outbreak (Fig.1).

However, irrespective of that worldwide crisis, the novel COVID-19 outbreak has another side from an environmental perspective (Fig.1). Wuhan is the capital city of the Hubei Province, the leading economic and industrial heart of mainland China. Just before two days of the Chinese New Year, on 23 January 2020, the Chinese government enacted a lockdown in Wuhan City along with other 15 cities in the

Hubei Province on 24 January 2020 (Wells et al., 2020) to limit the spread of the COVID-19 outbreak in an attempt to quarantine the epicenter of this outbreak. Eventually, entire mainland China including Beijing, other megacities, imposed a lockdown, which paralyzed the economy. Because of this economic shutdown, the novel COVID-19 outbreak has influenced air quality in the atmosphere dramatically, resulting in lowering down the air pollution, specifically fine particulate matter, NO₂, and SO₂ emissions (i.e., the major source of air pollution) over mainland China (Virghileanu et al., 2020) (Fig.2). India, which is the neighbouring developing economy and second most populated country after China, also faced severe consequences due to COVID-19 spread. A lockdown was imposed by the Government of India for the period 24 March-31 May 2020, which resulted in significant improvement of air quality over major Indian cities (e.g., Sahu et al., 2020; Singh and Tyagi, 2021). However, some regions in India could not show the decrease in pollution reported at other places (Tyagi et al., 2021) due to unaffected sources over these regions. Air pollution was found to have a significant correlation with the polluted regions (Sahu et al., 2021) and hence understanding pollution change over different areas becomes crucial to combat COVID-19 spread.

Similar consequences also have been reported extensively from several case studies (He et al., 2020; Shi et al., 2021). Various meteorological, climatological, or orographic factors control the air pollution reduction in the tropospheric column (Kang et al., 2020; Hammer et al., 2021). Moreover, the impact of the COVID-19 outbreak on NO₂ pollutants has also been reported from China, South Korea, western Europe, and the United States by considering observations from the Tropospheric Monitoring Instrument and the Ozone Monitoring Instrument (Bauwens et al., 2020). Observations from these instruments reveal a decrease in the concentration of NO₂ over these regions as a result of the Covid-19 outbreak. Moreover, data from several Air Quality Monitoring Station from eastern India and from the overall Indian sub-continent shows a significant increase in air quality parameters (PM_{2.5}, PM₁₀, NO_x, O₃, and CO), which are attributed to the local emission from several power plants and coal mines (Singh and Tyagi, 2020; Sahu et al., 2020, 2021; Tyagi et al., 2021). Hence, it has now appeared that the exact relationship is not at all straightforward indeed. Irrespective of that inherent complexity, it has been argued that such abrupt lowering down the air pollution or particulate matter in the tropospheric column has significantly influenced the signal propagation of Global Navigation Satellite Systems (GNSS), as the dual-frequency measurements from the GNSS satellites provide information about the tropospheric column. Therefore, in this present paper, it has been demonstrated whether the



Fig.1. The Novel 2019 Coronavirus outbreak and its impact on two contrasting sides related to worldwide pandemic crisis vs. improvement in terms of environmental status. All the image files have been archived from various sources (<https://www.who.int/>; <https://www.bbc.com/news/world-asia-india-56798248>; <https://edition.cnn.com/travel/article/himalayas-visible-lockdown-india-scli-intl/index.html>; <https://europemc.org/article/med/32758842>; <https://www.biotechnika.org/2020/06/human-impact-on-wildlife-revealed-by-covid-19-lockdown/>).

GNSS signal propagation process within the tropospheric column can be used as an alternate proxy for the pollution-monitoring tool in the future. To test our hypothesis, a case study from mainland China and adjacent regions is presented. However, the hypothesis can be tested globally, considering more long-duration GNSS datasets with local climatological conditions.

