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Impact of aerosols and reactive trace gases concentrations in India

RAHUL SHARMA, SATISH PRAKASH*, RAMASHRAY YADAV**, R. K. GIRI** and LAXMI PATHAK**

Chaudhary Charan Singh University Meerut, India – 250 001, India

**Meerut College Meerut-Uttar Pradesh – 250 004, India*

***India Meteorological Department, Ministry of Earth Sciences, New Delhi – 110 003, India*

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e mail : rahul.dr.sharma@gmail.com

सार – वातावरण में प्रतिक्रियाशील अल्प मात्रा वाली गैसों की सांद्रता मानव स्वास्थ्य को अलग तरह से प्रभावित करती है। यह अध्ययन भारतीय क्षेत्र में कोपरनिकस एटमॉस्फियर मॉनिटरिंग सर्विस (CAMS) **डेटा की मदद से हाल के दिनों में वातावरण में एयरोसोल और प्रतिक्रियाशील गैसों के भार में परिवर्तन को प्रस्तुत करता है।**

EAC4 (ECMWF **वायुमंडलीय संरचना पुनर्विश्लेषण** 4) **डेटा सेट का उपयोग स्थानिक रूप से परिवेशी अल्प मात्रा वाली गैसों** (NO_2, O_3, SO_2 **और** CO) **और एरोसोल में मौजूद एरोसोल ऑप्टिकल डेप्थ** (AOD) **के रूप में करने के लिए किया गया था। इस अध्ययन के चार साप्ताहिक चरण अप्रैल,** 2020 (01-07, 08-14, 15-21 **और** 22-30) **के लिए हैं। उपरोक्त चरणों के दौरान यह देखा गया है कि एरोसोल, रासायनिक रूप से प्रतिक्रियाशील गैसों और ग्रीन हाउस गैसों की सांद्रता सीएएमएस की दीर्घ अवधि औसत (एलपीए)** 17 **वर्षों** (2003-2019) **के आंकड़ों से** ~ 60-70% **तक की उल्लेखनीय कमी संपूर्ण भारतीय उपमहाद्वीप में दिखती है इसमेंमध्य (दुर्ग, इंदौर, बिलासपुर आदि) और दक्षिण पश्चिम (कोल्हापुर, गुजरात आदि) भारत के कुछ हिस्से शामिल नहीं हैं। अप्रैल**-2020 **के दूसरे और तीसरे सप्ताह में इनके थोड़े अधिक मान मॉनसून पूर्व धूल भरे तूफान की गतिविधि और** 850/**एनसीएआर पुनर्विश्लेषण पर ऊर्ध्वाधर वायु प्रवाह ओमेगा में अच्छी तरह से होने के कारण होता है।**

अप्रैल-2019 **और** 2020 **के** CAMS, LPA **डेटा के साथ भारत के** 12 **विभिन्न केंद्रीय प्रदूषण नियंत्रण बोर्ड** (CPCB) **स्टेशनों से प्रतिक्रियाशील गैसों की सांद्रता की तुलना की गई है और यह पाया गया है कि** PM-2.5 **और** PM-10 **के संदर्भ में एयरोसोल भार** (60-70%) **आईजीपी से अधिक और भारत के अन्य भागों में** 25-30% **कम है। अप्रैल,** 2019 **और** 2020 **के वास्तविक आंकड़ों के साथ अन्य प्रतिक्रियाशील गैसों** (NO_2, SO_2 **और** CO) **की सांद्रता भी** IGP **की तुलना में** ~ 32%, 7%, 17% **और भारत अन्य भागों में क्रमश:** 16%, 8%, 9% **कम हुई है। ओजोन की सांद्रता आईजीपी पर थोड़ा सकारात्मक और भारत के अन्य हिस्सों में नकारात्मक व्यवहार प्रदर्शित करता है।**

यह अध्ययन भविष्य के लिए एक संदेश देता है कि हमें प्राकृतिक संसाधनों का विवेकपूर्ण उपयोग करना चाहिए क्योंकि उनके दीर्घकालिक प्रभाव से गंभीर स्वास्थ्य समस्याएं हो सकती हैं और इस COVID-19 **की प्रसार अवधि के दौरान वैश्विक स्तर पर मनोवैज्ञानिक भार या तनाव हो सकता है।**

ABSTRACT. The concentration of reactive trace gases in the atmosphere affects the human health differently. This study presents the changes of aerosol and reactive gases load in the atmosphere from the recent past with the help of Copernicus Atmosphere Monitoring Service (CAMS) data in Indian domain.

The EAC4 (ECMWF Atmospheric Composition Reanalysis 4) data sets were used to examine spatially the load of ambient trace gases (NO_2, O_3, SO_2 & CO) and aerosol present in the atmosphere as aerosol optical depth(AOD). The four weekly phases of the study are for April, 2020 (01-07, 08-14, 15-21 & 22-30). It has been observed during the above said phases that the concentration of aerosols, chemically reactive gases and greenhouse gases shows appreciable reduction up to ~60-70 % from CAMS Long Period Average (LPA) 17 years (2003-2019) data over the entire Indian sub-continent, except few pockets of Central (Durg, Indore, Bilaspuretc.) and South West (Kolhapur, Gujaratetc.) India. These slightly higher values in 2nd and 3rd week of April-2020 are due to pre-monsoon dust storm activity and well captured in vertical air flow Omega at 850/NCAR reanalysis.

