

# Atmospheric Ozone And Its Biosphere - Atmosphere Exchange In A Mangrove Forest Ecosystem: A Case Study From Sundarbans, NE Coast Of India

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**ABSTRACT:** Temporal variation of atmospheric O<sub>3</sub> and its biosphere – atmosphere exchange were monitored in the Sundarbans mangrove forest from January 2011 to December 2011 on bimonthly basis. O<sub>3</sub> mixing ratios at 10 m and 20 m heights over the forest atmosphere ranged between 14.66 ± 1.88 to 37.90 ± 0.91 and 19.32 ± 6.27 to 39.80 ± 10.13 ppbv, respectively; having maximal premonsoon and minimal monsoon periods. Average daytime O<sub>3</sub> mixing ratio was 1.69 times higher than nighttime; indicates significant photo chemical production of O<sub>3</sub> in forest atmosphere. Annual averaged O<sub>3</sub> mixing ratio in 10 m height was 13.2 % lower than 20 m height; induces exchange of O<sub>3</sub> across mangrove biosphere – atmosphere interface depending upon micrometeorological conditions of the forest ecosystem. Annual average biosphere – atmosphere O<sub>3</sub> exchange flux in this mangrove forest environment was – 0.441 μg m<sup>-2</sup> s<sup>-1</sup>. Extrapolating the value for entire forest surface area, the mangrove ecosystem acts as a sink of 58.4GgO<sub>3</sub> annually, indicating significant contribution of Sundarbans mangroves towards regional atmospheric O<sub>3</sub> budget as well as climate change.

**KEYWORDS:** atmosphere, exchange flux, India, mangrove, micrometeorology, ozone, Sundarbans.

## 1. Introduction:

After CO<sub>2</sub> and CH<sub>4</sub>, ozone (O<sub>3</sub>) is the third most important greenhouse gas in the earth's atmosphere, having a radiative forcing of + 0.35 Wm<sup>-2</sup> (IPCC, 2001). Each additional molecule of O<sub>3</sub> produced in the atmosphere is 1200 - 2000 times more effective in global warming than an additional CO<sub>2</sub> molecule (Lal et al., 2007). Moreover, oxidizing capacity of the atmosphere is highly influenced by tropospheric O<sub>3</sub> level both through its direct role and through its role as a precursor of the OH radical, which act as initiator of most atmospheric photochemical transformations (Chand and Lal, 2004; Reddy et al., 2008b). Being a potent green house gas and significantly correlated to atmospheric photochemistry, it is a subject of great interest to study atmospheric O<sub>3</sub> which at certain ambient levels may cause damages to vegetation as well as human beings (Finlayson-Pitts and Pitts, 1997; Hogsett et al., 1997). In the forest environment, O<sub>3</sub> is not directly emitted into the atmosphere and it is produced through a complex set of photochemical transformation processes involving NO<sub>x</sub> (NO + NO<sub>2</sub>) and volatile organic compounds (VOCs) (Fishman and Crutzen, 1978).

In particular, formation of O<sub>3</sub> in the atmosphere critically depends on ambient NO levels when NO concentrations reach to its critical limit (10 pptv) (Lin et al., 1988). Additionally, the formation of HO<sub>2</sub> and RO<sub>2</sub> in the atmosphere through coupled interactions between CO, NO<sub>x</sub> and VOC with OH radical also promote O<sub>3</sub> production in the forest atmosphere (Sillman, 1999). Along with the photochemical O<sub>3</sub> production occurring in the mangrove atmosphere, micrometeorological variables especially sunlight, cloud cover and water vapor concentration play a decisive role in production and distribution of O<sub>3</sub> in the atmosphere. Decreasing sunlight restrains the production of free radicals in the forest atmosphere inhibiting atmospheric photochemical O<sub>3</sub> production (Sillman, 1999). In addition, dry deposition of O<sub>3</sub> on vegetation, water and stratospheric - tropospheric O<sub>3</sub> exchange also contribute partially to regional atmospheric O<sub>3</sub> budget. Dynamics of atmospheric O<sub>3</sub> and its controlling factors have been previously reported by several researchers but till now there is a scarcity of published report on forest ecosystem, especially no reports are available on mangrove forest ecosystem. The primary objective of this paper is to report atmospheric O<sub>3</sub> level and its biosphere – atmosphere exchange in a tropical mangrove forest environment, the Sundarbans. Beyond this primary objective another objective was to study micrometeorological influence on atmospheric O<sub>3</sub> distribution and its biosphere – atmosphere exchange flux.