RESULT AND DISCUSSION

Air Pollutant and COVID-19 Lockdown

Figure 2 represents the monthly time-averaged spatial distributions of NO_2 in the tropospheric column over the region of mainland China from December 2019 to February 2020, in comparison with the previous year during December 2018 to February 2019. From this systematic comparison, it has been observed that there is a dramatic drop of tropospheric NO_2 level during the recent quarantine period (February 2020), in contrast to the pre-quarantine period (December 2019). It is also evident that the substantial reduction in NO_2 pollutants is first observed near the Wuhan City surrounding region; however, it eventually spread across the other parts of mainland China, including Beijing further north. The TROPOMI sensor, a related Tropospheric Monitoring Instrument onboard the Copernicus satellite, controlled jointly by NASA and European Space Agency, also have reported identical measurements over the region of mainland China and other major cities (Virghileanu et al., 2020). Moreover, such a substantial reduction of tropospheric NO_2 level during the lockdown period in a wider geographical area of mainland China appears to be more pronounced than the gradual drop in NO_2 level during the worldwide economic recession that began during 2008 (Virghileanu et al., 2020). Although, the various other air pollutants (e.g., O_3 , CO , SO_2 , NO , liquids, and particulate matters, which are the major source of air pollutants) have dramatically decreased in the tropospheric column over the region of mainland China. In the absence of direct (or satellite) based quality measurements of other air pollutants, the spatio-temporal distributions and the variation of NO_2 in the tropospheric column over the region of mainland China has been considered as a representative proxy for the other air pollutants (as presented in Fig.2). Moreover, NO_2 has adverse health effects, and the emissions of NO_2 are well regulated in many countries (Bauwens et al., 2020). The long-term

data record of NO_2 columns has been previously used to assess the effectiveness of long term abatement strategies (Duncan et al., 2016) and the effects of economic recession (Castellanos & Boersma, 2012). In that regard, NO_2 is considered as the reference pollutant to

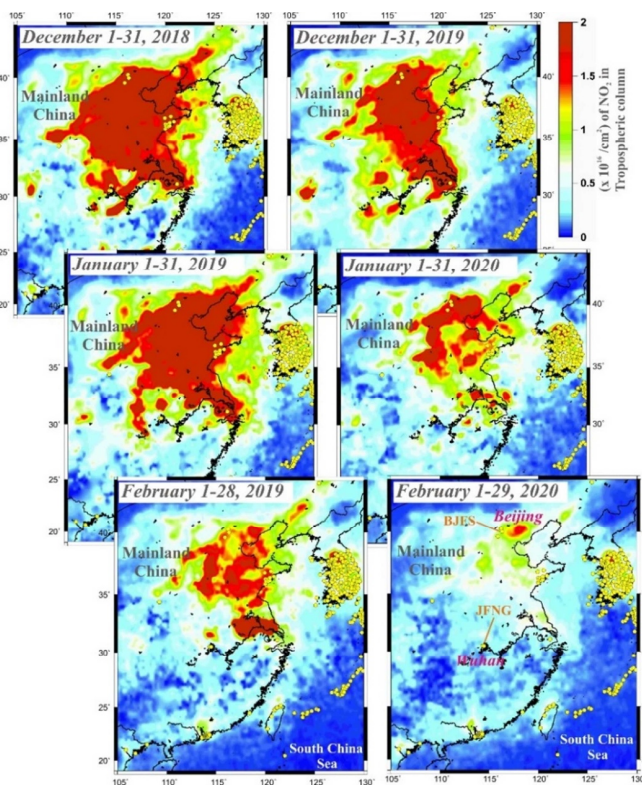


Fig.2. Monthly time-averaged spatial distributions of NO_2 in the tropospheric column over the region of mainland China from December 2019 to February 2020, in comparison with the previous year during December 2018 to February 2019. Yellow dots represent the location of the GNSS sites (archived from <http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap.html>). Note the changes in concentration of NO_2 before and after the Covid-19 lockdown.

characterize the air quality in the atmosphere and its correlation with the GNSS signal in the present study.

Proposed Hypothesis

We suggest that such a sudden decrease of air pollutants in the tropospheric column over wider geographical domains has significantly influenced the microwave signals, which have transmitted from the GNSS satellites to the receiver on the ground surface (Fig.3). GNSS signal propagation and observations are associated with several sources of error; specifically, errors due to the ionospheric/tropospheric delay have been exploited extensively for various ionospheric disturbances (e.g., TEC-GNSS study) to mesoscale convective systems (Heki, 2020; Adams et al., 2011, 2014). The ionospheric delay is a frequency-dependent process, which can be eliminated using dual-frequency receivers, as L_1 (~1.5 GHz) and L_2 (~1.2 GHz), are the two carrier frequencies that transmit the GNSS signal. However, on the contrary, the tropospheric delay can be eliminated only by the computational model, such as the Hopfield scheme (Hopfield, 1971) or Saastamoinen scheme (Saastamoinen, 1973). Moreover, the GNSS signal is sensitive to the refractive index (n) of the tropospheric column (as it has been considered a refractive medium) that is further dependent on the pressure, temperature, moisture, air pollutants, etc. (Hall, 1979).

