Measurement of Atmospheric Carbon Dioxide Levels at Dokriani Bamak, Garhwal Himalaya, India

Ashish Anthwal, Varun Joshi, Suresh C. Joshi and Kireet Kumar

Abstract Increase in surface temperature at global scale has already affected a diverse set of physical and biological systems in many parts of the world and if it increases at this rapid rate then the condition would be worst one could have ever thought off. Garhwal Himalaya, major part of the great Himalayan mountainous system is also much sensitive and vulnerable to the local, regional and global changing climate. Due to large altitudinal gradient, varied climatic conditions and diverse set of floral and faunal composition, the impact of climate change seems to be much perceptible in coming future. Natural ecosystems at high elevations are much more sensitive to the climatic variations or global warming then the managed systems. This paper highlights measurement of atmospheric Carbon dioxide at Dokriani Bamak, Uttarkashi District, Uttarakhand. Concentration of CO_2 averaged 383.5 ± 2.12 ppm in 2005. Daily variations of CO_2 values showed minimum during the daytime (376.5 ppm) and peaked in the evening (393.8 ppm). At monthly intervals, the CO_2 values varied from 381.9 ± 3.70 (May) to 385.52 ± 7.05 ppm (August). Average temperature recorded during the year was 4.7 °C and during the growing season (May–October 2005) was 6.8 °C. Although phenology is significant in controlling CO_2 levels, short-term changes

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cannot be explained without the anthropogenic perturbations. The CO_2 concentration in Dokriani Bamak (383.5 ppm) was higher and comparable with those of other major monitoring locations around the world.

Keywords Atmospheric carbon dioxide · Diurnal · Phenology · Climate change · Dokriani Bamak · Garhwal Himalaya

1 Introduction

Carbon dioxide is a trace gas in the earth's atmosphere of which exchange occurs between the major environmental reservoirs such as the oceans and the biosphere. Being the most abundant greenhouse gas in the atmosphere (besides water vapour) atmospheric CO_2 contributes most significantly to global climate change (Bolin et al. 1986; Houghton et al. 1996). The great industrial demands for energy promoted to release vast quantities of carbon dioxide into the earth's atmosphere since the beginning of the industrial revolution. Monitoring of atmospheric CO_2, as conducted constantly since the late 19th century, showed a steady and continuous increase in its concentrations. Because of the increasing human activities, its atmospheric concentration increased from 280 ppm in pre-industrial revolution to current level of 380 ppm (IPCC 2007). According to IPCC (2001), atmospheric CO_2 concentrations increased by 31 % over the last 250 years. The average increase rate of CO_2 was maintained at 1.4 ppm $year^{-1}$ for the period 1960–2005 (IPCC 2007). The rate of its increase in the last 10 years (1995–2005) is estimated to be 1.9 ppm $year^{-1}$ to show the highest growth rate since its direct measurements from 1950s (IPCC 2007).

Carbon dioxide levels recorded at various locations around the world consistently show a direct link with fossil fuel combustion (Denning et al. 1995; Colombo et al. 2000). Other sources of atmospheric CO_2 include plants, animals, microbial respiration, ocean emission, and land use change. As such, fossil fuel combustion and cement production have increased carbon dioxide emissions by 70 % in the last 30 years (Prentice et al. 2001; Marland et al. 2006). As the increase in atmospheric greenhouse gas concentrations is the main cause of global warming, it is predicted to affect trend of climate change in both regional and global scales. Detailed information concerning the source/sink of greenhouse gases and their emission strengths has been one of the major goals of global climate study. Because the distribution of CO_2 is subject to geographical and temporal variations (Keeling 1961; Pales and Keeling 1965; Inoue and Matseuda 1996), model predictions with a relatively wide geographical coverage were not necessarily useful to accurately quantify CO_2 exchange on a global scale (Massarie and Tans 1995; Keeling et al. 1995). By considering such limitations, numerous attempts have been made to build a database of CO_2 to cover diverse environmental conditions (Levin 1987; Levin et al. 1995; Schmidt et al. 1996). For instance, a continuous measurement of CO_2 (and the related isotopic carbon ratios) has been reported in the Krakow region, Poland (Kuc 1991) or in the K-puszta region of Hungary (Haszpra 1995). However, despite the importance of CO_2 data acquisition, relatively little is known about its distribution on hilly areas of the world. This paper reports the results of CO_2 measurements made in the atmosphere of Dokriani Bamak lying in the high altitude region of the Northwest Himalaya, India. The purpose of this study is to primarily evaluate the carbon dioxide concentration levels and its temporal variabilities in the hilly region of Garhwal Himalaya at Dokriani Bamak, India. The results of this study will provide some insights into the environmental behaviour of CO_2 in mountainous environs.

