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RESEARCH ARTICLE

# DIURNAL AND SEASONAL VARIATIONS OF ATMOSPHERIC $CO_2$ OVER TRIVANDRUM, INDIA

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**ABSTRACT**

Continuous measurements of $CO_2$ mixing ratio and meteorological parameters have been made in National Centre for Earth Science Studies (NCESS), Trivandrum (8.5°N 76.9°E) from June 2014 to May 2015 and analyzed the diurnal and seasonal variation of $CO_2$ mixing ratio. The average atmospheric $CO_2$ during study period was 321±14.78 ppm. The diurnal variation with a maximum during the early morning and late night and a minimum in the afternoon is clearly observed. Photosynthetic activity and the atmospheric boundary layer play an important role in diurnal variation of $CO_2$. The analysis of its seasonal trend indicated that highest value of $CO_2$ mixing ratio was found in summer (382 ppm) and the lowest during monsoon (274.3 ppm) season. The mean day –night ratio (D/N) for the study period was 0.94. All the months the night time concentration is higher than the day time concentrations since Photosynthetic activity is higher during day time. Wind speed plays a dominant role in controlling the $CO_2$ mixing ratios at this station.



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## INTRODUCTION

Humankind is causing global warming through the emission of greenhouse gases (GHG), particularly carbon dioxide ($CO_2$). $CO_2$ concentrations has increased by 40% since pre-industrial times, mainly from fossil fuel emissions (IPCC, 2013). Carbon dioxide ($CO_2$) is the primary greenhouse gas emitted through human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle both by adding more $CO_2$ to the atmosphere and by influencing the ability of natural sinks, like forests, to remove $CO_2$ from the atmosphere (NRC, 2010). Atmospheric $CO_2$ measurements are very important tools for understanding the carbon cycle because $CO_2$ mixing ratios in the atmosphere are strongly affected by photosynthesis, respiration, oxidation of organic matter, biomass and fossil fuel burning, and air–sea exchange process (Machida *et al*., 2003). Local temperature and moisture conditions also affect the diurnal cycle and seasonal variations in atmospheric $CO_2$. Near-surface $CO_2$ mixing ratios have been documented in several cities across the world (Vancouver, Canada; Kuwait City, Kuwait; Mexico City, Mexico; Basel, Switzerland; Nottingham, UK; Phoenix, USA) to evaluate the dynamics of atmospheric $CO_2$ over short periods of time.(Velasco *et al*., 2005; Vogt *et al*., 2006). In India, long-term analysis of atmospheric $CO_2$ using the flask sample measurement technique carried out at Cape Rama (Bhattacharya *et al*., 2009; Tiwari *et al*., 2011, 2013). The continuous measurements of $CO_2$ at Hanle and Pondicherry (Indira *et al*., 2013). Flux measurements over agricultural site at Modipurumnear Meerut, Uttar Pradesh (Patel *et al*., 2011). Analysis of $CO_2$, water vapor, and energy fluxes over mixed deciduous forest (Jha *et al.,* 2013). Variations in atmospheric $CO_2$ mixing ratios in, Dehradun and Gadanki (Sharma *et al*., 2013, 2014), Sriharikota (Mahesh *et al*., 2014). Influence of meteorology and interrelationship with greenhouse gases at Shadnagar (Sreenivas *et al*., 2015) is studied. Here, we report an analysis of continuous measurements of $CO_2$ mixing ratios and examine diurnal and seasonal variability in $CO_2$ concentrations over National Centre for Earth Science Studies (NCESS),Trivandrum in India.

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### Monitoring site and general meteorology

The observational site National Centre for Earth Science Studies (NCESS), Trivandrum (8.5°N 76.9°E) is a tropical semi-urban, coastal station located in the southern part of India in the state Kerala (Fig. 1). It is an active station under

"Modelling Atmospheric Pollution and Networking" (MAPAN) network of stations coordinating by Indian Institute of Tropical Meteorology (IITM), Pune. The site is about 0.5 Km away from the Akkulam back waters, about 3 Km away from the cost of Arabian Sea and is 9.5 Km away from city. The continuous measurements of $CO_2$ were carried out on the roof of NCESS Building institute, Trivandrum. Roads are situated on two sides of the institute where automobile and vehicular emissions are the principle sources of air pollution. An open land that receives plenty of sunshine throughout the day without any shadows, and this site has a large area of vegetation and tress. The most prominent meteorological feature at this location is the monsoon rainfall occurring in two spells during a year. The southwest monsoon is quite active during the months of June, July August and September. This is followed by the return monsoon or northeast monsoon which lasts till November. Hence October and November are marked as the post-monsoon season with some scattered showers accompanied by heavy thunder and lightning. The intensity of summer is masked by the southwest monsoon season over this region because intense rainfall occurs in the months of June, July and August and September of every year. About 80 % of the total rainfall occurs from June to September which constitutes the main monsoon season. During the first phase of the monsoon season (June– September), winds are stronger and the circulation is south-westerly (from ocean to land).

