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Impact of barren island volcanic eruptions on climatic conditions over Port Blair

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ABSTRACT
The impact on climate parameters, direct radiation, sunshine duration, precipitation chemistry and turbidity coefficient over Port Blair are examined using 31 years of data during major volcanic eruptions of Barren Island volcano. A fall of about 0.8°C to 1°C in mean maximum and minimum temperature is observed during the period of volcanism (Mar-Oct, 1991 and Dec, 1994 –May, 1995). However there is no evidence of winter warming during this period. Though there is no significant reduction in mean annual bright sunshine duration, a drop of the order of 0.8 to 1.2 hours is noticed during the concerned months with respect to volcanically quiescent period. Measurements on cloudless days showed significant changes in solar radiation during 1991. An increase in diffuse sky total radiation and a concomitant decrease in total radiation were observed. Extreme perturbations in turbidity values are noticed during the major volcanic eruptions.

INTRODUCTION

Studying the impacts of volcanic eruptions on weather and climate is important because it helps us to improve climate models, it allows us to make seasonal and inter-annual climate forecasts following large eruptions and it allows us to separate the natural causes of inter-decadal climate change from anthropogenic effects and giving us greater confidence in the attribution of recent global warming to anthropogenic causes.

Major explosive volcanic eruptions can inject large amounts of sulfur-rich gases (mainly SO_2) into the lower stratosphere (Rampino & Robock 1984). These gases undergo rapid oxidation to sulfuric acid vapor, H_2SO_4, which has a low volatility and condenses with water to form aerosol haze. The resulting volcanic aerosols can enhance the mass of the natural, ubiquitous background sulfate layer by a factor of 100 or more. They are carried by the strong zonal winds in the lower stratosphere to circle the globe in a few weeks (Robock & Matson 1983). Later, they are transported equatorward or poleward by the mean meridional circulation and eddy to form a hemispheric or global dust veil. These aerosols stay suspended in the stratosphere for a few years, with a mean residence time of about one year (McCormick, Thomason & Trepte 1995).

Volcanic aerosols scatter incoming solar radiation to space, increasing planetary albedo and cooling the earth's surface and troposphere. They also absorb terrestrial radiation, warming the stratosphere. Downward long wave radiation from the warmer stratosphere acts to warm the surface, but except for the winter in the polar region, this warming effect is an order of magnitude smaller than the cooling effect due to reduction of shortware radiation (Harshvardhan 1979).

Port Blair is one of the background stations in the Indian Global Atmospheric Watch (GAW) stations network and hence any weather/climate modification due to external factors such as volcanic, seismological effects attracts importance. The Barren Island volcano, which is located at 135 km ENE of Port Blair, is the only active volcano in the Indian subcontinent. In this paper, an attempt has been made to assess the impact of the recent volcanic eruptions of Barren Island volcano and other major volcanos on the surface temperature, direct radiation and sunshine duration, precipitation chemistry and turbidity coefficient during recent volcanic activities using meteorological and air-pollution data.

DATA AND METHODOLOGY

Climatological records, radiation and sunshine duration data for the period of 32 years from 1969 to 2000 and atmospheric turbidity and precipitation chemistry data for period of 23 years from 1975 to 1997 were obtained from the National Data Center, Pune of India Meteorological Department and utilized for this study. Long-term monthly, seasonal and annual means were worked out suitably for analysis. The standardized monthly turbidity anomaly is also worked out to examine the extent of perturbations during the period of volcanic activity.

RESULTS AND DISCUSSION

The effect of volcanic eruption on atmospheric turbidity

The impact of volcanic eruptions on the atmosphere depends not only on the strength of the eruption but also on the geographic location. A large volcanic eruption establishes a reservoir in the lower stratosphere at the latitude of injection, moving with and stretching out in the direction of the wind circulation. Equatorial reservoir has a residence time of about two years while, middle and high latitude injections have a residence time of about three to nine months according to the latitude and time of injection in the annual cycle of stratospheric transport (Dyer 1974). Aerosol observations suggest that two transport regimes exist in the lower tropical stratosphere. A lower transport regime is suggested by the rapid poleward and downward movement of volcanic material deposited within a layer several kilometers above the tropopause (Kent & McCormick 1984). In the upper transport regime detrainment of aerosol from the upper equatorial reservoir depends upon the intensity of planetary wave activity and on the phase of quasi-biennial oscillations (QBO). During the westerly phase of the QBO, the stratospheric surf zone is able to penetrate deeper into the tropics and eddy mixing can tap the core of the aerosol reservoir lying near the equator. On the other hand during the easterly phase of the QBO planetary waves are shielded from the equator and only aerosol lying near the subtropics can experience further poleward moving (Trepte and Hitchman 1992). Stratospheric Aerosol and Gas Experiment II observations indicate that the primary transport of Mt. Pinatubo aerosol from low latitude to southern latitude occurred above. 20 km (McCormic & Veiga 1992).

