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Impact of Land-Sea Breeze and Rainfall on CO_2 Variations at a Coastal Station

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Abstract

Carbon dioxide (CO_2) observations collected at 5 min interval at Sriharikota during October 2011-January 2012 from the Vaisala GMP-343 sensor were averaged on an hourly basis. The baseline of atmospheric CO_2 during study period is 382 ppm. Minimum (maximum) mixing ratios were observed during the afternoon (night times) indicating the role of photosynthetic activity and the atmospheric boundary layer on this parameter. Sriharikota being a coastal station, the land and sea breezes mainly control CO_2 mixing ratios. The correlation between CO_2 and the wind speed is significantly less during sea breeze than during land breeze in October, compared to other months, where the correlations are more during sea breeze. The less correlation during sea breeze in October is due to the heavy rainfall in this month during daytime.

Keywords: Carbon dioxide (CO_2) mixing ratios; Rainfall impact; Land and sea breezes

Introduction

Carbon dioxide (CO_2), one of the major Greenhouse Gases (GHG) in the atmosphere, plays a prominent role in climate change. The global mean concentration of CO_2 in 2005 was 379 ppm, leading to a Radiative Forcing (RF) of +1.66 [± 0. 17] W m-2 [1]. Recently, the CO_2 levels have gone up to a daily mean of 400 ppm in May 2013 at Mauna Loa, Hawaii [2]. Local meteorological and environmental factors control the CO_2 mixing ratios. During night times, temperature inversions prevent thorough mixing of the atmosphere. There is also an absence of photosynthetic activity consuming CO_2. Due to these two processes, CO_2 mixing ratios increase at night. During the daytime due to increase in photosynthesis activity, CO_2 mixing ratio decreases [3].

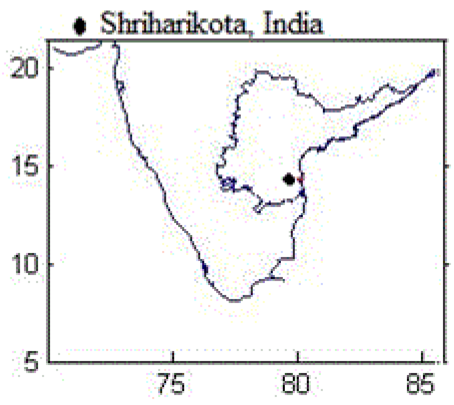

Figure 1: Study location.

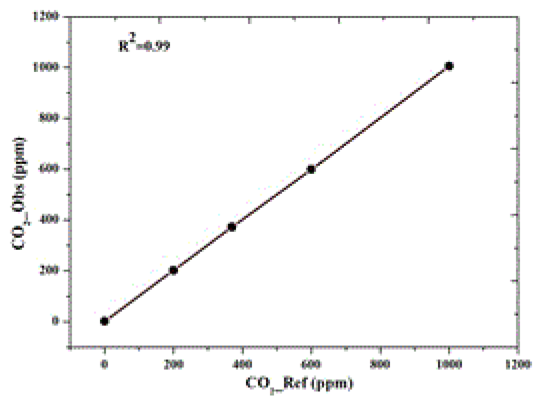

Figure 2: Calibration curve.

To understand the carbon cycle in the atmosphere, several surface CO_2 measuring network stations have been established across the county under National Carbon Project (NCP). NCP is a component of Geosphere Biosphere Programme (IGBP) of the Indian Space Research Organization (ISRO). Under this program terrestrial, ocean and atmospheric components of carbon balance are studied. Instruments are installed to measure the atmospheric CO_2 [3], flux measurements in forests [4] and in soil [5]. As a part of this program, GMP-343 is installed in 2011 at Sriharikota High Altitude Range (SHAR). Since this is a coastal station, we report the impact of the wind vector, particularly the land and sea breezes, on CO_2 variations from October 2011 to January 2012. While pure water has pH of 7.0, normal rain is slightly acidic with pH range from 5.0-5.6 [6] because of dissolving of CO_2 in water droplets forming a weak carbonic acid. The dissolution of CO_2 in rain drop depends upon the partial pressure of CO_2 and the atmospheric temperature. Since the study region influenced by North East (NE) monsoon, we also studied the impact of rainfall on CO_2 mixing ratios.