Figure 2. shows the monthly mean variations of meteorological parameters like wind speed, temperature, relative humidity and solar radiation in NCESS during the period of observation from June 2014-May 2015. The wind speed was high during the period from June to September and low from November to May. The maximum average wind speed ranged from 3.3 to 4.0 m/s and the minimum from 0.5 to 1.6 m/s were monitored during the period of observation. The temperature was high in the months March to May and was low during July through January. The average monthly high temperature ranged from 34.3 to 37.4°C and low temperature ranged from 14.9.9 to 24.0°C. The maximum humidity was measured during monsoon (June-September) and its minimum was observed in the months of, January, February, March and April. The maximum monthly average of relative humidity ranged from 81.41 % to 82.41 % and minimum of 73% to 80 % at this location. The maximum rainfall was recorded during monsoon, while minimum was observed in winter season. The surface flow patterns obtained from NCEP/NCAR reanalysis have been (http://www.cdc.noaa.gov) used to ascertain the synoptic meteorological conditions and source variability to the observation site. Fig. 3. shows the synoptic pattern of seasonal mean surface wind speeds during the four seasons post monsoon, winter, summer and monsoon over the Indian subcontinent.

## MATERIALS AND METHODS

The atmospheric $CO_2$ concentration was measured installed at a height of 10 m from the ground on the top of the Institute building, with a non-dispersive infrared gas (NDIR) analyzer (Ecotech Serinus 30 analyser). We installed an air intake at 1 m above the roof of a building on the campus. $CO_2$ mixing ratios were recorded at 5 minutes interval, at the stations, during June 2014–May2015. In addition to this, meteorological parameters like wind direction, wind speed, temperature, relative humidity and rainfall are measured using tower based instruments Automatic weather station at the same site.

## RESULTS AND DISCUSSION

### Diurnal Variation

Diurnal variation of $CO_2$averaged over the period of one year from June 2014 to September 2015 shows in Fig.4 (a). The diurnal variation with a maximum during the early morning and late night and a minimum in the afternoon is clearly observed. The pattern is characterized by high $CO_2$ level (about 341.6 ppm) during early morning (05.00 hrs.), which is due to the accumulation of $CO_2$ mixing ratios during early morning, before the sunrise and low levels (about 301.4ppm) during afternoon hours (14.00 hrs.)This is due to the increased photosynthesis activity and increasing boundary layer. Similar diurnal variations are observed at Dehradun, Gadanki and Sriharikota (Sharma *et al*., 2014, Mahesh *et al*., 2014). The variation of daily mean concentrations $CO_2$ mixing ratios shown in fig. 4(b).The annual average$CO_2$, mixing ratios is 321±14.78 ppm over the period of observation. During the entire study period, the highest peak of $CO_2$ was observed on 10th December 2014 (416.2ppm) when the temperature (20.8. °C) and wind speed (0.7 m/s) were found to be very low and the lowest $CO_2$, mixing ratios concentration was on 7th June 2014 (271.2 ppm) when the temperature (27.4°C) and wind speed (2.3 m/s) were found very high.

### Seasonal variations

The diurnal cycles of $CO_2$, mixing ratios for different seasons, are shown in Fig. 5. All the season exhibit similar cycles of mixing ratios with a morning maximum followed by an afternoon minimum. The minimum (maximum) mixing ratios are present during the seasons with high (low) ecosystem productivity. (Sharma *et al*., 2014).Monsoon and post-monsoon seasons have high ecosystem productivity, and winter and summer seasons have low productivity. Average values of $CO_2$ observed during different seasons are 286.1, 317.5, 336.2 and 353.6 ppm with respectively monsoon, post monsoon, winter and summer. Among the maximum concentration, the highest value of $CO_2$ mixing ratio was found in summer (382 ppm) and the lowest during monsoon (274.3 ppm). Enhancement in summer is due to higher temperature and solar radiation prevailing during these months which stimulate the assimilation of $CO_2$ in the daytime and respiration in the night (Fang *et al*., 2014). Surface $CO_2$ concentration recorded a minimum during monsoon months can be mainly because of enhanced photosynthesis processes with the availability of greater soil moisture (Patil *et al*., 2013). Further increase during post monsoon$CO_2$ is associated with high ecosystem productivity (Sharma *et al*., 2014). The maximum range (~51 ppm) is observed during summer season, whereas minimum range (~27 ppm) during monsoon season.

### Variation of $CO_2$ with wind speed

Figure 6 (a) shows the variation of $CO_2$ with wind speed and 6(b) shows the scatter plot between $CO_2$ and wind speed.