Perturbations in the background turbidity over Indian stations are apparent in the periods following major volcanic activities such as El-Chichan in 1982, Mt Pinatubo and Barren Island in 1991 (Soni & Kannan 2003). Since tropospheric aerosols and molecular scattering usually dominate the turbidity values, it is expected that several smaller volcanic eruptions are not evident in the record. The effect of EL-Chichan, Mt. Pinatubo and Barren Island eruptions can be examined by normalizing each turbidity value to form a standardized monthly turbidity anomaly (Fig. 1).

Since the volcanic activities of Mt. Pinatubo and Barren Island volcano were coincided in 1991, the impact was largely felt over Port Blair than other GAW stations where the causes were mainly attributed to Mt. Pinatubo. In order to find out the extent and persistence of the effect of Mt. Pinatubo and Barren Island eruptions, monthly mean values of turbidity

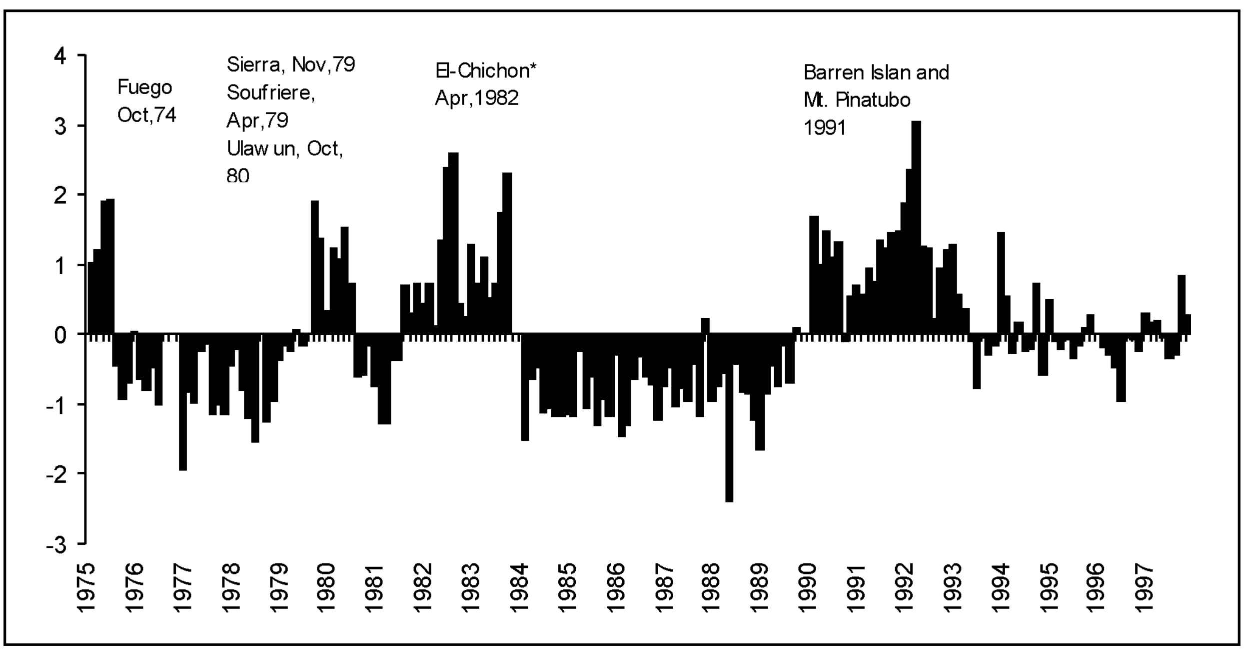

Figure 1. Standardised Monthly Turbidity Anomaly for Port Blair (Oct-May).

for the years 1991, 1992, 1993 have been compared with the average values for the period 1986-90, the relatively volcanically quiescent period before the Mt. Pinatubo and Barren Island eruptions. It is found that the turbidity increase associated with the aerosol injected into the stratosphere after the volcanic eruption of Mt.Pinatubo and Barren Island were observed after a lag of about one month from the episode. The increase in atmospheric turbidity values following the volcanic eruptions was discernible for 1.5 to 2 years after the eruption.

