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Aerosol optical properties over a coastal site in Goa, along the west coast of India

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ABSTRACT

Spectral characteristics of the Aerosol optical depths (AODs) measured over a coastal site in Goa (15.46°N and 73.83°E), from a plateau ~50 m above mean sea level, for the period 2008–2010, are analyzed to understand the inter-seasonal and intra-seasonal variability and to delineate different aerosol sources. A Microtops-II sunphotometer having five different wavelengths centered at 0.380, 0.440, 0.500, 0.675 and 0.870 μm was used to estimate AODs in different seasons classified as: winter monsoon season from December to March (WMS), spring inter-monsoon season from April to May (SIMS), summer monsoon season from June to September (SMS) and fall inter-monsoon season from October to November (FIMS). The number of data (AODs) generated in each season is 569 in WMS, 131 in SIMS, 38 in SMS and 256 in FIMS. The highest AOD at 500 nm (AOD_{500}) was recorded in SIMS (0.43 ± 0.18) while the lowest value was observed in SMS (0.32 ± 0.10). The seasonal mean values of Ångström α computed from the least-square method in the wavelength range 0.440–0.870 μm showed higher values (1.23 ± 0.20) in FIMS than those in SMS (0.75 ± 0.34). The highest Ångström β values were noticed in SIMS (0.25 ± 0.10) and lowest in FIMS (0.17 ± 0.06). To make a source appropriation and thus to resolve the complexity of aerosols in the study area, α was computed in different wavelength ranges, viz: short wavelengths (0.440–0.500 μm) and long wavelengths (0.675–0.870 μm), which revealed differing α values for different ranges of wavelengths. To account for the curvature, a second order polynomial fit is introduced. Subsequently, the second-order Ångström exponent ($\acute{\alpha}$) and the coefficient of the second-order polynomial fit are analyzed to understand the dominant aerosol type.

1. Introduction

Aerosols influence climate directly by affecting the radiative balance of the Earth and indirectly by changing the cloud microphysical properties (Charlson et al., 1992). Depending upon the source, size and formation process, aerosols exhibit large variability on a global scale. Such variability on a temporal and spatial scale and with short residence time hinders the understanding of aerosol effects on the Earth's radiation budget (Boucher et al., 2013). Aerosols advected from different distant sources mix with those locally present, leading to changes in the spectral characteristics of the aerosol optical depth (AOD) (Moorthy et al., 1991). This makes the aerosol distribution in their atmospheric column bimodal, constituting a fine-mode fraction of anthropogenic origin and naturally produced coarse-mode aerosols (Eck et al., 1999). AOD varies exponentially with wavelengths, quantified by an empirical equation proposed by Ångström (1961),

$$\tau_p(\lambda) = \beta\lambda^{-\alpha} \quad (1)$$

where $\tau_p(\lambda)$ is spectral AOD, α is the Ångström wavelength exponent and β is the Ångström turbidity coefficient, which is equal to AOD when λ is 1 μm. Eq. (1) is fairly accurate if the columnar aerosol is unimodal. However, the presence of aerosols from multimode sources introduces a significant error while applying the above mentioned equation over a wide range of wavelengths to compute α. The probable sources of aerosols are those from industry, biomass burning, mineral transport or sea salt. In such a situation, the spectral AOD deviates significantly from the Ångström equation and introduces a curvature in the AOD spectrum. Results of the measurements carried out along the west coast of India revealed the presence of aerosols from multi-sources with seasonal characteristics (Moorthy et al., 1991). Following this study, extensive investigations have been carried out over different parts of the Indian subcontinent and Indian Ocean (e.g. Beegum et al., 2009; Kalapureddy et al., 2009; Kaskaoutis et al., 2011; Kedia and Ramachandran, 2011; Guleria et al., 2012). Under the aegis of the Indian Space Research Organization's Geosphere Biosphere (ISRO-GBP) programme, one of the research components identified was the estimation of the aerosol radiative forcing

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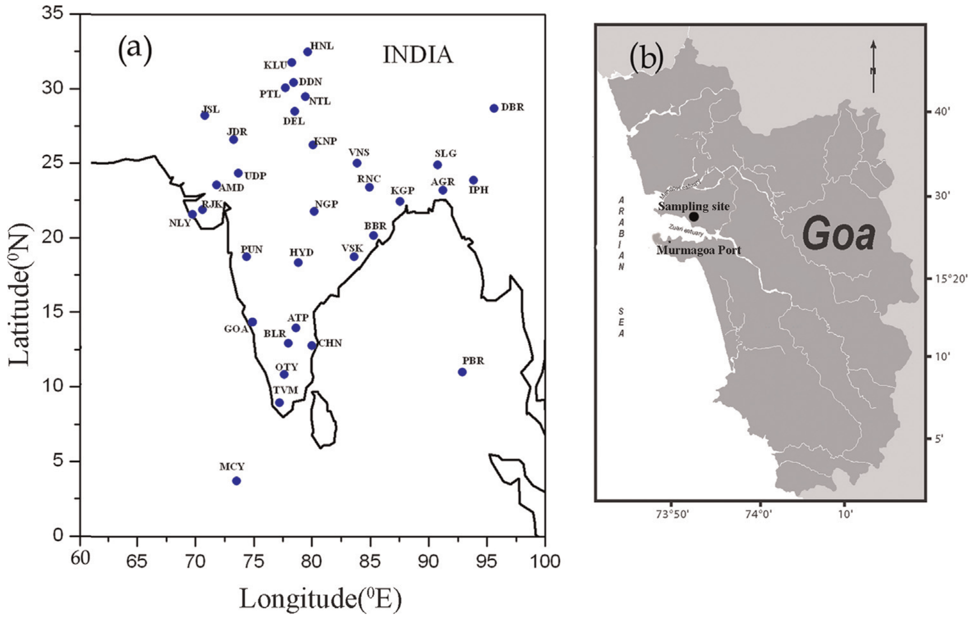