2 Materials and Methods

The concentration data of CO_2 were collected using infrared CO_2 gas analyzer (LI- 820, LI-COR, USA). Air was drawn at a flow rate of 1 L min^{-1} through air filter (Balston 25 μm) attached to non-CO_2 absorbing Teflon tubing into the gas analyzer. Sampling interval was set to 30 s, and the data were recorded every 2 h by a data logger (LI-1400, LI-COR, USA). The incoming air was passed through a column of magnesium perchlorate to eliminate the possible interference due to water vapour. The CO_2 gas analyzer was calibrated prior to measurement by checking span and zero values with CO_2 calibrant gas (505 ppm). The measurement range of CO_2 by the NDIR analyzer was 0–1,000 ppm with an accuracy of <2.5 % and a total drift of <0.4 ppm/°C at 370 ppm. The CO_2 values recorded at two hourly intervals were converted into daily or monthly for the analysis of its temporal variabilities at different intervals.

3 Results and Discussion

3.1 General Pattern of Temperature and CO_2 Distribution at Study Site

The present study was conducted at Dokriani Bamak, a high altitude area situated in Uttarkashi district of Uttarakhand Himalayan region in India (Fig. 1).

Carbon dioxide concentrations were recorded at the Base camp of Dokriani Bamak (altitude of 3,600 m above mean sea level, Latitude 30° 50′–30° 52′N, Longitude 78° 47′–78° 50′E). The study area is accessible only during the summers i.e. May to November. During rest of the months the area is inaccessible due to heavy snow. So the temperature data were only measured during the growing season. Average temperature recorded during the year was 4.7 °C and during the growing season (May–October 2005) was 6.8 °C. Concentrations of CO_2 in air were monitored at 1.5 m above the ground at two hourly intervals (for up to 9 h: 0600 to 2200 h (local time) throughout the study period (May to

