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The observational case study of total columnar ozone associated with meteorological synoptic conditions over the Indian peninsular station

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ABSTRACT

The Total Columnar Ozone (TCO_3) was measured over the rural site of Mahabubnagar of south India, as a part of Cloud Aerosol Interaction and Precipitation Enhancement Experiment – Integrated Ground Observations Campaign (CAIPEEX-IGOC), during October-November 2011. Along with TCO_3, the collocated high resolution profiles of air temperature, water vapor and wind speed up to mid-stratosphere (~ 30 km) was also obtained by GPS Sonde. The TCO_3 variations show higher amount of TCO_3 in the morning hrs than that of evening hrs. Also a sudden reduction of TCO_3 of the order of 100 - 110 DU in 12 h time scale was observed.

Key words: Total column ozone, cyclonic storm, Atmospheric chemistry, Atmospheric electricity, CAIPEEX.

INTRODUCTION

Ozone is very rare gas in the atmosphere, but plays a vital role with the human life. The ozone layer in the stratosphere around the globe absorbs most of the biologically damaging ultraviolet sunlight and filters them from reaching the ground and thereby protects the whole biosphere from its harmful effect (Kondratyev and Varotsos, 1996; Katsambas et al., 1997). On the other hand, tropospheric ozone is a strong contributor to the global warming. At the earth surface, ozone plays a destructive role as its high levels are toxic to living systems and have harmful effect on the crop production. The changes in total ozone influence the biologically active UV radiation (Calbo et al., 2005), and since the detection of the Antarctic ozone hole, the development on monitoring the Earth's ozone has been a key focus in atmospheric research (Farman et al., 1985). Ozone occurs naturally at ground-level in low concentrations.

There is a large latitudinal variation in ozone concentrations worldwide, generally depicting high values in polar region and low in the tropics. On a seasonal timescale, the total ozone content in the atmosphere is controlled by both transport of ozone within the stratosphere and photochemical processes. Daily tropospheric ozone data derived from Aura OMI (Ozone Measuring Instrument) and MLS (Microwave Limb Sounder) measurements found lowest global values of tropospheric ozone (20 DU or less) over the broad tropical Pacific and in the southern polar region in summer and autumn months (Ziemke et al., 2006). The OMI/MLS tropospheric ozone climatology exhibits large temporal and spatial variability which includes ozone accumulation zones in the tropical south Atlantic year-round and in the subtropical Mediterranean/Asia region in summer months (Ziemke et al., 2011). High levels of tropospheric ozone in the Northern Hemisphere also persist in mid-latitudes over the eastern part of the North American continent extending across the Atlantic Ocean and the eastern part of the Asian continent extending across the Pacific Ocean; and the largest stratospheric ozone lies in the Northern Hemisphere and extends from the eastern Asian continent eastward across the Pacific Ocean and North America (Ziemke et al., 2011). The systematic seasonal variation pattern of TCO_3 could be due to the general circulation pattern in the stratosphere (Raj et al., 2004). Over the Antarctic region, a study shows the possibility of precipitating charged particles role to decrease short-lived ozone through production of OH radical (Sonbawne et al., 2009). Atmospheric composition has changed significantly over the past few decades from increasing urbanization and as a response to environmental policy changes (Wenig et al., 2003; Vingarzan 2004; Parrish et al., 2009). In the present scenario, with increasing populations, more automobiles and industries contributed for the increasing ozone in the lower atmosphere. The ozone which is a byproduct of certain human activities does become a problem at ground level.

Over the Tibetan Plateau region, lower value of total ozone of ~190 DU reported by Bian et al., (2006). Such rapid and localized reduction and recovery in TCO_3 (1000-3000 km spatial and 1-5 days time scale) is referred as an 'ozone mini hole' event (Newman et al., 1988). Such events have frequently been observed throughout in the mid-latitudes of both the hemisphere with greater frequency over North Atlantic European sector (James 1998a; James 1998b). The dynamic processes contributing to ozone mini hole in high latitudes of Europe have been well documented on the meridional transport of sub-tropical ozone poor air

