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Research Article

Observing Source Distributions, Interannual Variability and Transport Pathways of NO_x over India During 2003-2011 Using SCIAMACHY

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Abstract

The combustion of fuels, and biomass and certain industrial activities release highly toxic air pollutants in the natural environment. Nitrogen dioxide (NO_2) is also an important trace gas pollutant affecting the climate. In India air pollution is monitored by various government organizations with innovative technologies developed by private sector. Such monitoring networks and tools provide necessary data to be used to frame policy decisions and communicate air quality status to the public at large. It is necessary to know the exact causes and factors responsible for air pollution in India due to certain activities as mentioned earlier. So that people could choose their mode to avoid or minimize the air pollution by adopting suitable actions by them. In this paper, Scanning Imaging Absorption Spectrometer for Atmospheric CartograpHY (SCIAMACHY) is used to observe tropospheric NO_2 during 2003-2011 over India. The highest tropospheric NO_2 concentration (153-137 μgm^{-3}) is observed in the summer season of 2010-2011 over Northern Indo Gangetic (IG) plain. The NO_2 mixing ratios at 350 hPa during November-May for 2003-2011 over Arabian Sea ranged from 200-230 μgm^{-3} and 90 μgm^{-3} over Bay of Bengal. It also observed that the NO_2 mixing ratios decreased 80-110 μgm^{-3} over the Arabian Sea and 80 μgm^{-3} over the Bay of Bengal due to thunderstorms and long range transport of pollutants during monsoon season. These data may be useful for India's National Clean Air Programme to be used for control of vehicular emissions and industrial emission.

Keywords

Climate, Tropospheric, Interannual Variability, Concentration, Pollutant

1. Introduction

The rapidly developing economy and an unprecedented population of India have increased the demand of more energy for agriculture, industry, power generation, and vehicles [1-3]. The combustion of fuels and biomass is not only harmful to human beings but also affects the climate [4]. The global climate is continuously changing due to anthropogenic activities since the last several decades [5]. The oxides of nitrogen (NOX), i.e., nitric oxide (NO) and nitrogen dioxide (NO_2) [6, 7], are formed due to the emissions in India, 40% contribution of these gases comes from the combustion of coal and 30%

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due to automobiles [8]. NOX is a major concern over India during last decades as other trace gases like CO, SO_2 and Pb are easily trace out by various emission control and legislative policies [9]. The tropospheric NO_2 is one of the important elements affects on human health and plant growth [10]. The increased level of NO_2 concentrations not only effects on photochemical smog, acid rain and nitrate aerosols but also affects the global greenhouse gas budget through abundance of OH radicals in the atmosphere [11, 12]. The advent of satellite technology in the last two decades has improved our understanding of the spatial and temporal variations in NOX concentrations, their source distribution and transport mechanisms. Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIMACHY) is used for global measurement of trace gases including NOX [11, 13, 14].

The study of tropospheric NO_2 is highly important due to the chemistry of climate and radioactive balance in the lower troposphere [15, 16]. The tropospheric NO_2 measurements have been carried out by several researchers using different approaches such as vertical distribution of lightning NOX [13], inter-comparison of SCIAMACHY and OMI tropospheric NO_2 columns [17], lightning NOX emissions [16] and temporal variations of urban NOX concentration in India [18]. The spatial and temporal variations, source distributions, and interannual variability of tropospheric NO_2 are very important to predict the future trend of the climate [17]. Utilizing the recent updates, including rapid $CH_3O_2NO_2$ and ANs production, in UT NOx lifetime and fate improves our understanding of mean lightning NOx (LNOx) emission rates per flash [21]. In this paper, we have analyzed SCIAMACHY tropospheric NO_2 data spanning 9 years (2003-2011) to illustrate the spatial variations of NO_2 over India. We also observe interannual variability and various transport pathways during this period. The amount of local forcing associated with thunderstorm activity depends strongly upon the cloud optical depth and on where the NO_2 resides within the clouds [27]. The Vdata contains only one generic pressure grid field [28]. Strengthened quantification of emissions of the included species and other, closely associated ones – notably CO_2, generated largely by the same processes and thus subject to many of the same parameter uncertainties – is essential not only for science but for the design of policies to redress critical atmospheric environmental hazards at local, regional, and global scales [29].