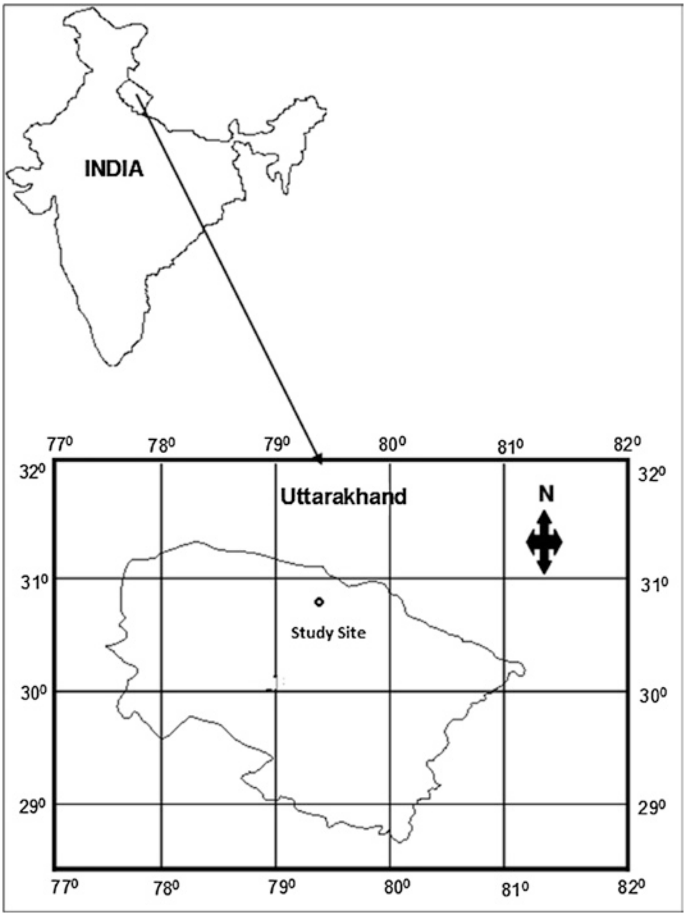

Fig. 1 Location map of the study site

November 2005 except September 2005). The concentration data of atmospheric CO_2 have been collected continuously from various locations in the world since its measurements at Antarctica and Mauna Loa observatory (Hawaii) in 1958. In India, CO_2 was monitored for the first time in the air and soil layers near the ground in the year 1941 (Mishra 1950): The study was conducted to measure CO_2 in the open as well as crop fields. The longest monitoring of atmospheric CO_2 in India was first made at Cape Rama, a maritime site located in the west coast of India for a 10 year period (1993 and 2002: Bhattacharya et al. 1997). The results of this study are the first attempt to continuously measure atmospheric carbon dioxide in the hilly region of Dokriani Bamak, Uttarkashi, Uttarakhand. In Table 1, the basic statistical parameters of CO_2 data monitored in this study are presented. The overall mean value of CO_2 measured in this study was 383.5 ± 2.8 ppm.

Table 1 Statistical summary of atmospheric CO_2 recorded at Dokriani Bamak, Uttarkashi

Months	Mean	Median	SD	Minimum	Maximum	N	SE	RA
May	381.85	381.00	3.7	378.41	388.13	9	1.23	9.72
Jun	385.95	381.95	8.6	377.64	400.61	9	2.86	22.97
Jul	384.44	385.09	7.5	373.85	394.18	9	2.49	20.33
Aug	385.51	385.49	7.0	373.69	395.49	9	2.35	21.8
Oct	380.61	379.85	4.2	375.01	387.32	9	1.41	12.31
Nov	382.82	381.01	5.1	376.96	390.48	9	1.69	13.52

3.2 Diurnal Variation in Carbon Dioxide Levels

To assess the diurnal variation of CO_2, the data obtained above the ground at every 2 h intervals are plotted and examined in many respects. In Fig. 2a, the CO_2 concentrations for each 2 h interval are compared diurnally using all data sets. The CO_2 levels at this site maintained a diurnal pattern that is consistent enough to show the highest values (393.8 ppm) in the night time (2200 h) and lowest values (376.5 ppm) in the afternoon (1200 h) with the relative amplitude of 4.5 %. Figure 2b depicts the diurnal pattern of CO_2 between different months of the year 2005. The differences in hourly CO_2 concentration levels varied significantly between minimum (373.7 ppm in August) and maximum values (400.6 ppm in June) across the months. If the strengths of diurnal variation were compared by

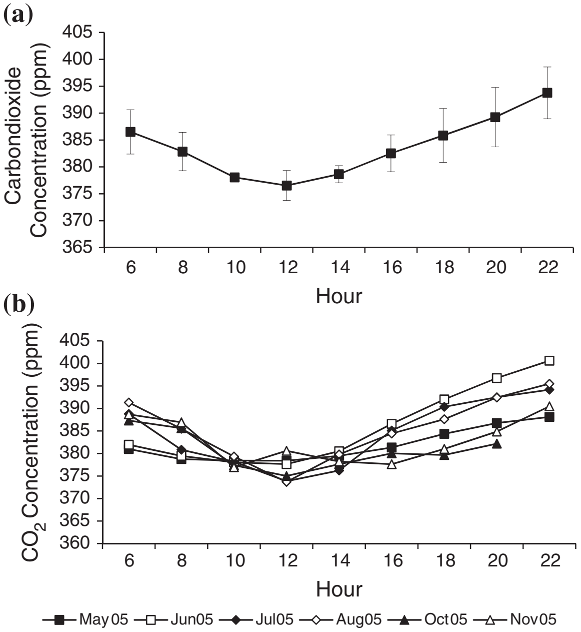

Fig. 2 Diurnal variation in the atmospheric CO_2 using all hourly measurements for **a** all data sets and **b** monthly data sets of CO_2

