

Variation of water vapor and CO₂ at Goa during ARMEX phase-I and II

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सार – राष्ट्रीय अंटार्कटिक और महासागर अनुसंधान केन्द्र (एन. सी. ए. ओ. आर.) वास्को डिगामा, गोआ, के परिसर में अरब सागर मानसून प्रयोग (आरमेक्स) के रूप में, 9 मी. ऊँची सूक्ष्म मौसम वैज्ञानिक मीनार पर 5 मी. ए. जी. एल. से कार्बनडाइऑक्साइड और जलवाष्प के द्रव्यमान घनत्व के उतार चढ़ाव मापे गए। खुलापथ अवरक्त (आई. आर.) हाइग्रोमीटर (एल. आई. – 7500) का उपयोग 10 प्रति सेकेंड की दर से नमूने इकट्ठा करने के लिए किया गया। आरमेक्स के चरण – I (जून–सितंबर, 2002) चरण – II (मार्च, अप्रैल, मई, जून, 2003) में प्रत्येक माह के 3 दिनों के लिए दैनिक परिवर्तन का अध्ययन करने हेतु कार्बनडाइऑक्साइड और जलवाष्प के घंटेवार औसत मान का उपयोग किया गया।

ABSTRACT. Mass density fluctuations of CO₂ and water vapor were measured at 5 m above ground level (agl) on a 9 m high micrometeorological tower in the premises of the National Centre for Antarctic and Ocean Research (NCAOR) Vasco da Gama, Goa, as a part of the Arabian Sea Monsoon Experiment (ARMEX). Open path Infra Red (IR) Hygrometer (LI – 7500) was used to collect samples at a rate of 10 per second. Hourly averaged values of CO₂ and water vapor were used to study the diurnal variation for 3 days every month in ARMEX phase-I (June-September 2002) and phase-II (March, April, May, June 2003).

Key words – ARMEX, Goa, Boundary layer, CO₂, Water vapor.

1. Introduction

Natural mechanism for the production and absorption of CO₂ has spatial, diurnal, seasonal and inter annual variability. So the study of spatial and temporal variability of concentration of CO₂ in the atmosphere is necessary. Atmospheric Boundary Layer (ABL) is a region in which we find sources and sinks of CO₂. Hence it is necessary to understand the spatial and temporal variation of CO₂ concentration and its variation with topography, climatic zone, vegetation etc. In India studies on both observational and modeling of ocean CO₂ are of late in progress since 1989. Studies by Sarma *et al.*, (1998); Poisson *et al.*, (1993); Takahashi (1989) and Louanchi *et al.*, (1996) showed Indian Ocean to be a net sink of atmospheric CO₂. Takahashi, (1989) and Tans *et al.*, (1990) found that North Indian Ocean is rich in oceanic CO₂ than atmospheric CO₂. Notwithstanding, atmospheric CO₂ studies in India are a few. Observational studies on the natural variability of CO₂ and its fluxes in both space and time over the Indian region is required for assessment of pollution and in global warming studies.

The present study describes the variation of CO₂ and water vapor observed using an open path H₂O/ CO₂ Gas analyzer/IR Hygrometer (LI – 7500) at 10Hz sampling rate. Diurnal and seasonal variation of CO₂ and water vapor are discussed.

2. Topography of the site

A 9 m high tower was installed by the Indian Institute of Tropical Meteorology (IITM), Pune, on the headland (58.5m asl) in the premises of the National Center for Antarctic and Ocean Research(NCAOR), Vasco da Gama (15° 21' N, 73° 51' E), Goa, 25-30m away from the Arabian Sea coast (Fig. 1). The NCAOR buildings are to the North about 100-150 m away from the tower. During monsoon jungle plants and grass (~ 1 m tall in July) grew over the terrain on NW-NE sector. The site was without vegetation in pre-monsoon months of 2003. Since the tower is on the coast, upwind flow is mainly from the sea (with winds S - W) during the monsoon. The experimental site has a large fetch (sea) in the upwind direction. The foot print of the measurement on the tower