**Table 1. Correlation of $CO_2$ with meteorological parameters**

| Season | Correlation of $CO_2$ with meteorological parameters | | | |
|---|---|---|---|---|
| | Temperature | RH | Wind Speed | Rain fall |
| Monsoon | -0.12 | 0.04 | -0.41 | 0.09 |
| Post monsoon | -0.26 | 0.29 | -0.44 | 0.04 |
| Winter | -0.88 | 0.48 | -0.36 | 0.36 |
| Summer | -0.24 | 0.48 | -0.18 | 0.21 |
| Annual | -0.14 | -0.13 | -0.47 | 0.10 |

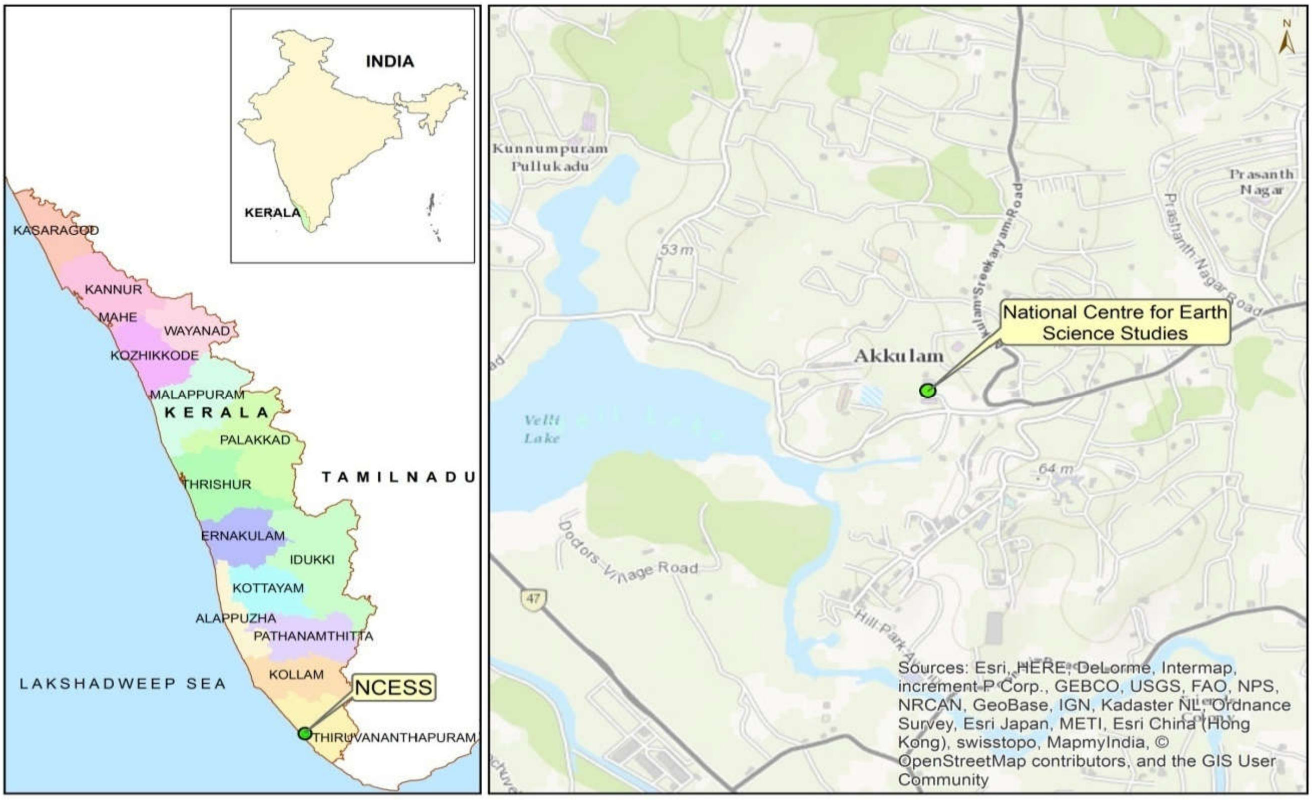



**Fig. 1. Location map of the observational site NCESS, Trivandrum**

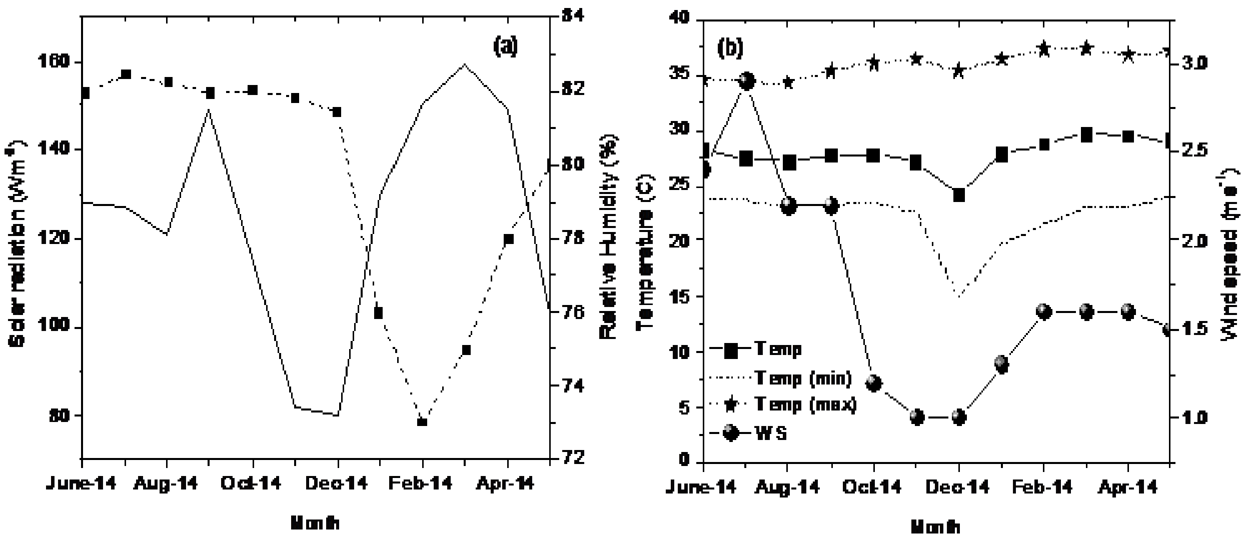
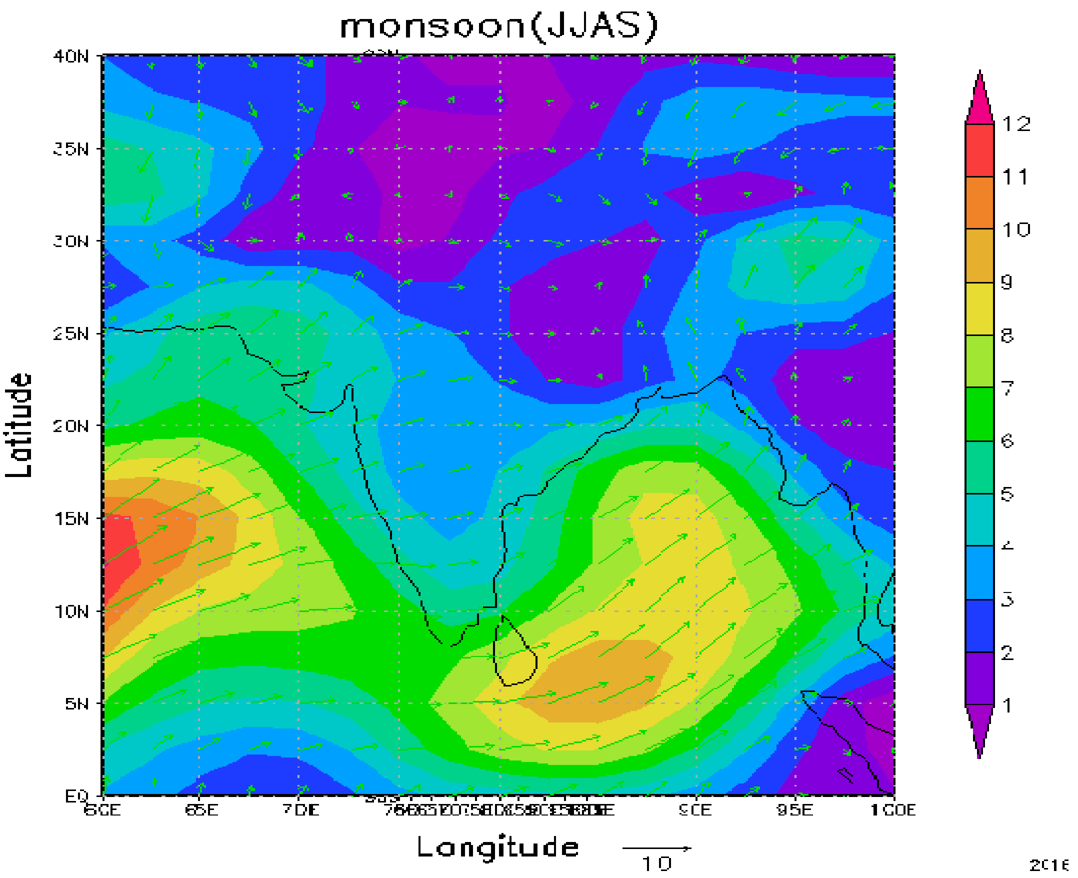



**Fig. 2. Monthly mean variation of (a) solar radiation and relative humidity (b) ambient air temperature, wind speed, Maximum and Minimum temperature over Trivandrum during June 2014-May 2015**