Concentrations of reactive gases from 12 different Central Pollution Control Board (CPCB) stations of India with CAMS, LPA data of April -2019 & 2020 has been compared and show that aerosol load in terms of PM-2.5 & PM-10 is appreciably drop down (60-70 %) over IGP and 25-30 % in other parts of India. The concentration of other reactive gases (NO_2, SO_2 & CO) with actual data from the month of April, 2019 &2020 also decreases ~ 32 %, 7 %, 17 % over IGP and 16 %, 8 %, 9 % in other parts of India respectively. The concentration of Ozone shows slightly positive behaviour over IGP and negative at other parts of India.

This study is further brought out a message for future that we should use the natural resources judiciously as their long term exposure can cause severe health problems and a psychological burden or stress globally during this COVID-19 spread period.

Key words – Copernicus Atmosphere Monitoring Service (CAMS), Lock down, COVID-19, Aerosol Optical Depth (AOD), Trace Gases.

1. Introduction

Copernicus Atmosphere Monitoring Service (CAMS) data is globally available for study. Air quality is a burning problem and global concern and pollution driving through wind patterns from one location to another. Observations recorded from ground as well as satellites represents the snapshot of air quality at that moment and used for air quality forecasting. The assimilations of quality controlled observations in numerical weather prediction models will provide predictive or forecasting ability. So, keeping in view we have utilized CAMS data as latest state of the art computer models have been used to assimilate both satellite and non-satellite observations to provide global data and forecast. Many studies in recent past have shown appreciable reduction of air pollutants and reactive gases concentration in the atmosphere. The studies related to performance of CAMS data especially over Indian domain are a few. Corona Virus affected badly throughout globe and air quality affects the respiratory health, therefore we have chosen the lock down phase of India for this study[Lock down period].

Corona virus disease COVID-19, spread globally, is an infectious disease caused by severe acute respiratory syndrome corona virus 2 (SARS-CoV-2) and 1st case in India came in light on 30th January-2020 in Thrissur Kerala. Keeping in view the severity of the virus spread, India announced complete lock down starting from 25th March-2020. Indian Government took initiative and issued the general guidelines for each and every group of society peoples (approximately 1.3 billion) like general public, doctors, policemen's, essential service peoples etc. The nature of the COVID-19 spread or mutations have varied patterns all over the globe, which led to great difficulty in diagnose the exact nature of virus. Even the life cycle of this COVID-19 virus is completely different from the other viral infections in the past. Global spread and deaths due to COVID-19 in almost all age groups motivate group of elite people's to work day and night in an interdisciplinary way to brought out feasible solution. Past studies by Dey *et al*. (2004), El-Askary, *et al*. (2004, 2006) & Gautam *et al*. (2010) on remote sensing data over Indo Gangetic Plain (IGP) of India shows appreciable increase of dust load mainly in pre-monsoon and winter season. Over the last decade, emissions from the power plant, petroleum refineries, oil, industrial and domestic sectors have increased considerably (Mallik *et al*., 2014, Kumar *et al*., 2011; Kumar *et al*., 2013; Lawrence & Lelieveld, 2010) over south-Asia.

Recently many authors studied the impact of ambient trace gases before and after the lock down activities all over the world (He *et al*., 2020a, 2020b, Faustini *et al*., 2014, Cohen *et al*., 2017) and subsequent reduction the load of aerosols and ambient trace gases due to limited social and economic activities (Dutheil *et al*., 2020).

2. Data and methodology

In this study, the reactive trace gases and aerosol concentration anomalies from mean (17 years) are brought out during Covid-19 period of April, 2020 (01-07, 08-14, 15-21 & 22-30) in the month of April-2020. For this purpose, CAMS global reanalysis data of atmospheric composition has been utilized. These data sets are the latest global reanalysis dataset of atmospheric composition produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), consisting of three-dimensional time-consistent atmospheric composition fields, including aerosols and chemical species (Inness *et al*., 2019). CAMS data collected from different sources and satellite instruments are assimilated after establishment of the quality of the measurements. This new reanalysis data set has horizontal resolution of about 80 km (0.75° × 0.75°), smaller biases for reactive gases and aerosols, improved and more consistent with time as compared to earlier versions. New data sets uses the four-dimensional variational (4D-VAR) data assimilation technique to combine satellite observations with chemistry-aerosol modelling to obtain the mass mixing ratios of atmospheric trace gases and aerosols.