## 2. Study area:

Sundarbans (21°32' and 22°40'N : 88°05' and 89°E) is the largest mangrove forest in the world situated at the land ocean boundary of Ganges-Brahmaputra delta and the Bay of Bengal having an area of 10,200 sq km of which, 41% Reserved Forest is spread over India and the rest is in Bangladesh. The Indian part of Sundarbans is extended over an area of 9600 sq km which is demarcated as Sundarbans Biosphere Reserve constituting of 4200 sq km. mangrove reserve forest, 1800 sq. km estuarine waterways and 3600 sq. km. reclaimed areas. The Indian part of the Sundarbans (Fig.1) is crisscrossed by the estuarine phases

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of several rivers namely Mooriganga, Saptamukhi, Thakuran, Matla, Bidya, Gosaba and Haribhanga forming a large number of discrete islands. One of these Islands is the Lothian Island, covering an area of 38 km<sup>2</sup> has been notified as a sanctuary and is situated at the confluence of Saptamukhi river and Bay of Bengal. Mangrove like *Avicennia alba*, *Avicennia marina* and *Avicennia officinalis* are the dominant species, *Excoecaria agallocha* and *Heritiera fomes* are thinly distributed and *Ceriops decandra* is found scattered all over the island. Mangrove plants rarely exceed 10 m in height, and the over-forest trajectory of the wind (fetch) is about 15 km. The Sundarbans has a typical tropical climate having three seasons with four months duration for each season as follows; premonsoon (February - May), monsoon (June - September) and postmonsoon (October - January). The present study has been carried out in the Lothian Island, which can be ideally taken as a representative of Sundarbans mangroves to study atmospheric O<sub>3</sub> and its biosphere – atmosphere exchange flux.

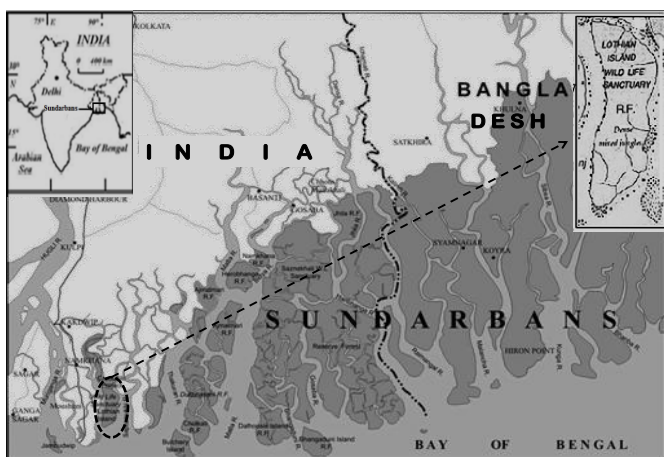


Fig.1: Map Showing location of the study point.

### 3. Materials and methods:

The present study was carried out from January 2011 to December 2011 on bimonthly basis covering diurnal variation in every 3 hours. The atmospheric O<sub>3</sub> samples along with micrometeorological data were collected from 10 m and 20 m height of a watch tower located in the middle of the Lothian Island (21° 42' N and 88° 18' E).

