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# Signature of Variation of Total Ozone Column during Tropical Cyclone, Aila 2009 over the Bay of Bengal and the Land of West Bengal

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## Abstract:
**The paper presents the variation of the total ozone column (TOC) over Bay of Bengal and the land of West Bengal, India before, during and after the tropical cyclone, Aila that occurred in the month of May 2009. Total ozone data derived from OMI instrument on Aura platform has been used for this study. The daily total ozone anomalies have been calculated and found related to the intensification of the cyclonic system. Analysis reveals the steady decrease in the total ozone column (TOC) before and during the formation of the cyclone followed by a more or less increase after the dissipation of the cyclone. The steep fall in total ozone column (TOC) by more than 16 DU is exhibited at the peak intensity of the cyclone characterized by maximum wind speed over those regions where the cyclone has intensified. The observed variation of total ozone column (TOC) is in accordance with the existing chemical and dynamical theories of ozone depletion.**

**Keywords:** Ozone depletion, TOC, Tropical cyclone

## 1.0 Introduction:
Cyclone, an area of closed, circular fluid motion rotating in the same direction is usually characterized by inward spiraling winds that rotate anti-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Cyclones that develop in the regions between the tropics of Capricorn and Cancer are known as tropical cyclones.Tropical cyclones are formed due to the latent heat driven by significant thunderstorm activity, and are warm core. A tropical cyclone is a storm system characterized by a low pressure center often known in a mature tropical cyclone as the eye, high pressure outside and numerous thunderstorms that produce strong winds and flooding rain. Generally, the 'eye' of the storms has three basic shapes- circular, concentric and elliptical. The main physical feature of a mature tropical cyclone in the Indian Ocean is a concentric pattern of highly turbulent giant cumulus thundercloud bands. A tropical cyclone feeds on heat released when moist air rises, resulting in condensation of water vapour contained in the moist air. They are fueled by a different heat mechanism than other cyclonic windstorms such as nor'easters, European windstorms and polar lows, leading to their classification as "warm core" storm systems. Tropical cyclogenesis involves the development of a warm core cyclone, due to significant convection in a favorable atmospheric environment. According to the World Meteorological Organisation (WMO, 1976), 'tropical cyclone' refers to the weather systems in which winds exceed 'gale force' (minimum of 34 knots or 63 $kmh^{-1}$). In India, cyclones are classified on the basis of strength of the associated winds, storm surge and exceptional rainfall occurrences. Severe cyclones have wind speed in the range 88-117 $kmh^{-1}$ or 47-63 knots, very severe cyclones in the range 117-220 $kmh^{-1}$ or 63-119 knots and super cyclones have wind speed more than 221 $kmh^{-1}$ or 119 knots. Cyclone category-01, 02, 03, 04 and 05 has wind speed 120-150 $kmh^{-1}$, 150-180 $kmh^{-1}$, 180-210 $kmh^{-1}$, 210-250 $kmh^{-1}$ and more than 250 $kmh^{-1}$,

respectively. The tropical cyclones are manifested in three stages- formation and initial development stage, mature tropical cyclone stage, and modification and decay stage.

Tropical cyclones occur in the months of May-June and October-November. The cyclones of severe intensity and frequency in the north Indian Ocean are bi-modal in character, with their primary peak in November and secondary peak in May. The disaster potential is particularly high at the time of landfall in the north Indian Ocean (Bay of Bengal and the Arabian Sea) due to the accompanying destructive wind, storm surges and torrential rainfall. Of these destructive wind, storm surges and torrential rainfall, storm surges are the greatest killers of a cyclone, by which sea water inundates low lying areas of coastal regions and causes heavy floods, erodes beaches and embankments, destroys vegetation and reduces soil fertility.

Baray *et al.* (1999) and Laclair de Bellevue *et al.* (2006) observed transfer of ozone from the stratosphere to mid-troposphere and pumping of ozone-poor air masses from the boundary layer to the upper troposphere. Zou and Wu (2005) showed variations of total ozone amounts during the life stage of a hurricane. According to Richard *et al.* (2001), a low water vapour and ozone and high methane had been noticed in the lower stratosphere above a cyclone due to local dehydration and upward transport of ozone poor and methane rich tropospheric air. The first in situ measurements of ozone within a tropical cyclone were made from a U 2 plane at pressure levels between 50 and 300 hPa in hurricane Ginny (Penn 1965). From the cloud top pressure of 200 hPa to near the tropopause at about 120 hPa, ozone mixing ratios were elevated by 40 % approximately as compared with the surrounding environment of about 8-72 km distant. A subsequent U 2 flight over hurricane Isbell (Penn 1966) exhibited no significant horizontal variation of ozone mixing ratios or temperature from the lower stratosphere to just below the tropopause at about 100hPa. Again total ozone had been over-estimated within the eye of hurricanes Katrina and Rita (Joiner *et al.* 2006). On the basis of aircraft measurements they showed relatively small or negligible amount of stratospheric intrusion into the eye region. Kondratyev (2008) reported that a typical increase in total ozone (TO) at the periphery of the developing tropical depression 2-4 days before its transformation into a tropical storm can be considered as a very early prognostic sign of a TC (Tropical Cyclone). Rodgers *et al*. (1990) found enhanced total ozone in the eye region of tropical cyclones resulting from stratospheric intrusion of ozone rich air. Again, Newell *et al.* (1996) reported no evidence for significant entrainment of stratospheric air into the eye of typhoon Mireille. But, Carsey and Willoughby (2005) found relatively low concentration of ozone in the eye walls of intensifying hurricanes in the middle of lower troposphere and concentration of ozone in the center of the eye near the local environmental values for hurricane Georges and Floyd. On the analysis of the perturbation in the total ozone due to four severe tropical cyclones formed over Arabian Sea and Bay of Bengal, Singh and Nair (2008) observed the negative anomalies in daily total ozone by more than 20 Dobson units at the time of maximum intensity of cyclones. From the critical analysis of tropical cyclones in the pre-monsoon and post-monsoon periods over the Bay of Bengal and the Arabian Sea for the period 1997-2009, Midya *et al.* (2012) also concluded that TOC decreased steadily before and during the formation of a cyclone, followed by a more or less increasing trend after the dissipation of cyclone. They observed a sudden fall in TOC over those regions where the cyclone had intensified.