To calculate week-wise anomaly (A) long period average (LPA) of 17 years (2003-2019) was generated for Indian region (Fig. 1). This data set was extracted from CAMS global reanalysis (EAC-4) data and week-wise

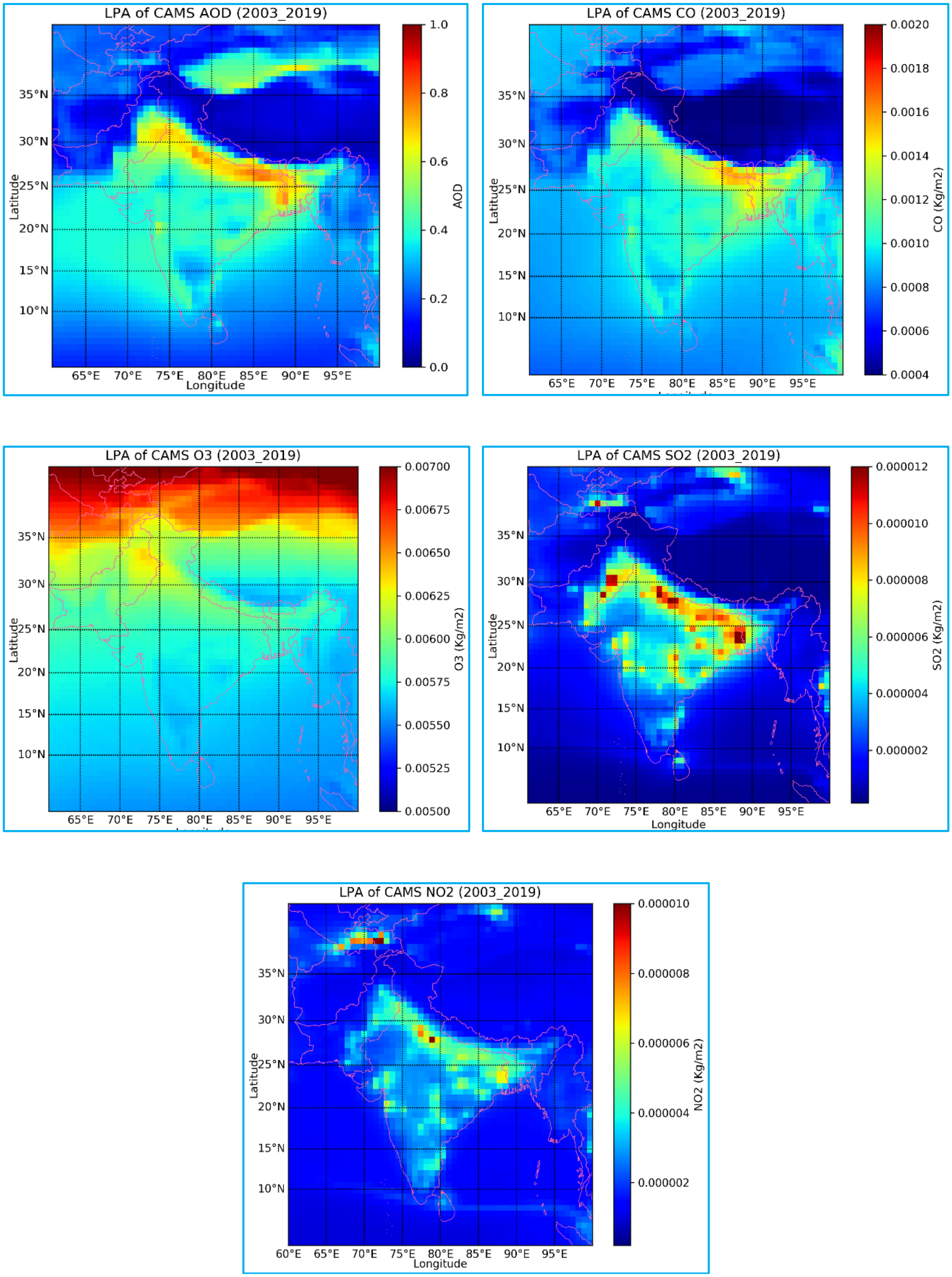
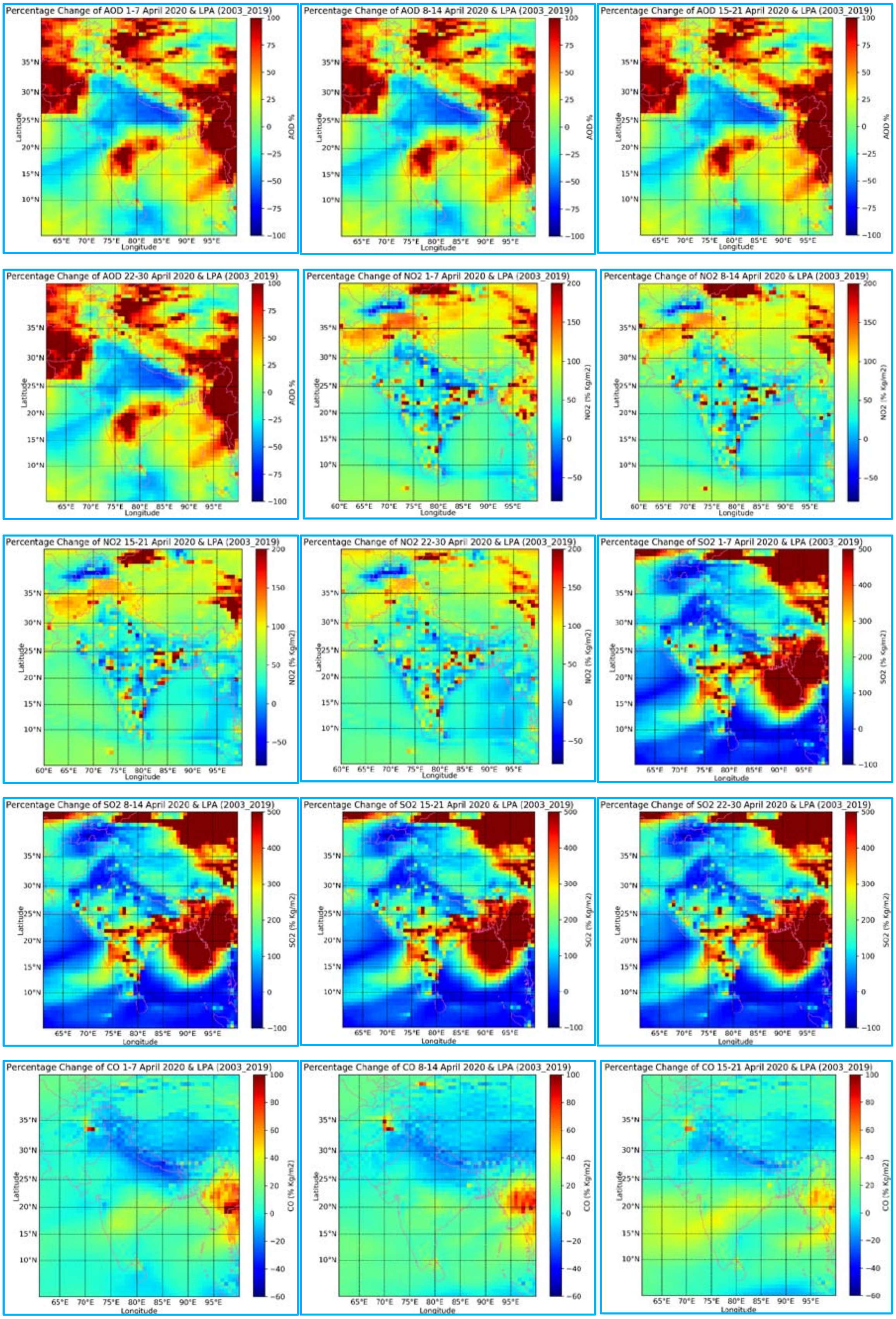