Changes in solar radiation fluxes

The post eruption scenario of 1991 episode on radiation fluxes are investigated using the global, diffuse and direct radiation data. The effects of the aerosol cloud on solar radiation were analysed. There is a marked rise in aerosol depth for 1992, which results in significant reductions of about 10% in direct total radiation and a significant increase in diffuse total radiation. Global total radiation fluxes show a slight decrease in the order of 2% between 30^{o} and 60^{o} solar elevation.

Unlike total radiation, diffuse, direct and global radiation fluxes in the UVB range shows no changes between 1991 and 1992. In the UVA range, only the diffuse flux is slightly elevated (by about 5%) in 1992. The aerosol cloud thus weakened UV radiation to a considerably smaller extent than it did total radiation. This result coincides with spectral transmission measurements of the aerosol cloud emitted by Pinatubo (Valero & Pilewskic 1992).

From this analysis, it seems realistic to base models of climate on a changed radiation balance caused by the Barren Island and Mt Pinatubo aerosol cloud to estimate changes in temperature (Kerr 1993).

Volcanic signals in surface temperature and sunshine duration

The determination of volcanic signals in climate change in global scale is a bit complex, because first we need to remove two principal non-volcanic components with which we are concerned. One is low frequency variations. The causes of these variations may include natural internal oscillations, green house gases, tropospheric aerosol, periods of volcanism, or solar variations (Robock 1979). The other component is the high-frequency Southern Oscillation signal. As our analysis in this paper is restricted to a single station, the aforesaid filtration procedures are not employed. The monthly mean values of maximum temperature for the years 1991 and 1995 have been compared with the average values for the period 1986-90, the relatively volcanically quiescent period before the Mt. Pinatubo and Barren Island eruptions and shown in Fig. 2 as a sample.

The analysis of volcanic and post volcanic period shows that a fall of about 0.8^{o}C to 1^{o}C in mean maximum and minimum temperature is observed during 1991 and 1995. However there is no evidence of winter warming during this period.

A similar attempt has been made to find the impact in bright sunshine duration. Though there is no significant reduction in mean annual bright