2. SCIAMACHY Tropospheric NO_2 Data

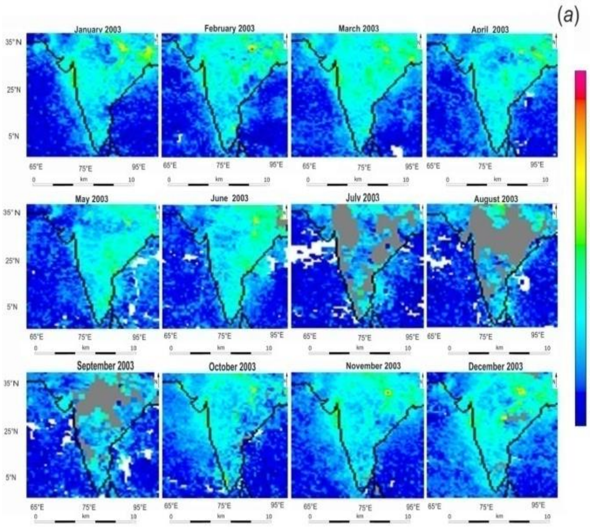
SCIAMACHY is a spectrometer on board ENVISAT satellite that was launched by European Space Agency (ESA) in March 2002 from French, Guiana. It measures reflected solar radiance and terrestrial emissions in the ultraviolet, visible and near-infrared wavelength region (240 nm-2380 nm) with a spectral resolution of (0.2-1.5 nm) [19]. It operates in a polar sun-synchronous orbit at an altitude of about 800 km provides global coverage after six days. SCIAMACHY is designed to be used for understanding the tropospheric and stratospheric pollution, troposphere-stratosphere exchange processes, and the distribution of atmospheric trace gases globally [11, 20, 21]. The emission measurement of NOX by recent bottom up inventories has limited scope and large uncertainties due to coarse resolution [22]. The inverse modeling approach is useful to overcome these difficulties which adjusts the emissions to minimize the errors between the model predations and observations [23]. SCIAMACHY measures tropospheric NO_2 concentrations on planetary boundary layer under the cloud-free conditions [11]. Earth radiance measurement by satellite sensor provides slant column densities (SCD) of trace gases which not only depend on density of gas but also on other parameters. For obtaining the vertical column density (VCD), we must divide SCD by air mass factor (AMF), which depends on surface reflectivity, aerosol properties, and the vertical distribution of the absorbing trace gas. The concentration and lifetime of NOX in the planetary boundary layer depends upon meteorological condition, temperature, humidity, and OH radicals [24]. SCIAMACHY retrieved tropospheric NO_2 data have been used for estimating the NO_2 distributions, atmospheric transport, sources and sinks [2, 25]. SCIAMACHY tropospheric NO_2 data for a period of 2003-2011 from Tropospheric Emission Monitoring Internet Service (TEMIS) were downloaded from (http://www.temis.nl).