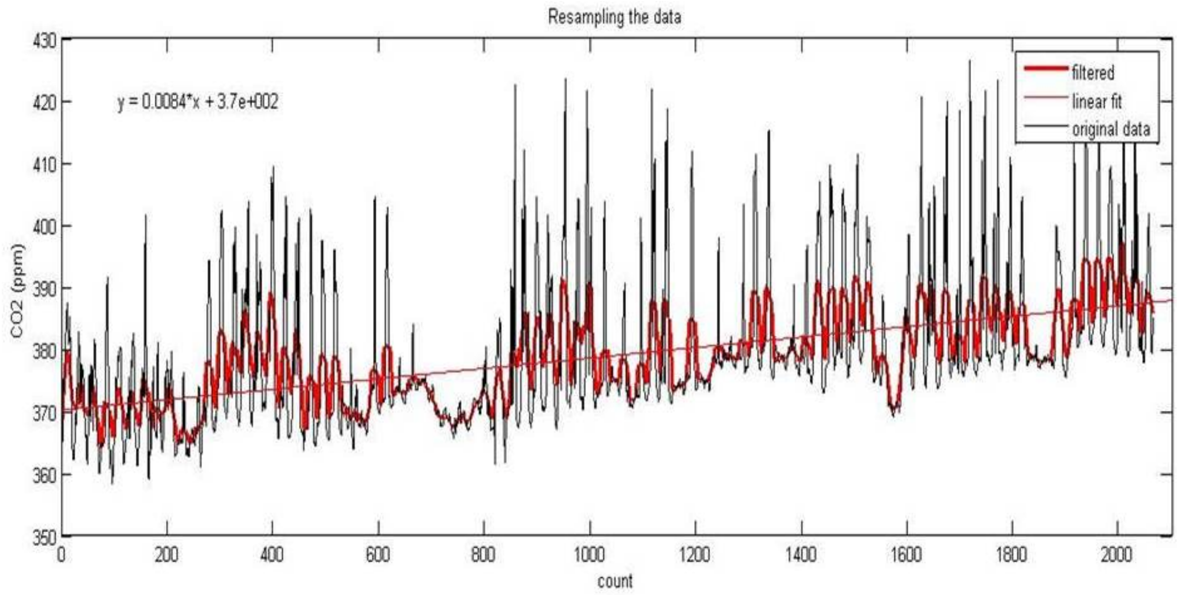

Figure 3: Baseline determination using Savitzky-Golay filter technique over SHAR region during the study period.