A severe tropical cyclonic storm, Aila crossed the coast of West Bengal near the Sagar Island 13:30 and 14:30 hrs IST of 25 th May which continued to move in a northerly direction across West Bengal. South west monsoon set in over Andaman and adjoining south Bay of Bengal on 20 May 2009 under its influence. The rise in the southerly surge resulted in increase in the horizontal pressure gradient and the north-south wind gradient over the region. Hence the lower level horizontal convergence and relative vorticity had increased gradually over the southeast Bay of Bengal that led to the development of the upper air cyclonic circulation extending up-to mid-tropospheric level on 21 May 2009 over southeast Bay of Bengal and associated convective cloud clusters persisted over the region. Under the influence of the cyclonic circulation, a low pressure area formed over the east central of adjoining west central Bay of Bengal on 22 May 2009 evening. It was concentrated into a depression and lay centered at 11:30 hrs (IST) on 23 May 2009 near latitude of 16.5$^oN$ and longitude of 80$^oE$ about 600 km south of the Sagar Island. A low level circulation had developed over south Bay of Bengal on 21 May 2009 at 08:30 hrs IST which had been transformed into a vortex with centre of 11.5$^oN$ and 85.5$^oE$ and intensity of J 1.0. It had gained intensity of J 1.5 corresponding to depression with center 16.5$^oN$ and 88$^oE$ of 23 May, 2009. It was the shear pattern at the time of cyclogenesis with maximum convection lying to south west of the system center. The wind shear which is considered as an important factor for cyclogenesis was 05-10 knots on 23 May, 2009 between the layers 150-300 hPa and 700-925 hPa. The sea surface temperature (SST) was warmer (28$^oC$) over central and north- Bay of Bengal being 0.5$^oC$ to 1$^oC$ above normal. The system could gain upper level divergence as the upper tropospheric ridge roughly ran along 17$^o$. The wind speed was relatively stronger in the south east sector due to strong southerly surge of the monsoon current.

The depression had moved mainly in a northerly direction and intensified into a deep depression and lay centred at 08:30 hrs IST of 24 May 2009 near latitude of 18$^oN$ and longitude of 88.5$^oE$ which had further intensified into cyclonic storm 'Aila' on 24 May 2009 lay centred near near latitude of 18.5$^oN$ and longitude of 88.5$^oE$. It had continued to move in northerly direction and intensified into severe cyclonic storm (SCS) on 25 May 2009 and lay centred over northwest Bay of Bengal near latitude of 21.5$^oN$ and longitude of 88$^oE$ closed to the Sagar Island. The system crossed West Bengal coast to the east of Sagar Island as a SCS with wind speed of 100 to 110 kmh$^{-1}$. The lowest estimated central pressure was of about 967 hPa at the time of landfall. After the landfall, the system had continued to move in a northerly direction gradually weakened into cyclonic storm and lay centred of 25 May 2009 over the Gangatic West Bengal close to Dumdum, Kolkata, weakened into a deep depression over Bardhaman (23.5$^oN$, 87.9$^oE$) and Malda (25$^oN$, 88.2$^oE$) and as low depression over Darjeeling (27$^oN$, 88.3$^oE$) on 26 May 2009 as shown in Fig. 1. Aila, severe tropical cyclone caused loss of about 100 human lives and left several injured. It also caused about 175 human deaths and left several injured in adjoining Bangaladesh. According to satellites and other instruments such as anemometers, anemographs and AWS sensors, the sustained maximum wind at the time of landfall had been about 60 knots (112 kmh$^{-1}$). A storm surge of 3m had submerged numerous villages in western region of Bangladesh. In West Bengal, the number of storm-affected people was about 2.2 million. More than 61000 houses collapsed and more than 132000 houses were partially damaged. It caused extensive damage of to rice and other crops that are still assessing losses. In Sundarban, heavy downpour raised river levels while the gushing waters of flooded mangroves burst mud embankments in the extensive delta region, destroying hundreds of thousands of houses. The mangroves forest area, home to the endangered Royal Bengal tiger, has been fully inundated, and high speed winds have destroyed all communication and transportation infrastructure. The entire Sundarban biosphere reserve area of 9600 square kilometers has suffered extensive damage under the impact of cyclone Aila.

The special features of Aila were that this storm moved in a near northerly direction throughout its life period. Its intensification was rapid only a few hours before landfall. The system maintained intensity of the cyclone even up-to 15 hours after the landfall. It was the first cyclone in the month of May to cross West Bengal after 1989.

