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High ozone episodes and their association to stratospheric intrusion over Northeast India

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Abstract

Surface ozone measurements in the northern hemisphere till date have found spring maximum. This spring maximum is a combined effect of photochemical production from anthropogenic emissions of precursors and intrusion of stratospheric air with high concentrations of ozone but quantification of contribution from each of these processes is still uncertain. Strong stratospheric intrusion have been observed in the month of April over 25-30 N latitude accompanied by intrusion of ozone rich air into the troposphere. Ground measurements also show higher ozone concentration (>40 ppb) near the surface. Observation of CO (carbon monoxide) is used to delineate the convective outflow of ozone and its precursors or contribution from biomass burning.

1. Introduction

Stratosphere–troposphere exchange (STE) process leads to dynamical, chemical, and radiative coupling between the stratosphere and troposphere. STE is associated with tropopause folding [1] which results in the transport of air and atmospheric constituents mostly the transport of trace chemical species (both natural and anthropogenic) between the stratosphere and the troposphere. Rapid vertical transport in convective cells takes place from the troposphere to stratosphere in the tropics via diabatic or moist adiabatic heating fueled by water vapor across the isentropes (lines of equal entropy). This is the main input and mechanism for transport into the stratosphere from the troposphere. While in the mid-latitudes and Polar Regions, stratospheric air intrudes into the troposphere along the sloping lines of constant potential temperature. STE is known to be the major contributor to the tropospheric ozone budget in the tropical region and hence an accurate knowledge of transport processes is important for trace gas budgets in global chemistry-transport models (CTMs). Although STE is important for the chemical composition of both the lowermost stratosphere (LS) and the troposphere [2], however due to the involved physical and dynamical processes on local to global scales and conceptual problems, it is still inadequately understood and quantified. STE is associated with strong mesoscale perturbations of the tropopause [3] occurring in both directions. Observations from both in-situ and satellite have substantiated the existence of tropospheric air in the mid-latitude lower stratosphere and stratospheric intrusions into the troposphere [2]. Model simulations have indicated the stratospheric contribution to ozone in the troposphere to be as large as that from net photochemical production [4],[5]. A study of global climatology of stratosphere–troposphere exchange by [6]has found that the subtropics around 30° in both the hemispheres and especially mountain ranges near these latitudes are mostly influenced by stratosphere to troposphere transport into the boundary layer. Studies have also evidenced the contribution of stratospheric intrusion in the upper troposphere over the Indian region and Bay of Bengal [7], [8]. Indian subcontinent being the tropical region is most likely to be influenced by stratospheric intrusion. [7] have reported the stratospheric ozone intrusion of ~100–200 ppb during the winter and pre-monsoon seasons over the Indian region.Observations suggest that there is increased frequency in stratospheric intrusion events in spring compared to other seasons [9]. Cyclone or land convection also lead to STE events over the tropics [10] which results in the mixing of pollutants in the UTLS region. Stratospheric intrusion can result in the mixing of trace gases transported from stratosphere in the troposphere, which may also reach down, to the lower troposphere/surface. Enhanced stratospheric-tropospheric exchange is likely to increase the future global tropospheric ozone [11]. Thus, an accurate knowledge of the transport processes is of utmost necessity in quantifying the roles of transport and chemistry in the budget of trace gases [12] from lower troposphere upto stratosphere.

Observation at Dibrugarh (27.3˚N; 94.6˚E; 111amsl) located in the upper Brahmaputra basin in the sub-Himalayan state of Assam in northeast India also shows this peculiar spring maximum both in surface [13] and tropospheric column ozone concentration [14]. It has also been observed that tropospheric column ozone concentration in northeast India higher than the densely populated IGP in the Indian subcontinent during spring. In the pre-monsoon season mostly in April and May, Northeast part of India experiences severe thunderstorms, which explained in part (~ 33%) the spring maximum in surface ozone [15]. The contribution of stratospheric intrusion if any is yet to be studied over this region. This work attempts to examine the influence of stratospheric intrusion on the level of tropospheric ozone over South Asia with special reference to Himalayan region. Moreover, this work also attempts to look into whether the intrusion affects ground level ozone.