relative amplitude (RA) values between different months, the RA values ranged from 2.55 (May) to 5.95 % (June). The diurnal cycle of CO_2 is generally known to exhibit a maximum at night (or morning) and a minimum during the daytime (Schnell et al. 1981; Baez et al. 1988; Yi et al. 2001). A nighttime maximum of CO_2 in rural areas has been attributed to respiration by plants (and animals) and its emissions from soils. In contrast, daytime minimum is explained by photosynthesis (Spittlehouse and Ripley 1977; Baez et al. 1988; Nasrallah et al. 2003). Such phenomenon can also be explained partially by the changes in meteorological conditions, as the height of the mixing layer increases under stronger solar radiation (Aikawa et al. 1995).

Many previous studies based on long-term monitoring of CO_2 also indicated that CO_2 fluctuates both diurnally and seasonally (Woodwell 1978; Keeling et al. 1984; Fung et al. 1987). The average relative amplitude in this study was found as 6.95 % between the daytime drawdown and night time buildups of CO_2. This RA value is smaller than those measured in the Savannah regions (21.6 %) and tropical rain forests (25.4 %) (Schnell et al. 1981), urban area of Basel city (Switzerland) with 15.5 % (Vogt et al. 2006), and urban area of Chicago with RA values of 9.02 % (Grimmond et al. 2002). The RA value of the present study is however comparable to that measured from four different sites in Phoenix (2.85–7.86 %: Day et al. 2002). Differences in the magnitude of RA values may be ascribable to such factors as the strength of biospheric photosynthesis, respiration, mixing conditions, and emissions from anthropogenic sources (Pales and Keeling 1965; Inoue and Matsueda 1996). Considering the magnitude of diurnal fluctuations in the study area, such variability CO_2 may have significant implications on the vegetation of the region due to its impact on the plant photosynthesis (Veste and Herppich 1995).

4 Comparison with Previous Studies of CO_2 Concentration

In an attempt to understand the factors controlling the distribution of CO_2 under various environmental conditions, we examined our monitoring data obtained from the mountainous area of Garhwal Himalaya, India with those reported from other parts of the world. Table 2 summarizes the yearly carbon dioxide values, measurements conditions, detection method, and amplitude of CO_2 data for all comparable data sets. For this comparative analysis, all the reference data were basically taken from the data sets of year 2006 from the WMO global atmosphere watch, world data centre for greenhouse gases (WDCGG).

The annual mean concentrations of CO_2 for all the recording stations except Romania (368.3 ppm) were well above the global background concentrations of CO_2 (380 ppm). Figure 3 depicts the absolute concentrations and relative amplitude of CO_2 measured from all stations examined for comparative purposes. The mean CO_2 concentration for India, Himalaya during the study year was higher (383.5 ppm), when compared to the stationary stations in Australia (379.1 ppm),

Table 2 Comparison of the mean CO_2 concentration measured from all different stations around the world