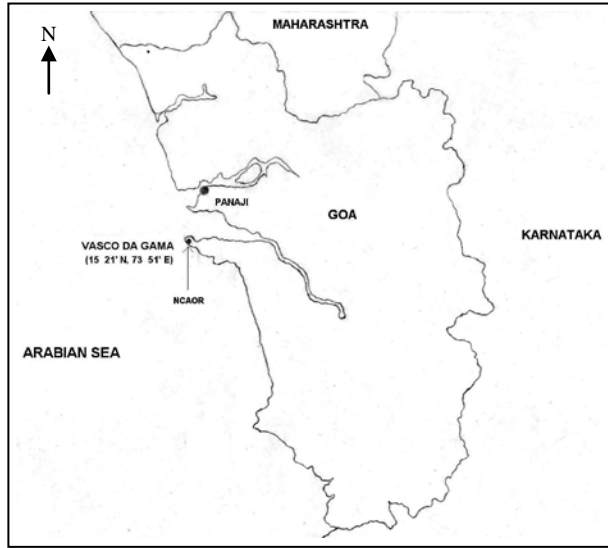


Fig. 1. Map of Goa : Arrow shows the location of micrometeorological tower erected in the premises of NCAOR, Vasco da Gama, Goa as part of ARMEX field experiment



Fig. 2. Licor – 7500 H₂O and CO₂ analyser (Left) on the tower at 5m agl at NCAOR, Goa

therefore signifies mostly the maritime air. During the field campaign the ambient monsoon flow enhances the local thermally-driven sea breeze circulation.

3. Experiment and data

3.1. Micrometeorological tower

The experimental set up of the 9 m high tower is described in detail by Sivaramakrishnan *et al.* (2003). The instruments to measure wind speed, direction, air temperature and relative humidity are located at about 1.5 m away from the tower on cross booms of 2 m length at four levels. Turbulence measurements were made using sonic anemometer (Applied Technology, USA), Gill propeller anemometer and H₂O/CO₂ gas analyzer (LI – 7500) at 5 m above surface with a sampling frequency of 10 Hz (Fig. 2). Radiation (Short wave-incoming, Short wave-reflected, Long wave-incoming, Long wave-outgoing) was measured by Eppley radiometers at 2 m above surface. Surface pressure and rainfall were also measured.

3.2. CO₂ and H₂O Analyzer (LI – 7500)

The CO₂/H₂O analyzer used in the study is a high performance, non-dispersive open path instrument (Licor, USA, Model LI-7500) for use in eddy covariance flux measurement. The measuring principle is : given a source with radiant power Φ , and a detector some distance away,

in the absence of reflection, absorptions by gas i can be determined from

$$\alpha_i = 1 - \tau_i = 1 - \Phi_i / \Phi_o$$

Where τ_i is the transmittance through gas i , Φ_i is transmitted radiant power in the absorption band with some concentration of gas i present, and Φ_o is the transmitted radiant power in the absorption band with zero concentration of i present. The LI-7500 approximates absorption by

$$\alpha_i = 1 - A_i / A_{i_o}$$

Where A_i is the power received from the source in an absorbing wavelength for gas i and A_{i_o} is the power received from the source in a reference wavelength that does not absorb gas i . The LI-7500 measures A_i and A_{i_o} alternately 152 times per second. Internal 150Hz measurements are digitally filtered to provide a true 5, 10 or 20Hz band width.

Absorption wavelength for water vapor is 2.59 μ m and CO₂ is 4.26 μ m. Detector is a thermo-electrically cooled lead solenoid. Path length between source and detector is 12.5cm and the instruments operating temperature range is from -25 to 50° C. LI-7500 gives number density, mole fraction and mass density of both CO₂ and water vapor. Data from the LI-7500 was transferred using communication software to a PC for storage and analysis through RS-232 interface. Accuracy