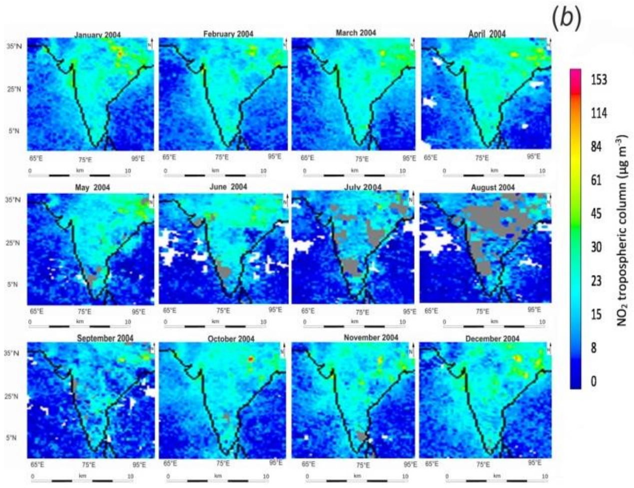
3. Results and Discussion

3.1. Spatial Distribution and Interannual Variability of Tropospheric NO_2 over India

The study focused on long-term monthly tropospheric NO_2 concentration during the period from 2003–2011 for each month January-December (Figure 1 to Figure 4). During the winter period from November to February, the tropospheric NO_2 emissions over the Northern and Indo-Gangetic basin are high as compared to the rest of India. In November, the tropospheric NO_2 emissions reach at the level of 153 μgm^{-3} whereas it gradually decreases up to 45 μgm^{-3} in May. A Lower tropospheric NO_2 level during May-October is due to less biomass burning; however, it was observed that, after 2010 (Figure 3 (b)-(c)), it has gradually increased in the northern IG region and North eastern part of India. The main reason for this increased tropospheric emission is due to recent industrial activities and a large number of vehicles [11, 26]. The tropospheric NO_2 does not get dispersed at planetary boundary layer and remain stable at higher surface temperature 36℃- 42℃ excluding the wet months 18-22℃ during June-September. During 2006 El Nino episode and long range transport of biomass burning, higher concentration of NO_2 observed (Figure 2a) during 2006 winter season. During the summer season of 2010-2011, the tropospheric NO_2 level was around 153 $\mu g\ m^{-3}$ over the northern part and 137 $\mu g\ m^{-3}$ over the eastern part of India. The tropospheric NO_2 data over southern part of country is missing due to presence of clouds.

The interannual variability of tropospheric NO_2 over India is estimated using the Ozone Monitoring Instrument (OMI) V3 model. The interannual variability of tropospheric NO_2 has been used to find out long-term monthly means as shown in Figure 4. The time series data of monthly tropospheric NO_2 concentrations for 2003-2011 show stable features during June to October months. The NO_2 concentration increases after this period and reaches maximum up to 153 µgm^{-3} in the summer season. The data are missing for a few places in India during the monsoon season and NO_2 concentration has slightly increased in the central part of India after 2008. During the winter months of 2010-2011, it was observed that NO_2 concentrations increased from 114 µgm^{-3} to 137 µgm^{-3} over the northern part of India. At higher altitude tropospheric NO_2 concentration is stable during 2003-2011, average values of 153 µgm^{-3} in winter,45 µgm^{-3} in summer and 10 µgm^{-3} in monsoon season. The biomass burning period October-November during the 2009 and 2010 exhibits large interannual variation and higher NO_2 tropospheric concentration over IG region and eastern part of India.





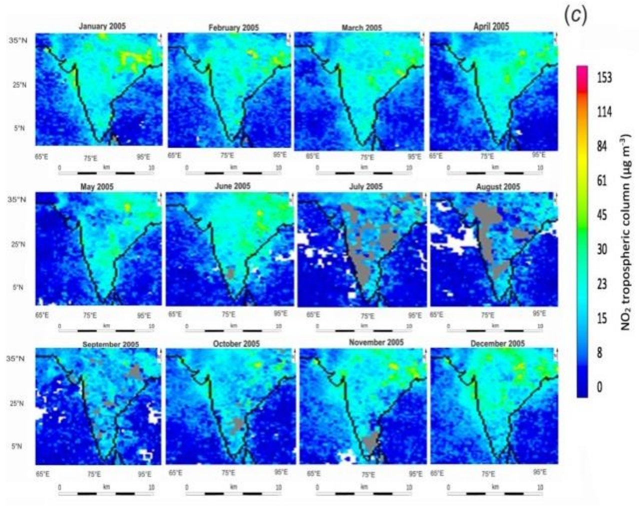
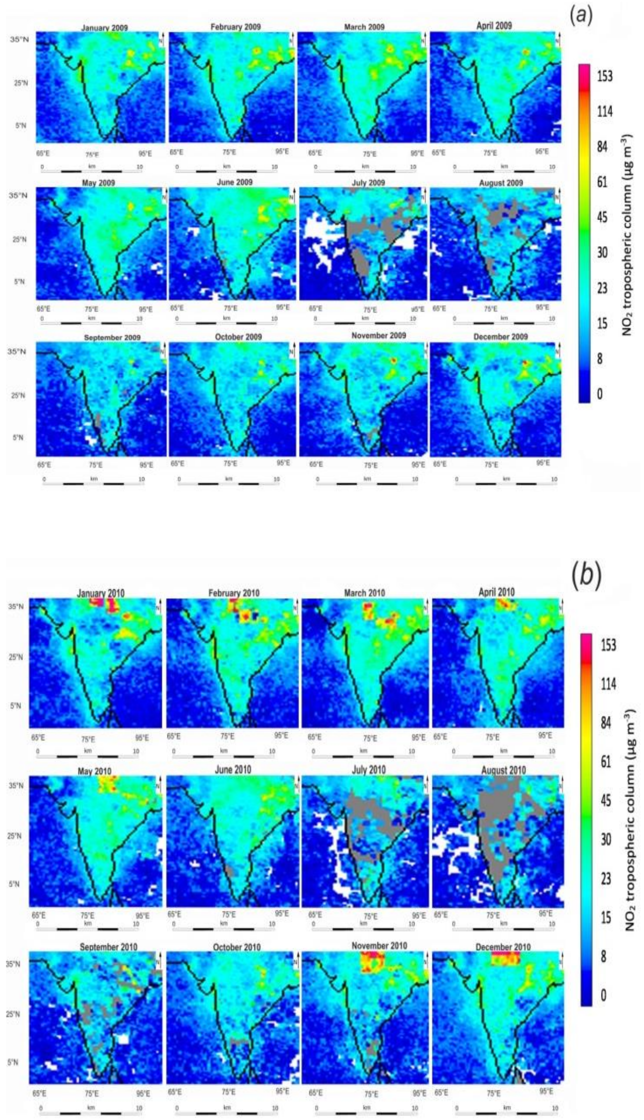