#### 3.1 Analytical method for estimation of atmospheric O<sub>3</sub> mixing ratio:

Air samples were drawn through 15 ml of absorbing solution (0.5% solution of 1, 2 – di - (4 - pyridyl) ethylene in glacial acetic acid) for 0.5 h at 0.5 Lmin<sup>-1</sup>. Absorbed solution were properly sealed and stored in ice box during transportation to the laboratory. In the laboratory to 10 ml of the solution, 1 ml of the color-developing reagent (0.2 % aqueous solution of 3-methyl-2-benzothiazolinone hydrazone hydrochloride) was added and heated in a boiling water bath for 20 min followed by cooling at room temperature led to formation of yellow-colored azine complex. Standard solutions of concentrations ranging between 0.0 and 10.0 µg of pyridine – 4 - aldehyde per milliliter in glacial acetic acid were used for calibration. Non-aerated blanks were prepared from absorbing solution that

stood in the field for the same length of time as the absorbing solution used in sampling. Finally, the absorbance was measured at 442 nm against the blank solution (Hauser and Bradley, 1966) using double beam UV- visible spectrophotometer (Systonics UV-VIS spectrophotometer 117) and the concentration empirically calculated considering 1.0 mg of O<sub>3</sub> per milliliter of absorbing solution generates 2.75 mg of pyridine - 4 - aldehyde per milliliter of absorbing solution. A precision of ± 1 % and a sensitivity of 0.0 – 3.65 µg of O<sub>3</sub> per milliliter of absorbing solution were obtained. To minimize sampling and analytical error, each method was calibrated before the measurement of collected samples.

#### 3.2: Micrometeorology and biosphere - atmosphere O<sub>3</sub> exchange flux:

Meteorological variables (temperature, wind speed and relative humidity) related to this study were simultaneously recorded using portable weather monitor (Model: Davis 7440) and the data was used to calculate other micrometeorological indices like friction velocity (u\*) and roughness height (Z<sub>0</sub>). Biosphere - atmosphere O<sub>3</sub> exchange flux (F<sub>O<sub>3</sub></sub>) was calculated using the following relation (Barrett, 1998):

$$F_{O_3} = V_c \Delta\chi.$$

Where,  $\Delta\chi$  = difference of mixing ratio of O<sub>3</sub> between 10 and 20 m height and  $V_c$  = exchange velocity which is defined as  $1/(r_a + r_s)$  [Where,  $r_a$  = aerodynamic resistance and  $r_s$  = surface layer resistance]. Negative flux indicates net transfer from the atmosphere to the biosphere and vice versa. Storage rate of O<sub>3</sub> during stable condition in the forest atmosphere was computed as follows (Fowler and Duyzer, 1989):  $\Delta O_3(\text{storage}) = \partial C / \partial t (Z_2 - Z_1)$ .

### 4. Results and discussion:

#### 4.1 Seasonal variation of O<sub>3</sub> mixing ratio in forest atmosphere:

Seasonal variations of O<sub>3</sub> mixing ratio over the forest atmosphere were found to be very clear and systematic. O<sub>3</sub> mixing ratios at 10 m and 20 m heights over the forest atmosphere ranged between  $14.66 \pm 1.88$  to  $37.90 \pm 0.91$  and  $19.32 \pm 6.27$  to  $39.80 \pm 10.13$  ppbv, respectively; having maximal premonsoon and minimal monsoon, periods. The concentrations measured in this mangrove forest environment were within the range of that reported by Wolfe et al., 2011 for forest ecosystems. The maximal premonsoon O<sub>3</sub> mixing ratio may be attributed to presence of favorable conditions for atmospheric O<sub>3</sub> formation like high temperature, high intensity of solar radiation and sufficiently high mixing ratio of NO/NO<sub>x</sub> ( $5.23 \pm 0.7$  ppbv; Ganguly et al., 2009). A very similar phenomenon was previously reported by Naja and Lal, 2002. Moreover, during premonsoon there is also the enhanced possibility of O<sub>3</sub> transport from the stratosphere resulting significant enrichment of atmospheric O<sub>3</sub> mixing ratio in forest atmosphere (Reddy et al., 2010). In contrast to premonsoon, minimal monsoon O<sub>3</sub> mixing ratio may be due to insufficient sunlight for photolysis of O<sub>3</sub> precursor species as well as massive rainfall promoting wet deposition of O<sub>3</sub>

on water droplets in this tropical forest ecosystem (Tarasova et al., 2003).