monsoon(JJAS)
Latitude
Longitude
40N
35N
30N
25N
20N
15N
10N
5N
EQ
60E
65E
70E
90E
95E
100E
10
12
11
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9
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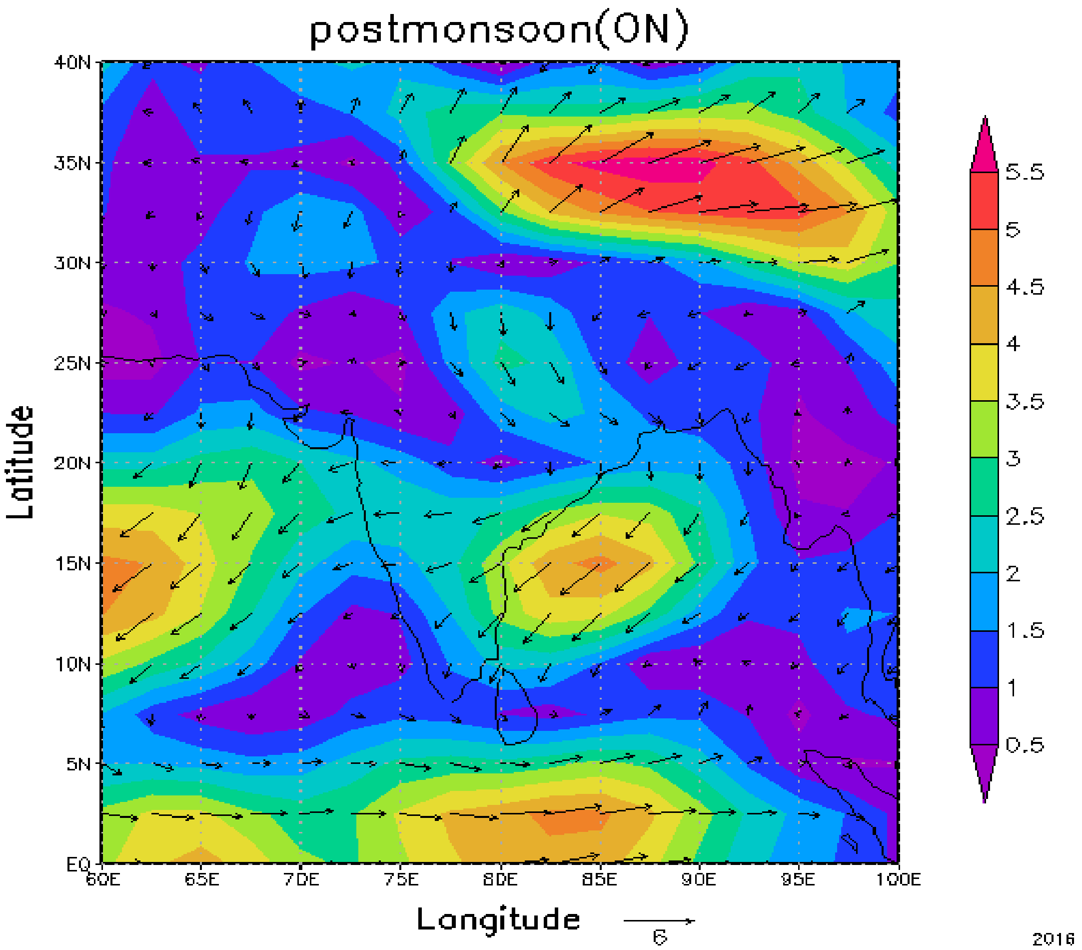
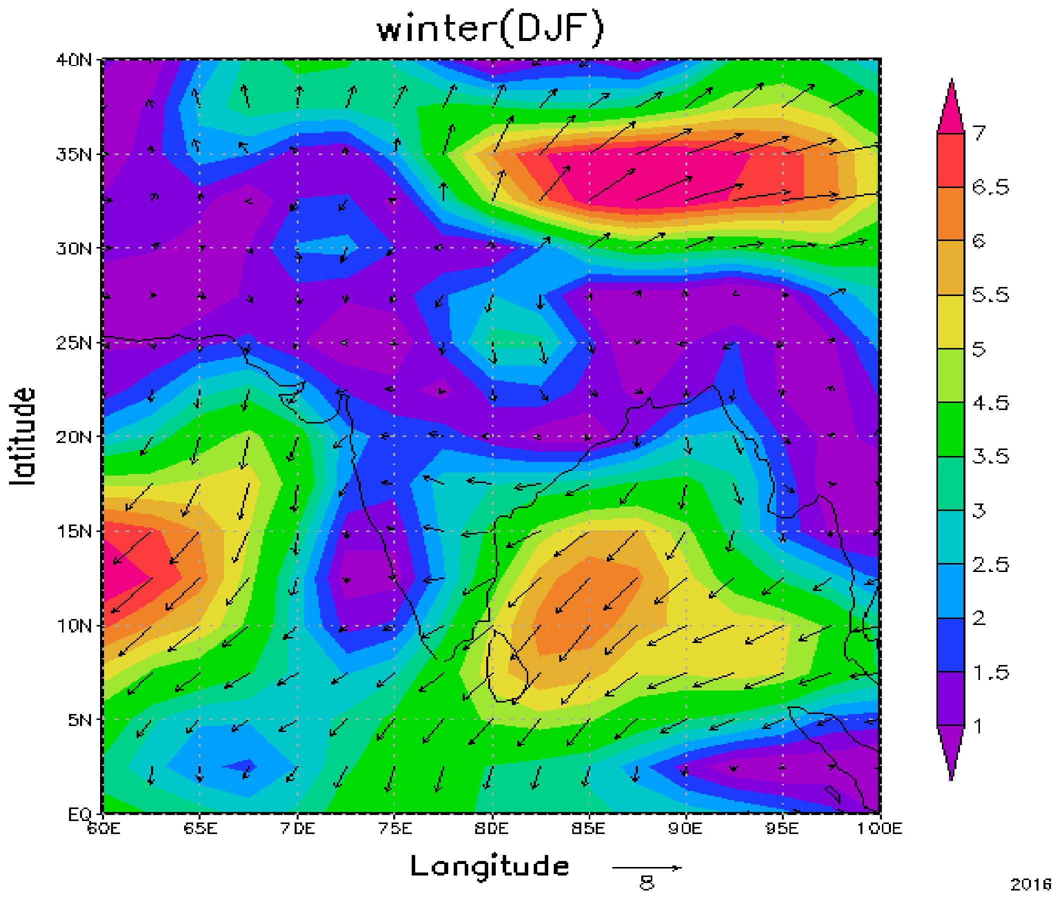
5
3
2
1
2016