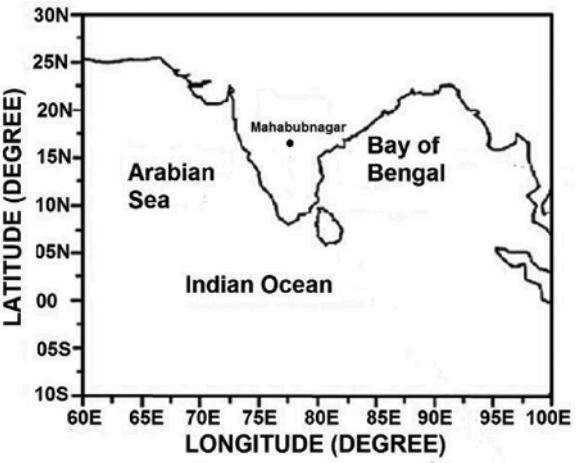

Figure 1. Map showing the location of experimental site (Mahabubnagar).

near the tropopause air and divergence of ozone rich air out of the air column in the lower troposphere (Koch et al., 2005; Keil et al., 2007). In the Asian continent, over Tibetan Plateau, such reduction of TCO_3 was observed, which attributed to the ozone reduction in upper troposphere and lower stratosphere region (below 25 km). This region generally caused by up-liftment of the local tropopause and northward transport of tropical air which contain low ozone concentrations associated with an anomalous anticyclone in the upper troposphere (Liu et al., 2010). In this paper, we explore high-resolution measurements of TCO_3 using ground-based portable spectrometer and air temperature, water vapour and wind speed observations with GPS radiosonde. An attempt has been made to investigate the local distribution of TCO_3 associated with the cyclonic storm formed in the Arabian Sea.

DATA AND METHODOLOGY

The Portable spectrometer (UV-VIS-NIR Range) and GPS radiosonde systems were installed over a station Mahabubnagar (16.44° N, 77.59° E, 498 m a.s.l.) in south India in the October-November 2011 as a part Cloud Aerosol Interaction and Precipitation Enhancement Experiment – Integrated Ground Observations Campaign (CAIPEEX-IGOC). The measurement site is in the outskirt of the city having rural characteristics. The location of experimental station is shown in Figure 1.

Ground-based observations of zenith-sky scattered sunlight were performed (Meena et al., 2016). The spectrometer used in the present study, is a high-spectral resolution spectrometer Model HR2000, manufactured by Ocean Optics, Dunedin, Florida, USA. It is the first model of a new line of modular optical bench spectrometers. It is a modular spectrometer having high-optical resolution of 0.035 nm and focal length of 101.6 mm at 5f/4, works on symmetrical crossed Czerney-Turner optical design. The high-reflectivity AgPlus mirrors facilitates high-resolution measurements in low-light level situations. Moreover, it is extremely low power (~ 05 W) device. The detector is a linear CCD array with 2048 pixels (each 14 μm × 200 μm). The instrument has been mounted on the top roof stairs of a 20 m tall building. The scattered sunlight is received by a telescope with 46 mm diameter and 300 mm focal length, and lead to spectrometer through a quartz fiber. Observations of TCO_3 from spectrometer were taken for half an hour just after the sunrise and before sunset period for the zenith angle between 85° – 90°. The spectrometer data are analyzed using Differential Optical Absorption Spectroscopy (DOAS) technique. Absorber (trace gas) concentration n is derived from Lambert–Beer's law as

$$I = I_o \exp(-\sigma n l) \quad \text{.....(1)}$$

Where, I is the measured spectrum intensity (i.e., zenith sky scattered light intensity) at the ground, I_o is the reference spectrum intensity outside the atmosphere, however, it is difficult to measure the spectra outside the atmosphere. Therefore, noon time spectrum is taken as a reference spectrum, l is the optical path length (cm), σ is the absorption cross section (cm^2 $molecule^{-1}$) of the absorbing molecule and n is the absorber concentration (molecules cm^{-3}). To obtain the vertical profiles of winds, temperature and dew point (water vapor), the Vaisala make GPS upper-air sounding system was used. The synoptic weather analysis by India Meteorological Department shows that a low level cyclonic circulation was existed over the southeast and adjoining east-central Bay of Bengal from October 12, 2011 onwards (India Meteorological Department, 2012). There was an active east-west shear zone passing through this circulation. As a result, the low level relative vorticity and convergence was increased. The upper tropospheric ridge at 200 hPa level was to far north of the area of circulation (around 19° N on October