City/station	Recording year	Method	Sampling type	No of sampling months	Average	SE	Amplitude	Relative amplitude
Australia (Cape Fergusson)	2006	GC (FID)	Flask	12	379.1	0.2	2.2	0.59
Austria (Sonnblick)	2006	NDIR	Continuous	9	381.71	1.8	13.0	3.41
Finland (Pallas-Sammaltunturi)	2006	NDIR	Continuous	12	384.38	1.8	18.0	4.68
Germany (Deuselbach)	2003	GC (FID)	Continuous	11	386.15	1.7	15.0	3.88
Israel (Sede Boker)	2006	NDIR	Flask	12	383.57	1.1	11.0	2.87
Kazakhstan (Sary Taukum)	2006	NDIR	Flask	12	385.35	1.8	16.0	4.15
Mongolia (Ulaan Uul)	2006	NDIR	Flask	12	383.66	1.6	17.0	4.43
Kenya (Mt. Kenya)	2006	NDIR	Flask	7	379.63	0.5	3.3	0.86
Norway (Zeppelinfjellet)	2006	NDIR	Continuous	12	383.07	1.6	15.0	3.92
Portugal (Terceira Island)	2007	NDIR	Flask	11	383.06	1.2	12.0	3.13
Russia (Teriberka)	2006	NDIR	Flask	11	384.63	1.6	17.6	4.58
Seychelles (Mahe Island)	2006	NDIR	Flask	12	380.42	0.3	3.0	0.79
USA (Southern Great Plains)	2006	NDIR	Flask	12	384.98	1.1	12.0	3.12
Romania (Fundata)	2005	NDIR	Continuous	12	368.32	4.3	54.1	14.69
India (Dokriani bamak)	2005	NDIR	Continuous	6	383.5	0.7	17.2	4.49

Source WMO global atmosphere watch, World data centre for greenhouse gases (WDCGG)

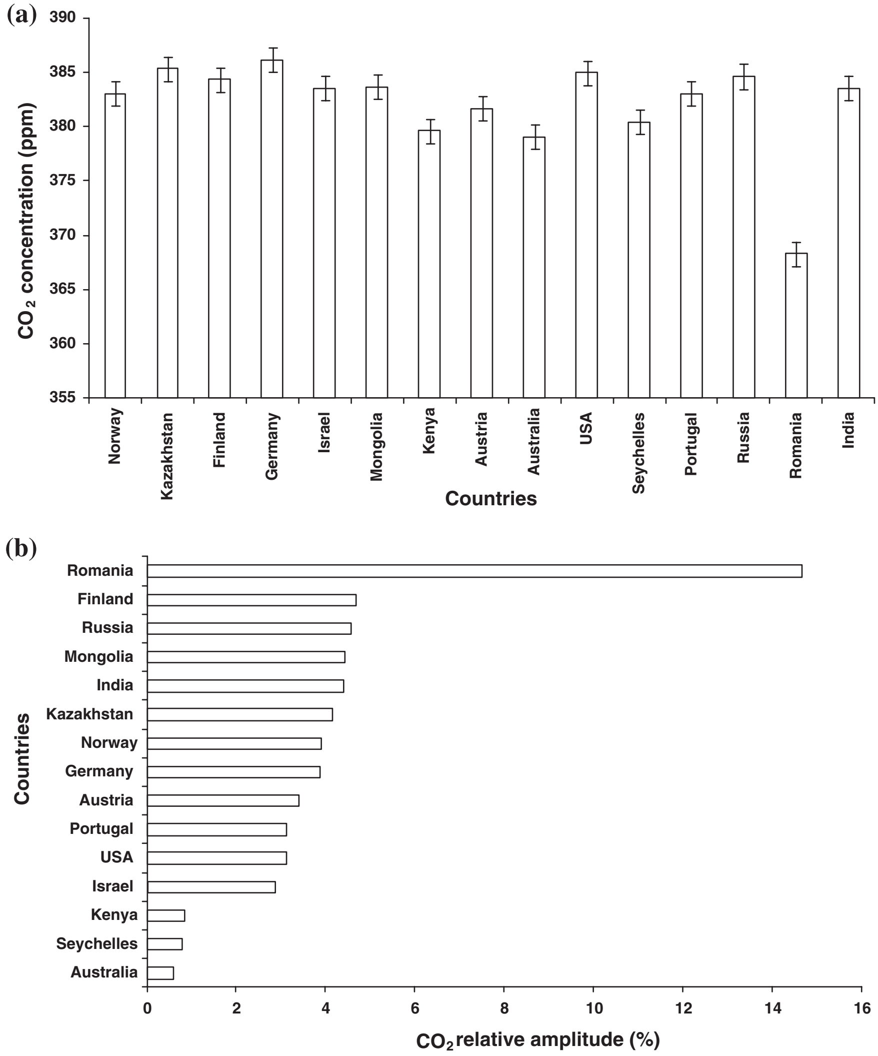

Fig. 3 A comparison of **a** absolute concentration (ppm) and **b** relative amplitude (%) of CO_2