2. Methodology

Stratospheric intrusion in the upper troposphere can be explained by, variation in certain meteorological variables such as, Potential Vorticity (PV), tropospheric column concentration of some trace gases e.g. ozone (O_3), carbon monoxide (CO) etc. Distribution of CO helps in characterizing the seasonal changes in convective outflow and biomass burning [10]. High level of O_3 and PV along with low Q_{vap} values indicates high free tropospheric values due to downward transport from the stratosphere. For this study, the daily assimilated O3, PV and CO data products for April 2012 have been taken from MERRA2 (Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA2), produced at NASA's GMAO from 1980 to the present [16]. MERRA2 is a global reanalysis dataset produced by NASA Global Modeling and Assimilation Office (GMAO), using Goddard Earth Observing System Model, version 5 (GEOS-5) [17]. The GEOS-5 model coupled with the Goddard Chemistry Aerosol Radiation and Transport model (GOCART) aerosol module and simulates five types of bulk aerosols [18], [19]. The model spatial resolution is 0.5° latitude× 0.625° longitudes respectively, with 72 hybrid-eta layers from the surface through 0.01 hPa. This provides regularly-gridded, homogeneous documents of the global atmosphere that integrates additional aspects of the climate system including trace gas constituents, land surface image, and cryospheric processes. Several studies have validated the ability of MERRA-2reanalysis datasets for the study of trace gases. One such study by Knowland et al.[20] has demonstrated the capability of MERRA-2 reanalysis by evaluation the stratospheric intrusions and have shown that it captures the fine scale features of the intrusion. Surface level ozone, nitrogen oxides and carbon monoxide have been obtained from the trace gas analyzers at Dibrugarh University which are detailed in [13].

3. Results and Discussions

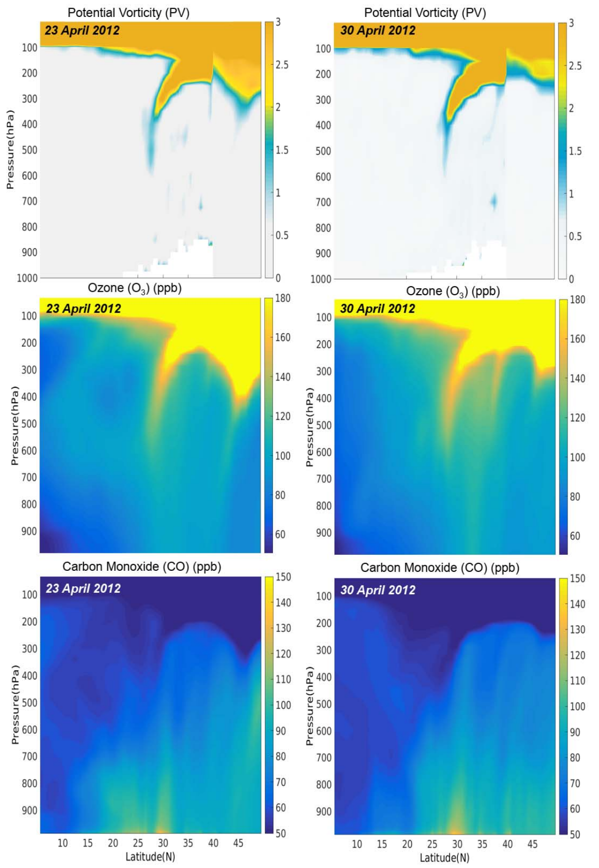

Figure 1. Latitudinal cross-section of Potential Vorticity, Ozone and Carbon Monoxide for two stratospheric intrusion events on 23rd and 30th April 2012