Figure 1. *SCIAMACHY tropospheric NO_2 levels over India from January 2003 to December 2005.*



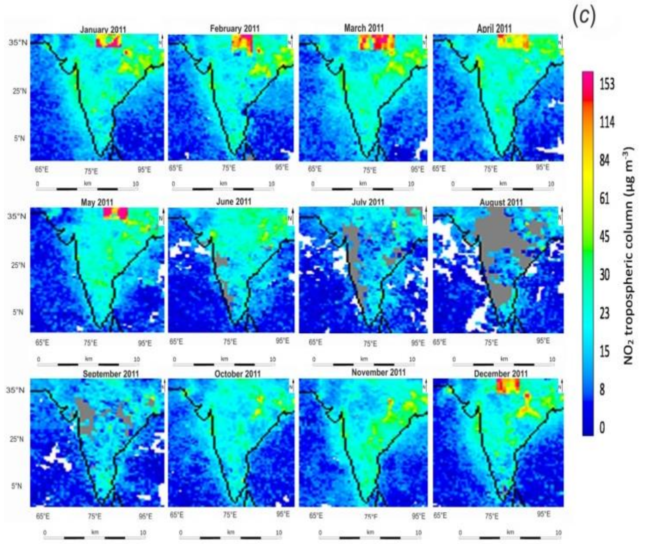
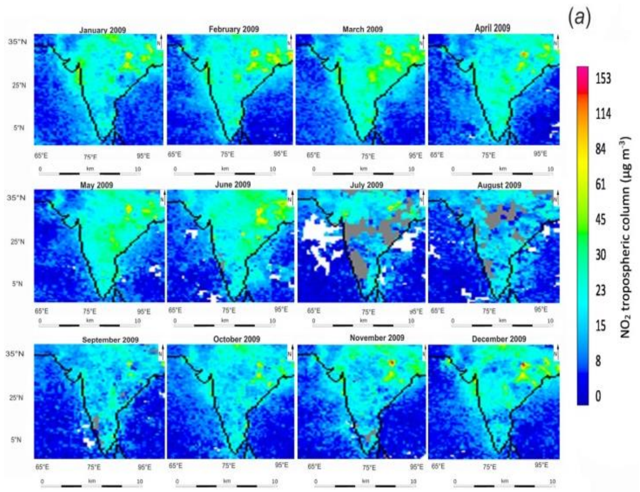
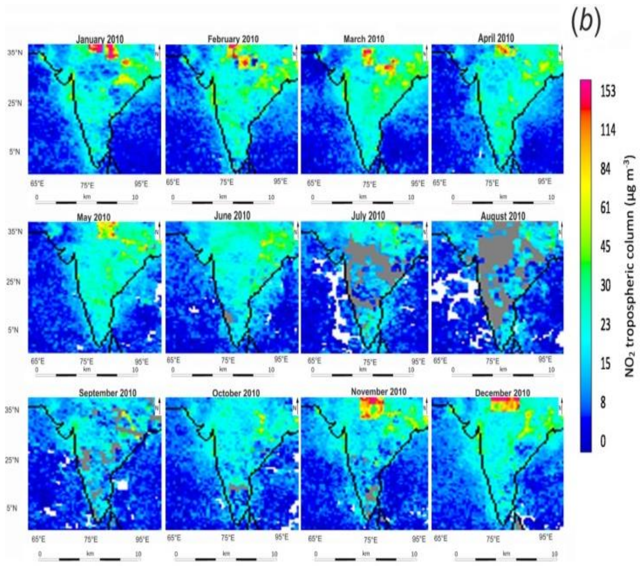


Figure 2. SCIAMACHY tropospheric NO_2 levels over India from January 2006 to December 2008.





