

Impact of forest fires on the regional climate

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Forest fires of short- to medium-return intervals are quite common during summer seasons in Garhwal Himalaya. Despite the importance of forest fires as an important source of greenhouse gases and aerosols, no research till date has focused on the impact of forest fires on regional climate. This article shows how forest fires of different severity, in terms of forest area burnt (1747.48 ha and 40,195 ha in 1996–97 and 1999, respectively), modify the atmospheric CO₂ concentrations and environmental variables such as temperature, solar radiation and relative humidity. These variables were measured for 40 days from 10 April to 19 May during the year of 1996 and 1999 at Srinagar (Garhwal) using Binos 100 gas analyser and an automatic weather station with datalogger. The year 1999 was characterized by extensive fires in the Garhwal region during the said period, including that in the vicinity of the measurement site, whereas in 1996, fire (less extensive) was observed from Garhwal Himalaya, but not in the vicinity of the measurement site. The data indicate that forest fires, depending upon their severity, may have the potential to cause significant changes in the CO₂ content and climatic elements, particularly solar radiation and temperature only in the short-term rather than in the long-term basis. The fire impacts vanished with the onset of rainfall in May. However, to obtain factual information on the long-term effect of these short-term fluctuations on regional and global climate, monitoring of these variables on long-term basis is needed.

THERE is growing evidence that the build-up of greenhouse gases (H₂O, CO₂, CH₄, N₂O and CFCs) in the atmosphere, primarily due to human activities, is causing global warming and climate changes^{1,2}. Of these trace gases, CO₂ has a significant contribution in greenhouse effect because it is the most abundant trace gas in the atmosphere³. The concentration of CO₂ in the atmosphere has increased by nearly 30% since the beginning of the industrial revolution, from 280 ppm to its present value of more than 365 ppm, and is projected to reach a concentration of 550 ppm during the middle of this century², due largely to fossil-fuel combustion and deforestation. Now, there is evidence that forest fire or biomass burning (biomass burning includes all forms of combustion that rely on vegetative fuels) is a large source of trace gases, particularly CO₂ and particulate matter (aerosols), that are accumulating in the atmosphere^{4–6}, and contributing to the increased seasonal amplitude of atmospheric CO₂ (ref. 7) and changes in the world's climate as a large extent of the areas burnt annually^{8–10}.

Further, it has been demonstrated that over the last few decades, frequency and extension of fires have increased at a global scale. It has also been argued that under chang-

ing climatic conditions frequency and intensity of fires may increase, which would have additional detrimental consequences not previously considered^{11–13}. Thus forest fire has become one of the most relevant environmental problems. However, the amount of CO₂ being released on account of fires is not well documented, probably because of lack of systematic monitoring of the fire cases and the extent of forest area burnt¹⁴. Earlier attempts to estimate the contribution of forest fires to increased CO₂ in the atmosphere exhibit large variability^{9,15,16}. However, one may possibly be able to approximately estimate the relative contribution of forest fires to increased atmospheric CO₂ concentration and climate change by measuring the atmospheric CO₂ concentrations and climatic variables (temperature, solar radiation and relative humidity) prior to, during and subsequent to forest fires, and by comparing these variables between the years differing in the magnitude of forest area burnt.

While the relative importance of fire in modifying the global climate is increasing, our understanding of how forest fires might affect regional climate is still rather limited¹⁷. In context to the Central Himalayan region, particularly in Garhwal Himalaya (lat 29°45'–31°30'N and long 78°2'–80°7'E), occurrence of fires of short- to medium-return intervals (2 to 4 year interval) during summer seasons, when drought conditions prevail, has become a regular phenomenon. Fires are mostly man-made, occurring due to intentional or reckless acts committed by

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humans, and caused primarily to obtain good growth of grasses. Depending on the frequency and intensity of fires experienced in this region of Himalaya, they may play a significant role in climate modification. While a few studies have been made on the impact of forest fires on the vegetation of the region^{18,19}, no research till date has focused on real-time assessment of the impact of forest fires on regional climate. Here an attempt has been made to determine how different fire regimes, in terms of forest area burnt, alter the atmospheric CO₂ concentrations and other climatic variables (solar radiation, temperature and relative humidity) in this region.