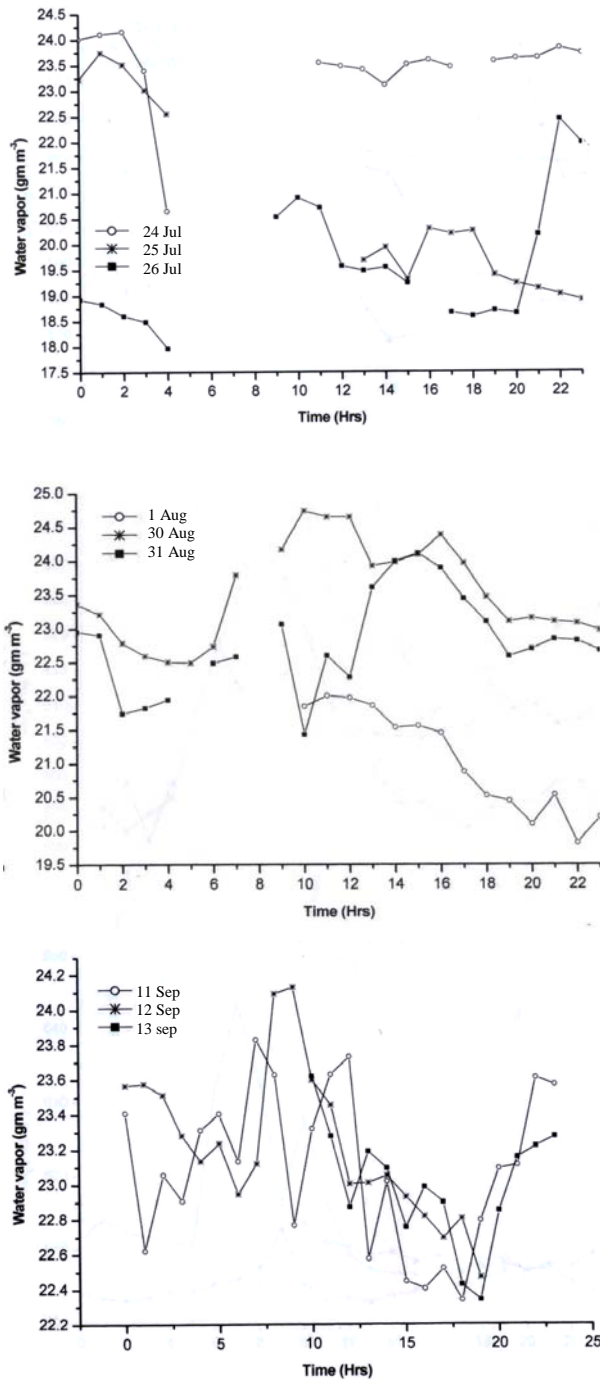


Fig. 3(a). Diurnal variation of water vapor at NCAOR, Goa during ARMEX-I, July, August, September 2002 respectively

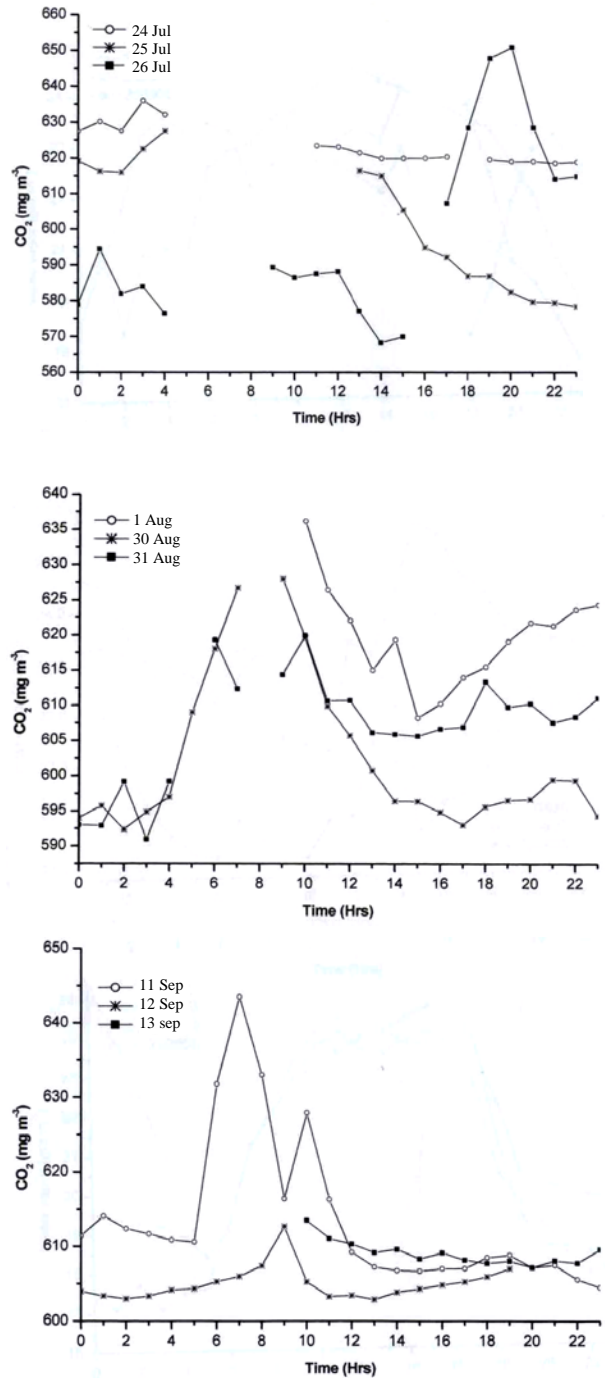


Fig. 3(b). Diurnal variation of CO₂ at NCAOR, Goa during ARMEX-I, July, August, September 2002 respectively

of the instrument for CO₂ is 1% nominal and for H₂O is 1%. During rain or snow, flying droplets and flakes in the optical path will affect the performance of LI-7500, even if the total light blockage is small enough. Hence we ignored the spikes in the data due to rain and other adverse factors.