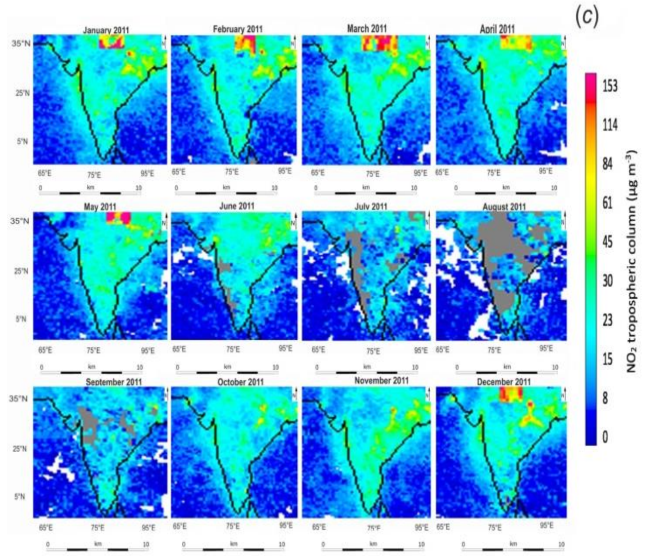


Figure 3. SCIAMACHY tropospheric NO_2 levels over India from January 2009 to December 2011.

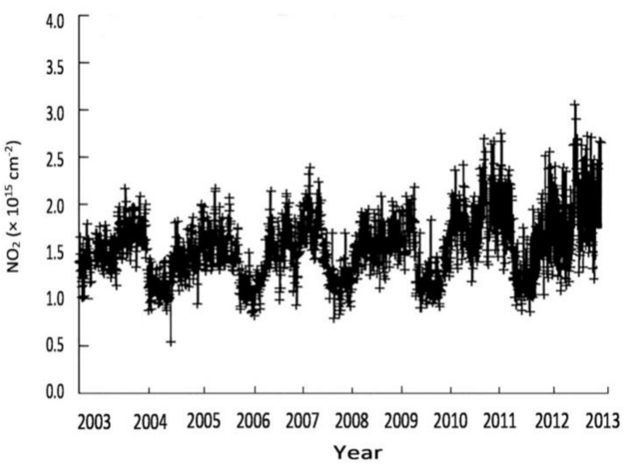


Figure 4. Time series of monthly NO_2 tropospheric column over India.

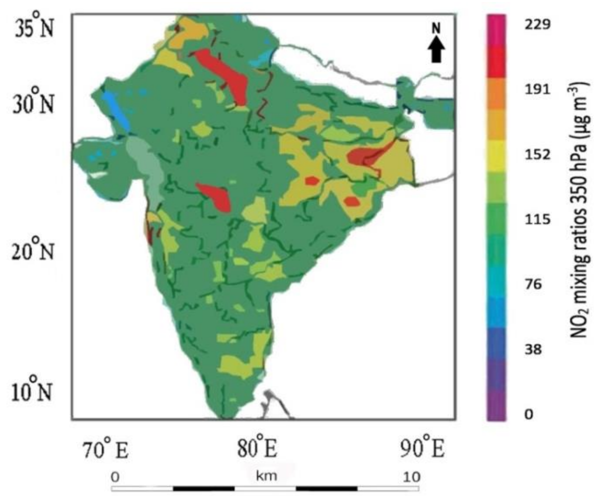


Figure 5. SCIAMACHY NO_2 mixing ratios at 350 hPa from November to May for a period of 2003-2011.

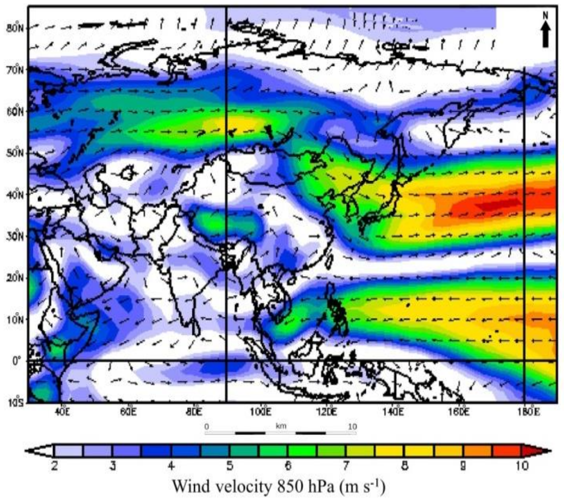


Figure 6. Wind velocity (m s^{-1}) at 850 hPa: Average from November to May for a period of 2003-2011.