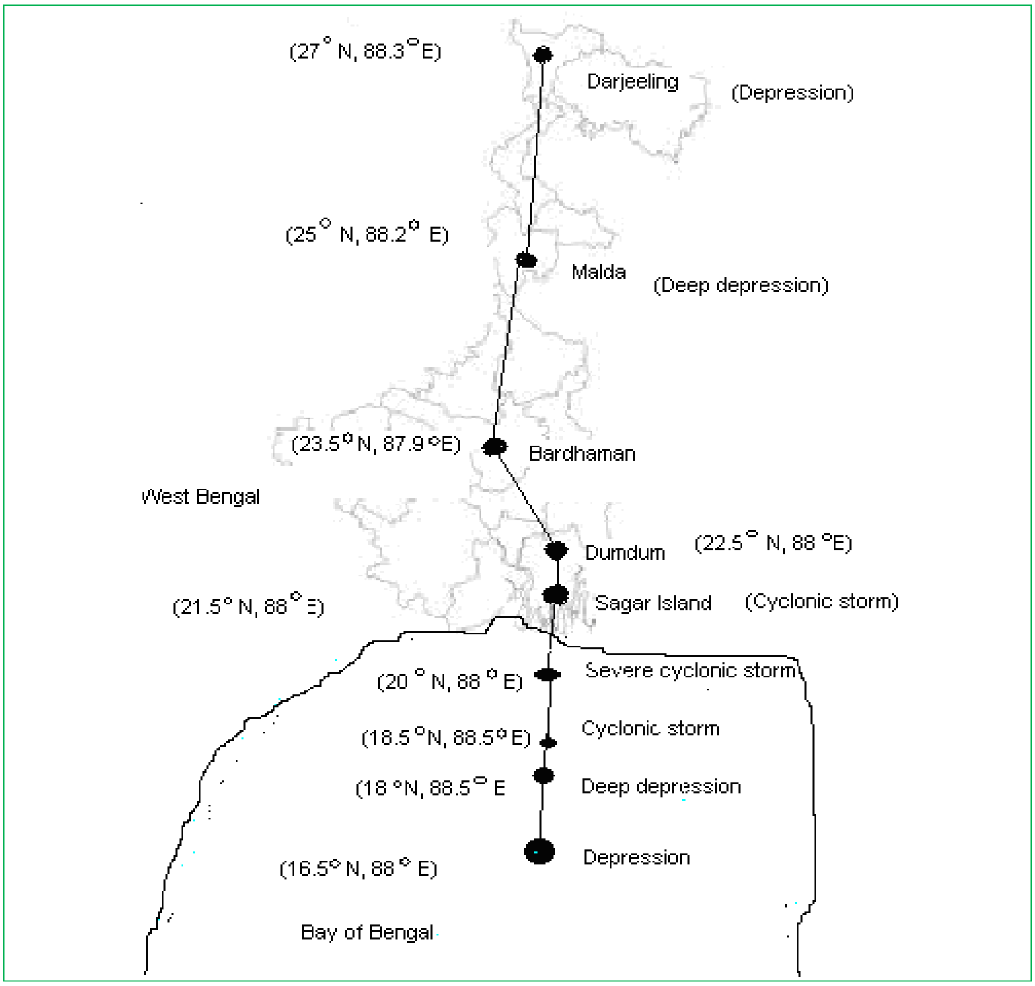



**Figure 1:** Path of the tropical cyclone, Aila over the Bay of Bengal and West Bengal, India.

In this paper, we present the path of Aila over the Bay of Bengal and the land of West Bengal, India; the effect of Aila, a severe cyclone on the amount of TOC over Bay of Bengal and the different sites of West Bengal before, during and after the cyclone from 26 April 2009 to 25 June 2009. Peak anomalies of total ozone column with respective maximum wind speed and pressure drop over different sites are also depicted. Variation of maximum total ozone decline for several latitudes at the time of maximum impact of cyclone is also represented. A possible chemical and physical explanation has been offered for such variation of TOC. Consequent damage on life, land and environment is also mentioned.

## 2.0 Data and Methodology:

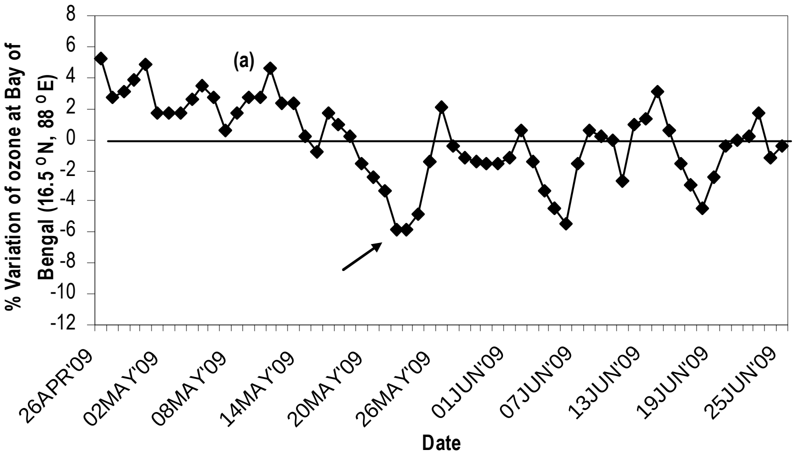
Daily average value of total ozone column (TOC) over Bay of Bengal and the land of West Bengal, India measured by the Ozone Monitoring Instrument (OMI), a nadir-viewing wide-field-imaging spectrometer, providing daily global coverage that is going on the Total Ozone Mapping Spectrometer (TOMS) record for total ozone and other atmospheric parameters related to ozone chemistry and climate has been obtained from internet website http://jwocky.gsfc.nasa.gov published from NASA, USA. OMI and the other instruments are working together effectively on the Aura platform. The OMI instrument employs hyper-spectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet that improves the accuracy and precision of the total ozone amounts and also allows for accurate radiometric and wavelength self calibration over the long term. The instrument measures Earth's backscattered radiation with a wide-field telescope feeding two imaging grating spectrometers each of which uses a convective cloud differential (CCD) detector. Onboard calibration comprises a white light source, light emitting diodes (LEDs), and a multi-surface solar-calibration diffuser. A depolarizer removes the polarization from the backscattered radiation. It can measure many more atmospheric constituents than TOMS and provides much better ground resolution than GOME (Global Monitoring Experiment) (13 km x 25 km for OMI vs. 40 km x 320 km for GOME). The instrument is a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the Aura mission. For this work, total ozone column (TOC) data were collected from OMI instrument which provides total ozone data from July 2004 to present. OMI data are gridded into one degree latitude and 1.25 degree longitude, latitude ranging from + 90$^o$ (North Pole) to -90$^o$ (South Pole).