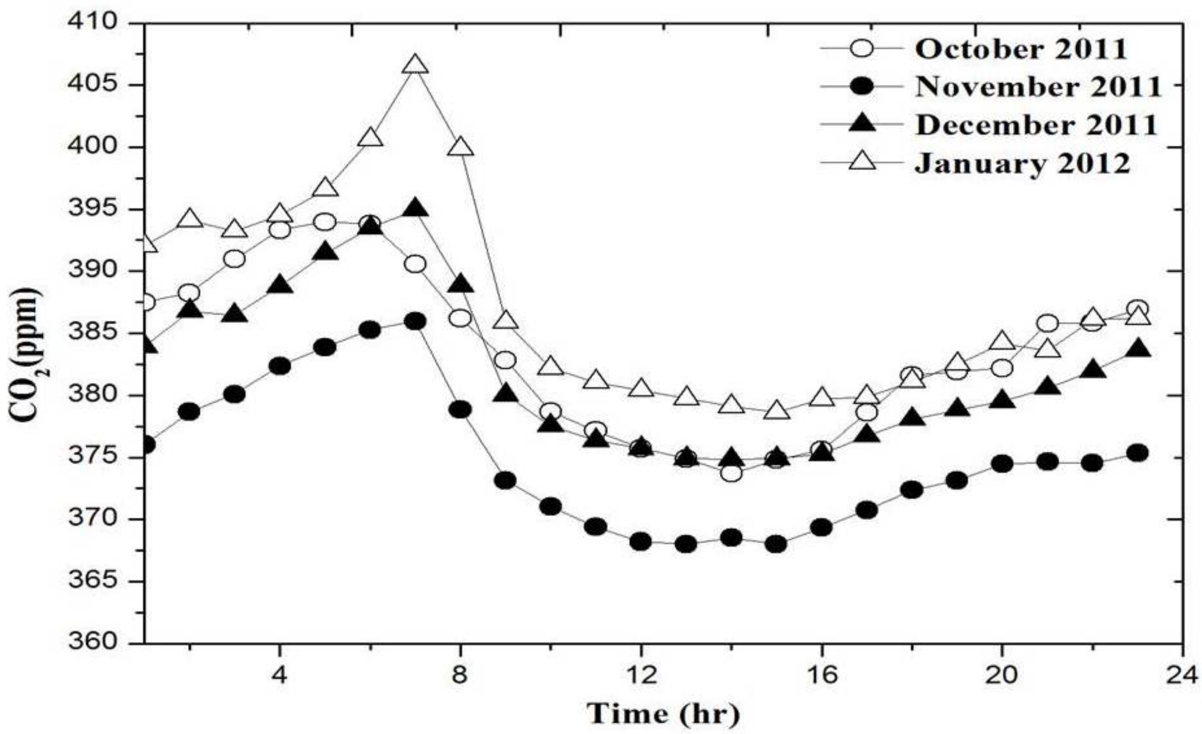

Figure 4: Diurnal variation of hourly mean CO_2 mixing ratios during October 2011-January 2012.

Study Area and Instrumentation

The study region (Figure 1) in Sriharikota is a coastal Island, 0.5 km away from the coast of Bay of Bengal (BoB) and connects to an urban area with a road. This site has a large area of vegetation and trees with less pollution. The GMP-343 was installed at a height of 30 m from the ground on the top of a building. The sensor is mounted above the rooftop to insulate from the heating effects. It measures the atmospheric CO_2 mixing ratio by utilizing the silicon based Non-Dispersive Infrared (NDIR) sensor to detect the absorbance of IR radiation by CO_2. The instrument is calibrated at the factory with 5 known concentration of CO_2 values (0-1000 ppm). The graph between the CO_2 measured by the instrument and the standard values are shown in Figure 2. Most of our observations are below 500 ppm and the difference between two observations varies from 1 and 3 ppm. This calibration is carried out at 26.2°C and the pressure varying between 1016.4 to 1016.7 hpa. These differences are much within the permissible limit. As per the Vaisala standard calibration procedure, the accuracy of the instrument is ±2 ppm for a temperature range of -40 to 60°C and for concentration range 0-1000 ppm. The precision of the instrument at 370 ppm with 30sec output averaging is ±1 ppm. The instrument (reference cylinder) drift in one year is ≤ 2% (± 0.5%) of the reading (Vaisala GMP-343 user guide and calibration report). The station has two towers of 100 m and 50 m. The 100 m tower has wind sensors at 100 m, 80 m, 60 m, 40 m, 30 m, 20 m and 10 m height. The 50 m tower has temperature and humidity sensors at 50 m, 32 m, 16 m, 8 m and 4 m. The continuous CO_2 observations were collected through a panoptic data logger at 5 min interval. The technical details and schematic diagram of the instrument are given in [3]. These CO_2 mixing ratios and wind vectors are analyzed for four months during October 2011 to January 2012.