#### 4.2 Diurnal variation and changes of O<sub>3</sub> concentration during daytime/nighttime:

The diurnal variation of O<sub>3</sub> in the mangrove forest atmosphere is characterized by higher mixing ratios during daytime (14.36 – 54.99 and 15.40 – 49.35 ppbv for 10 m and 20 m heights, respectively) compare to nighttime (2.18 – 32.79 and 6.69 – 33.78 ppbv for 10 m and 20 m heights, respectively). On annual basis daytime O<sub>3</sub> mixing ratio was 1.69 times higher than nighttime. During daytime presence of intense solar radiation promotes NO<sub>2</sub> photolysis rate in the forest atmosphere producing atomic oxygen in an energetically excited state. In the next step of the reaction sequence, the atomic oxygen produces two OH radicals which in turn favor photochemical production of O<sub>3</sub> in the atmosphere (Crutzen et al., 1995). Moreover, Seinfeld and Pandis, 1998 reported significant photo-production of O<sub>3</sub> from oxidation of natural and anthropogenic hydrocarbons, carbon monoxide (CO), and methane (CH<sub>4</sub>) by hydroxyl radical in the presence of sufficient amount of NO<sub>x</sub>. In addition to this chemical transformation, during daytime due to convective heating there occurs downward transport of O<sub>3</sub> from upper atmosphere enriching O<sub>3</sub> mixing ratio in the lower atmosphere of this tropical mangrove forest to a considerable level (Lal et al., 2000). The low nighttime O<sub>3</sub> concentrations principally may be attributed to the absence of NO<sub>2</sub> photolysis. Moreover, formation of night inversion layer and a rapid reaction between O<sub>3</sub> and NO<sub>x</sub> titration during nighttime may result a steady decrease of O<sub>3</sub> mixing ratio in this tropical forest atmosphere (Tyson et al., 1998). In order to compute increase rate of atmospheric O<sub>3</sub> from nighttime to daytime we have divided the total 24 hours time span as 07:00 - 19:00 h as daytime and 19:00 - 07:00 h as nighttime. The change of O<sub>3</sub> concentration from nighttime to daytime varied between 0.57 – 2.07 and 0.70 – 1.41 ppbv hr<sup>-1</sup> at 10 m and 20 m height, respectively (table – 1); having an annual average of 1.15 ppbv hr<sup>-1</sup>. The O<sub>3</sub> increment rate calculated for this site was in the range of that reported by Reddy et al., 2010 at Anantapur, South India. Storage rate of O<sub>3</sub> between 10 m and 20 m heights of the forest atmosphere varied between 9.34 x 10<sup>-5</sup> to 1.54 x 10<sup>-3</sup> µg m<sup>-2</sup> s<sup>-1</sup> with an annual average of 9.06 x 10<sup>-4</sup> µg m<sup>-2</sup> s<sup>-1</sup>.

Table – 1: Average O<sub>3</sub> mixing ratios at Sundarbans mangrove forest during nighttime (19:00–07:00 h) and daytime (07:00– 19:00 h) and its increase rate for the study period.