Fig. 1. Long Period Average of CAMS Total Column- AOD, CO, O_3, SO_2 and NO_2 for the period of 2003 to 2019


Percentage Change of AOD 1-7 April 2020 & LPA (2003_2019)
Percentage Change of AOD 8-14 April 2020 & LPA (2003_2019)
Percentage Change of AOD 15-21 April 2020 & LPA (2003_2019)
Percentage Change of AOD 22-30 April 2020 & LPA (2003_2019)
Percentage Change of NO2 1-7 April 2020 & LPA (2003_2019)
Percentage Change of NO2 8-14 April 2020 & LPA (2003_2019)
Percentage Change of NO2 15-21 April 2020 & LPA (2003_2019)
Percentage Change of NO2 22-30 April 2020 & LPA (2003_2019)
Percentage Change of SO2 1-7 April 2020 & LPA (2003_2019)
Percentage Change of SO2 8-14 April 2020 & LPA (2003_2019)
Percentage Change of SO2 15-21 April 2020 & LPA (2003_2019)
Percentage Change of SO2 22-30 April 2020 & LPA (2003_2019)
Percentage Change of CO 1-7 April 2020 & LPA (2003_2019)
Percentage Change of CO 8-14 April 2020 & LPA (2003_2019)
Percentage Change of CO 15-21 April 2020 & LPA (2003_2019)
Latitude
Longitude
AOD %
NO2 (% Kg/m2)
SO2 (% Kg/m2)
CO (% Kg/m2)

