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Comparison of aerosol radiative forcing over the Arabian Sea and the Bay of Bengal

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Abstract

Aerosols play an important role in controlling the earth's radiation budget, which influence the climatic processes. Marine aerosols are the single largest contributor of the aerosol optical depth. Ocean Color Monitor data onboard Indian Remote Sensing Satellite Polar Series 4 (IRS-P4) has been analyzed to retrieve the aerosol parameters over the Arabian Sea and the Bay of Bengal. Top of the Atmosphere (TOA) and the surface forcing have been deduced over the Arabian Sea and the Bay of Bengal. The nature of the aerosol forcing and seasonal effects over the Bay of Bengal and the Arabian Sea have been compared. Surface forcing shows strong seasonal influence, which has not been found on the TOA forcing. In general, higher forcing over the atmosphere has been observed over the Bay of Bengal (−30 to −54 W/m^2) compared to those over the Arabian Sea (−26 to −48 W/m^2). During the winter season, the surface forcing over the Arabian Sea (−28 to −45 W/m^2) is observed to be higher than the Bay of Bengal (−25 to −38 W/m^2).

1. Introduction

Tropospheric aerosols, one of the most important components of the earth–atmosphere–ocean system, affect the climate through three mechanisms (King et al., 1999). First, the direct radiative forcing results in changes in atmospheric radiation and circulation budget. Second, indirect forcing influences the cloud properties leading to the change in cloud albedo and lastly aerosols have pronounced impact over the other constituents of the atmosphere changing their concentrations. The radiative forcing by anthropogenic tropical aerosols provide one of the largest uncertainties in climatic predictions (Satheesh and Ramanathan, 2000). It is not possible to monitor the aerosols over the ocean, however, remote sensing methods have been proved to be a powerful technique to study spatial and temporal distributions of aerosols on a global scale. Aerosol optical properties over the ocean can be estimated much more reliably compared to those over the land due to the low albedo of the ocean surface using satellite data. Numerous sensors onboard various satellites have been designed to study the aerosols over the oceans. In this paper, we have used IRS-P4 OCM data to retrieve the aerosol parameters and radiative forcing over the Arabian Sea and the Bay of Bengal to study the aerosol characteristics over the oceans surrounding the Indian sub-continent.

2. Data and methodology

IRS-P4 OCM data have been used to retrieve the spectral Aerosol Optical Depth (AOD) over the regions (1) bounded by 65.84°E to 79.49°E longitude and 31.29°N to 16.76°N latitude covering part of the Arabian Sea along western part of India and region (2) is bounded by 75.82°E to 89.67°E longitude and 19.34°N to 5.08°N latitude covering southern part of the Bay of Bengal and southeastern part of India. IRS P4 OCM have eight channels (Kundu et al., 2001), whose center

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wavelengths are 412, 443, 490, 510, 555, 670, 765 and 865 nm. The present study is based on the limited data since OCM data are not freely available. The Rayleigh radiance has been computed for the study area from the available data, the details are given in Dey and Singh (2002). At 765 and 865 nm wavelengths, the water leaving radiance is almost zero and hence can be neglected. At these wavelengths, aerosol radiance has been calculated knowing the total radiance and the Rayleigh component. AOD is calculated from the method given by Doerffer (1992). The details of the retrieval methods of AOD and the size distribution have been given by Dey and Singh (2002). AOD at other wavelengths of the sensor have been calculated using extrapolation methods proposed by Gordon (1997). Higher aerosol radiative forcing has been found over the tropical Indian Ocean–atmosphere system during December to April of each year (Satheesh and Ramanathan, 2000). We have considered IRS P4 OCM data of January 2, 2000; February 29, 2000; March 3, 2000 and April 28, 2000 over the northeastern Arabian Sea and of August 16, 1999; November 16, 1999; December 10, 1999; January 21, 2000; February 3, 2000; March 21, 2000; April 29, 2000 and May 28, 2000 over the southern Bay of Bengal. The spectral AOD and single scattering albedo (SSA) have been considered to deduce the radiative forcing at TOA (Chou et al., 2002). Direct radiative forcing has been estimated from the following equation (Charlson et al., 1992):

$$\Delta F = -0.5 F_{\mathrm{T}} T^2 (1 - A)(1 - R_{\mathrm{s}})^2 \beta_{\mathrm{u}} \tau_{\mathrm{a}},$$

where F_{T} is the solar constant (1370 W/m^2), A is the fractional cloud cover, T is the transmittance above the aerosol layer, R_{s} is the albedo of the underlying surface, β_{u} is the SSA and τ_{a} is the AOD. The SSA has been assumed to be varying within a very narrow range despite the large fluctuation of AOD and taken from Satheesh and Ramanathan (2000). The fractional cloud cover has been calculated from the OCM images. The atmospheric forcing gives the differences between TOA forcing and the direct radiative forcing.