The raw data collected continuously using H₂O/CO₂ gas analyzer at 5 m above surface with a sampling frequency of 10 Hz was averaged over one hour (36000 samples) for 3 days of each month in ARMEX phase I (July to September 2002) and phase II (March, April, May, June 2003).

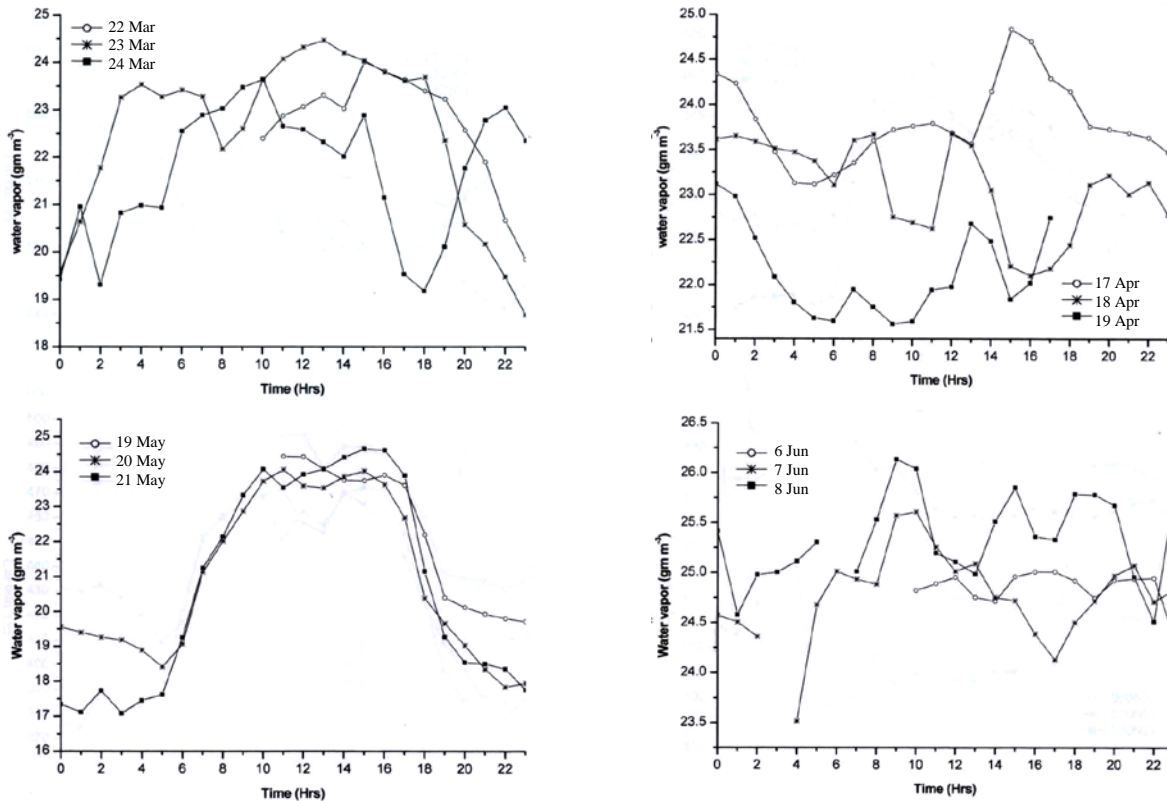


Fig. 4(a). Diurnal variation of water vapor at NCAOR, Goa during ARMEX-II, March, April, May, June 2003 respectively

4. Results and discussion

Figs. 3(a&b) and Figs. 4(a&b) show the diurnal variation of one hour averaged values of CO₂ and water vapor for three days in (24-26) July, (01,30& 31) August and (11-13) September of ARMEX-I and (22-24) March, (17-19) April, (19- 21) May and (06-07) June of ARMEX-II. We have chosen different scales for each graph of Fig. 3 & Fig. 4 to show the amplitude of diurnal variation of the quantities.

4.1. Winds at the site

Since the micrometeorological tower was located on a sea coast, the wind direction fluctuation can affect the variation of CO₂ and water vapor. Because of the fact that sea is a sink for CO₂ and source for water vapor, the magnitude of both the quantities can possibly vary in opposite phase if wind blows from the sea towards the sensor. To study the variation of CO₂ and water vapor relative to wind direction we have shown in Figs. 5 (a-d) the wind direction data acquired from wind vane (1 Hz sampling rate averaged over a minute) installed at 8m level on the micrometeorological tower. To get the

prevailing wind direction we divided 0° - 360° into 8 sectors of 45° each such as N, NE, E, SE, S, SW, W and NW respectively, and computed the maximum no. of times the direction happens to be in a particular sector during every hour (60 samples). Percentage maximum frequency of occurrence of wind direction in a given sector, has been computed and classified as follows :

Class A $\leq 25\%$

B $\leq 50\%$

C $\leq 75\%$

D $> 75\%$.