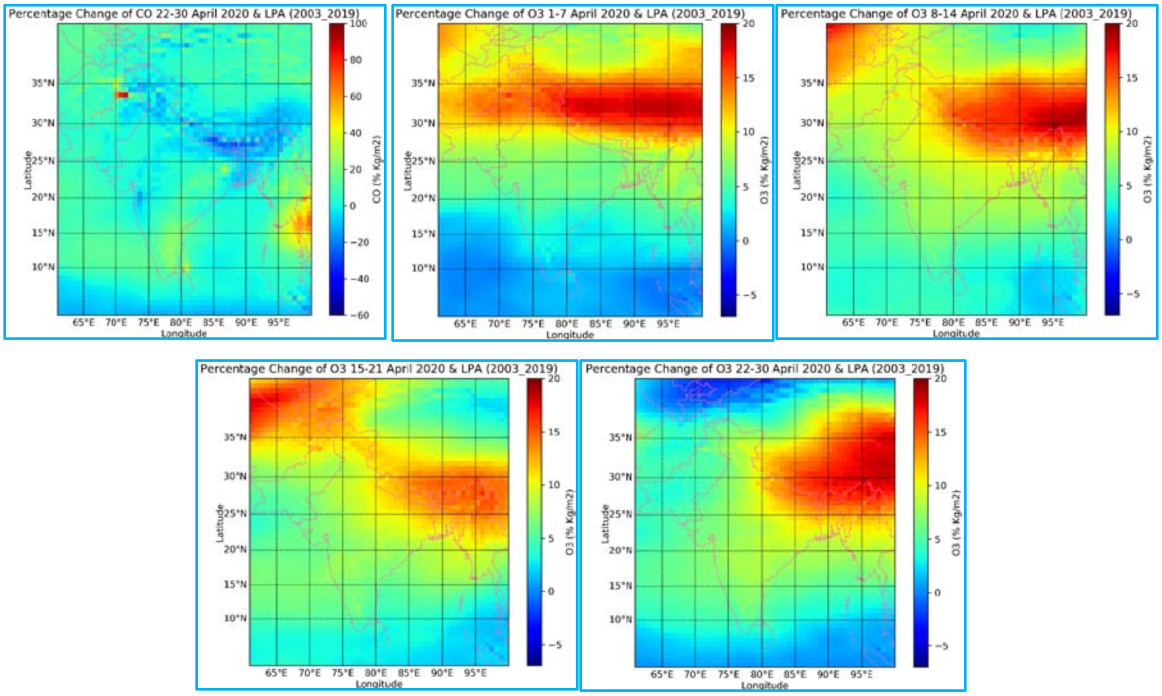


Fig. 2. Percentage Change of CAMS Total Column- AOD, CO, O_3, SO_2 and NO_2 of 1-7, 8-14, 15-21 & 22-30 April 2020 and Long Period Average (2003 to 2019)

anomalies are generated using equation (1). Then percentage departure (Fig. 2) for each week observation average is brought out by using equation (2).

$$\text{Anomaly (A)} = \text{Actual value} - \text{LPA} \quad (1)$$

$$\%\text{Percentage} = \left[\frac{\text{Anomaly}(\text{A})}{\text{LPA}}\right] \times 100 \quad (2)$$

The vertical airflow (omega) map is generated from 850 hPa NCEP/NCAR reanalysis data (Fig. 3). The data was collected from the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA (http://www.esrl.noaa.gov/psd/) at horizontal resolution of 2.5 × 2.5 degree at 850 hPa of pressure level for the period of 1-30 April 2020. The vertical airflows (omega) at 850 hPa were utilized to analyse the atmospheric capability to disperse the concentration of aerosols, chemically reactive gases and aerosols. Downwards airflows are indicating positive values of omega (in Pa/s), while upwards airflows are indicating negative values of omega. In regions where positive omega is observed, the atmosphere will force to increase the concentration of aerosols & to stay close to the surface and hence, more population is exposed. In contrast, in regions with negative omega, the atmospheric conditions will disperse these gases further away and to higher altitudes. In these regions, the population is less exposed to the air pollution and to its associated health risks.

3. Results and discussions

3.1. *Spatial Distribution of Nitrogen dioxide (NO_2)*

Air pollution monitoring with the help of space borne measurements through CAMS is very useful where ground based measurements are not available. CAMS data are interpolated in time and space based on the location of the observations and then model equivalents of the observations are calculated. For this study, percentage departure from LPA (Fig. 1) for weekly episodes of total column NO_2 data are generated from global EAC4 data sets (Fig. 2). It is seen that NO_2 decreases appreciably (60-70 %) at the most places of India (almost entire IGP, are, Aligarh, Banras, Bihar, Kota, Bhopal, Allahabad, etc.) except few pockets in south (Tamilnadu, Guntur, Mumbai etc.) and NE India (Chota Nagpur, Hugli etc.)where it drop down 20-30% depending on the shutdown of industrial activities. The NCEP/NCAR reanalysis generated mean values of vertical airflow (omega-Pa/s) values at 850 hPa are negative at drop down areas (Fig. 3) and indicates a vertical mixing of ambient NO_2 gases and not closer to the surface and less harmful for humans. The increase in the concentration may be due ongoing industrial activities for essential services during