Norway (383.07 ppm), Austria (381.7 ppm), Mt. Kenya (379.6 ppm) and Romania (368.3 ppm) stations. The relative amplitude of the CO_2 values for all the comparative data can be estimated as the difference between the maximum and minimum values (amplitude) over mean. The relative amplitude of our study site was found to be more or less similar (4.50 %) to the RA recorded at Finland (4.68 %), Mongolia (4.43 %), Russia (4.58 %) and Kazakhstan (4.15 %).

Figure 4 shows the comparison of the monthly mean values of CO_2 measured at different stations over the globe. Pallas-Sammaltunturi (Finland) and Mt. Kenya

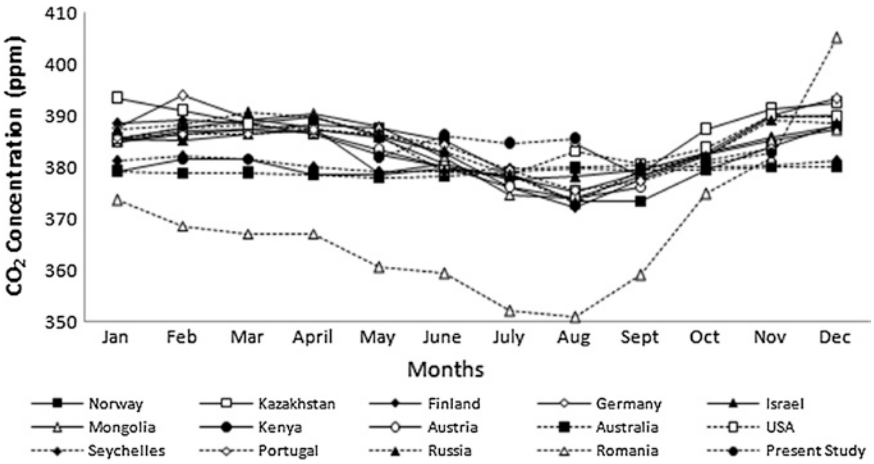

Fig. 4 Month- to- month variation of CO_2 in all stations selected for comparison

(Kenya) represent the global CO_2 concentration sites, whereas all the other stations for regional CO_2 concentration. Among all the sites shown in the Table 2, a number of stations including Sonnblick, Deuselbach, Fundata, Ulaan Uul, Sary taukum, etc. represent mountainous sites. All of these stations are stationary, while they are free from direct effect of any known anthropogenic sources. The annual mean CO_2 concentration for mountainous sites, if derived using all those data sets, was much lower or similar (384.2 ppm, range: 381.7–386.2 ppm) than that of our study (383.5 ppm). If the relative amplitude values are compared between all mountainous sites (3.41–4.43 %), their values are quite analogous to our results (4.50 %).

5 Conclusion

In the present study, the temporal variations in the atmospheric carbon dioxide in the mountainous area of Dokriani bamak were investigated using the data sets collected from May to Nov 2005 except September. The diurnal variation of CO_2 was characterized by relative enhancement in the night. As the green plants intensively absorb atmospheric CO_2 (through photosynthesis), the concentrations of CO_2 are maintained in the least level during the daytime. When the diurnal variations are assessed across different months, the patterns confirmed the combined effect of biogenic and meteorological factors. It should be stressed here that the mean carbon dioxide concentration during the growing season in Dokriani bamak were higher (383.5 ppm) than the global mean atmospheric CO_2 value of around 380 ppm. The present work is the first preliminary report covering continuous monitoring of CO_2 in the mountainous region of Garhwal Himalaya, India. According to our analysis, it may be important to explain the possible cause of the high CO_2 levels in this clean area. As the troposphere baseline data of CO_2 concentration were not measured over the Himalayan region previously, precise measurements of atmospheric CO_2 are needed for an extended period. Such efforts can offer more insights into the factors governing the CO_2 concentration under diverse environmental settings.

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