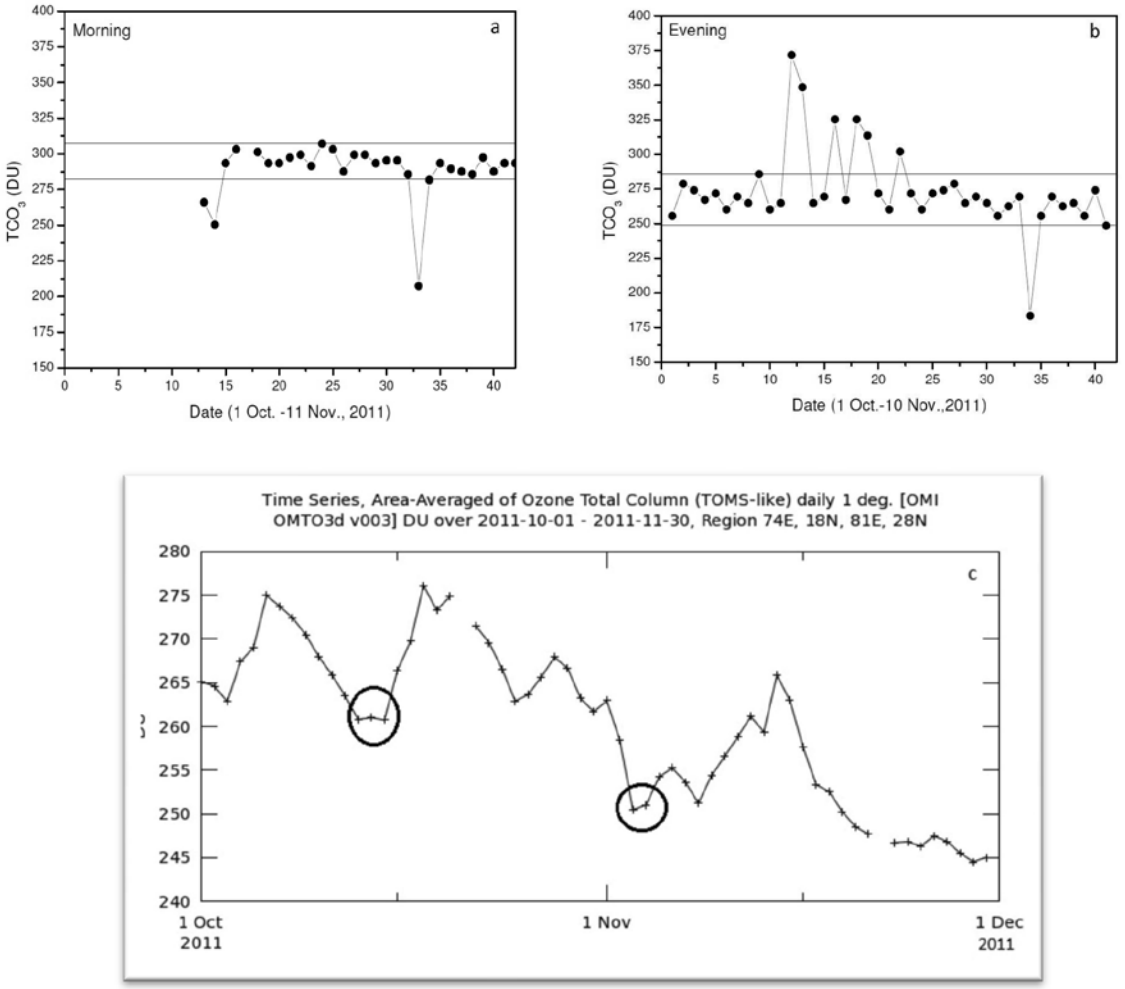

Figure 2. Daily variation of TCO_3 during the (a) sunrise (b) sunset period and (c) day to day observations of TCO_3 over Indian subcontinent from 1 October to 30 November 2011 by OMI.