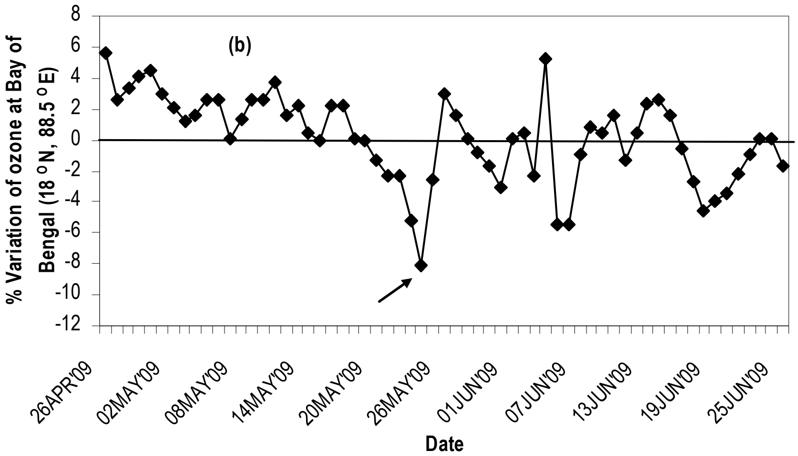
Observation of total ozone column has been made on and from 26 April, 2009 to 25 May, 2009 that comprised the time period one month before, during and after the cyclone Aila. Variation of total ozone column (X-M) for each day has been computed by subtracting the average ozone value (M) for the period from 26 April, 2009 to 25 May, 2009 from daily mean ozone value (X) which enables to calculate the percentage of ozone variation for each day [(X-M) × 100/X].

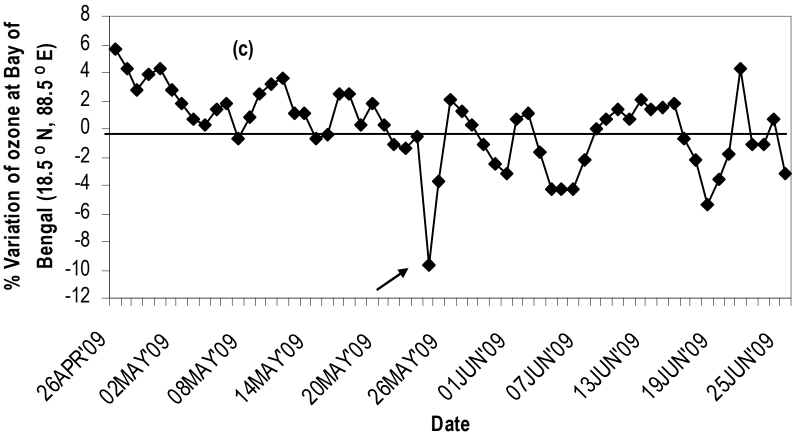
The data of cyclone wind speed and estimated pressure drop had been collected from India Meteorological Department (IMD), New Delhi. IMD has recently installed 20 High Wind Speed Recorders (HWSR) along the East and West Coasts of India. It has also installed four numbers of S-band DWRs (Doppler Weather Radar) along the east cost of India for tracking tropical cyclones and other severe weather events at Chennai and Kolkata, Machiliptanam and Visakhapatnam which were procured from Germany (Pradhan et al. 2012). HWSR has a solid-state sensor with no moving parts. The HWSR includes a data logger, a Serial to VGA converter called Viewmet, a TFT touch panel for continuous graphical display of wind direction and speed and a 36-point round LED display for distant monitoring of wind. User-friendly menu driven options facilitate easy operation. The continuous recording of the instantaneous value of wind speed and wind direction on a single chart is done so that the wind is completely described as vector quantity. Wind direction is measured and recorded by means of a wind vane and a mechanical twin pen recorder. Wind speed is measured by means of a pitot static tube and recorded by a sensitive float manometer. The DPTA has a threshold of 1 knot. It is capable of providing uninterrupted data in cyclonic prone coastal areas in severe weather conditions including high winds and heavy rains. The system is capable of measuring wind speeds up to 0-65 $ms^{-1}$ with an accuracy of 1.5 percent rms and a resolution of 0.01 $ms^{-1}$ (Mali *et al.* 2003). DWR can probe the atmosphere with very high spatial and temporal resolution. The two important products of DWR are radial reflectivity that is the backscattered radiation from any object along the radar beam in the direction of radar scan and the radial wind which is estimated from the phase delay of the backscattered radiation from moving targets. WDSS-11 (Warning Decision Support System) software is applied for detecting and removing anomalous propagation echoes from the Indian DWR data. This software is used to track storm cells and mesocyclones through successive scans. Assimilation of the quality controlled radar data of the WDSS-11 has a positive impact for improving mesoscale prediction (Roy Bhowmik *et al.* 2011). The monitoring of the DWR data is done as per other conventional data monitored at National Centre for Medium Range Weather Forecasting (NCMRWF) (i.e., ± 3 hour time window for each assimilation cycle) (George *et al.* 2011).

## 3.0 Results and Discussion:

Variations of percentages of daily total ozone column (TOC) at the sites closest to the cyclone at its peak intensity have been plotted over Bay of Bengal (15.5$^o$N to 20$^o$N) (Fig. 2a-d) and the land of West Bengal, India (21.5$^o$N to 27$^o$N) (Fig.3a-e) about one month preceding cyclone formation, during cyclone and until one month after dissipation from 26 April 2009 to 25 June 2009. Figs. 2 and 3 reveals the gradual fall of total ozone column (TOC) before and during the cyclone development, followed by a more or less build-up after dissipation of the cyclone. For severe and very severe tropical cyclone a sudden fall in ozone concentration had been noticed when the cyclone had reached its maximum intensity over the Bay of Bengal (5.83%-9.63%), the Sagar Island, Dumdum, Bardhaman, Malda and Darjeeling (5.9%-10.31%).