Pilot area and measurements

To assess the impact of forest fires on the regional climate, measurements of above-mentioned variables were made before and after the fire. A systematic measurement of CO₂ and other environmental factors was conducted for 40 days from 10 April to 19 May in 1996 and 1999 at Garhwal Unit of G.B. Pant Institute of Himalayan Environment and Development, Srinagar (Garhwal) (altitude 550 m amsl; lat 30°13'N; long 78°48'E). The year 1999 was characterized by extensive fires during the said period in the Garhwal region (comprising five districts, viz. Chamoli, Dehradun, Pauri, Tehri and Uttarkashi), including the one in the vicinity of the measurement site, whereas in 1996, fire (less extensive) was observed from the Garhwal Himalaya, but not in the vicinity of the measurement site. The values of the above-mentioned variables for the corresponding period (i.e. from 10 April to 19 May) for the year 1996, differing in the extent of forest area burnt, are given to know the impact of two levels of fire regimes on regional climate. On 13 April 1999, fire was detected in the surrounding vegetated areas (predominated by grasses, shrubs and pine trees). Within a couple of days many individual fires or group of fires were reported from different parts in Garhwal region (Table 1). The CO₂ content of the air (2.5 m above the surface) was recorded at 2-hourly intervals during daytime from 0900 to 1800 h (local time) using Binos 100 gas analyser (Rosemount GmbH and Co., Germany) in the absolute mode. The CO₂ gas analyser was calibrated prior to use. Air was drawn through non-CO₂-absorbing Teflon tubing into the gas analyser after passing through a column of magnesium perchlorate to remove residual moisture content. The daytime mean values of CO₂ concentrations were calculated by averaging CO₂ values obtained at 2-hourly intervals from 0900 to 1800 h. Climatic data such as minimum, maximum and average solar radiation, temperature and relative humidity during the experimental period were also recorded using an automatic weather station with a datalogger system (Campbell Scientific, USA).

Results and discussion

The number of reported fire cases and burnt area in the year 1996–97 and 1999 (Table 1) show that fire destroyed 1747.48 ha (0.12% of forest area) of forests in Garhwal region in the year 1996–97, whereas in 1999 about 40,195 ha (2.84% of forest area) of forests, including 27,218 ha of reserve forests and 12,977 ha of civil soyam forests were damaged. It is worth mentioning here that the fire statistics is based on ground observations and thus subject to improvements, if one considered satellite-based data. Prevalence of dry weather conditions (an almost complete absence of rainfall, low humidity and high air temperature) during March and April 1999 may have accounted for more incidences of forest fire in this year, as weather is an important determinant of forest fires^{11,12}. The average relative humidity, temperature and total rainfall during March and April 1999 were 54.27 and 33.63%; 19.97 and 25.41°C; 1.8 and 0 mm, whereas the values of these variables for the corresponding period for the year 1996 were 67.66 and 47.44%; 19.02 and 22.85°C; 45.8 and 37.1 mm, respectively (Table 2).

As expected, there was an enhancement of atmospheric CO₂ during the fire period. The enhancement was observed in the year 1999, characterized by extensive fires. This increase in atmospheric CO₂ concentration in 1999 may be attributed to forest fires as there were no other known major anthropogenic sources of CO₂ in the vicinity of the measurement site. The daytime mean values of CO₂ were significantly ($P \leq 0.05$) higher during forest fire in the year 1999 than those prior to forest fire as well as those during the corresponding period in the year 1996. There were considerable variations in the mean daytime values of CO₂ during the forest-fire period in 1999 (Figure 1). Mean daytime concentration of atmospheric CO₂ ranged from 330 to 342 ppm during the study period (10 April to 19 May) in 1996, and it varied from 338 to 382 ppm in the year with high severity of fire (1999), with maximum value observed on 17 April. However, a complete recovery of CO₂ levels to pre-fire levels of about 338 ppm was observed with the arrival of rainfall, that started from 10 May 1999. It is worth mentioning here that normal monsoonal rain in general occurs in this region only after 31 June of every year. Further, the atmospheric CO₂ concentration followed a typical diurnal pattern during both