Figure 3 represents the effect of the tropospheric refraction on GNSS signal propagation in a horizontally stratified vertical column, where the refractive index (n) decreases with altitude and with significant variation of air pollutants. Substantial variation of air pollutants in the tropospheric column over wider geographical domains can be quantified through the variation in zenith tropospheric delay (ZTD), which has been defined as the difference between the optical path and geometrical path in the zenith between receiver and GNSS satellite. Further total ZTD includes the contribution from the dry-ZTD and wet-ZTD (Gurbuz, 2016; Jin and Luo, 2009). Since the troposphere consists of various mixtures of gases, including air pollutants and the refractive index of the tropospheric column is the summation of the contribution of each component that contains the troposphere multiplied by its respective density (Hall, 1979). The total refractive index of the tropospheric column consists of two parts, the hydrostatic dry components (i.e., from air pollutant contribution) and the non-hydrostatic wet components (i.e., only from the water vapor contribution), moreover ~90% of the ZTD is associated with dry atmosphere (Bosy and Borkowski, 2005). Therefore, the difference in ZTD between two contrasting tropospheric conditions (i.e., higher vs. significantly lower air pollutants) has expressed as (Fig.3):

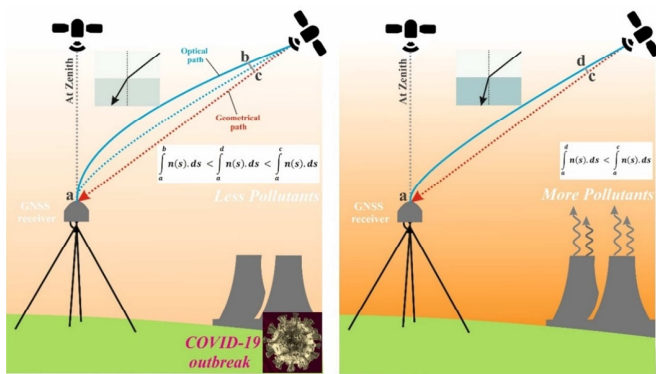


Fig.3. Schematic diagram showing the effect of atmospheric refraction on GNSS signal propagation process in a horizontally stratified atmosphere in which refractive index decreases with altitude. Note, the significant variation in tropospheric pollutants can influence the GNSS signal propagation and tropospheric Zenith Tropospheric Delay (ZTD).

$$\Delta ZTD_{high-low} = f \left(\int_a^d n(s).ds - \int_a^b n(s).ds \right)$$

Hence, such difference in ZTD ($\Delta ZTD_{high-low}$) correlates positively with the tropospheric air pollutant (i.e., NO_2 content as the proxy for air pollutant), assuming other parameters remain unchanged. However, testing this hypothesis is challenging indeed, as accurate information about the meteorological (or climatological) condition, spatio-temporal distribution of air pollution or particulate matter in the tropospheric column is needed, along with quality measurements.

Air Pollutant and their Impact on GNSS Signal

To test the proposed hypothesis, six permanent GNSS sites located over mainland China (i.e., BJFS, BJMN, JFNG, HKKT, KMMN, NTP1) are considered and systematically computed daily time series of ZTD (that includes total-ZTD, wet-ZTD, and dry-ZTD) and tropospheric temperature. Time series from the Julian day 280-75 has been considered (i.e., 2019 October to 2020 mid-March) and subtracted from all individual components of ZTD concerning previous years (i.e., 2018 October to 2019 mid-March), which has considered as the regular year with higher air pollutant (Fig.4). An identical strategy has also been adopted to compute the change of NO_2 in the tropospheric column, considering $100 \times 100 \text{ km}^2$ spatial domain taking respective GNSS site location at the center. The systematic comparison and visual inspection among daily time series from two representative GNSS sites exhibit an overall positive correlation between ΔNO_2 and $\Delta \text{Dry-ZTD}$, explicitly during the lockdown period (January to mid-March) (Fig.4). Further, statistical lag cross-correlations between ΔNO_2 and $\Delta \text{Dry-ZTD}$ of all respective GNSS sites has been presented in Fig.5, with considering the different degree of moving average in the time series. It is acknowledged that the respective range of cross-correlation values ~0.25-0.55 has been considered modest (Fig.5). However, one should not forget about the spatio-temporal resolution of the