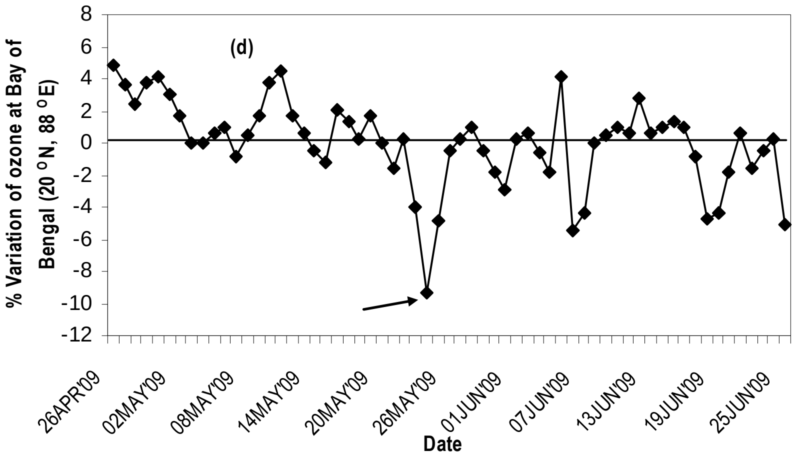
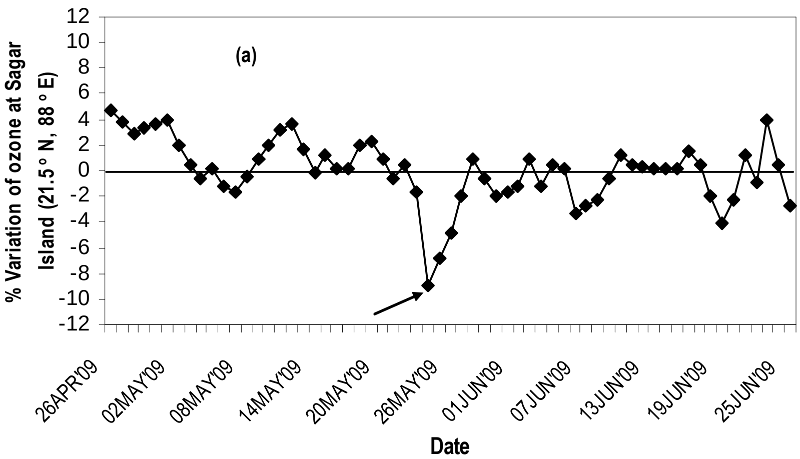
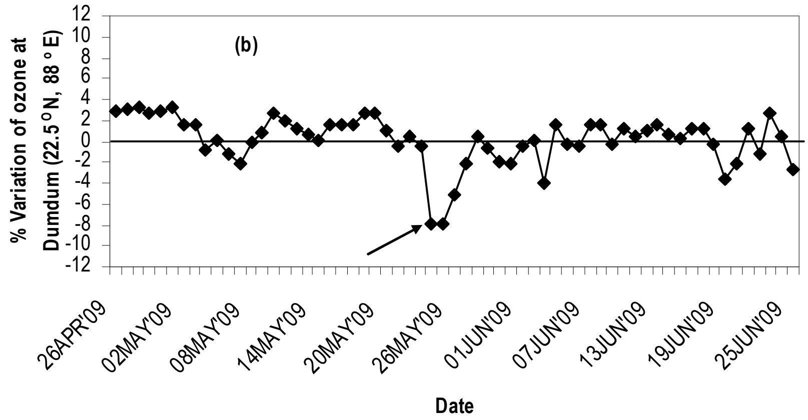
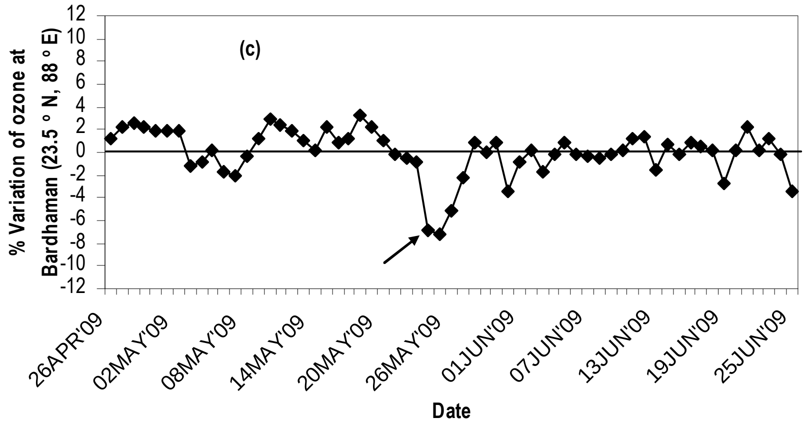


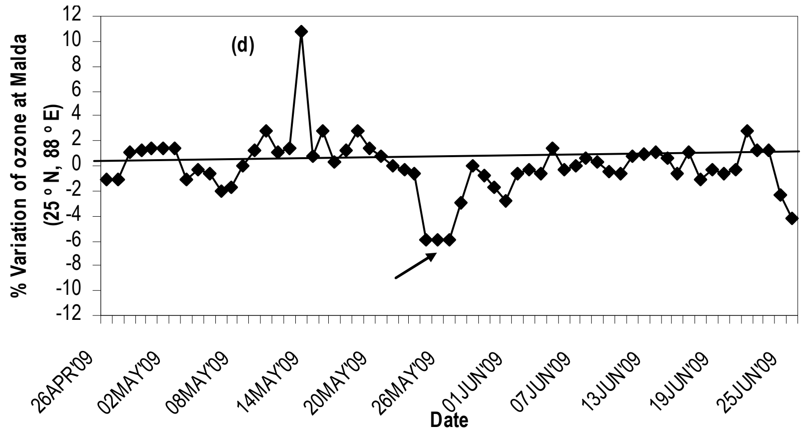

**Figure 2:** Variations of percentage of total ozone column at (a) 16.5°N and 88°E, (b) 18°N and 88.5°E, (c) 18.5°N and 88.5°E, and (d) 20°N and 88°E over the Bay of Bengal during the tropical cyclone, Aila.