Figs. 5(a-d) shows the prevailing wind direction in August 2002 and March, April, May 2003. If more number of successive hourly observations of wind direction falls into same category then it is denoted by a bold phase letter in the figure. The geometry of Vasco da Gama coast (Fig. 1) is such that except wind from NNE - ESE sector, the wind approaching the coast from all other

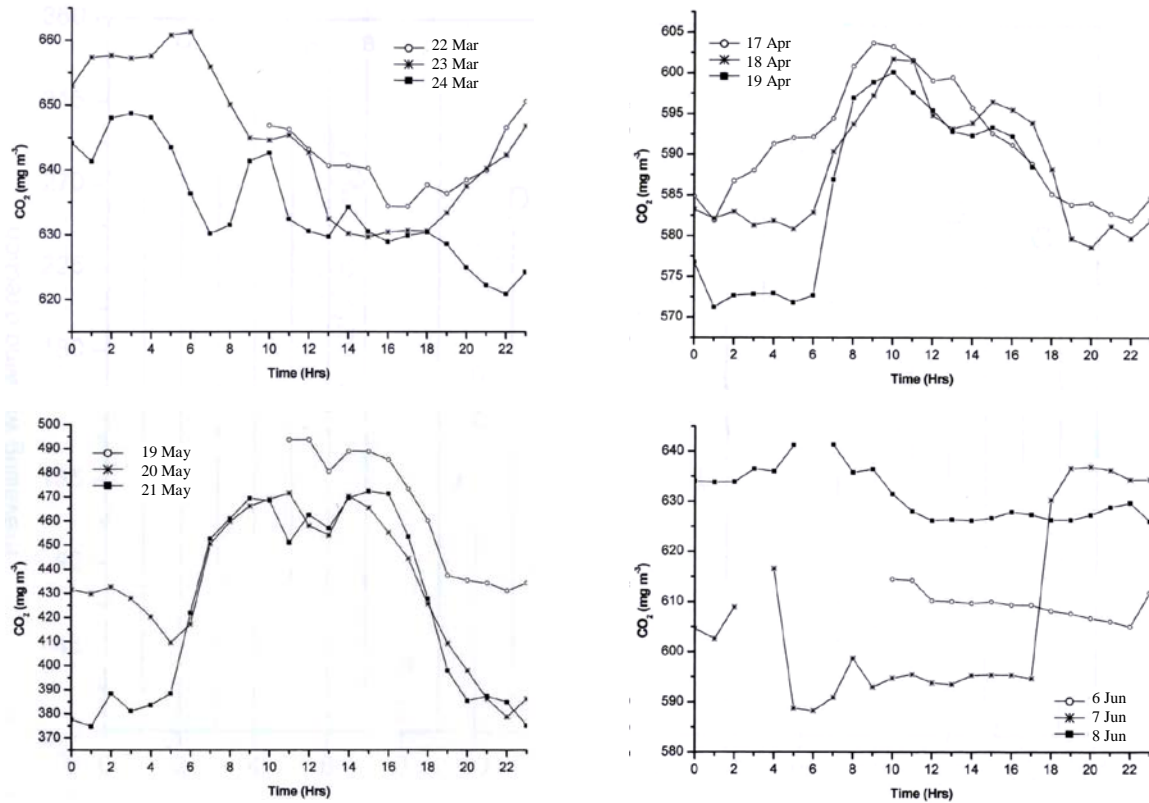


Fig. 4(b). Diurnal variation of CO₂ at NCAOR, Goa during ARMEX-II, March, April, May, June 2003 respectively

angles will be from the sea. So we roughly took the criteria that winds from N – ESE (0° to 112.5°) is from land (Fig. 1).

4.2. Variation of water vapor

Fig. 3(a) shows that the diurnal variation of water vapor is highly variable in July and August whereas in September the climatological pattern of diurnal variation (day time maximum) of water vapor in tropics is noticed. The maximum and minimum value differs by only 2 gm m⁻³ in September. The irregular variation of water vapor in July and August 2002 can be due to the effect of monsoon circulation pattern at the surface *viz.* convergence/divergence.