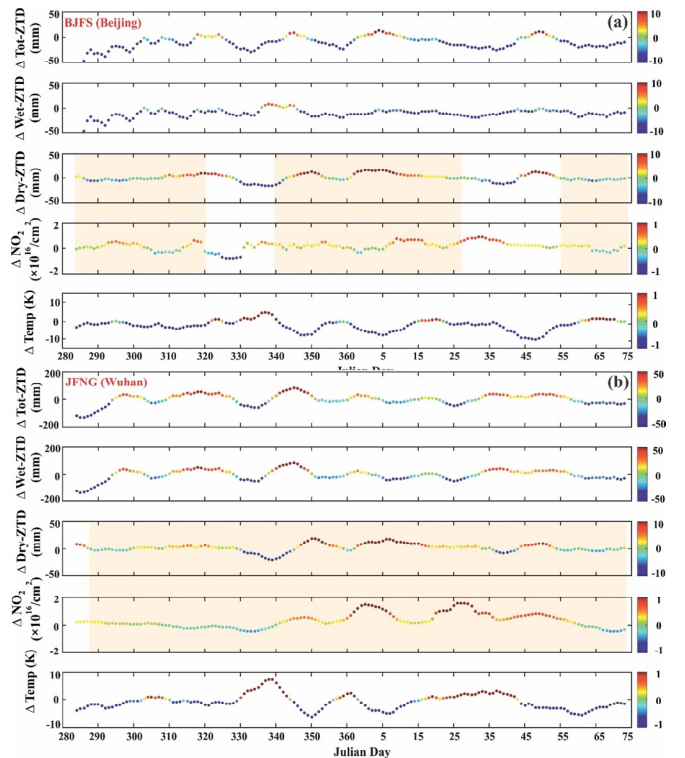


Fig.4. The variation in ZTD in GNSS signal, atmospheric temperature, and NO_2 as a proxy of the tropospheric pollutant over the region of two representative cities from mainland China, (a) BJFS in Beijing and (b) JFNG in Wuhan. Light yellow shaded regions represent better visual correlation in the time series.

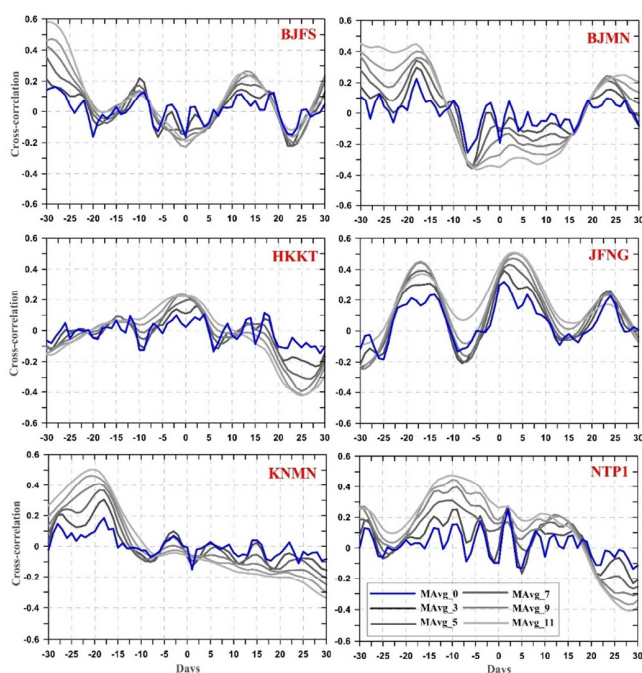


Fig.5. Lag cross-correlation between tropospheric Δ Dry-ZTD and Δ NO₂ at the respective GNSS sites over mainland China. We have considered all available permanent GNSS sites over mainland China (i.e., BJFS, BJMN, JFNG, HKKT, KMMN, and NTP1). Different color lines mark the cross-correlation values by considering different ranges of moving average of the Δ Dry-ZTD and Δ NO₂ datasets.