Table 1. Number of fire instances and burnt area in 1996–97 and 1999 in the Garhwal region of the Central Himalaya*

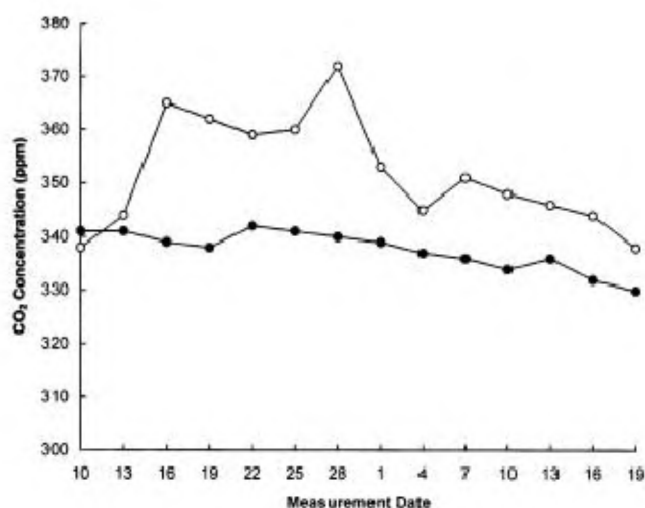
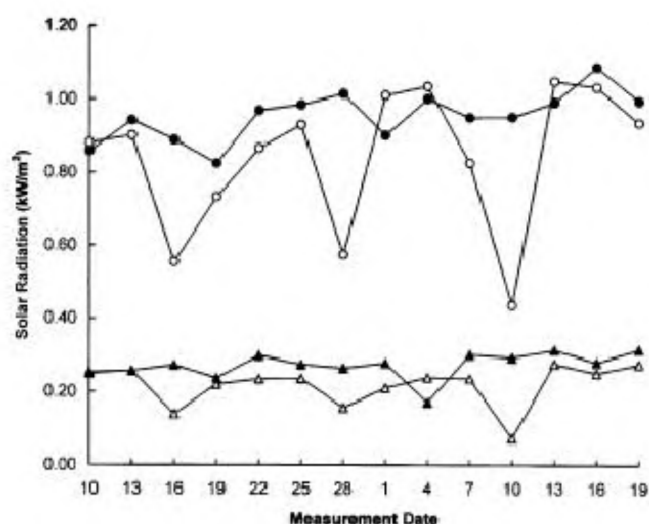
Year	Number of fire instances	Total area burnt (ha)	Average area burnt (ha)	Percentage of total forest area burnt**
1996–97	404	1747.48	4.33	0.12
1999	2514	40195.00	15.99	2.84

*Source: Chief Conservator of Forests, Garhwal region, Dehradun.

**Based on State of Forest Report 1999.

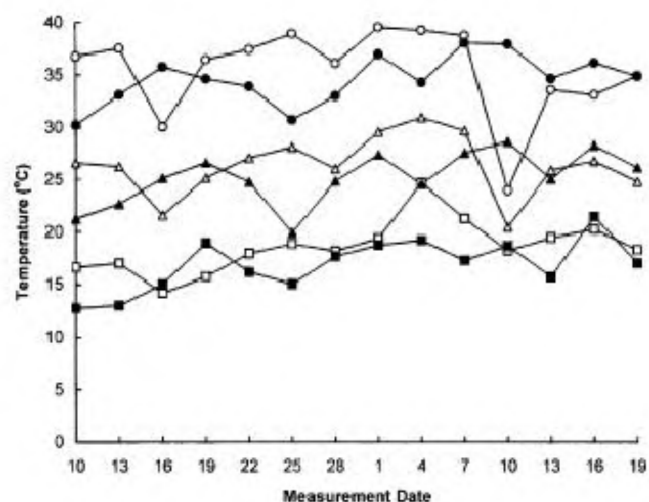
Table 2. Average solar radiation, temperature, relative humidity and total rainfall during March–May in 1996 and 1999