Corresponding negative anomalies in total ozone column over Bay of Bengal varied from 16.33 DU to 27.06 DU, while it was 16.92 DU-29.42 DU over West Bengal as estimated respectively. Higher amount of TOC in the month of May was due to the larger formation rate of ozone than the destruction rate of ozone due to enhanced solar radiation because of smaller distance between the earth and the sun (Jana *et al*. 2012a and 2012b), while comparatively higher value of TOC over Malda and Darjeeling as shown in Fig.3d and Fig. 3e was because of greater density of oxygen than other places due to higher latitude (Jana and Nandi 2006).




(b)
% Variation of ozone at Dumdum (22.5 O N, 88 o E)
Date
26APR'09
02MAY'09
08MAY'09
14MAY'09
20MAY'09
26MAY'09
01JUN'09
07JUN'09
13JUN'09
19JUN'09
25JUN'09


(c)
% Variation of ozone at Bardhaman (23.5 o N, 88 o E)
Date
26APR'09
02MAY'09
08MAY'09
14MAY'09
20MAY'09
26MAY'09
01JUN'09
07JUN'09
13JUN'09
19JUN'09
25JUN'09


(d)
% Variation of ozone at Malda (25 o N, 88 o E)
Date
26APR'09
02MAY'09
08MAY'09
14MAY'09
20MAY'09
26MAY'09
01JUN'09
07JUN'09
13JUN'09
19JUN'09
25JUN'09

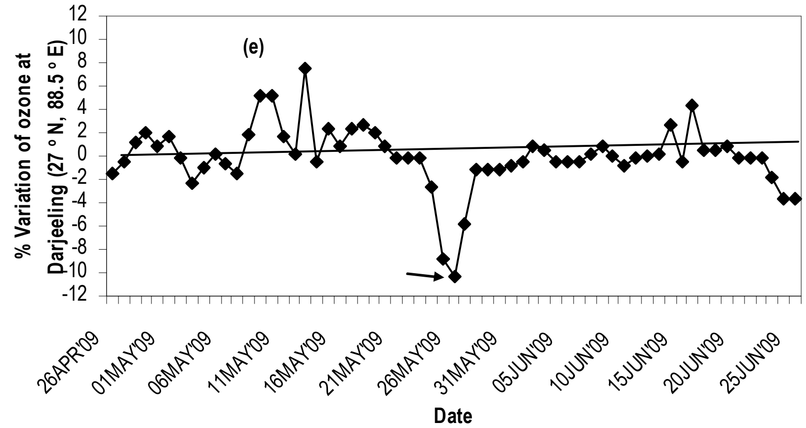



**Figure 3:** Variations of percentage of total ozone column at (a) the Sagar Island (21.5°N, 88°E), (b) Dumdum (22.5°N, 88°E), (c) Bardhaman (23.5°N, 88°E), (d) Malda (25°N, 88°E), and (e) Darjeeling (27°N, 88.5°E) over the West Bengal, India during the tropical cyclone, Aila.

An increase in the percentage drop in ozone values with the enhancement of both the surface wind (Fig. 4a) and drop in pressure (Fig. 5a) over the Bay of Bengal, but decrease in the percentage drop in ozone values, followed by the minimum value and then an increase with the enhancement of both the surface wind (Fig. 4b) and central pressure (Fig. 5b) over the land of West Bengal had been noticed.

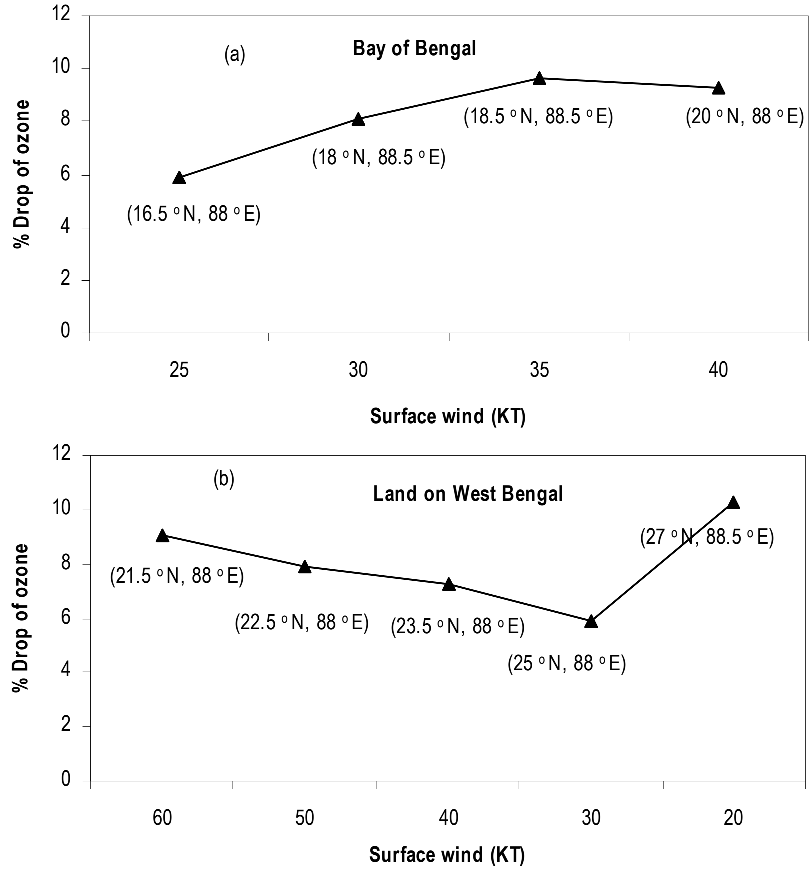



**Figure 4:** Variations of percentage drop of ozone over the (a) Bay of Bengal and (b) Land of West Bengal with the variation of surface wind speed (KT) during the tropical cyclone, Aila.