Water vapor in pre monsoon season of 2003 [Fig. 4(a)] shows a day time peak in all the months. May shows a well marked diurnal peak whereas March, April and June, shows multimodal variation. In March the water vapor varied from 19-24 gm m⁻³ and in May 17-25 gm m⁻³ which show significant diurnal variation. April and June showed less diurnal variation. In April the magnitude of water vapor was around 22-24 gm m⁻³, in June it was between 24-26 gm m⁻³. Comparison of water

vapor between different months showed that the diurnal variation was less in April and June than in May. The magnitude of water vapor varied significantly from month to month with a maximum in June 2003 (26 gm m⁻³).

4.3. Variation of CO₂

Fig. 3(b) and Fig. 4(b) shows CO₂ variation during ARMEX-I and II. In August and September 2002 increase in CO₂ was observed before noon. During ARMEX-II in March, CO₂ showed maximum before noon (660 mg m⁻³). In April CO₂ showed diurnal peak at 0900hr (IST) whereas in May we observed peaks at 0900 and 1500hr (IST) but the average maximum concentration has dropped from 600 mg m⁻³ in April 2003 to 470 mg m⁻³ in May 2003. In July 2002 the variation in CO₂ was found to be highly irregular as in June 2003. Lowest values of CO₂ were observed during late night hours in May (380 to 490 mg m⁻³) and the highest in the morning hours of March (660 mg m⁻³). Comparatively May 2003 showed high diurnal variability. The CO₂ plots when compared showed that in most of the months of ARMEX *i.e.* July, August & September 2002 and June 2003 the mean value of CO₂ was around 600-625 mg m⁻³. In March 2003 the

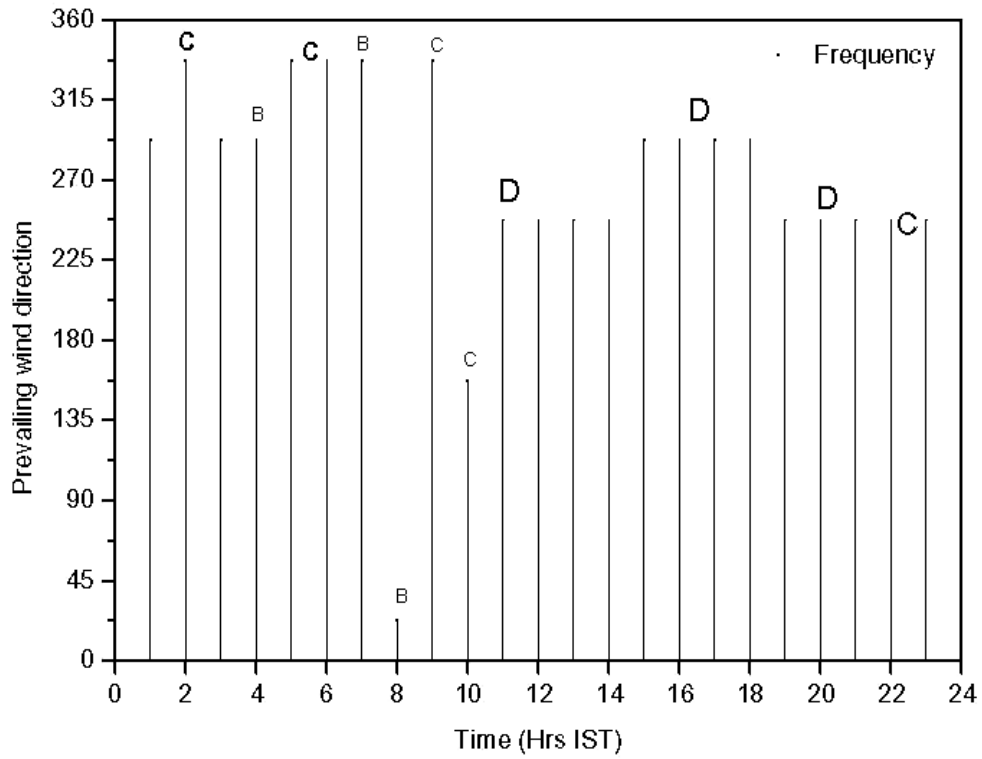


Fig. 5(a). Frequency distribution of prevailing wind direction on 1st August 2002. A, B, C, D indicate the percentage frequency distribution