15, 2011) and provided the required divergence over the region. The cyclone, Banyan over the South China Sea existed as a depression near 17.5° N and 116° E on October 14, 2011 and became less marked on October 15, 2011. Under the influence the cyclonic circulation, a low pressure area formed over the Bay of Bengal region with associated cyclonic circulation extending up to mid tropospheric level on October 17, 2011. It became well marked over east central and adjoining north and west central Bay of Bengal on October 18, 2011. The well marked low pressure area was concentrated into a depression over north Bay of Bengal and centered at 00 UTC of October 19, 2011 over north Bay of Bengal near latitude 20° N and longitude 90.5° E.

RESULTS AND DISCUSSION

During the observational period, the TCO_3 concentration was ranging from 183.5 to 371.5 DU (Figure 2 a, b). The monthly mean of TCO_3 for October 2011 was 284.82 DU. In the earlier study (Kalita et al., 2011), based on satellite observations, the monthly mean of TCO_3 over the nearby area of observational site was in the range of 255-260 DU for the months of October 2007. The difference of ~30 DU in the satellite observed TCO_3 and measured by the ground based remote sensing instrument in the present study could be due to the different instrumentations and methodology adopted in both the studies.

During the sunset of October 12, 2011, the TCO_3 was increased to 371.7 DU from its previous concentration of 264.9 DU, sudden rise of TCO_3 is 106.8 DU in 12 h. Similarly, during sunrise of November 2, 2011, the TCO_3 was 285.7 DU which suddenly reduced to 183.5 DU in the sunset showing sudden fall of 102.2 DU in just 12 h. The largest 24 h change (sunset to sunset) in TCO_3 concentration was found to be 107.7 DU, whereas it was 75.0 DU during sunrise to sunrise. As seen in Figure 2b, six days with greater TCO_3 concentrations, recorded during the sunset time from October 12-22, 2011. These days were

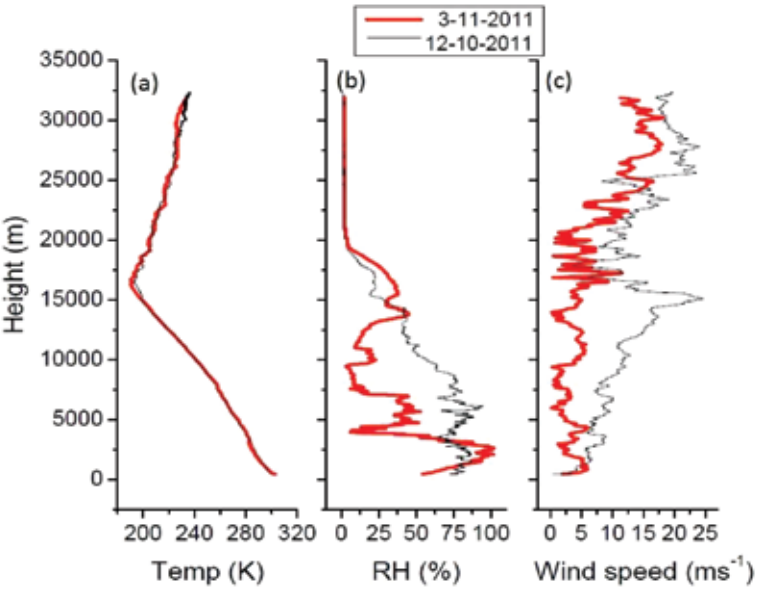

Figure 3. Air temperature (a), relative humidity (b) and wind speed (c) profiles observed on October 12, 2011 and November 3, 2011.

associated with the cyclonic synoptic weather conditions over the Indian subcontinent. The development of low pressure system in the Bay of Bengal could have played the role in exchanging air mass. The greater amount of ozone (~ 90%) is mainly found in the lower portion of the stratosphere (20 - 30 km), though its thickness varies seasonally and geographically. Hence, it is important to look change in relevant parameters with respect to TCO_3 in this region. To show this, one day with high TCO_3 concentration (October 12, 2011) and one day with low TCO_3 concentration (November 2, 2011) was selected. The TCO_3 concentration was low (183.5 DU) on November 3, 2011, evening and it was high (371.7 DU) on October 12, 2011 evening. Daily time series of total column ozone (Toms-like) (OMTO3d v003) with 1 degree spatial resolution (source OMI) derived from Giovanni data for the period of 1 October – 30 November 2011 are shown in Figure 2c. This time series also show the reduction of TCO_3 around 12 October 2011 and 3 November 2011. We do not found any significant change in the observed air temperature in lower stratospheric region on the above two days (Figure 3a). It is seen that, on the day of high TCO_3, there was an increase in the water vapor in the mid to upper troposphere (4-14 km) region (Figure 3b).