postmonsoon(ON)
Latitude
Longitude
40N
35N
30N
25N
20N
15N
10N
5N
EQ
60E
65E
70E
75E
80E
85E
90E
95E
100E
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
2016



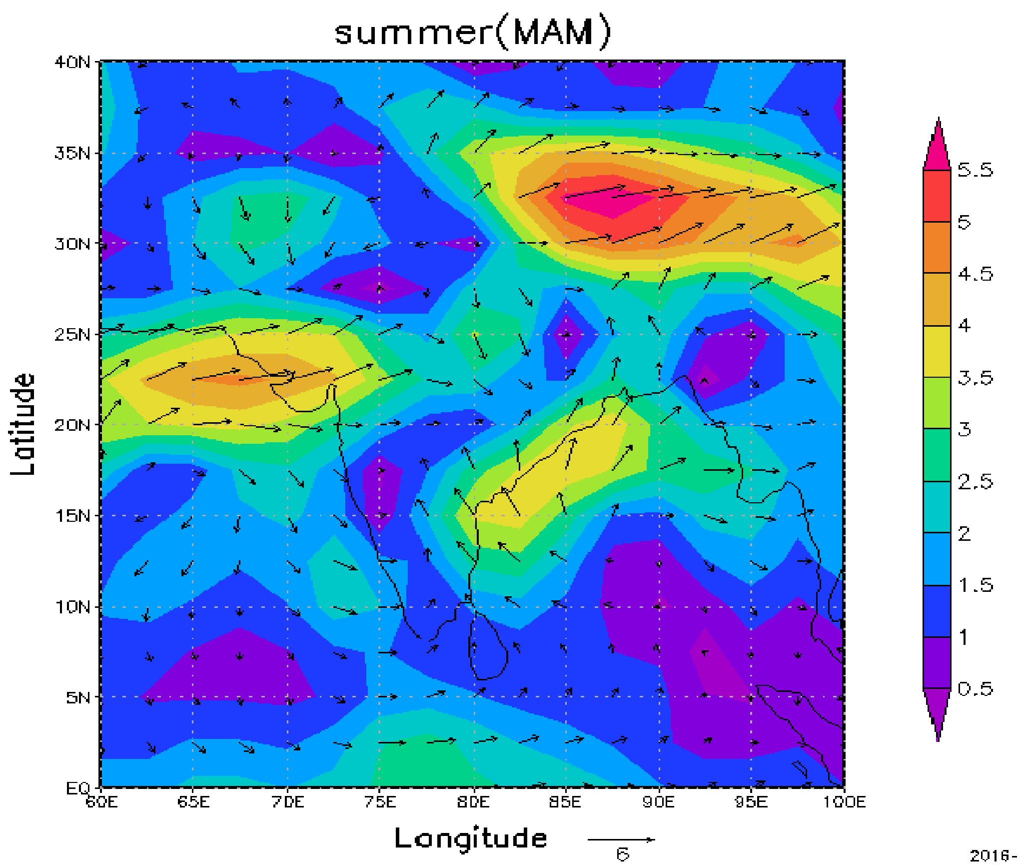




**Fig. 3. NCEP/NCAR re-analysis mean vector wind composites at 1000 mb level for different seasons during the measurement period (June 2014–May 2015)**