tropospheric pollutant (i.e., satellite-based NO₂ observations) and meteorological or orographic conditions of the respective GNSS sites. Further, NO₂ has been considered as a representative proxy, instead of all other components of tropospheric pollutants. It has been also correlated Δ Dry-ZTD of all respective GNSS with the Aerosol Optical Depth (AOD), which can be considered as a quantitative estimate of the amount of aerosol and air pollutant present in the atmosphere; however, we do not find any visual correlation. Hence, it is argued that NO₂ in the tropospheric column appears to be a better proxy than AOD. Moreover, it has also been argued that possibly the atmospheric pollutants affect the refractive index of the troposphere and the effect of temperature on the refractive index is significant. Hence, some of the observed effects in the ZTD variation could be explained as changes in temperature.

Irrespective of the complexity in the atmosphere, the present evidence infers that the GNSS signal propagation and associated variation in dry-ZTD in the tropospheric column probably can be used as a proxy for the pollution-monitoring tool in the future. Although it requires more rigorous investigations globally, considering more long-duration GNSS observations with local climatological conditions. The work is also crucial to understand the NO₂ and GNSS variations over India, where the original NO₂ concentrations are high and a small percentage change in NO₂ concentrations can significantly alter the GNSS signal, allowing it to be used as a proxy for change in concentration and pollution monitoring. However, in the present Indian scenario, unavailability of dense GNSS datasets in public archive from the interior of the Indian sub-continent on the major cities poses limitation on characterization of pollution monitoring during lockdown of COVID-19.

Acknowledgment: We thank Prof. Harsh Gupta for his invitation to contribute to this novel project of JGSI. We also thank Geoff Blewitt, Bill Hammond, Roland Burgmann, and V. K. Gahalaut for their helpful

discussion on this topic, which significantly improves the quality of the present work. We thank two anonymous reviewers for their constructive comments, which significantly improved the quality of the present work. NO₂ content in the tropospheric column has archived from OMI/Aura Nitrogen Dioxide (NO₂) Total and Tropospheric Column 1-orbit L2 swath (https://disc.gsfc.nasa.gov/datasets/OMNO2_003). Aerosol Optical Depth (AOD) gridded data can be archived from <https://modis.gsfc.nasa.gov/data/dataproduct/mod08.php>. Measurements of ZTD of respective GNSS time series can be archived from <http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap.html>. All the other information used in the present work is available openly in the public domain and presented in the text/figures.