Also, the wind speed was very high from surface to lower stratosphere (Figure 3c). The opposite scenario, i.e., low water vapor in the mid -to- upper troposphere and low wind speed in troposphere and stratosphere, was observed on a day of low TCO_3.

To verify the synoptic feature, the cloud pictures for those two days are shown in Figure 4 (a-b) associated with lightening events (Figure 5). There was less cloudiness (Figure 4a) and less number of lightening events (Figure 5a) on the day of low TCO_3 concentration. On the contrary, there was greater cloudiness (Figure 4b) and high lightening events (Figure 5b) on the day of high TCO_3 concentration.

Thus, the synoptic weather conditions may have played a significant role in enhancing the TCO_3 concentrations drastically. As shown in Figure 2, during October 31, to November 4, 2011, the TCO_3 concentration was fluctuated from 183.6 to 293.5 DU. It is seen that a sudden reduction (78.3 DU) in TCO_3 concentration was observed from the morning of November 1 and November 2, 2011. It was further increased by 74.4 DU on morning of November 3, 2011. In the evening of November 3, 2011 the TCO_3 was again decreased by 98.2 DU and the concentration was 183.6 DU. Again in the morning of November 4, 2011 it increased by 109.9 DU and the concentration was 293.5 DU. This sudden reduction in the TCO_3 concentrations is likely to resemble with the localized ozone mini hole (Figure 2a,b). We cannot attribute this reduction to the cyclone formed in the Arabian Sea, but it was associated with the transition of cyclonic storm 'Keila' in the Arabian Sea. A cyclonic storm 'Keila' developed over the southeast Arabian Sea with genesis of depression on October 29, 2011. It moved initially west-northwestwards and then northwestwards and crossed Oman coast close to north of Salalah as shown in Figure 6.

It then emerged into Arabian Sea and dissipated gradually. The track of the cyclone 'Keila' was rare in nature as it made a loop after the landfall over Oman near Salalah. One speculation is that, this cyclone could have pooled the ozone rich air from the observational site and later, the air mass over the observational site is replaced with