Seasons	Height (m)	[O <sub>3</sub> ] <sub>daytime</sub> (ppbv)	[O <sub>3</sub> ] <sub>Nighttime</sub> (ppbv)	Increase O <sub>3</sub> rate (ppbv/hr)
Premonsoon	10	45.39 ± 7.27	29.46 ± 3.82	1.33
	20	41.98 ± 7.72	33.62 ± 11.55	0.70
Monsoon	10	16.52 ± 2.43	9.70 ± 3.26	0.57
	20	24.43 ± 2.17	14.21 ± 4.18	0.85
Postmonsoon	10	37.40 ± 7.39	12.57 ± 11.59	2.07
	20	37.81 ± 8.81	20.90 ± 10.29	1.41

#### 4.3 Impact of micrometeorology on atmospheric O<sub>3</sub> mixing ratio:

Meteorology plays an important role in production and transportation of O<sub>3</sub> in the forest atmosphere. As a result, substantial variations in meteorological conditions can exert such a large impact on atmospheric O<sub>3</sub> concentrations. Seasonal variations of micrometeorological parameters are presented in table – 2. Temperature at 10 m height of the forest atmosphere was varied between 17.34 ± 4.09 and 30.34 ± 0.91°C being maximal premonsoon and minimal postmonsoon periods. Following same trend of seasonal variation temperature at 20 m height over the forest atmosphere was varied between 16.17 ± 1.80 and 29.73 ± 1.13°C. The ratio between air temperature at 10 m and 20 m height was computed as 1.04:1, indicating higher temperature in 10 m height compare to 20 m. This may be attributed to dry adiabatic lapse rate, which states that adiabatic expansion of a parcel of air as it rises; air raised to higher altitudes has a lower temperature than the air of the same composition and initial temperature at lower altitude. In order to evaluate the influence of air temperature on atmospheric O<sub>3</sub> mixing ratio a simple regression analysis was done between these two variables assessing different functional, linear, multiplicative, exponential and reciprocal dependencies. Statistical analysis revealed that these two variables were best fitted by the following exponential equation as follows (Fig.2):

$$[O_3] = 0.477 e^{0.1498T} \quad (R^2 = 0.41, n = 22)$$

The correlation coefficient explains 41% variability between these two dependent and independent variables; indicates partial impact of air temperature or indirectly solar radiation on variation of atmospheric O<sub>3</sub> mixing ratio in this tropical mangrove forest atmosphere. The relationship between O<sub>3</sub> concentration and temperature can be explained on theoretical grounds. High temperature promotes propagation rate of the radical chain in the atmosphere (Ruiz - Suarez et al., 1995) producing higher O<sub>3</sub> in the forest atmosphere.

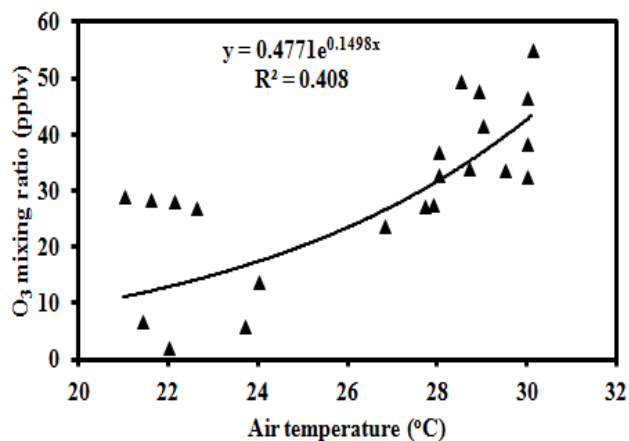


Fig.2: Scattered plot between O<sub>3</sub> mixing ratio and air temperature

Wind velocity during the survey period varied between 0.41 ± 0.36 and 1.32 ± 1.11 ms<sup>-1</sup> having maximal monsoon and

minimal postmonsoon periods. Following same trend for seasonal variation average wind velocity in 20 m height in the forest atmosphere was 1.40 times higher than 10 m height.

Table – 2: Seasonal variation of O<sub>3</sub> mixing ratio and other micrometeorological parameters over Sundarbans mangrove forest atmosphere.