Fig. 1. (a) Network of stations under the Aerosol Radiative Forcing over India (ARFI) project. (b) Sampling site over a coastal station in Goa.

over India (ARFI). Within the framework of ARFI, about 36 stations were chosen for aerosol measurements across the Indian mainland and adjacent Islands (Fig. 1a). This study uses the measurements performed during ARFI at Goa in the period 2008–2010.

2. Data and methods

2.1. Study area and general meteorology

Goa is positioned on the west coast of India, with Arabian Sea and Western Ghats on the west and east respectively (Fig. 1b). The wind pattern, the associated precipitation and aerosol characteristics were considered as the criteria to divide the study period into four distinct seasons, namely; Winter Monsoon Season (WMS) from December to March, Spring Inter-Monsoon Season (SIMS) from April to May, Summer Monsoon Season (SMS) from June to September and Fall Inter-Monsoon Season (FIMS) from October to November. The measurements were performed at Goa University Campus (15.46°N and 73.83°E), which is ~50 m above the mean sea level, 0.7 km from the Arabian Sea and ~5 km from the capital city, Panjim. Murmagao port (Fig. 1b), which mainly handles mine ore for export, is 6 km from the measurement site. Since the measurements were carried out in a coastal area, the possibility of emission from ships to the site by land and sea breeze could not be ruled out. The data on the entry and exit of the ships (number of ships entering and leaving Murmagoa port) were obtained from Murmagoa Port Trust, (MPT). Since the site is close to the coast, land and sea breeze need to be accounted for while analyzing aerosol dynamics.

2.2. In-situ measurements

2.2.1. Meteorological parameters

While wind speed and direction play a significant role in the dynamics of aerosols, relative humidity is responsible for their hygroscopic growth. Though all the atmospheric parameters were measured using an automatic weather station (AWS) installed at the site of the AOD observations, rainfall data were obtained from Indian Meteorological Department situated ~4 km away from the site. Table 1 shows the seasonal mean meteorological parameters

Table 1
Seasonal mean values of meteorological parameters during WMS, SIMS, SMS and FIMS for the period of 2008–2010.

Meteorological parameters	WMS(D,J,F,M)	SIMS(A,M)	SMS(J,J,A,S)	FIMS(O,N)
Wind speed (m/s)	1.09 ± 0.07	1.37 ± 0.02	2.10 ± 0.45	1.00 ± 0.11
Wind direction (deg)	171 ± 14.91	232 ± 2.70	226 ± 6.95	153 ± 3.42
Relative humidity (%)	70 ± 1.13	73 ± 2.11	88 ± 5.2	80 ± 9.7
Rainfall (mm)	17 ± 12.22	30 ± 13.10	725 ± 106	161 ± 138

for the study period of 2008–2010. The mean wind speed during WMS, SIMS, SMS and FIMS is 1.09 ± 0.07 ms^{-1}, 1.37 ± 0.02 ms^{-1}, 2.10 ± 0.45 ms^{-1} and 1 ± 0.11 ms^{-1} respectively. However, further analysis of a wind speeds revealed, gusts varying between 0 and 8 ms^{-1} during WMS. Further, it is also evident that north-westerly wind gust of ~10 ms^{-1}, was prevalent throughout SIMS. As the season of SMS approached, south-westerly to westerly winds were noticed with gusts reaching as high as 14 ms^{-1}. However, wind originating from south-east during FIMS exhibited decreased gusts between 0 and 6 ms^{-1}. Relative humidity showed an increasing trend from WMS to SMS, and then decreased during FIMS. During SMS, the study site received an average rainfall of 725 mm, which is above normal. Rainfall during SIMS witnessed a seasonal mean of 30 mm while the amount of precipitation received during FIMS was 161 mm. Using the wind data provided by the National Center for Prediction (NCEP), the synoptic wind pattern at 850 hPa have been prepared for all the four seasons; the analysis revealed that the wind was moderate from east during WMS, while it was weak and north-westerly during SIMS. Further, the wind originating from south-west was strong during SMS while it was moderate and north-easterly during FIMS.

Long-range transport of aerosols has been investigated using the Hybrid Single Particle Lagrangian Interpolated Trajectory (HYSPLIT) model (http://ready.arl.noaa.gov/) (Draxler and Hess, 1998). Trajectories at altitudes of 0.5 km and 1.5 km for 5 days were classified into three distinct source regions namely (a) Continental, (b) Maritime, and (c) West Asia (Table 2). These heights were chosen to understand the aerosol flux at the surface and within the planetary boundary layer, which was in the range of 1.5–2.0 km (Dharmaraj et al., 2006). The air mass trajectories