References

- Adams, D.K., Fernandes, R.M., Kursinski, E.R., Maia, J.M., Sapucci, L.F., Machado, L.A., Vitorello, I., Monico, J.F., Holub, K.L., Gutman, S.I., Filizola, N. and Bennett, R.A. (2011) A dense GNSS meteorological network for observing deep convection in the Amazon, Atmos. Sci. Lett., v.12, pp.207-212, <https://doi.org/10.1002/asl.312>.
- Adams, D.K., Minjarez, C., Serra, Y., Quintanar, A., Alatorre, L., Granados, A., Vázquez, E., and Braun, J. (2014) Mexican GPS Tracks Convection From North American Monsoon, Eos Trans. AGU, v.95, pp.61–68, <https://doi.org/10.1002/2014EO070001>.
- Bauwens, M., Compernelle, S., Stavrakou, T., Müller, J.F., Van Gent, J., Eskes, H., Levelt, P.F., van der A, R., Veeffkind, J.P., Vlietinck, J. and Yu, H. (2020) Impact of coronavirus outbreak on NO₂ pollution assessed using TROPOMI and OMI observations. Geophys. Res. Lett., v.47(11), p.e2020GL087978.
- Castellanos, P. and Boersma, K.F. (2012) Reductions in nitrogen oxides over Europe driven by environmental policy and economic recession. Scientific reports, v.2(1), pp.1-7.
- Duncan, B.N., Lamsal, L.N., Thompson, A.M., Yoshida, Y., Lu, Z., Streets, D.G., Hurwitz, M.M. and Pickering, K.E. (2016) A space based, high resolution view of notable changes in urban NO_x pollution around the world (2005–2014). Jour. Geophys. Res.: Atmospheres, v.121(2), pp.976-996.
- Gurbuz, G. and Jin, S.G. (2016) Evaluation of ocean tide loading effects on GPS-estimated precipitable water vapour in Turkey. Geod. Geodyn., v.7, pp.32-38. doi: 10.1016/j.geog.2015.12.008.
- Hall, M.P. (1979) Effects of the troposphere on radio communication. Peter Peregrinus LTD on behalf of the Institution of Electrical Engineers.
- Hammer, M.S. et al. (2021) Effects of COVID-19 lockdowns on fine particulate matter concentrations. Science Advances, v.7(26), doi: 10.1126/sciadv.abg7670 S
- He, G., Pan, Y. and Tanaka, T. (2020) The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nature Sustainability, v.3(12), pp.1005-1011.
- Heki, K., (2020) Chapter 5-3: Ionospheric disturbances related to earthquakes in *Advances in Ionospheric Research: Current Understanding and Challenges. Space Physics and Astronomy, Vol. 3*, edited by C. Huang and G. Lu, pp.320, Wiley/American Geophysical Union, ISBN:978-1-119-50755-0.
- Hopfield, H.S. (1971) Tropospheric effect on electromagnetically measured range: Prediction from surface weather data. Radio Science, v.6(3), pp.357–367.
- Jin, S.G., Luo, O.F., and Gleason, S., (2009) Characterization of diurnal cycles in ZTD from a decade of global GPS observations. Jour. Geodesy, v.83(6), pp.537-545, doi: 10.1007/s00190-008-0264-3.
- Kang, Y.H. et al., (2020). The impacts of COVID-19, meteorology, and emission control policies on PM_{2.5} drops in Northeast Asia. Scientific reports, v.10(1), pp.1-8.
- Paules, C.I., Marston, H.D. and Fauci, A.S. (2020) Coronavirus infections—More than just the common cold. JAMA, v.323, pp.707–708.
- Saastamoinen, J. (1973). Contributions to the theory of atmospheric refraction, part II., Bull. Geod., v.107, pp.13–34.
- Sahu, S.K., Tyagi, B., Beig, G., Mangaraj, P., Pradhan, C., Khuntia, S. and Singh, V. (2020) Significant change in air quality parameters during the year 2020 over 1st smart city of India: Bhubaneswar. SN Applied Sciences, v.2(12), pp.1-8.

- Sahu, S.K., Mangaraj, P., Beig, G., Tyagi, B., Tikle, S. and Vinoj, V. (2021) Establishing a link between fine particulate matter (PM_{2.5}) zones and COVID-19 over India based on anthropogenic emission sources and air quality data. *Urban Climate*, p.100883.
- Singh, J. and Tyagi, B. (2021) Transformation of Air Quality over a Coastal Tropical Station Chennai during COVID-19 Lockdown in India. *Aerosol and Air Quality Research*, 21.
- Shi, Zongbo, et al. (2021) Abrupt but Smaller than Expected Changes in Surface Air Quality Attributable to COVID-19 Lockdowns. *Science Advances*. doi:10.1126/sciadv.abd6696.
- Tyagi, B., Choudhury, G., Vissa, N.K., Singh, J. and Tesche, M. (2021) Changing air pollution scenario during COVID-19: Redefining the hotspot regions over India. *Environmental Pollution*, v.271, p.116354.
- Virghileanu, M., (2020) Nitrogen Dioxide (NO₂) Pollution Monitoring with Sentinel-5P Satellite Imagery over Europe during the Coronavirus Pandemic Outbreak. *Remote Sensing*, v.12, pp.3575.
- Wells, C.R. et al., (2020) Impact of international travel and border control measures on the global spread of the novel 2019 corona virus outbreak, *PNAS*; 117 (13) 7504-7509; doi:10.1073/pnas.2002616117.
- World Health Organization, "Coronavirus disease 2019 (COVID-19)" (Situation Report 32, World Health Organization, 2020).