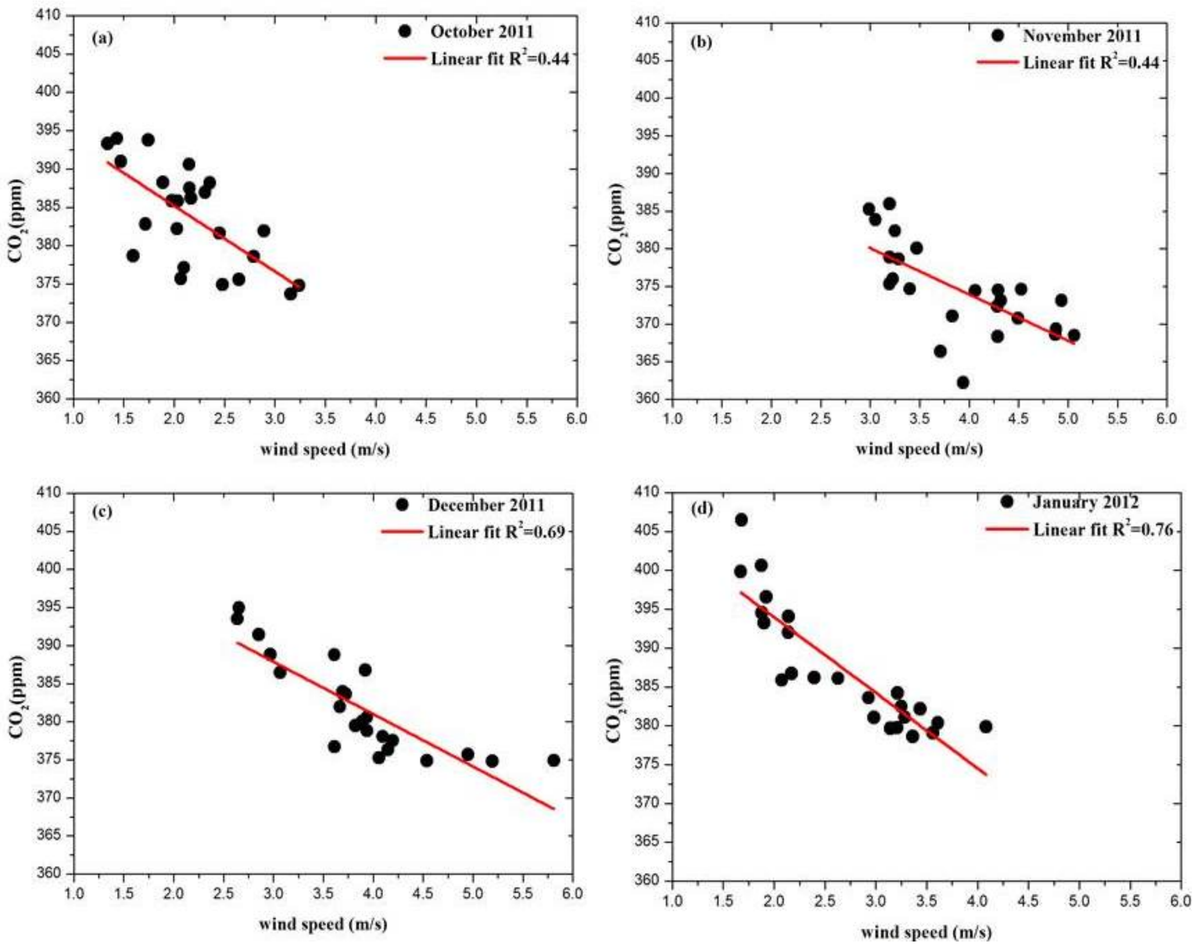

Figure 5: Scatter between wind speed and CO_2 mixing ratios during (a) October 2011, (b) November 2011, (c) December 2011 and (d) January 2012.

Methodology

The measurements were made using Vaisala made GMP-343 sensor. These values were recorded at 5min interval at 30 m height. The GMP-343 was well calibrated with standard CO_2 gas cylinders and instrument bias was removed from the observations. CO_2 observations were corrected for atmospheric moisture from Wagner [7] equation using saturated vapour pressure of CO_2:

$$\ln(p/pc) = (a1\tau+a2\tau1.5+a3\tau3+a4\tau3.5+a5\tau4+a6\tau7.5)Tc/T \quad (1)$$

Where, p = es (saturated vapour pressure), T_c (critical temperature) = 647.096K, p_c (critical pressure) = 220 64 kP_a, a1 = −7.859 51783, a2 = 1.844 082 59, a3 = −11.786 6497, a4 = 22.680 7411, a5 = −15.961 8719, a6 = 1.801 225 02 and $\tau = 1-(T+273.15)/T_c$

$$\text{Relative Humidity (RH)} = (e/es)*100 \quad (2)$$

$$CO_2dry=CO_2wet/(1-0.001*e) \quad (3)$$

The correction to be applied to the instrument measurements varies from 1.2 ppm to 14 ppm during October to January. The correction in October is more because of the more atmospheric water vapour in this month. Savitazky-Golay filter technique [8] was used to reduce the time series signal noise. This technique can be applied to any continuous and more or less smooth data with a fixed and uniform

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interval along the axis [9]. The 5 min observations have been averaged to hourly daily values. Along with the 100 m and 50 m tower observations, we have also computed 5-day back trajectory analysis at an altitude of 100 m for the study period using Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model [10].