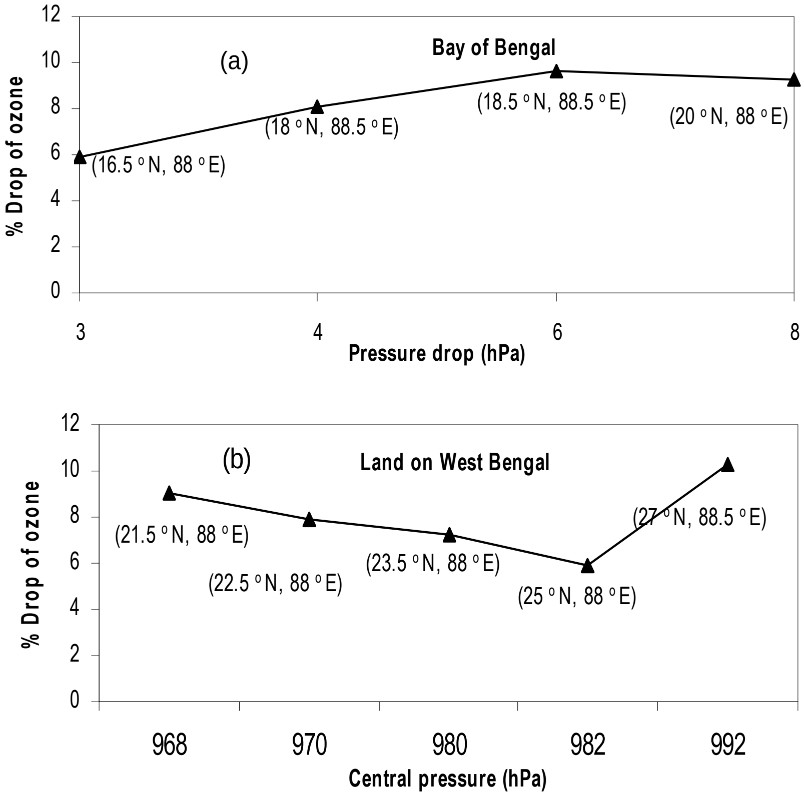



**Figure 5.** Variation of percentage drop of ozone over the (a) Bay of Bengal with variation of pressure drop (hPa) and the (b) Land of West Bengal, India with the variation of surface central pressure (hPa) during the tropical cyclone, Aila.

The percentage of total ozone column (TOC) depletion had increased from 16.5°N to 18.5°N over the Bay of Bengal, then gradually decreased to 25°N and again increased steeply to 27°N over the land of West Bengal due to the cyclone Aila at its peak intensity as revealed in Fig. 6. It also vividly indicates that the percentage of ozone depletion was the maximum over Darjeeling.

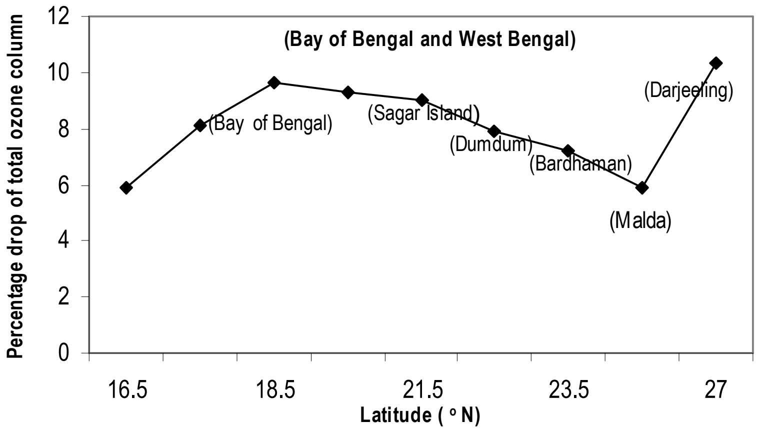



**Figure 6.** Variations of percentage drop of total ozone column with latitude (°N) during the tropical cyclone, Aila.

It is well established that the atmospheric ozone is catalytically depleted by a complex series of reactions involving NOx, ClOx and OHx catalysts. The concentration of these ozone depleting substances is partly governed by the mass exchange between the troposphere and the stratosphere. When air from the troposphere enters into the stratosphere across the equatorial tropopause, it becomes cooled to the temperature below 200K, the water vapor mixing ratio for such air would be less than of about $4.5 \times 10^{-6}$ (the saturation mixing ratio for T = 193 K and Z = 17 km). The stratospheric water vapor mixing ratios are generally in the range of $2 \times 10^{-6}$ to $4 \times 10^{-6}$, that agrees with the assumption of tropical injection.

Tropical cyclones contribute a disproportionate amount of the tropical deep convection that penetrates the tropopause (Romps and Zhiming 2010). They account for only 7 % of the deep convection in the tropics, but to 15% of the convection that reaches the stratosphere. It is also reported that the tropical cyclones could play a major role in injecting water vapor into the stratosphere. Thus, tropical cyclones can play an important role in setting the mixing ratio of stratospheric water vapor. The tropopause being the coldest part of the Earth's atmosphere acts as a barrier to the lifting of water vapor into the stratosphere. When air passes through the tropopause, it becomes so cold that most of its water vapour freezes and falls out. But very deep clouds present in tropical cyclones can penetrate the tropopause, deposit their ice in the warmer stratosphere and finally it evaporates. Sing and Sing (2007) also reported that water vapor can also be transported from the troposphere into stratosphere by shifting air currents. In the stratosphere water vapor gets photodissociated into OH radicals (Bates and Nicolet 1950) as follows:

$$H_2O + hv \rightarrow OH + H$$

$$OH + hv \rightarrow O + H$$

$$O + O + M \rightarrow O_2 + M$$

Where, M is the third body that conserves the energy and momentum of the reaction. The OH radical is also produced in the troposphere and lower stratosphere by photodissociation of nitrous and nitric acid as follows:

$$HONO + hv(\lambda = 400nm) \rightarrow OH + NO$$

$$HNO_3 + hv(\lambda = 350nm) \rightarrow OH + NO_2$$

The produced OH radical and atomic O can deplete ozone by following catalytic cycle.