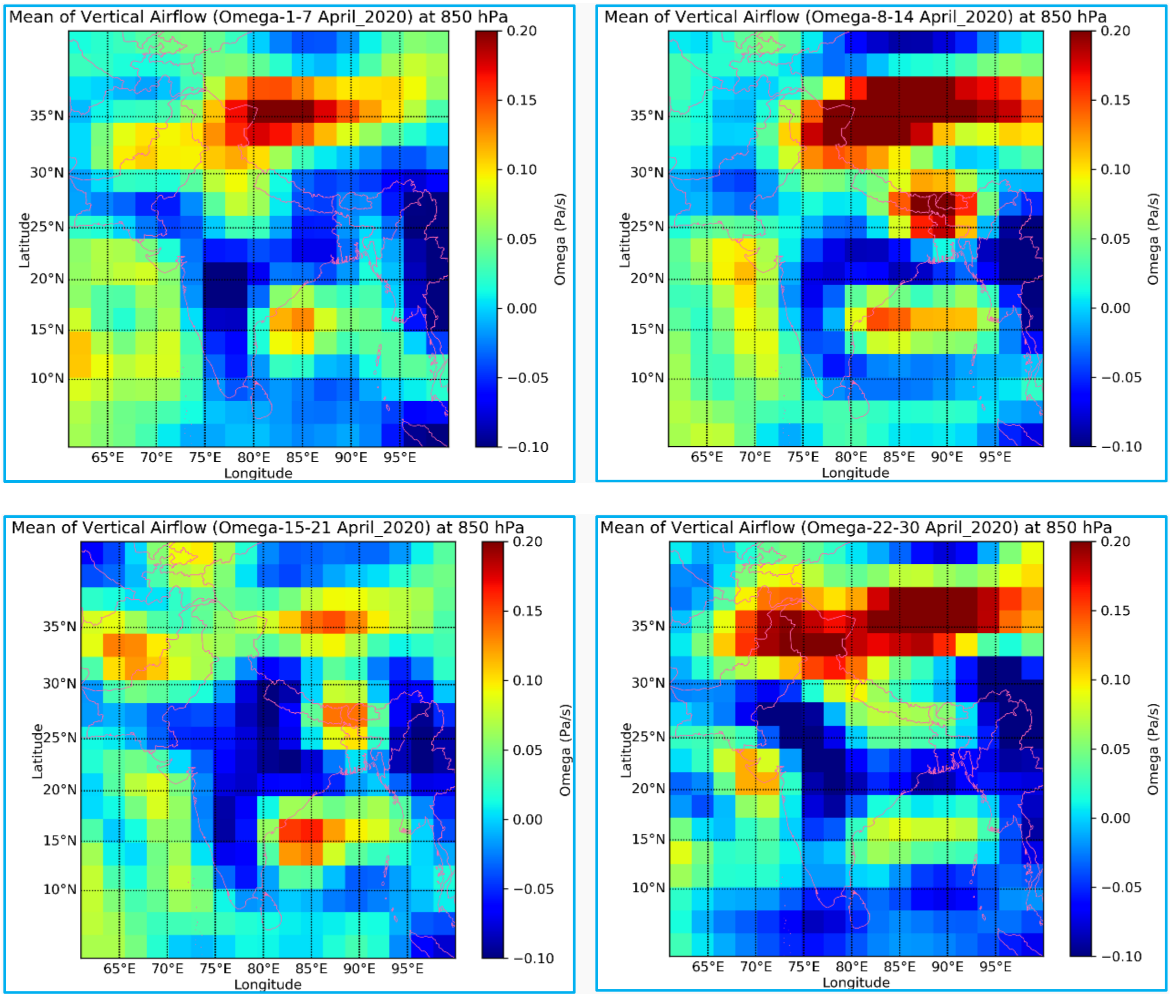


Fig. 3. Mean vertical airflow (omega) at 850 hPa for the period of 1-7, 8-14, 15-21 & 22-30 April 2020 from NCEP/NCAR analysis

lock down period (Fig. 4). The possible cause of drastic reduction in pollution levels during four week period of lock down period of April in India is due to decrease of fossil fuel consumption in energy, industry and transport sectors. The main drivers or sources of NO_2 are coal and petroleum industries in areas of UP, Orissa, Madhya Pradesh (MP) and Southern parts of India. Few pockets in India did not shows appreciable NO_2 reduction it may be due to delayed shutdown the coal and petroleum industries essential services (Fig. 4) and increased the labourer migration activities.

3.2. *Spatial Distribution of Sulphur dioxide (SO_2)*

The maximum emissions of SO_2 in South Asia are from the industrial and power sectors, which contribute approximately 87% mainly vehicles, pulp and paper industries (Gurjar *et al.*, 2018). Total column SO_2 spatial distribution data for Indian domain is extracted from global EAC4 data sets and a long term mean of 17 years data is generated (Fig. 1). To see the lock down impact during 4 weeks of April 2020 weekly anomaly maps are generated (Fig. 2). During this time almost all potential drivers of SO_2 emissions like fossil fuel consumptions and coal and petroleum industries were closed. This results an appreciable reduction of 70 % SO_2 concentration in the most part of India except few pockets of north east, peninsular and southern parts of India. Li *et al.* (2017) reported, India is the world's largest emitter of anthropogenic SO_2. SO_2 is short lived air pollutant and inhalation of high ambient concentrations of sulphur dioxide can cause stimulation of the nerves in the air passages, resulting in a reflex cough, irritation, and chest tightness. Exposure can cause oxidative damage to lungs, heart, brain, liver, as well as testicles of the body; and this effect of SO_2 shows a gender difference in oxidative stress and anti-oxidation status.