Variable	March		April		May	
	1996	1999	1996	1999	1996	1999
Solar radiation (kW/m ²)	0.200	0.221	0.251	0.210	0.279	0.247
Temperature (°C)	19.02	19.97	22.85	25.41	27.70	27.03
Relative humidity (%)	67.66	54.27	47.74	33.63	36.38	53.42
Rainfall (mm)	45.80	1.80	37.10	0.0	13.40	85.40

**Figure 1.** Daytime means of CO₂ concentration during the study period 10 April to 19 May in 1996 (●) and 1999 (○). Calculated *t* value is 2.20 ($P \leq 0.05$).**Figure 2.** Changes in maximum (○) and average (Δ) solar radiation during the study period in 1996 (closed symbol) and 1999 (open symbol). Calculated *t* values for maximum and average solar radiation are 2.32 and 2.84, respectively ($P \leq 0.05$).

the years, with highest values in the morning and lowest values in the afternoon. However, the differences between the maximum and minimum concentrations of atmospheric CO₂ in 1999 were not considerably different from those of pre-fire values and also those during the corresponding dates in 1996 (data not shown). Therefore, it would be worthwhile to study the impact of forest fires on photosynthetic capacity of the vegetation of the region.

In addition to causing a short-term increase in CO₂ content of the atmosphere, forest fires in 1999 also resulted in the formation of a smoky haze, an important factor for climate change, which blanketed the entire region. Although the amount of haze and its composition was not studied in the present investigation, it has been shown that haze is caused by high concentrations of tiny particles or aerosols, primarily comprising soot, sulphates, nitrates, acids, ash and other particles^{20–23}. The haze, emanating from forest fires, in addition to causing irritation to the eyes and breathing problems (visual observations), significantly reduced the visibility and insolation as well as air temperature, when compared with their respective pre-fire values as well as with those of corresponding dates in 1996 (Figures 2 and 3, Table 3). However, this effect also vanished with the onset of rainfall. During the study period in 1999, maximum and average solar radia-

**Figure 3.** Changes in minimum (□), maximum (○) and average (Δ) temperature during the study period in 1996 (closed symbol) and 1999 (open symbol). Calculated *t* values for minimum, maximum and average temperature are 1.59, 0.66 and 1.12, respectively (NS).

tion ranged from 0.882–0.251 kW/m² on 10 April to a minimum of 0.532–0.137 kW/m² on 17 April to 0.935–0.277 kW/m² on 19 May, whereas the values for this

Table 3. Average solar radiation, temperature, relative humidity and mean daytime atmospheric CO₂ concentration during 10–20 April 1996 and 1999

Date	CO ₂ concentration (ppm)		Temperature (°C)		Solar radiation (kW/m ²)		Relative humidity (%)	
	1996	1999	1996	1999	1996	1999	1996	1999
10	341	338	21.23	26.59	0.254	0.251	45.51	42.93
11	341	338	21.75	27.16	0.256	0.260	44.48	36.99
12	341	338	22.17	26.91	0.272	0.249	39.37	37.88
13	341	344	22.69	26.25	0.258	0.258	37.26	33.45
14	340	357	22.58	24.34	0.254	0.236	38.11	27.46
15	339	356	24.24	22.85	0.294	0.212	32.53	27.39
16	339	365	25.11	21.59	0.273	0.140	35.01	33.31
17	338	382	25.82	21.52	0.248	0.137	35.63	39.08
18	338	364	25.89	23.60	0.224	0.182	38.92	34.66
19	338	362	26.62	25.14	0.238	0.221	45.32	29.41
20	338	362	26.62	25.57	0.255	0.195	46.76	31.32

variable on corresponding dates in the year 1996 varied from 0.859–0.254 kW/m² (10 April) to 0.846–0.248 kW/m² (17 April) to 0.994–0.316 kW/m² (19 May). Likewise values of minimum, maximum and average temperatures on the corresponding dates in 1999 and 1996 were 16.63, 36.76, 26.59 and 12.71, 30.21, 21.23°C; 14.64, 30.66, 21.52 and 16.32, 35.16, 25.82°C; 18.33, 34.91, 24.79 and 17.05, 34.84, 26.13°C, respectively. In general, lower relative humidity was observed during the study period in 1999 than in 1996; minimum, maximum and average relative humidity for the year 1999 and 1996 varied from 14.31, 75.60, 42.93 and 21.33, 78.95, 45.51% on 10 April to 17.10, 63.53, 39.08 and 14.55, 66.79, 35.63% on 17 April to 37.15, 97.20, 70.90 and 14.36, 70.97, 38.97 on 19 May (Figure 4).