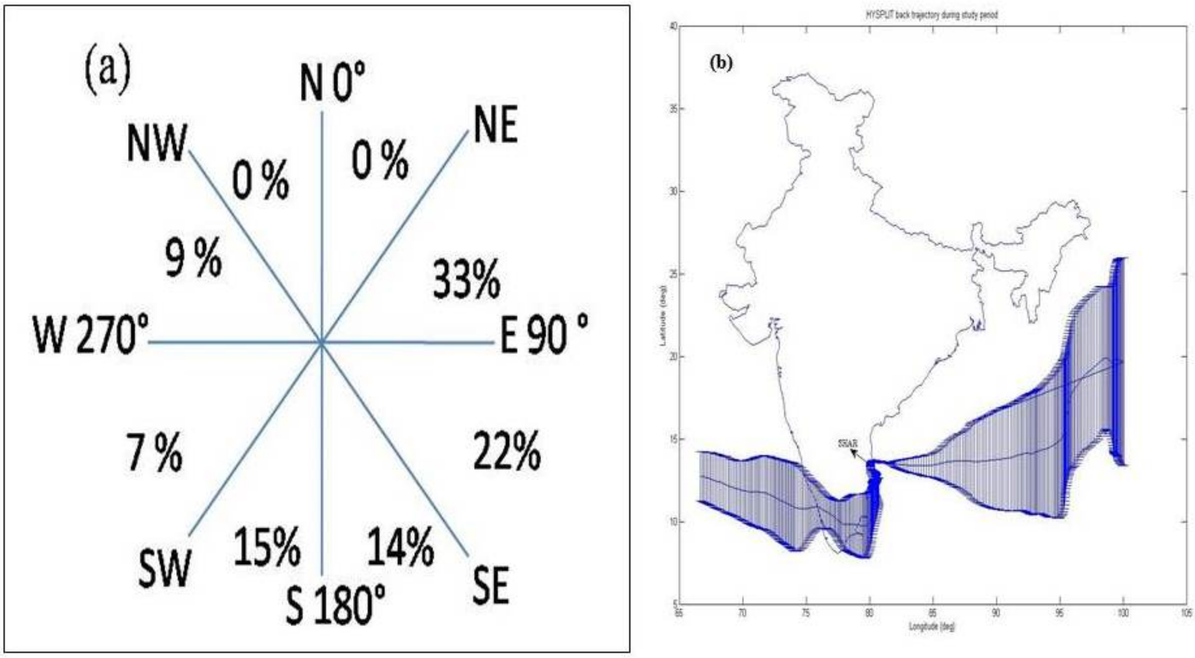

Figure 6: Wind direction from (a) AWS and (b) HYSPLIT model.