3. Results and discussion

Spectral variations of AOD (Figs. 1(a) and (b)) show contrast characteristic behavior over the Bay of Bengal and the Arabian Sea (Dey and Singh, 2002). The coastal regions show higher values of AOD compared to those over the deeper part of the oceans. The highest values of AOD have been observed during April (>0.4) over the Bay of Bengal and the Arabian Sea (cloud free data was only available during December to April). Significant increase (40–45%) in AOD has been observed during this month over the Arabian Sea. The Bay of Bengal (Fig. 1(a)) shows more spectral variations at the lower wavelengths compared to those over the Arabian Sea (Fig. 1(b)). This indicates the dominance of the finer aerosol particles over the Bay of Bengal compared to those over the Arabian Sea. The higher spectral variations in spectral AOD over the Bay of Bengal indicates the more dynamic nature of the Bay of Bengal compared to the Arabian Sea. The spectral variations of AOD over the Bay of Bengal and the Arabian Sea are less during the summer compared to those during the winter. This is attributed to the bimodal distribution of the aerosol particle size during the summer season, where the two modes are found at 0.3–0.4 and 1 μm. over the oceans. During the winter season the particle size distribution has been found to be monomodal (Dey and Singh, 2002), where the modal value is found to be 0.7 μm for the Arabian Sea and 0.5 μm for the Bay of Bengal. Higher aerosol loading from the continents during the summer season results in the change of bimodal size distribution from the monomodal distributions during the winter season (Ramachandran and Jayaraman, 2002). The modal values in the monomodal as well as the bimodal distributions of the aerosol particle size have been found to be higher over the Bay of Bengal compared to those over the Arabian Sea. The higher number concentrations of the aerosols over the Bay of Bengal may be attributed to the larger productions of the marine aerosols as well as larger transport from the continents. The range of particle size distribution over the Bay of Bengal has been found to be larger compared to those over the Arabian Sea. The wider range in the particle size spectra over the Bay of Bengal indicates mixing of the larger number of aerosol species compared to those over the Arabian Sea, which occurs due to the more input of the continental aerosols over the dynamic Bay of Bengal (Dey and Singh, 2002).

The aerosol spectral optical depth and spectral SSA are the most important parameters in estimating the aerosol forcing on the broadband fluxes at the surface and over the TOA (Satheesh, 2002). The aerosol radiative forcing indicates the interaction and effect of the aerosols on the solar radiative fluxes, which is the aerosol forcing efficiency multiplied by the AOD (Satheesh, 2002). The TOA forcing represents the radiative forcing without the effect of the aerosols and the surface forcing represents the maximum effect of the aerosols, the difference being the contribution of the aerosols only. The phase function at 510 nm has been taken to represent the whole wavelength range of the OCM sensor (412–865 nm).

The phase functions of aerosols have been taken from Hess et al. (1998), which assumes spherical particles. But as the size distribution has been retrieved using the power law distribution and AOD have been retrieved from near-infrared reflectance, the errors due to non-sphericity of the particles in AOD (±5%) and the