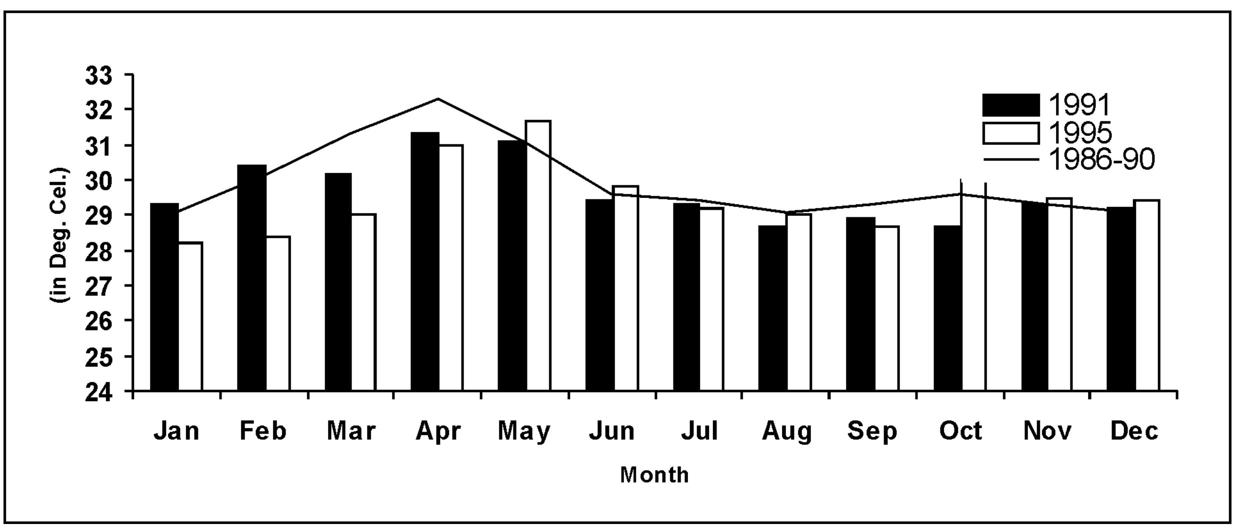

Figure 2. Maximum Temperature during volcanic episodes in 1991 and 1995 Vs mean value of volcanically quiescent period (1986-90).

sunshine duration, a drop of the order of 0.8 to 1.2 hours were noticed during the concerned months of volcanic eruptions with respect to the mean values for the period (1986-90) and it is shown in the Table 1.

Table1. Bright sunshine hours during 1991 and 1995 eruptions Vs mean value of volcanically Quiescent period (1986-90)

	1991	1995	Mean (1986-90)
Jan	9.7	8.3	8.7
Feb	10.2	9.1	9.6
Mar	8.9	8	8.7
Apr	7.8	7.9	8.2
May	5.3	5.1	6.5
Jun	3.7	4.1	4.0
Jul	2.8	-	3.3
Aug	1.8	-	3.4
Sep	2.9	3.4	4.0
Oct	4	6.2	5.6
Nov	7.9	6	6.2
Dec	7.2	8.7	7.8

Influence of eruptions on chemical wet deposition

The volcanic activity of Barren Island is found to have considerable impact in chemical wet depositions occurred due to rainwater at Port Blair. It is also appears to be an obvious candidate for higher SO_4^{2-} and NO_3^- and the lower pH values. After the first eruption noticed in April 1991 began with hot gases and strong ash emissions with activity continuing through October (Haldar et al.,) Another eruption was noticed in December 1994 and January – March, 1995, thick clouds of pale brownish gas, dark ash particles and white steam were observed. Very high values of sulfate ion concentrations in rainwater were observed from January to April in 1995 (January 159, March 120 and April 107 meq/l) when predominant winds are northeasterly. The volcanic emission of smoke was also reported during January, 2000. The pH values show a decreasing and sulfate and nitrate concentrations show an increasing tendency from the year 1995 onwards.

Fig.3 shows that the comparison of SO_4 concentration values observed during the major volcanic activity period against the mean value for the period (1986-90) that has very less number of volcanic activities. It is also noted that the values observed may not be the contribution of Barren island volcano alone but from the combined effect of other major eruption sources.