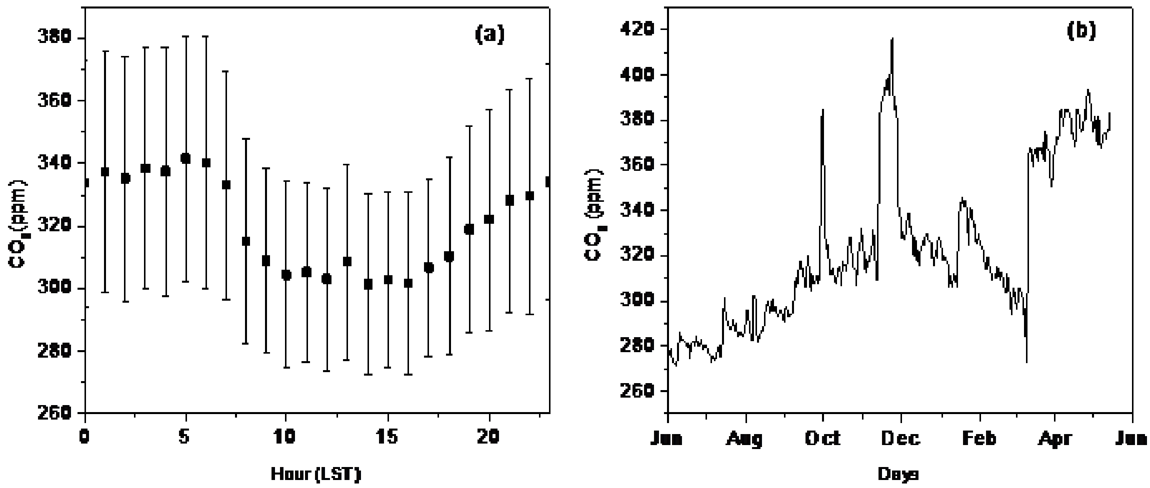



**Fig.4.(a) Diurnal variation of $CO_2$,vertical bar indicate the standard error (b) Daily variation of $CO_2$ mixing ratio over Trivandrum during June 2014-May 2015**

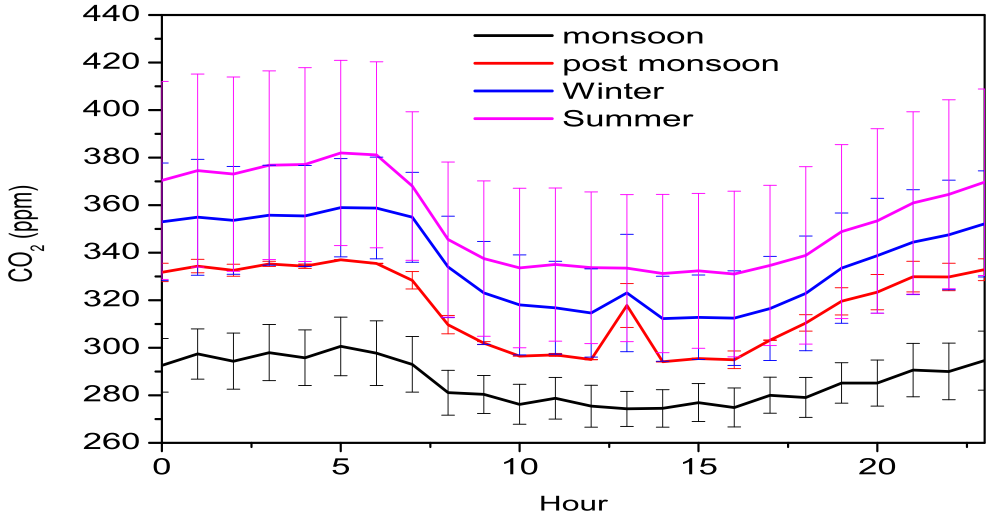



**Fig. 5. Variation of $CO_2$ mixing ratio over Trivandrum during different seasons. Vertical bar indicate the standard error**

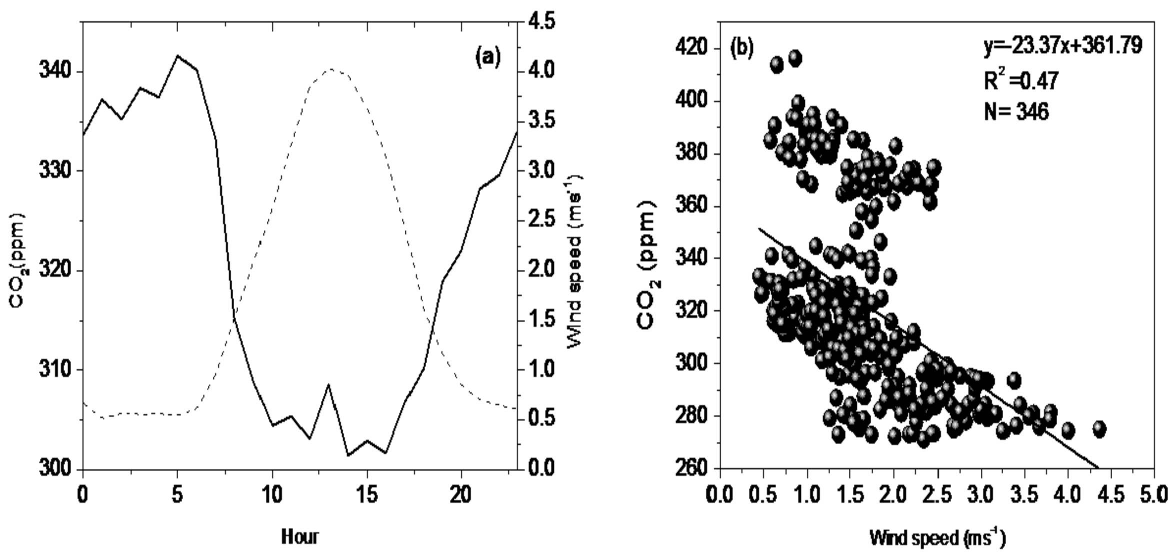



**Fig. 6. (a) Variation of $CO_2$ with wind speed solid line indicates $CO_2$ and dashed lines indicate wind speed. (b) scatter plot between wind speed and $CO_2$ during the period of study**