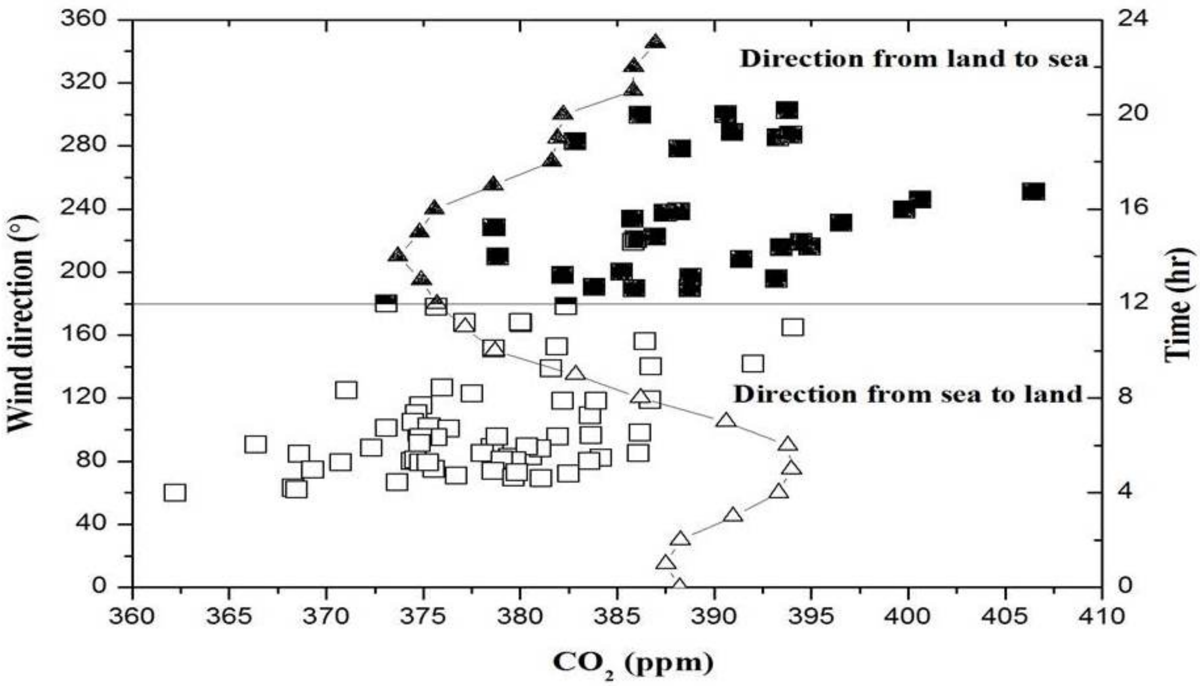

Figure 7: The prevailing mean wind direction from land and Ocean during the study period.

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Results and Discussions

Setting up the atmospheric CO_2 background

To have a quality control of the data, setting the background level (baseline) is required. For this purpose, we first filtered all the data following Savitazky-Golay technique [8]. The original data (black curve) and the data after filtering (red curve) are shown in Figure 3. These filtered values are used to compute the hourly means. These hourly observations were checked for consistency and only those observations, where the difference between the two consecutive values is less than 0.5 ppm are considered (4 % of the observations were removed in this way). Then the regional background level (baseline) was computed as a means of the hourly data following Zhou [11]. Thus, the baseline of this region is 382 ppm with a standard deviation of 8.1 ppm.

Month	R^2	R^2	Y-intercept	Y-intercept
	Without dummy analysis	With dummy analysis	Without dummy analysis	With dummy analysis
Oct-11	0.42	0.65	409	402.2
Nov-11	0.4	0.44	392	398.5
Dec-11	0.64	0.68	398.2	408
Jan-12	0.72	0.76	407	413.3

Table 1: Correlation between CO_2 mixing ratios and wind speed with and without including months as a dummy variable.

Month	Sea breeze			Land breeze		
	Average Wind speed (m/s)	Average CO_2 mixing ratio (ppm)	R^2	Average Wind speed (m/s)	Average CO_2 mixing ratio (ppm)	R^2
Oct-11	2.38	379	0.15	1.97	388	0.58
Nov-11	4.22	371	0.66	3.59	377	0.45
Dec-11	4.17	379	0.94	3.55	385	0.65
Jan-12	3.01	385	0.95	2.37	390	0.82

Table 2: Correlation between CO_2 mixing ratios and wind speed during land-sea breezes.

Month	rainfall (mm)	
	Day	Night
Oct-11	181.5	89.7
Nov-11	6.52	7.9
Dec-11	1.6	1.3
Jan-12	0.74	0.02

Table 3: Rainfall during October 2011 to January 2012.

Diurnal variation of CO_2

Diurnal variation of CO_2 mixing ratios are shown in Figure 4. The diurnal variations are similar during all the months but with varying concentrations. The first peak (crest) in every plot is at around 0700 to 0800 IST, which is due to the accumulation of CO_2 mixing ratios during early morning, before the sunrise. As the day advances the level of CO_2 decrease gradually and reaches a minimum by afternoon (1300 IST to 1500 IST) due to high atmospheric mixing [12] and due to the increased photosynthesis activity. The mixing ratios again increase after the evening, after the sunset, peaking around 1900 IST-2100 IST due to the absence of photosynthesis activity besides wind effects, which will be discussed later. The maximum diurnal variation is during January 2012 with maximum value of 407 ppm at 0700 IST and minimum value of 380 ppm at 1500 IST. Similar diurnal variations are observed by Neerja [3,13] at Dehradun and Gadanki, India. Though the pattern remains almost same, the mixing ratios vary from month to month with January (November) having highest (lowest) values. Since the atmosphere is relatively calm and stable with frequent inversions during winter season, the high values are present during January and December compared to other months. November CO_2 mixing ratios are less than those in October by ~10 ppm through the day. This could be due to high rainfall in October with more moisture content which in turn increases the wet correction and increases the value of dry CO_2.