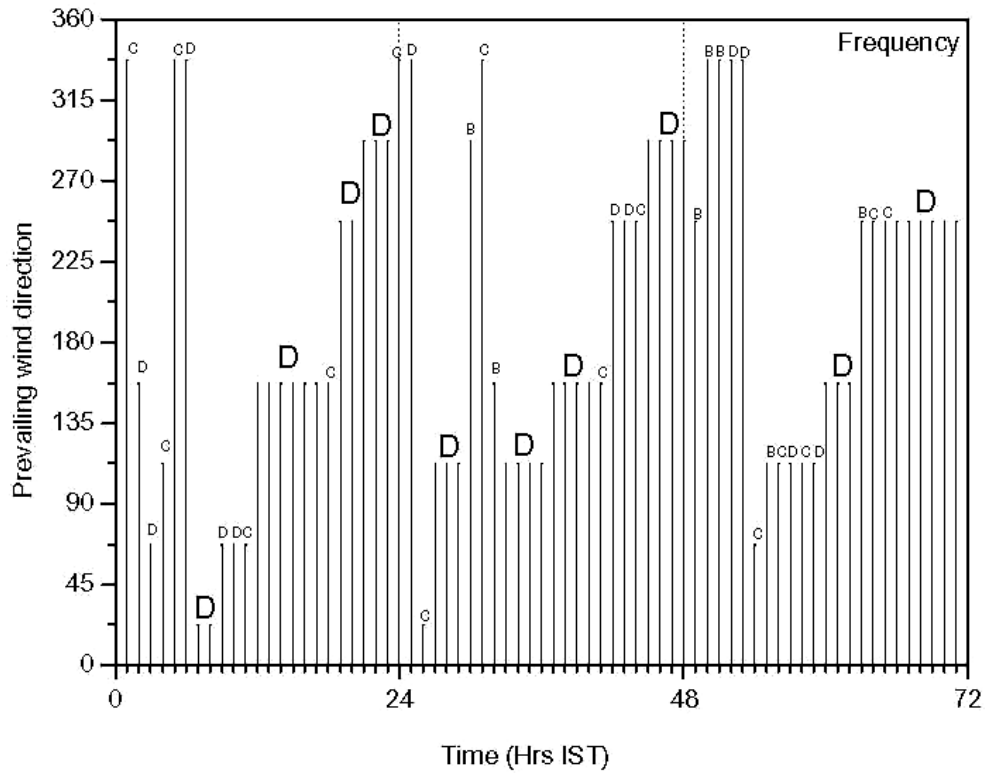


Fig. 5(b). Frequency distribution of prevailing wind direction on 22-24 March 2003. A, B, C, D indicate the percentage frequency distribution

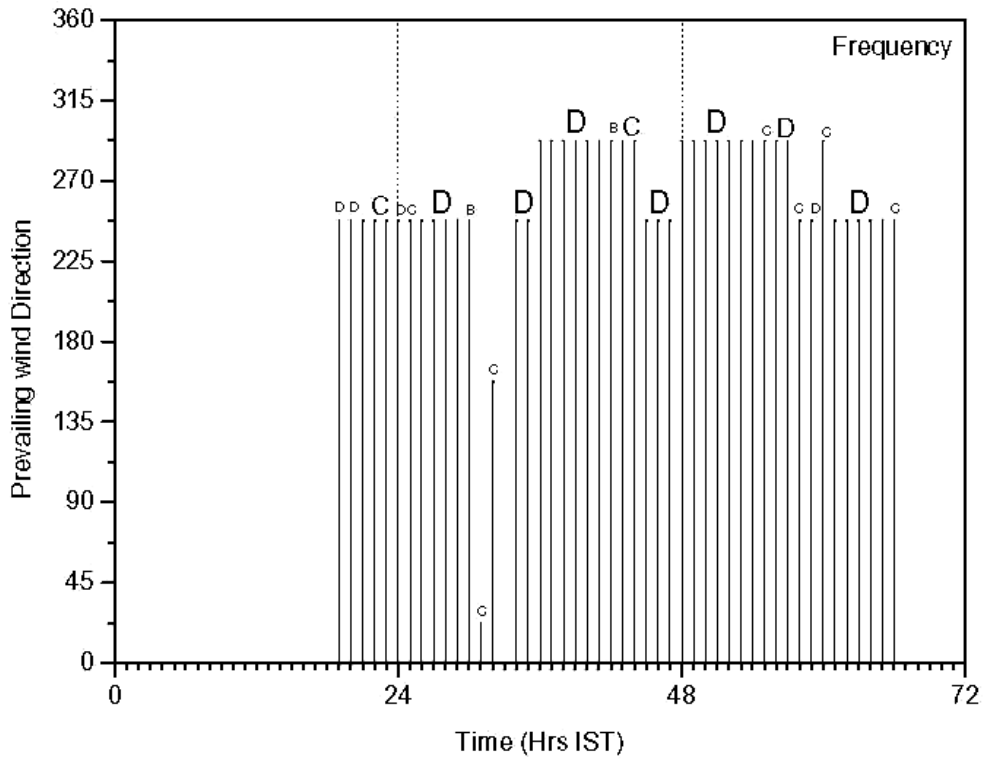


Fig. 5(c). Frequency distribution of prevailing wind direction on 17-19 April 2003. A, B, C, D indicate the percentage frequency distribution