TABLE 1

Difference of air quality elements actual observations of CPCB stations during April-2020 & April-2019

Gases / Station	Pm-2.5	Pm-1.0	NO_2	SO_2	CO	O_3
Delhi-ITO	-31.72	-56.47	-16.64	-2.00	-22.04	-22.04
Agra	-51.47	0.00	-15.79	-4.67	-2.40	-0.03
Ghaziabad	-102.28	-141.82	-61.67	-16.54	-26.89	6.68
AP-VSK	-8.55	-20.36	-4.13	-5.96	-14.65	4.68
Chennai	-23.29	0.00	-0.65	-0.27	-25.42	-9.41
Kolkata	-13.62	-11.00	-20.22	-21.00	-7.32	15.30
Patna	-3.30	0.00	-12.20	-22.80	-4.13	0.00
Bihar-Muzaffarpur	-21.00	0.00	-3.07	-0.36	-0.86	-17.00
Gujrat-AHM	-127.15	0.00	-56.15	-52.14	-16.32	-9.04
Bengaluru	-14.11	-15.05	-14.11	-0.31	-17.48	-9.07
Mandi	-74.24	-87.90	-2.64	-15.27	-6.43	-10.62
Mumbai	-5.65	-9.42	-17.36	-1.00	-7.90	13.70

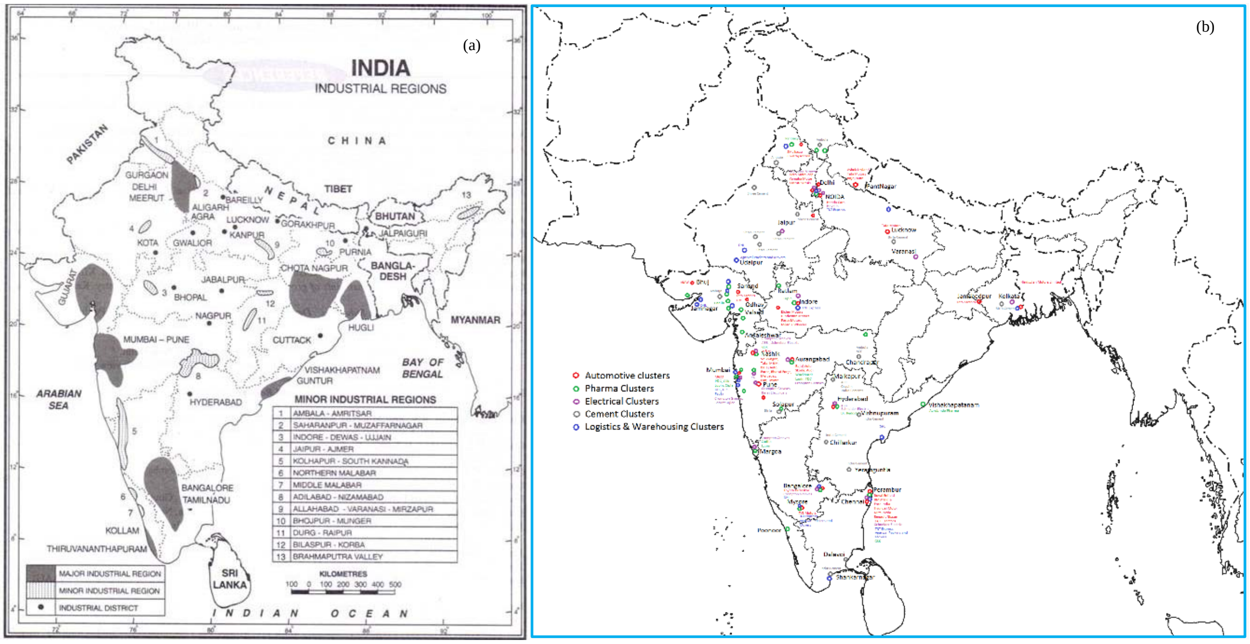
Thus the higher sulphur concentration near the ocean surface is due to the presence of large sea-salt particles in the air. As in the case of aerosols, the excess sulphur quantity in precipitation water is practically equal to the mass of sea-salt sulphur. Ambient concentration of gases varies widely according to local sources and sinks. The nitrogen dioxide is associated with combustion sources. Increase of SO2 concentration in north east Bay of Bengal marine atmosphere boundary layer is may be due to receiving more pollutants containing higher non-sea salt sulphate. Another reason may be slight positive bias present in the EAC-4 data sets used for this study.