In Figure 1, two events have been shown for the month of April (23rd and 30th), 2012. It shows strong intrusion of ozone rich stratospheric air into the troposphere. Ozone concentration >140 ppb is observed to enter the troposphere. Such an intrusion has a strong impact in the ozone concentration over a region. Stratospheric intrusion is a significant source of ozone in the troposphere. In fact studies report increasing trend in ozone in the upper troposphere owing to downward transport of ozone during intrusion [21]. Studies suggest stratospheric intrusion occurs during winter and spring season over Southeast Asia. For the present work, we focus in such events during pre-monsoon since several incidents of anomalous increase in surface ozone have occurred during season over Dibrugarh. During pre-monsoon several other factors influence ozone in the upper troposphere. The high biomass burning during this period over Southeast Asia emits large amount of precursor gases which contributes to the tropospheric ozone burden. In the present study the intruding air is devoid of carbon monoxide (Figure 1, bottom two panels) indicating that the intruding ozone is of purely stratospheric origin. Moreover extensive convective activities with thunderstorm during this season over Northeast part of the country also add to the ozone level in the upper troposphere. Studies also suggest that extreme weather events such as cyclone, convection also influence stratospheric intrusion and ozone level in the troposphere [22], [23].

It is interesting to note that the surface ozone concentration was also higher (>30 ppb) from 23rd to 30th April. Figure 2 shows the daily mean O_3, NO_x, CO variation. It is evident that although the precursor gases NO_x and CO were very low during these days, there was significant rise in the surface O_3 concentration. Bharali et al.[15] have linked the pre-monsoonal high ozone episodes over this this region to lightning activities (33%). But it still is not sufficient to explain such a remarkable rise in surface ozone during cloud covered days (as well as nights). Stratospheric intrusion events appear to be one of the possible explaining. There are reports that episodic stratospheric intrusion linked with severe weather conditions enhances the surface level ozone [22]. In addition deep convections also perturb the tropopause resulting in intrusion of stratospheric air [24]. Das et al. [23] has reported a significant increase in surface ozone (~10 - daytime and 10–15 ppbv - night-time) during cyclone. The estimation of the contribution of stratospheric intrusion

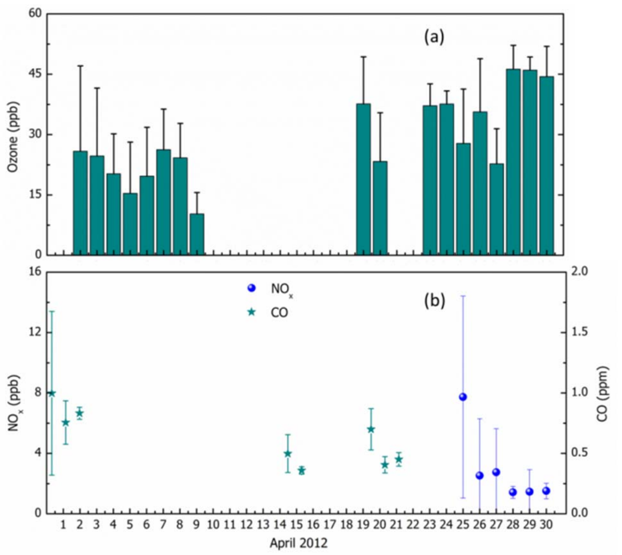

Figure 2. Daily variation of average ozone, NOx and CO over Dibrugarh for April 2012

4. Conclusions

This study aimed to study the influence of stratospheric intrusion to the ozone concentration in the troposphere over Northeast India. We have observed that significant intrusion occurs over this region. Two such events have been shown in this work where increases in the surface concentrations of ozone have also been observed. This increase is partly attributed to lightning events and partially to stratospheric intrusion. Stratospheric intrusion is associated to several factors which complicates the estimation of its contribution to ozone burden. Further analysis is required to have a clear picture of the sources contributing to ozone over this region.

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