Impact of wind vector on variation of CO_2

Wind speed

The impact of wind speed on the CO_2 mixing ratios varies from month to month (Figure 5). 76% (69%) of the variations in CO_2 are due to wind speed in January (December) with less control of wind during October and November (44%). 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. October and November being post monsoon months other factors like soil respiration and photosynthesis might have been controlling the CO_2 mixing ratios due to which the percentage contribution of wind is less in these two months. The observations with maximum (minimum) mixing ratios of 407 ppm (361 ppm) have wind speeds of 1.68 m/s, (3.16 m/s). 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 coastal station.

Wind direction

Analysis of 100 m tower wind data shows that the prevailing wind direction during the study period at SHAR (Figure 6a) is from west-southwest [200°-340°] and east-northeast [20°-160°]. Besides analyzing the AWS winds, we have also computed the 5-day model vertical velocity air mass back trajectories at an altitude of 100 m (Figure 6b) for the study period using the HYSPLIT model for the same period. This analysis also reveals that the majority of winds are from northeast direction.

Impact of land and sea breezes

To study how land and sea breezes affects the CO_2 mixing ratios, we considered all the winds coming from 0^0-180^0 as sea breeze and those coming from 180^0-360^0 as land breeze and accordingly CO_2 mixing ratios are divided. The demarcation of CO_2 coming from land and sea is shown in Figure 7. Higher concentrations of CO_2 are present during land breeze time. About 70% of the winds are from the Sea. Though coastal regions act as a source of CO_2, the amount of CO_2 concentrations from the ocean are less than those from land [14]. Thus, the sea breeze helps in reducing the CO_2 concentrations at SHAR. Since sea breeze is stronger than land breeze, the scavenging effect of strong winds is another cause for these low concentrations during sea breeze time.

We carried out a dummy variable regression analysis considering months as the mutually exclusive variables. The coefficient of determination (R^2) between the wind speed and the CO_2 mixing ratio for all months together is 0.73, which otherwise is 0.52. This improvement shows the impact of seasonality on the mixing ratios. The monthly R^2 and the y-intercepts with and without dummy variable analysis are given in Table 1. Monthly average wind speeds, mixing ratios and R^2 between wind speed and CO_2 mixing ratios during land and sea breezes separately for the four months is shown in Table 2. During sea breeze the mixing ratios (wind speeds) are slightly lower (higher) than those during land breeze. R^2 during land breeze is less than that during sea breeze during November-January. The land breeze explains 58% to 82% variation in CO_2 while the sea breeze explains 15% to 95%.

Impact of rainfall

To understand why R^2 during October is significantly less during sea breeze contrary to the other three months, we analysed the hourly rainfall data since rainfall is another factor that scavenges the CO_2. Depending upon the partial pressure of CO_2 and the atmospheric temperature, CO_2 dissolves in rain droplets producing a weak carbonic acid, H_2CO_3. Monthly total rainfall during the day (night) time during October 2011 to January 2012 is shown in Table 3. The comparatively heavy rainfall in October during daytime might have scavenged CO_2 thus reducing its relationship with wind speed during sea breeze. Hence, wind speed could explain only 16% of the variations in CO_2 during sea breeze in October.

Summary and Conclusions

The continuous 5 min interval CO_2 observations collected at SHAR, Sriharikota from Vaisala GMP-343 sensor were averaged on an hourly basis. The baseline of atmospheric CO_2 during study period is 382 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. SHAR being a coastal station, the land and sea breezes mainly control CO_2 mixing ratios. The mixing ratios have a seasonal behavior. Except during October 2011, the R^2 between the wind speed and CO_2 mixing ratios is more during sea breeze compared to that during land breeze for November, December and January. However, during October R^2 between CO_2 mixing ratios and wind speed is very less during sea breeze due to the very heavy rainfall in this month, which scavenged CO_2 from the atmosphere.

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