3.3. *Spatial Distribution of Carbon monoxide (CO)*

The potential contribution of carbon monoxide comes from domestic, industrial, transport and bio-mass burning sectors in India. India has been reported to be the highest contributor of CO (12,000 GgY-1) in South Asia, Streets *et al*., 2003. Mahato *et al*., 2020 reported, NO_2 and CO concentration decreased during lockdown period. The LPA concentration of CO generated from CAMS data is presented in given in Fig. 1. The significant reduction about 50-60 % in the concentration of carbon monoxide from its LPA value is seen over major parts across India in first week and increased marginal increase in subsequent weeks may be due to increased migration activities of labourers (Fig. 2). The anomaly maps of different phases of lock down shows trails of CO concentration in some areas of India this may be due to delayed shutdown of industrial activities or local incursion of moist dust air. According to World Health Organization (WHO), polluted air is dangerous and kills almost seven million people worldwide every year.

3.4. *Spatial distribution of Ozone (O_3)*

Ozone is one of the most important infrared and ultraviolet radiation absorber trace gas in the atmosphere. It has both benefits and harms life on earth. Its optimum value acts as cleaning agent and supports health of humans, animals and vegetation. It is also an important contribution to ongoing climate change and means concentration is shown in Fig. 1. The CAMS ozone data used here combines measurements from satellite instruments and *in situ* sensors with its numerical models to provide quality-assured information about the state of the ozone layer. The increased mean concentration of O_3 shown in the analysis of CAMS EAC-4 global data (2003-2019) alarms our eco system for long (Fig. 1). It inspires us to lower the burden of trace gases, like O_3 to frame the policies in win-win strategy for climate and health. An appreciable increase of 20-30 % O_3 is clearly shown in anomaly analysis of lock down period data (Fig. 2). Similar trends were also observed in many cities of India (Mahato *et al*., 2020; Sharma *et al*., 2020). No definite



Figs. 4(a&b). India Industrial regions (Cement Clusters, Refineries, Pharma clusters, Automotive Clusters, logistics & warehousing clusters and coal based thermal power plants. Some of them are active even during lockdown period or some of them were working below normative capacity) [*Courtesy from* : (a) https://www.yourarticlelibrary.com/industries/industrial-regions-8-major-industrial-regions-of-india/14159. and (b) https://upload.wikimedia.org/wikipedia/commons/d/d7/India-Industrial_ Clusters.png]

trend of ozone concentration has been observed throughout the country.

3.5. *Aerosol Optical Depth (AOD)*

The concentration of aerosols as Aerosol Optical Depth (AOD) represents the degree to which aerosols prevent the transmission of light by absorption or scattering of light over a vertical column of unit cross section. The weekly percentage change of total column AOD anomaly maps at 550 nm are generated to analyse the aerosol load week by week in lock down situations of India during April-2020 (Fig. 2). The LPA (2013-2019) maps shown in Fig. 1 indicate Indo Gangetic Plain (IGP) shows higher concentration as compared to other parts of India. This potential contribution is reduced appreciably about 60-70 % over the IGP region (UP, HP and Bihar regions) and many other parts of India (Fig. 2) during the different phases of lock down. It is well known that dust is a potential contributor of respiratory diseases. So, reduction in dust load is favourable to boost up the immunity of the peoples of each age group during this pandemic spread. The increase in aerosol load can increase the possibilities of respiratory dysfunction disorder and acute coronary syndrome etc. and COVID-19 sensitive. In few pockets of India AOD values are higher due to ongoing essential industrial activities over that area. Parts of Pakistan, NE India, China and adjoining sea are shows appreciable increase of AOD values this is possibly due to delayed shutdown the activities and slight positive bias in the data used for the study.

4. Conclusions

The following points are brought out from the above study.

(*i*) There is an appreciable decrease (60-70 %) has been observed of all the reactive gases (NO_2, SO_2, CO) including aerosol optical depth (AOD) from CAMS, LPA data analysis over IGP region of India during lock down period weeks of April, 2020 (01-07, 08-14, 15-21 & 22-30). This may be due to stop or slow down the emission sources and pre-monsoon thunder activities occurred in 2nd and 3rd week of April-2020.

(*ii*) The concentration of total column ozone (O_3) observed in CAMS data shows an increase 20-30% in most of the parts of India during lock down in April 2020. The results obtained from actual observations are quite different then CAMS data, it is due to very little number of representative stations is available for area (Table 1). This increase from its optimum value need to keep an eye and matter of concerned for future.

(*iii*) The concentration of SO_2 drop down is 50-60 % due to decrease in consumption of fossil fuel, coal and petroleum. The higher values of SO_2 on ocean are due to presence of large sea particles and slight positive bias in the data set used.

(*iv*) The concentration of reactive gases and aerosols in the atmosphere decreases 50-60% except some pockets in India due to some ongoing essential industry activities [Figs. 4(a&b)].

(*v*) The concentration of NO_2 decreases appreciably (50-60%) during lock down period of April 2020 except few areas of cluster of industries [Figs. 4(a&b)] may be due to delayed shutdown the coal and petroleum industries for essential services as labourer migration increases during lock down period.

(*vi*) The bias results of reactive gases and aerosol load CAMS analysis data with actual observations (April-2020 & April-2019) are quite encouraging over Indian region and this information is found to be very useful in future operational planning of Aviation control services and identifying the vulnerability areas of society.

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Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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