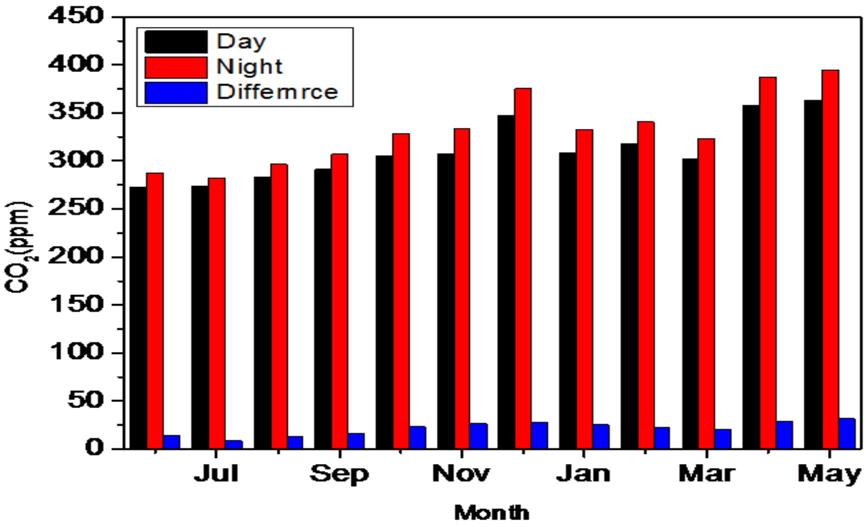



**Fig. 7. Monthly means variation of $CO_2$ mixing ratio for the day and night**

It clearly shows the inverse relationship of $CO_2$ with wind speed. The observations with maximum mixing ratios of $CO_2$ (407 ppm) have wind speeds of 0.5 m/s, and minimum mixing ratios of $CO_2$ (301ppm) wind speed of 4.0 m/s. Thus, wind speed played an important role in the $CO_2$concentrations during this time. As these observations are monthly means, the impact of winds on the mixing rations is significant. High winds have the scavenging effect besides reducing the stability of the atmosphere due to which high (low) concentrations are observed with low (high) winds. From this, we can conclude that the scavenging effect of wind magnitude plays a dominant role in controlling the $CO_2$ mixing ratios at this station.

**Correlation with Meteorological parameters**

To examine the factors controlling the distribution of $CO_2$ correlation analysis was conducted between $CO_2$ and meteorological parameters (Table 1). The correlation of different parameters in different season with $CO_2$ shows different values. Temperature showed an inverse relationship with $CO_2$ in all season where as RH showed a significant positive relationship with $CO_2$ in all the season but annual correlation shows a negative value. Wind speed showed a significant negative correlation with $CO_2$ in all season while rainfall showed a positive correlation, in all season with $CO_2$ data.

**Day –night variation in $CO_2$**

We examined monthly variation of the ratio of daytime (6 am to 18 pm) to nighttime (18 pm to 6 am) $CO_2$mixing ratio for the period (Fig .7). The mean day –night ratio (D/N) for the study period was 0 .94. D/N ratios are almost constant for all months (June –August it is 1.0 and remaining months it is 0.9). Season wise D/N ratio is found to be 0.96, 0.92, 0.93, and 0.93 during monsoon, post monsoon, winter and summer respectively. All the months the night time concentration is higher than the day time concentrations since Photosynthetic activity is higher during day time. Day –night difference is maximum observed during the month of May (31.8) and minimum on July (8.5).

**Summary and Conclusions**

The continuous 5 min interval $CO_2$ observations collected at NCESS, Trivandrum was averaged on an hourly basis. The annual mean of $CO_2$ over the study region is found to be 321 ppm. Minimum mixing ratios were present during the afternoon and maximum during nighttime reflecting the role played by the photosynthetic activity, the boundary layer dynamics and nighttime respiration. $CO_2$ showed a significant seasonal variation during the study period. Maximum $CO_2$ is observed during summer and minimum during monsoon season. Average values of $CO_2$ observed during different seasons are 286.1, 317.5, 336.2 and 353.6 ppm with respectively monsoon, post monsoon, winter and summer. The mean day –night ratio (D/N) for the study period was 0 .94.Wind speed plays a dominant role in controlling the $CO_2$ mixing ratios at this station.

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