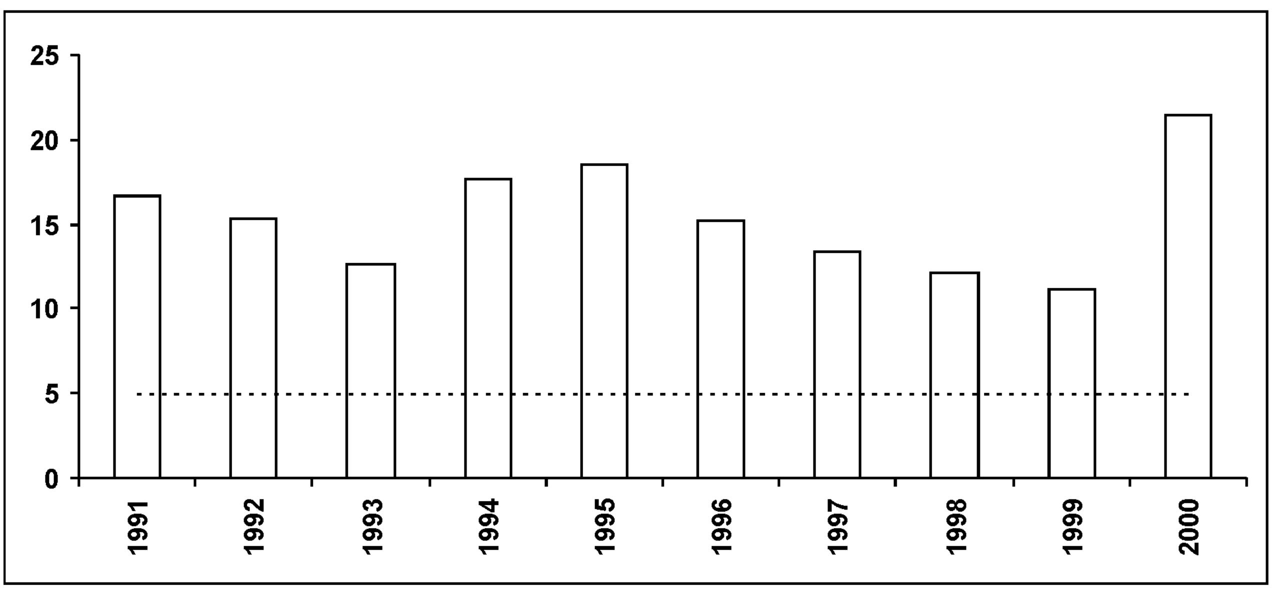

Figure 3. Annual SO_4 concentration against mean (1986-90) SO_4 values (showed as a dotted line).

CONCLUSIONS

Port Blair shows anomalously high values of atmospheric turbidity in 1982-83 and 1991-92 following the eruptions of El-Chichan, Mexico, in April, 1982, Barren Island in Mar-Oct, 1991 and Mt. Pinatubo, Philippines, in June 1991. The increase in atmospheric turbidity values following these eruptions was discernible for 1.5-2 years after the eruptions. There was a marked rise in aerosol depth for 1992, which results in significant reductions of about 10% in direct total radiation and a significant increase in diffuse total radiation. Global total radiation fluxes show a slight decrease in the order of 2% between 30^{o} and 60^{o} solar elevation. In the UVA range only the diffuse flux is slightly elevated (by about 5%) in 1992. A fall of about 0.8^{o}C to 1^{o}C in monthly mean maximum and minimum temperature is observed during the period of volcanic episodes in 1991 and 1994–95. However there is no evidence of winter warming during this period. Though there is no significant reduction in mean annual bright sunshine duration, a drop of the order of 0.8 to 1.2 hours is noticed during the concerned months of volcanic eruptions with respect to the mean values for the period (1986-90). The pH values show a decreasing and sulfate and nitrate concentrations show an increasing tendency after the volcanic eruptions of barren island in 1991, 1994-95 and 2000. The impact is also influenced by the prevailing seasonal wind speed and direction. As the volcanic eruption at Barren Island during 1991 almost coincided with major volcanic eruption of Mt. Pinatubo in June 1991 in Philippines and Mt. Pinatubo's eruption was of very large magnitude, it is very difficult to differentiate individual contributions during 1991 episode and hence it may be considered as a combined effect of both the eruptions.

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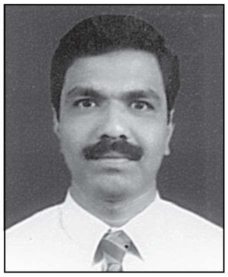

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The Daily surface meteorological parameters, air temperature, wind speed and direction, cloud cover, and radiation data (Direct, Diffusive and Total) for the period of 32 years from 1969 to 2000 were obtained from the National Data Centre(NDC), Pune of India Meteorological Department(IMD). The hourly sunshine data for the period of 32 years from 1969 to 2000 was also obtained from NDC, Pune. The entire air pollution data for the period of 23 years from 1975 to 1997 used in this study were obtained from the Air Pollution Section (APS), Pune of IMD, that maintains a network of observatories called Global Atmospheric Watch(GAW) to monitor the precipitation chemistry and turbidity conditions and Portblair is a GAW station. The daily turbidity co-efficient measured at 0.5µ using voltz-sunphotometer and monthly means of pH, Ca, Mg, Na and K determined by Flame Atomic Absorption Spectrophotometry and NH_4^+, SO_4^{2-}, NO_3^- and Cl^- ions determined using UV-Visible spectrophotometrically were utilized for this study. From the hourly and daily series, monthly, seasonal and annual means were worked out suitably for analysis. The standardized monthly turbidity anomaly is also worked out to examine the extent of perturbations during the period of volcanic activity. The volcanic event statistics such as date of occurrence, duration and intensity were collected from various sources on the web, including Geological Survey of India.