$$OH + O_3 \rightarrow HO_2 + O_2$$

$$HO_2 + O \rightarrow OH + O_2$$

The produced NO combines with atmospheric oxygen to form $NO_2$. $NO_2$ is removed with rain from atmosphere as acid rain during cyclone. The tropical cyclone which originated on Bay of Bengal had carried huge amount of water vapor from the Indian Ocean, Arabian Ocean and Bay of Bengal washed down most of the pollutants from troposphere through various processes of precipitation that were responsible for tropospheric ozone formation. Large appearance of clouds that allowed lesser amount of solar radiation to enter into the troposphere contributed less to the tropospheric ozone formation leading the steeply decline in tropospheric ozone density during this cyclone. Davis *et al.* (1996) had reported that the marine air carried significant amount of iodine compounds from oceans that directly depleted atmospheric ozone as follows:

$$2(I + O_3 \rightarrow IO + O_2)$$

$$IO + IO \rightarrow 2I + O_2$$

$$NET: 2O_3 \rightarrow 3O_2$$

$$I + O_3 \rightarrow IO + O_2$$

$$IO + HO_2 \rightarrow HOI + O_2$$

$$HOI + hv \rightarrow I + OH$$

$$NET: O_3 + HO_2 \rightarrow 2O_2 + OH$$

Climate change which is greatly caused by greenhouse gases can also influence atmospheric ozone by heating the upper troposphere and the lower stratosphere (Tzanis and Varotsos 2008) and cooling the upper stratosphere (ice house effect). The rise in temperature in the lower stratosphere speeds up the chemical reaction. As a result, ozone is destructed at a faster rate (Midya *et al.* 2012).

The ozone anomalies move with the cyclonic system and the magnitude depends on the intensity of the cyclone, so the correlation between the intensity of cyclone and the maximum ozone fall is quite expected at a particular place (Singh and Nair 2008). In the mature stage of cyclone, an outflow develops in the upper levels with high radial velocities that can extend beyond tropopause up to the lower stratosphere. As a result, the total ozone column (TOC) can also be reduced due to the removal of ozone with the outflow.

The main factors that affect the atmospheric radiative transfer at wavelengths important for ozone budget are the solar radiation, solar zenith angle, absorption by stratospheric ozone, reflection from the surface and clouds. Solar radiation is the most in the month of May due to the least distance between the earth and the sun. Solar zenith angles are small in the tropics and in such cases the increases in photolysis rates start at the lowest part of the clouds (Jana *et al.* 2012a). The lowest value of the total ozone column (TOC) during cyclone, Aila at its peak intensity over the Bay of Bengal, Sagar Island, Kolkata, Bardhaman, Malda and Darjeeling as shown in Figs. 2 and 3 was due to the large amount of water vapor injected into the stratosphere from troposphere through the processes of convection during cyclone which was mostly photodissociated into OH and atomic O by intense solar radiation in the upper and lower stratosphere leading to severe depletion of stratospheric ozone. Furthermore, below the cloud the rate of formation of tropospheric ozone had been decreased, while above it, the rate of ozone decline had been enhanced by the cloud due to backscattering. Besides, stratospheric ozone rich air had been gradually replaced by tropospheric ozone poor air through the upward transport of air before and during cyclone. Continuous fall in total ozone column (TOC) over the Bay of Bengal from 16.5 $^{o}$N latitude to 20.5$^{o}$N latitude as depicted in Fig. 4 had been observed as a result of gradual increasing trends of ozone rich air outflow and ozone poor air inflow from the surroundings induced by enhanced surface wind speed and drop of pressures. Again the decrease in percentage drop of total ozone column from 21.5$^{o}$N to 25$^{o}$N was due to the gradual decrease in surface wind speed. But, the maximum drop in total ozone column (TOC) over Darjeeling (27$^{o}$N) was due to the absence of pollutants that acted as ozone precursor and outflow of ozone rich air in the stratosphere caused by Jet stream in addition to cyclone.

## 4. 0 Conclusions:

The total ozone column (TOC) was declined sharply over the Bay of Bengal and the land of West Bengal from 22 May 2009 to 26 May 2009 during the passing of tropical cyclone, Aila at its peak intensity by (5.9%-10.31%). Corresponding negative anomalies in daily total total ozone column varied from 16.92 DU to 29.42 DU. A correlation existed between the maximum wind speed and low pressures with the depletion of total ozone column (TOC). The decline of the total column ozone had increased over the Bay of Bengal as well as on the land of West Bengal with the increase of surface wind velocity and pressure drop except over the site of Darjeeling due to the enhanced outflow of tropospheric and stratospheric ozone rich air, the increased rate of ozone destruction processes induced by more amount of OHx radicals which was obtained from photodissociation of water vapor and large appearance of iodine rich marine air. The steep decline of total ozone column (TOC) over Darjeeling was attributed to the very little amount of tropospheric pollutants that acted as ozone precursor and outflow of ozone rich air in the stratosphere caused by Jet stream in addition to cyclone. Thus, the quantitative measure of ozone may be the another indicator for qualifying and even prediction for tropical cyclone over the Bay of Bengal and the land of West Bengal, India with the essential requirements for the genesis of tropical cyclones, viz. low-level relative vorticity, minimum Coriolis force, minimum vertical wind shear, minimum thermal potential energy, minimum temperature, minimum equivalent potential temperature difference etc.

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