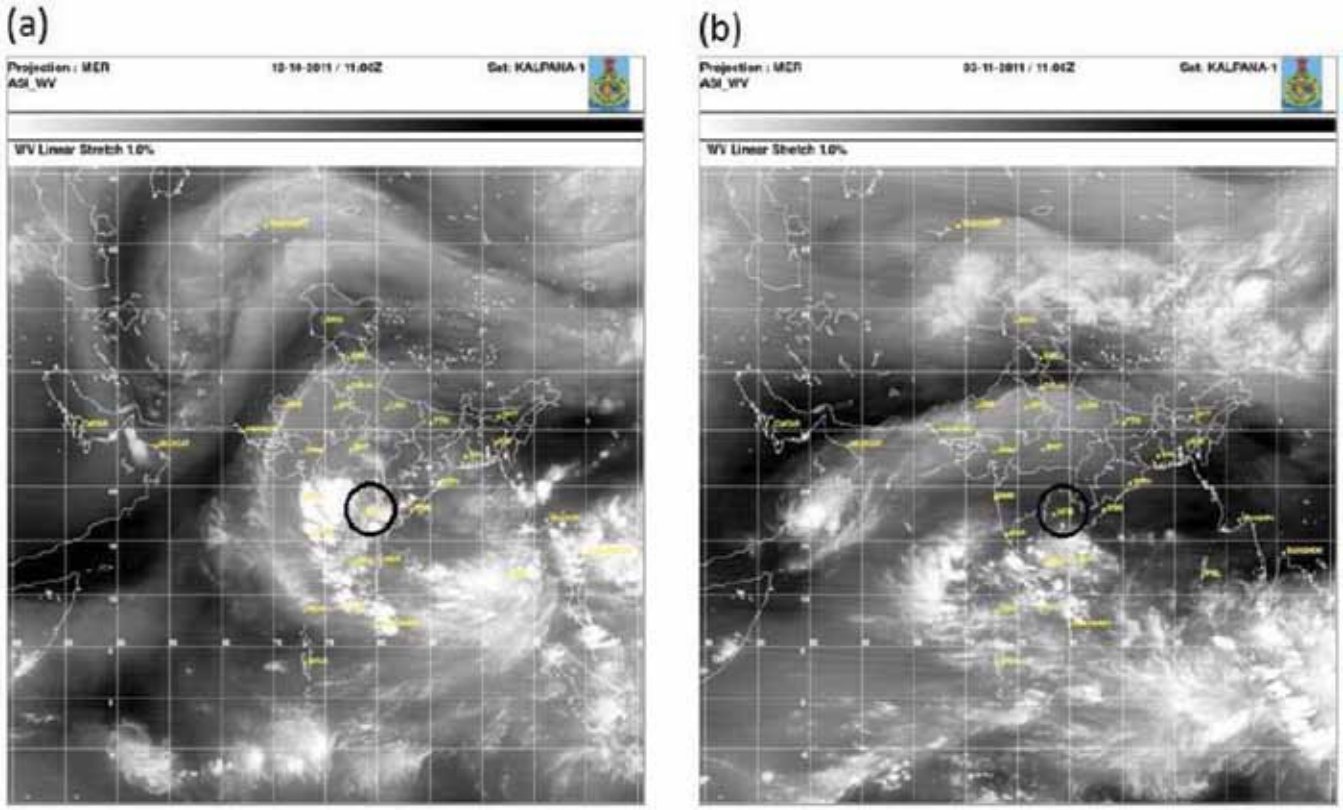

Figure 4. Clouds (water vapour) by Kalpana-1 satellite on (a) October 12, 2011, evening (b) November 3, 2011, evening. The area circled over India depicts the region near observational station.

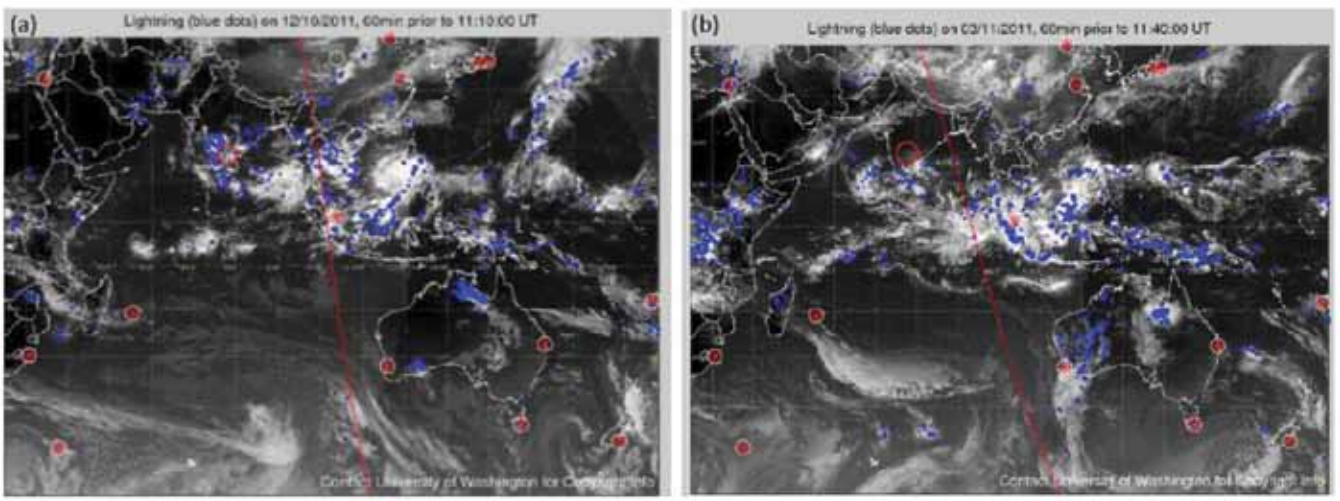

Figure 5. The lightening that occurs on (a) October 12, 2011, evening (b) November 3, 2011, evening. The area circled over India depicts the region near observational station.

poor ozone concentration air mass. Similar to the results reported in this study, in Aura-OMI satellite observations and high resolution ground-based measurements, sharp spikes and dips in TCO_3, of the order of 20 DU within less than 2 h, associated mostly with highly dynamic weather systems such as pressure changes, passage of a cold front with high stratospheric ozone content, or intrusion of low ozone air from lower latitudes (Tzortziou et al., 2012). The chemistry climate model study shows chemistry-induced effects of increasing water vapor lead to an overall decrease of the TCO_3 by about 1% in the tropics (Wenshou et al., 2009).