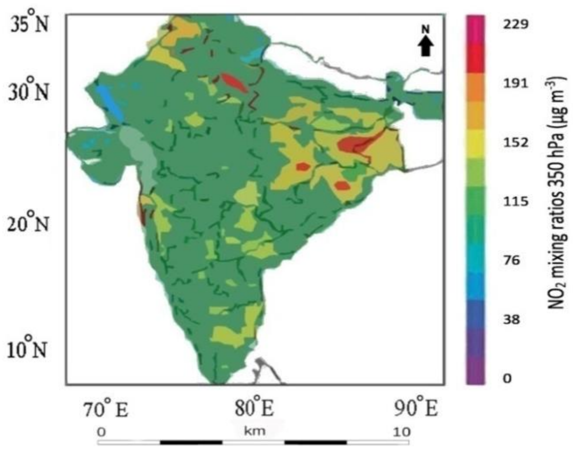


Figure 7. SCIAMACHY NO_2 mixing ratios at 350 hPa from June to September for a period of 2003-2011.

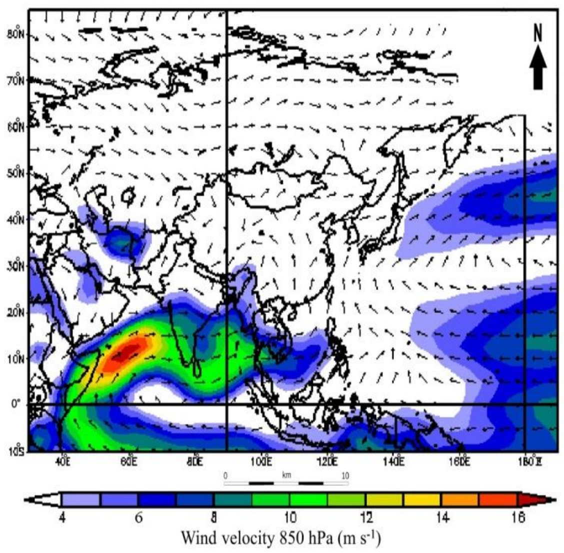


Figure 8. Wind velocity (m s^{-1}) at 850 hPa: Average from June to September for a period of 2003-2011.

4. Conclusions

As shown by the SCIAMACHY data, the tropospheric NO_2 levels over the Northern IG region is high as compared to the rest of India during winter. During the summer seasons of 2010–2011, the highest tropospheric NO_2 values ranging from 153–137 µg m^{-3} were observed over the Northern IG plain. The NO_2 mixing ratios at 350 hPa during November-May range from 200 to 230 µg m^{-3} over Arabian Sea and 90 µg m^{-3} over Bay of Bengal. Due to the long range transport and strong north-westerly wind speed of 40–42 m s^{-1} during the monsoon season, the NO_2 mixing ratios reduced to 80–110 µg m^{-3} over the Arabian Sea and 80 µg m^{-3} over the Bay of Bengal. This study presents the spatial and temporal variations of NO_X concentrations over India, but it would be better to understand the chemistry of NO_X at global level.

Abbreviations

SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric CartograpHY
NOX	Nitrogen Oxides
OMI	Ozone Monitoring Instrument
IG	Indo Gangetic
VCD	Vertical Column Density
SCD	Slant Column Density
NOX	Oxides of Nitrogen
TEMIS	Tropospheric Emission Monitoring Internet Service
AMF	Air Mass Factor
LNOx	Lightning NOx

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Author Contributions

Sandip Palve: Conceptualization, Resources, Data Curation, Writing - original draft, Investigation

Shivaji Patil: Methodology, Formal Analysis, Writing - review & editing

Nitin Mohite: Supervision

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Data Availability Statement

The data that support the findings of this study can be found at: https://earth.esa.int/eogateway/instruments/sciama-chy.

Conflicts of Interest

The authors declare no conflicts of interest.

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