Parameters	Height (m)	Premonsoon	Monsoon	Postmonsoon
O <sub>3</sub> mixing ratio (ppbv)	10	37.90 ± 0.91	14.66 ± 1.88	25.60 ± 4.89
	20	39.80 ± 10.13	19.32 ± 6.27	29.36 ± 12.66
Air temp (°C)	10	30.34 ± 0.91	29.74 ± 2.50	17.34 ± 4.09
	20	29.73 ± 1.13	28.37 ± 0.88	16.17 ± 1.80
Wind velocity (ms <sup>-1</sup> )	10	0.70 ± 0.42	1.32 ± 1.11	0.41 ± 0.36
	20	0.95 ± 0.44	1.64 ± 1.37	0.80 ± 0.88
Humidity (%)		86.75 ± 2.60	78.03 ± 17.31	74.79 ± 2.55
u* (ms <sup>-1</sup> )		0.20 ± 0.04	0.15 ± 0.15	0.17 ± 0.49
Z <sub>0</sub> (m)		3.77 ± 3.01	1.63 ± 1.02	2.97 ± 2.98

It is known that there is a clear relationship between ambient air quality and wind speed and wind direction. Duenas et al., 2002 reported the influence of wind speed and wind direction for the dispersion and transport of O<sub>3</sub> and its precursors from their emission sources which insisted us to carry out a statistical analysis between O<sub>3</sub> concentration and respective wind velocity of the study site (Fig.3). The relationship between atmospheric O<sub>3</sub> mixing ratio and wind velocity (V) was best fitted with the following regression equation as follows:

$$[O_3] = 17.565 \ln V + 33.76 \quad (R^2 = 0.50, n = 21)$$

The equation explains 50% variability between these two parameters indicating moderate impact of wind velocity on distribution of atmospheric O<sub>3</sub> in this tropical forest atmosphere by the process of dispersion or transportation. The reason for this partial influence may be attributed to insufficient wind dynamics and local wind circulation patterns that could not make any alteration on the dispersion and transportation of surface O<sub>3</sub>. A similar phenomenon was noticed by Elampari et al., 2011 at tropical semi – urban site, Nagercoil, India.

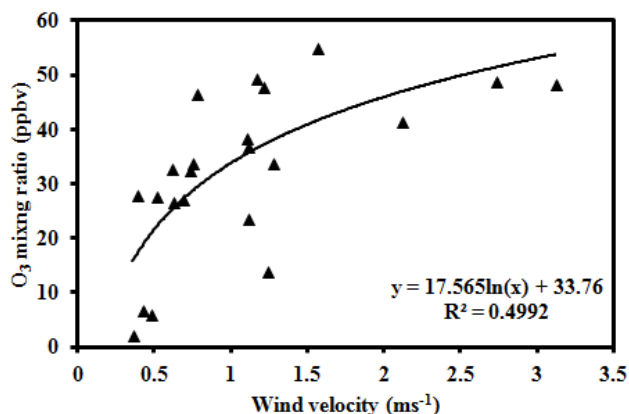


Fig.3: Scattered plot between O<sub>3</sub> mixing ratio and wind velocity

Relative humidity during the observation period varied between 74.79 ± 2.55 and 86.75 ± 2.60 % being maximal premonsoon and minimal postmonsoon periods. Atmospheric O<sub>3</sub> mixing ratio was best fitted with relative humidity (H) of the study site with the following regression equation as follows (Fig.4):

$$[O_3] = - 1.0645 H + 116.46 \quad (R^2 = 0.14, n = 21)$$

The correlation coefficient indicates insignificant negative correlation between these two variables; indicates enhancement of photo-chemically O<sub>3</sub> removal pathway with increment of percentage of relative humidity in the atmosphere. A similar correlation was previously reported by Elampari et al., 2011. Values of other micrometeorological indices like friction velocity (u\*) and roughness height is presented in table – 2.