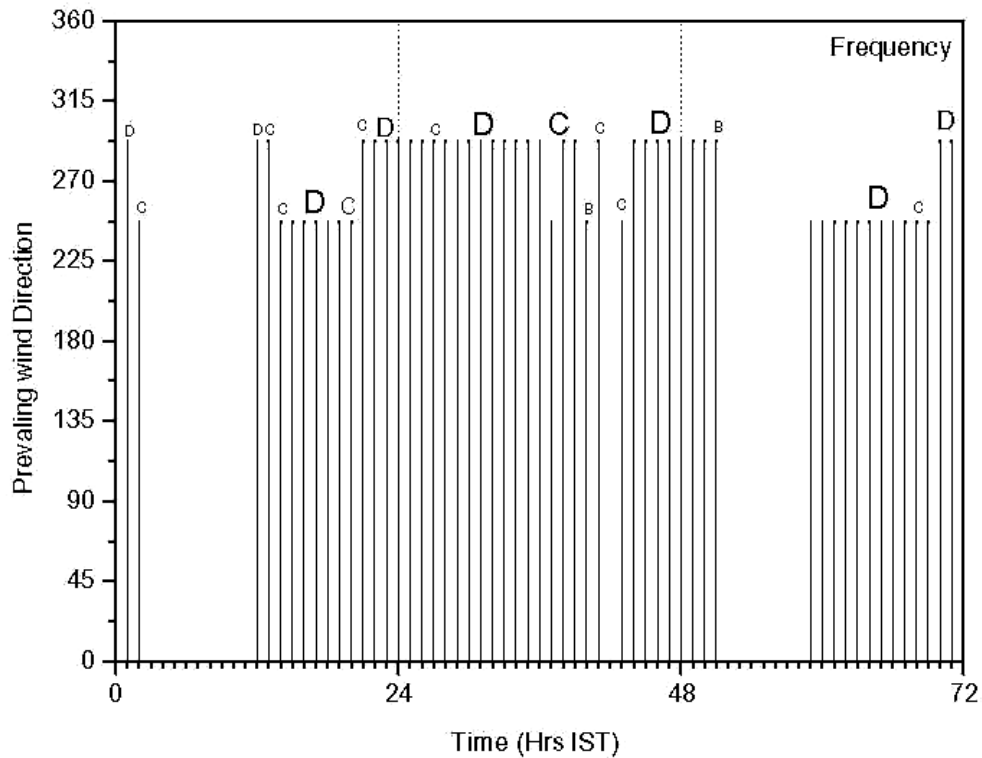


Fig. 5(d). Frequency distribution of prevailing wind direction on 19-21 May 2003. A, B, C, D indicate the percentage frequency distribution

mean CO₂ concentration was 625-660 mg m⁻³, and in April 575-600 mg m⁻³. But May showed minimum values of magnitude between 375 & 475 mg m⁻³, with a relatively high diurnal variation. On the whole the diurnal variation was small when compared to monthly.

Measurements of CO₂ (2002) were carried out elsewhere over different stations at various latitudes and longitudes (<http://cdiac.esd.ornl.gov>). The annual averaged value of CO₂ in the year 2002 shows 666 mg m⁻³ from the stations elsewhere. We shall see that this value compares well with the values measured at the NCAOR, site at Goa.

Frequency distribution of wind direction is shown in Figs. 5(a-d) for the corresponding months. When we classified the percentage frequency occurrence of wind direction we find that most of the time, the frequency came under class 'D' or 'C'. This shows the prominence of winds from sea. In March the land breeze circulation in the morning hours (wind direction < 135°) was observed. The increase in CO₂ during morning hours of March 2003 may be due to this fact. In the afternoon around 1100 or 1200 hr (IST) sea breeze sets in (wind direction >135°) with a relative decrease in the magnitude of CO₂ by about 30 mg m⁻³. Comparatively a decrease in CO₂ concentration and an increase in water vapor were observed in all the months when the wind direction change from the coastline to the open sea during the period.

5. Conclusions

The present study leads to the following

- (i) Water vapor and CO₂ concentrations exhibit diurnal variation during pre (April, May 2003) and Post monsoon (September 2003) season.
- (ii) CO₂ concentration was high when winds in the morning hours were from the land in March 2003.
- (iii) The magnitude of monthly variation is relatively large. There is a progressive change in the mean maximum concentration of CO₂ (decrease during March

to May) and water vapor (increase during April to May) with the wind direction changing from SSE in March (from the coastline) to W in May (from the sea).

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