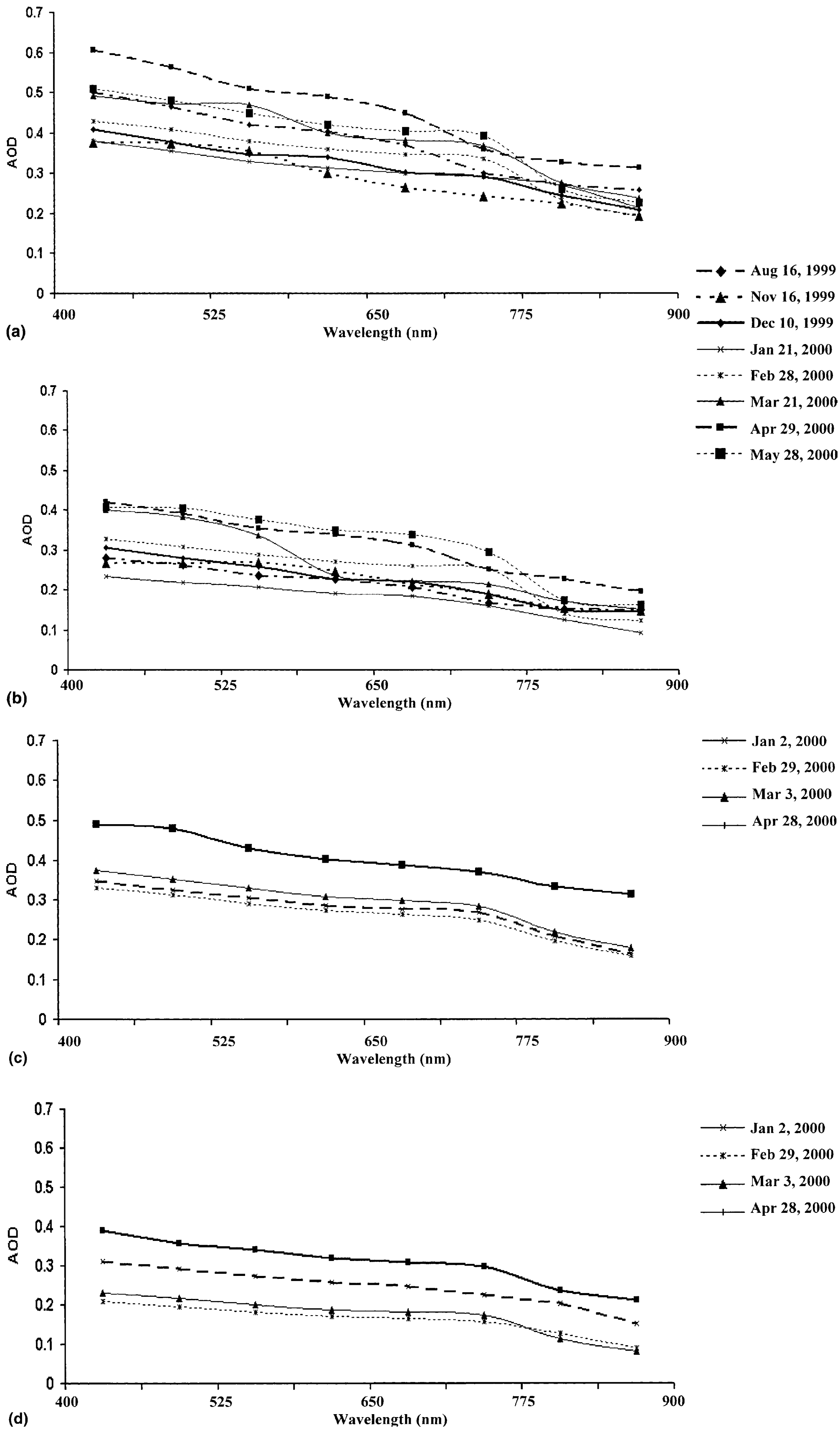

Fig. 1. Variations of AOD (a) along the Bay of Bengal coast, (b) over deeper parts of the Bay of Bengal, (c) along the Arabian Sea coast and (d) over deeper part of the Arabian Sea.

estimation of forcing are within limits (Mishchenko et al., 1995). TOA and the surface aerosol forcing have been deduced over the Bay of Bengal and the Arabian Sea and the monthly variations have been shown in Fig. 2. The surface forcing over the Arabian Sea and the Bay of Bengal shows strong seasonal variations, whereas the seasonal effect is minimal in the case of TOA forcing. Large differences have been found between the TOA and the surface forcing over the oceans, which is attributed to the aerosol loading over the oceans. Highest negative surface forcing have been observed along the Arabian Sea coast (−52 W/m^2) during March and along the Bay of Bengal coast (−58 W/m^2) during April. Highest negative surface forcing has been observed during January over the deeper regions of the Arabian Sea (−42 W/m^2) and during May over the deeper regions of the Bay of Bengal (−47 W/m^2). Radiative forcing at the atmosphere has been found to be positive, which is likely due to higher concentration of the absorbing aerosols. Large changes in the radiative forcing over the atmosphere above the Arabian Sea (29.4 W/m^2) has been found during March and that above the Bay of Bengal (44 W/m^2) during May (Fig. 3). Large differences in TOA forcing and the forcing at the surface have also been found by Satheesh and Ramanathan (2000). The higher values of surface forcing during March over the deeper parts of the Arabian Sea is attributed to the aerosol plume generated in the north-eastern Arabian Sea during this period Dey and Singh (2002). Over the coastal regions, the highest change in radiative forcing over the atmosphere above the Arabian Sea (48.6 W/m^2) has also been found during March, whereas, over the Bay of Bengal (54 W/m^2) during April. Higher values of the radiative forcing over the atmosphere during the summer season over the Bay of Bengal and the Arabian Sea indicate higher aerosol loading. The surface forcing due to the sea-salt aerosols alone (for spectral AOD of 0.4 at 500 nm) over the tropical oceans have been found to be ~−6.1 W/m^2 (Satheesh, 2002). Similar spectral values of AOD (>0.4) over the Arabian Sea have been found during April and over the Bay of Bengal during August and March–May (Fig. 2). During these periods, higher values of the surface forcing and the forcing at the atmosphere (Fig. 3) have been observed over the Bay of Bengal and the Arabian Sea, which clearly indicate the transport of the continental aerosols over the oceans. Higher surface forcing has been observed over the Bay of Bengal during the summer and over the Arabian Sea during the winter seasons (Fig. 2). The forcing at the atmosphere has always been found to be higher over the Bay of Bengal compared to those over the Arabian Sea. This is attributed to the complex nature of the atmosphere over the Bay of Bengal.