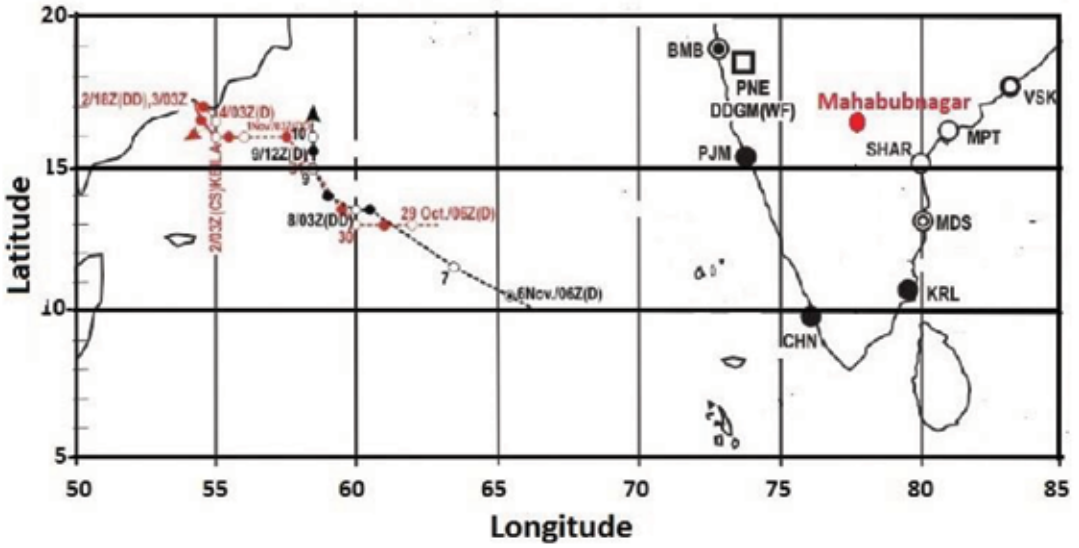

Figure 6. Track of the cyclonic storm Keila in Arabian Sea during 29 Oct-4 Nov, 2011.

SUMMARY AND CONCLUSIONS

The analyses presented in this article include the concentrations of Total Column Ozone obtained in a monitoring campaign that took place at a south Indian site of Mahabubnagar during 42 days in the post-monsoon season. The results indicate that, on most of the days, the TCO_3 was ranging from 250-300 DU. It is found that the water vapor and wind speed in the upper troposphere and lower stratosphere plays a role in controlling the TCO_3 concentrations. The existence of high water vapor and strong winds were associated with high TCO_3. Similarly, more lightning strike events were also associated with high TCO_3. Localized sudden decrease of ~ 110 DU of TCO_3 with time scale of 12 h was observed, first time over the Indian subcontinent, in association with the cyclonic storm Keila formed in the Arabian Sea.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

Bian, J., Wang, G., Chen, H., Qi D., Lü D. and Zhou, X., 2006. Ozone mini-hole occurring over the Tibetan Plateau in December 2003. Chinese Sci. Bull., 51(7), 885-888.

Calbo, J., Pages, D. and Gonzalez, J.A., 2005. Empirical studies of cloud effects on UV radiation: A review. Rev. Geophys., 43, doi: 10.1029/2004rg000155.

Farman, J.C., Gardiner, B.G. and Shanklin, J.D., 1985. Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction. Nature., 315, 207–210.

India Meteorological Department, 2011. Report on cyclonic disturbances over north Indian Ocean during 2011, RSMC-Tropical Cyclone Report No 02/2012.

James, P.M., 1998a. An interhemispheric comparison of ozone mini-hole climatologies Geophys Res. Lett., 25(3), 301-304.

James, P.M., 1998b. A climatology of ozone mini-holes over the northern hemisphere; International. J. of Climatol., 18(12),1287-1303.