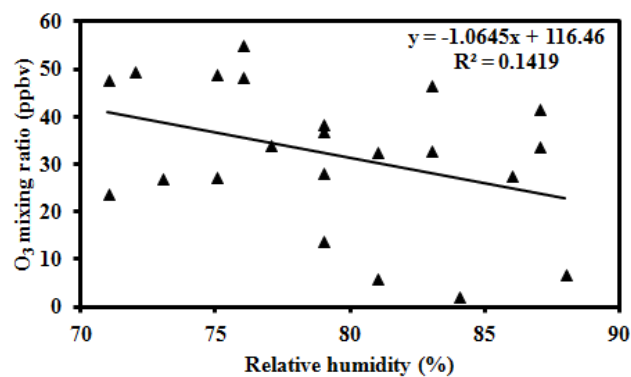


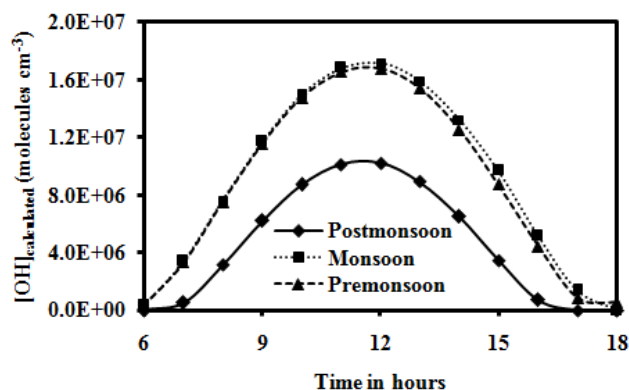
Fig.4: Scattered plot between O<sub>3</sub> mixing ratio and relative humidity

#### 4.4 Photolysis frequency of O<sub>3</sub> and computation of atmospheric OH radical concentration:

From hourly deviation of solar zenith angle (x) in this tropical mangrove forest photolysis frequency of O<sub>3</sub> [J(O<sup>1</sup>D)] was computed as follows (MCM version 3):

$$J(O^1D) = 6.073 \times 10^{-5} \cos x^{1.743} \exp(-0.474 \sec x)$$

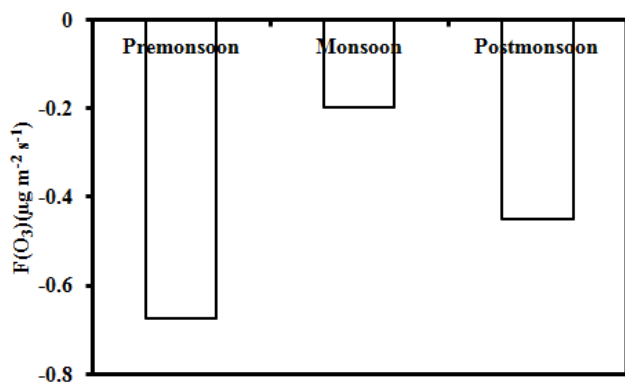
The value of J(O<sup>1</sup>D) was computed between 8.54 × 10<sup>-8</sup> - 3.58 × 10<sup>-5</sup>, 1.14 × 10<sup>-7</sup> - 3.71 × 10<sup>-5</sup> and 2.21 × 10<sup>-12</sup> - 1.72 × 10<sup>-5</sup> s<sup>-1</sup> for premonsoon, monsoon and postmonsoon, respectively; having an average of 1.32 × 10<sup>-5</sup> s<sup>-1</sup>. From the values of J(O<sup>1</sup>D), OH radical concentration in this forest atmosphere was computed using empirical equation ([OH] = a J(O<sup>1</sup>D)<sup>b</sup>) (Ehalt and Rohrer, 2000) and the value of 'a' (1.77 × 10<sup>10</sup> s cm<sup>-3</sup>) and 'b' (b = 0.68) were taken from Berresheim et al., 2003. Using the empirical relation OH radical concentration in this forest atmosphere was varied between 2.76 × 10<sup>5</sup> - 1.68 × 10<sup>7</sup>, 3.37 × 10<sup>5</sup> - 1.72 × 10<sup>7</sup> and 2.10 × 10<sup>2</sup> - 1.02 × 10<sup>7</sup> molecules cm<sup>-3</sup> for premonsoon, monsoon and postmonsoon, respectively (Fig.5); having an average of 7.40 × 10<sup>6</sup> molecules cm<sup>-3</sup>.