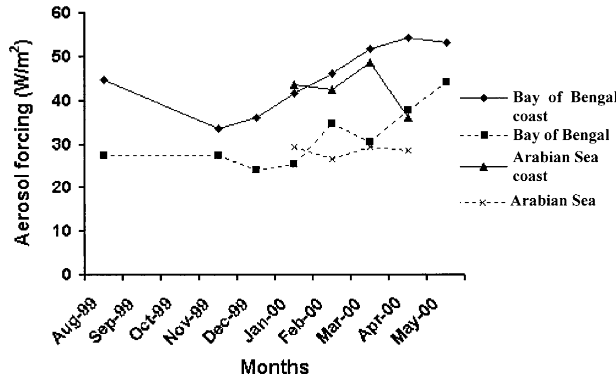

Fig. 3. Atmospheric forcing over the Arabian Sea and the Bay of Bengal.

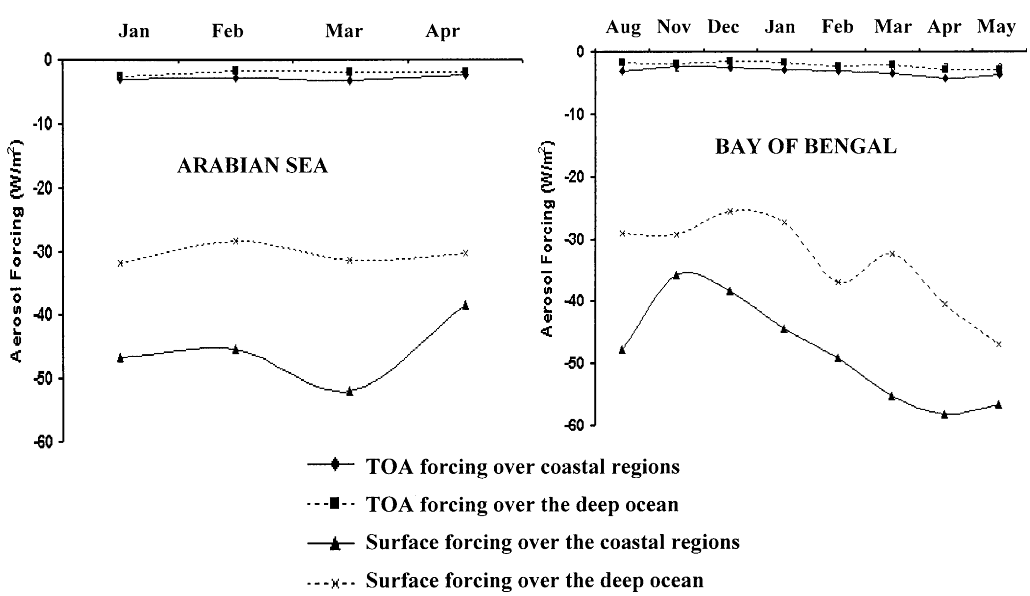

Fig. 2. Variations of aerosol forcing over the Arabian Sea and the Bay of Bengal.

4. Conclusion

The aerosol distributions over the Arabian Sea and the Bay of Bengal show characteristic seasonal behavior. Highest spectral variations in AOD have been found during April over the Arabian Sea and the Bay of Bengal. The Bay of Bengal shows more dominance of the continental aerosols over the coastal regions compared to those over the Arabian Sea. The aerosol forcing at the surface as well as over the atmosphere above the Arabian Sea and the Bay of Bengal show strong seasonal influences, but the influence is not prominent over the TOA forcing. During the summer season, highest aerosol forcing over the atmosphere has been observed above the oceans. Higher forcing over the atmosphere has been observed above the Bay of Bengal compared to those above the Arabian Sea, which indicates higher aerosol concentration over the Bay of Bengal and more complex nature of the atmosphere. Surface forcing has been found to be higher over the Arabian Sea during winter and over the Bay of Bengal during summer seasons.

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