Kalita, G., Pathak, B., Bhuyan, P.K. and Bhuyan, K., 2011. Impact of zonal wind on latitudinal variation of total columnar ozone over the Indian Peninsula. International Journal of Rem. Sens., 32(24), 9509-9520.

Katsambas, A., Varotsos, C.A., Veziryianni, G. and Antoniou, C., 1997. Surface solar ultraviolet radiation: a theoretical approach of the SUVR reaching the ground in Athens, Greece. Environ. Sci. and Poll. Res., 4, 69-73.

Keil, M., Jackson, D.R., and Hort, M.C., 2007. The January 2006 low ozone event over the UK. Atmos. Chem. and Phys., 7(3), 961-972.

Koch, G., Wernli, H., Schwierz, C., Staehelin, J. and Peter, T., 2005. A composite study on the structure and formation of ozone miniholes and minihighs over central Europe. Geophys. Res. Lett., 32(12), 1-5.

Kondratyev, K.Y. and Varotsos, C.A., 1996. Global total ozone dynamics – impact on surface solar ultraviolet radiation variability and ecosystems. Environ. Sci. and Poll Res., 3, 205-209.

Liu, C., Liu, Y., Cai, Z., Gao, S., Bian, J., Liu, X. and Chance, K., 2010. Dynamic formation of extreme ozone minimum events over the Tibetan Plateau during northern winters 1987-2001. J. Geophys. Res. 115, D18311, doi:10.1029/2009JD013130.

Meena, G.S., Devara, P.C.S. and Patil, M.N., 2016. Diurnal asymmetry in slant column density of NO2, O3, H2O and O4 during CAIPEEX−IGOC over Mahabubnagar, a rural site in Southern Peninsular India. Natural Hazards, 82, 389-400.

Newman, P.A., Lait, L.R. and Schoeberl, M.R., 1988. The morphology and meteorology of Southern Hemisphere spring total ozone mini□holes. Geophys. Res. Lett., 15(8), 923-926.

Parrish, D.D., Millet, D.M. and Goldstein, A.H., 2009. Increasing ozone concentrations in marine boundary layer air inflow at the west coasts of North America and Europe. Atmos. Chem. and Phys., 9, 1303-1323.

Raj, P.E., Devara, P.C.S., Pandithurai, G., Maheshkumar, R.S., Dani, K.K., Saha, S.K. and Sonbawne, S.M., 2004. Variability in sun photometer derived ozone over a tropical urban station J. Geophys. Res., 109, D08309.

Sonbawne, S.M., Raj, P.E., Devara, P.C.S. and Dani, K.K., 2009. Variability in sun photometer derived summertime total column ozone over the Indian station Maitri in the Antarctic region. International J. Rem. Sens., 30(15-16), 4331-4341.

Tzortziou, M., Herman, J.R., Cede, A. and Abuhassan, N., 2012. High precision, absolute total column ozone measurements from the Pandora spectrometer system: comparisons with data from a Brewer double monochromator and Aura OMI Journal Geophysics Res., 117, D16303 doi: 10.1029/2012JD017814.

Vingarzan, R., 2004. A review of surface ozone background levels and trends. Atmos. Environ., 38, 3431–3442.

Wenig, M., Spichtinger, N., Stohl, A., Held, G., Beirle, S., Wagner, T. and Jahne BPlatt, U., 2003. Intercontinental transport of nitrogen oxide pollution plume. Atmos. Chem. and Phys., 3, 387-393.

Wenshou, T., Chipperfield, M.P. and Daren, L., 2009. Impact of Increasing Stratospheric Water Vapor on Ozone Depletion and Temperature Change, Adv. in Atmos. Sci., 26(3), 423-437.

Ziemke, J.R., Chandra, S., Duncan, B.N., Froidvaux, L., Bhartia P.K., Levelt, P.F. and Waters, J.W., 2006. Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model. Journal Geophysics Res., 111, D19303, doi: 10.1029/2006JD007089.

Ziemke, J.R., Chandra, S., Labow, G.J., Bhartia, P.K., Froidevaux, L. and Witte, J.C., 2011. A global climatology of tropospheric and stratospheric ozone derived from Aura OMI and MLS measurements. Atmos. Chem. and Phys., 11(17), 9237-9251.

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