**Fig.5:** Diurnal variation of OH radical concentration at 10 m height in mangrove forest

#### 4.4 Biosphere - atmosphere O<sub>3</sub> exchange flux in forest ecosystem:

Comparing vertical distribution of O<sub>3</sub> in the forest atmosphere, it was evident that average O<sub>3</sub> mixing ratio at 10 m height was 13.2 % lower than 20 m height; induces biosphere - atmosphere O<sub>3</sub> exchange in the mangrove forest atmosphere depending upon micrometeorological conditions of the study site. Biosphere - atmosphere O<sub>3</sub> exchange fluxes in this tropical mangrove forest atmosphere varied between - 0.675 to - 0.197  $\mu\text{g m}^{-2} \text{s}^{-1}$  (Fig.6); having maximal premonsoon and minimal monsoon periods. Annual average biosphere - atmosphere O<sub>3</sub> exchange flux was - 0.441  $\mu\text{g m}^{-2} \text{s}^{-1}$ ; indicates the ecosystem acts as a net sink for atmospheric O<sub>3</sub> during the survey period.



**Fig.6:** Seasonal variation of biosphere - atmosphere O<sub>3</sub> exchange flux in mangrove ecosystems.

The sink of atmospheric O<sub>3</sub> may be explained by considering physical as well as biological activities operating in the forest ecosystem. The biological activity mainly involves O<sub>3</sub> uptake through leaf stomata and the fact has been reported previously by very few researchers (Kozlowski et al., 1991). Moreover, aperture of the plant leaf stomata being strongly correlated with air temperature which insisted us to carry out a statistical analysis (using MINITAB version 17) between air temperature (T) and biosphere - atmosphere O<sub>3</sub> flux (F<sub>O<sub>3</sub></sub>). These two variables were best fitted by second order polynomial equation as given below:

$$F_{O_3} = 1.44 - 0.153 T + 0.00325 T^2 \quad (R^2 = 59.3\%, F = 8.73, p = 0.005, n = 15)$$

The equation revealed significant correlation between dependent and independent variables with 59.3% variability indicating significant influence of air temperature on variability of O<sub>3</sub> exchange flux in this mangrove forest environment. However, mangrove and terrestrial plants stomatal physiology might differ in their stomatal response to O<sub>3</sub> dynamics because of high salt stress on the biochemical reaction system in mangroves. Among all the physical processes operating in this tropical forest ecosystem, dry deposition of O<sub>3</sub> on mangrove vegetation, water other material is the most active pathway for removal of O<sub>3</sub> from regional atmosphere. Average compensation point (where emission balances deposition i.e. net biosphere-atmosphere O<sub>3</sub> flux is zero) for O<sub>3</sub> in this subtropical mangrove forest was calculated to be 3.966 ppbv. Extrapolating the average biosphere - atmosphere flux rate over entire forest surface area, the ecosystem acts as a sink of 58.4Gg O<sub>3</sub> annually; indicates significant response of this mangrove forest towards regional atmospheric O<sub>3</sub> budget as well as climate change.

#### 5. Conclusion:

Distribution of O<sub>3</sub> in the forest atmosphere was partially regulated by micrometeorological processes operating in the atmosphere. Average mangrove biosphere - atmosphere O<sub>3</sub> exchange flux was - 0.441  $\mu\text{g m}^{-2} \text{s}^{-1}$  and fluxes were significantly regulated by air temperature. Total uptake of O<sub>3</sub> in this mangrove forest ecosystem was 58.4Gg on annual basis indicating significant contribution of Sundarbans mangroves towards reducing burden of atmospheric O<sub>3</sub>.

#### 6. Acknowledgment:

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