In the present study, decreased air temperature was often associated with decreased solar radiation. An autocorrelation has been shown between temperature and solar radiation²⁴. However, while both maximum and average solar radiations were significantly ($P \leq 0.05$) lower for the year 1999 than those of 1996, differences in temperature between the two years were not significant; the minimum, maximum and average temperatures were slightly higher in 1999. Further, considerable decrease in air temperature as well as relative humidity was observed during 14–19 April 1999, despite a significant increase in CO₂ content in the atmosphere (Table 3). This probably indicates the involvement of interactive effect of CO₂ and aerosols in modifying regional/local atmospheric temperature, as has been reported earlier²⁵. Further, considering 1999 and 1996 rainfall distribution patterns, more rain (84.9 mm) was observed in May 1999 than in May 1996 (13.4 mm; Table 2). There are reports which indicate that aerosols can also act as cloud-condensation nuclei and thereby influence cloud formation and precipitation^{21,26–28}. The occurrence of more rain on weekends than on weekdays in 16 years of records over Atlanta, USA has been attributed to heavy haze that provides condensation nuclei for moisture to foster growth of heavy clouds to shed rain

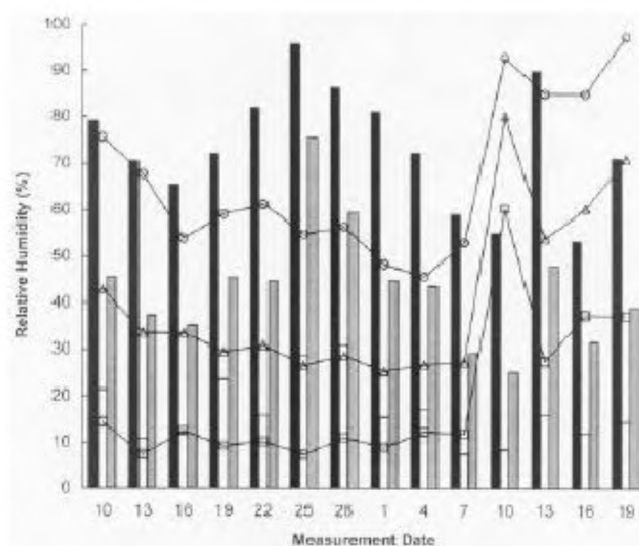


Figure 4. Changes in minimum (□, □), maximum (■, ○) and average (■, Δ) relative humidity during the study period in 1996 (bars) and 1999 (lines). Calculated *t* values for minimum, maximum and average relative humidity are 0.52, 1.20 and 0.41, respectively (NS).

on weekends²⁹. On the other hand, inhibition of rainfall due to aerosols has also been reported^{30,31}. Therefore, further detailed studies on fire-induced aerosols would be useful to resolve this issue.

This study has some limitations to make any definite conclusions as it is based on the ground observations of forest-fire statistics and includes only two years data with respect to atmospheric CO₂ and other climatic variables. Nevertheless, it implies that forest fires, depending upon their severity, may have the potential to cause significant changes in the CO₂ content and climatic elements, particularly solar radiation and temperature, only in the short-term rather than in the long-term basis. It needs to be mentioned here that remote sensing has been and is also being widely used for accurate monitoring of fire frequency and extent of forest area burnt. Therefore, to obtain accurate and factual information on the long-term effect of these

short-term fluctuations due to forest fires on regional/global climate, monitoring of these variables on long-term basis using satellite-based data would be useful.

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MEETINGS/SYMPOSIA/SEMINARS

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