Correlative measurements of aerosol optical depth and size distribution around INDOEX–FFP 98 from multi-spectral solar radiometry

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Spectral aerosol optical depth measurements by means of ground-based solar radiometry have been made at the Indian Institute of Tropical Meteorology, Pune, a continental urban station in India, as part of the INDOEX–FFP 98 during 17 February through 31 March, 1998. The aerosol optical depths and corresponding size distributions observed with both a multichannel radiometer (sun-photometer) and a spectroradiometer agree well and show marked variations during the experimental period. The day-to-day variation in the aerosol optical depth at 0.50 μm indicates an increasing trend. The results of a comparative study made between the continental urban and coastal aerosol characteristics using the sun-photometric observations carried out around the INDOEX–FFP 98 are also presented.

AEROSOL particles exert a significant forcing on climate through their formation and radiative properties of clouds, their effect on minor species concentration and their potential to scatter and absorb incoming solar radiation. Thus they exhibit a high degree of variability in space and time, and it is essential to monitor the aerosol features systematically. One such parameter that has been found very useful for the study of aerosol forcing on climate system is the spectral aerosol optical depth (AOD) which is the aerosol extinction coefficient integrated over the whole atmosphere for different wavelengths. AODs and aerosol size distributions (ASDs) can be determined by measuring the relative irradiance of directly transmitted sunlight at selected wavelengths (preferably wider wavelength spectrum) during cloud-free sky conditions. Sunphotometry, being a simple passive technique, has been widely used by many researchers for extensive studies of aerosols and some selected trace gas species[1,2].

Simply stated, the central theme of the Indian Ocean experiment (INDOEX) programme is the aerosol behaviour in the ITCZ where polluted continental air mass and pristine air mass mix and ascend to higher altitudes due to strong upward convection. Simultaneous observations over the land and oceanic regions then are essential in order to study this in detail. By utilizing such data sets, the spatial and temporal links between optical states of continental and maritime aerosols can be established through synoptic air mass characteristics. Keeping this in view, ground-based observations of spectral AOD using both sun-photometer and spectroradiometer (high spectral resolution radiometer) were conducted 21 days at the Indian Institute of Tropical Meteorology (IITM), Pune (18°32′N, 73°51′E, 559 m AMSL) during the INDOEX–FFP 98. In this paper, we present the details of the experimental and data retrieval techniques together with the main results of the study.

Radiometric systems and operation

The AOD data used in the present study have been obtained simultaneously with two different radiometers, namely, sun-photometer and spectroradiometer, both working on the same principle. The spectroradiometer provides optical depths continuously over the entire wavelength region (0.20–0.72 μm) while the sun-photometer gives at discrete wavelengths. The main specifications of these radiometers are compared in Table 1.

The sun-photometer is a conventional filter-wheel based radiometer and operates at 14 narrow-band wavelengths (ranging from 0.31 μm to 1.63 μm). The complete filter-wheel and detector assembly was attached to a metallic alt-azimuth mount in order to facilitate the radiometer for precise tracking of the sun's disc. The received solar radiation, after passing through each filter, is detected at its peak value and recorded by a readout meter. Thus at each solar zenith angle, a set of irradiance values corresponding to each filter in the wheel is stored for further analysis. The spectroradiometer mainly consisted of an automatic sun-tracking system, a double monochromator, and a detector with an on-line data acquisition/processing system. The parallel incident light rays from the sun enter the monochromator after passing through baffles and a shutter, which prevents the entrance of stray light into the radiometer. The received radiation, after being spectrally analysed and condensed, is focused on to a detector. The amplified output signals are acquired

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by a mini-computer after multiplexing with the time provided by a built-in master clock for further analysis. The above sun-photometer and spectroradiometer have been detailed in the literature[3,4].

Observations and analysis

Both the spectroradiometer and sun-photometer were operated from the terrace of the Institute to avoid the surrounding tall topographic targets while tracking the sun for a wider spectrum of solar zenith angles. The observations were made from morning till evening on days with nearly cloud-free skies and none near the line-of-sight to the sun. The observations were repeated at an interval of 5 min during early morning and evening hours when the changes in air mass are rapid and optical path lengths are longer: 30 min interval during the intervening period. Thus a total of about 35 sets of observations of direct solar radiation were collected in the photosynthetically active region (PAR) (0.4–0.7 μm) in the case of spectroradiometer and at all 14 wavelengths in the case of the sun-photometer on each experimental day.

AODs were estimated from these data sets by following the procedure described in our earlier publications[3,4]. Furthermore, the data archived with both radiometers on individual experimental days are grouped into forenoon (FN) and afternoon (AN) with respect to the local noon (time at which the air mass is minimum); the corresponding FN and AN optical depths are examined separately from the full-day (FD) optical depths computed from the observations of the whole day.

Table 1. Principal parameters of the radiometers employed in the INDOEX–FFP 98

Specification	High spectral resolution radiometer (spectro-radiometer)	Multi-wavelength radiometer (sun-photometer)
Source	Sun or moon	Sun
Spectral range	0.20–0.72 μm (continuous)	0.31–1.63 μm (discrete)
Spectrum analyser	Double monochromator equipped with holographic gratings (1800 grooves/mm)	Narrowband interference glass filters (0.002–0.005 μm FWHM)
Field of view	$1^\circ \times 4^\circ$	$< 3^\circ$
Detector	EMI model 9659 QB PMT	Barium selenide photocell
Amplifier	EMI CD–100 photon counter	Nexus model L-201 operational amplifier
Data acquisition	12–bit, analog devices A/D converter	Manual/multipen chart recorder
Data analysis	On-line	Off-line
Recording format	Optical depth vs solar zenith angle (air mass)	Optical depth vs solar zenith angle (air mass)
Commencement of observations	April 1993	February 1993
Operating frequency	On all clear-sky days(except SW monsoon season)	On all clear-sky days(except SW monsoon season)

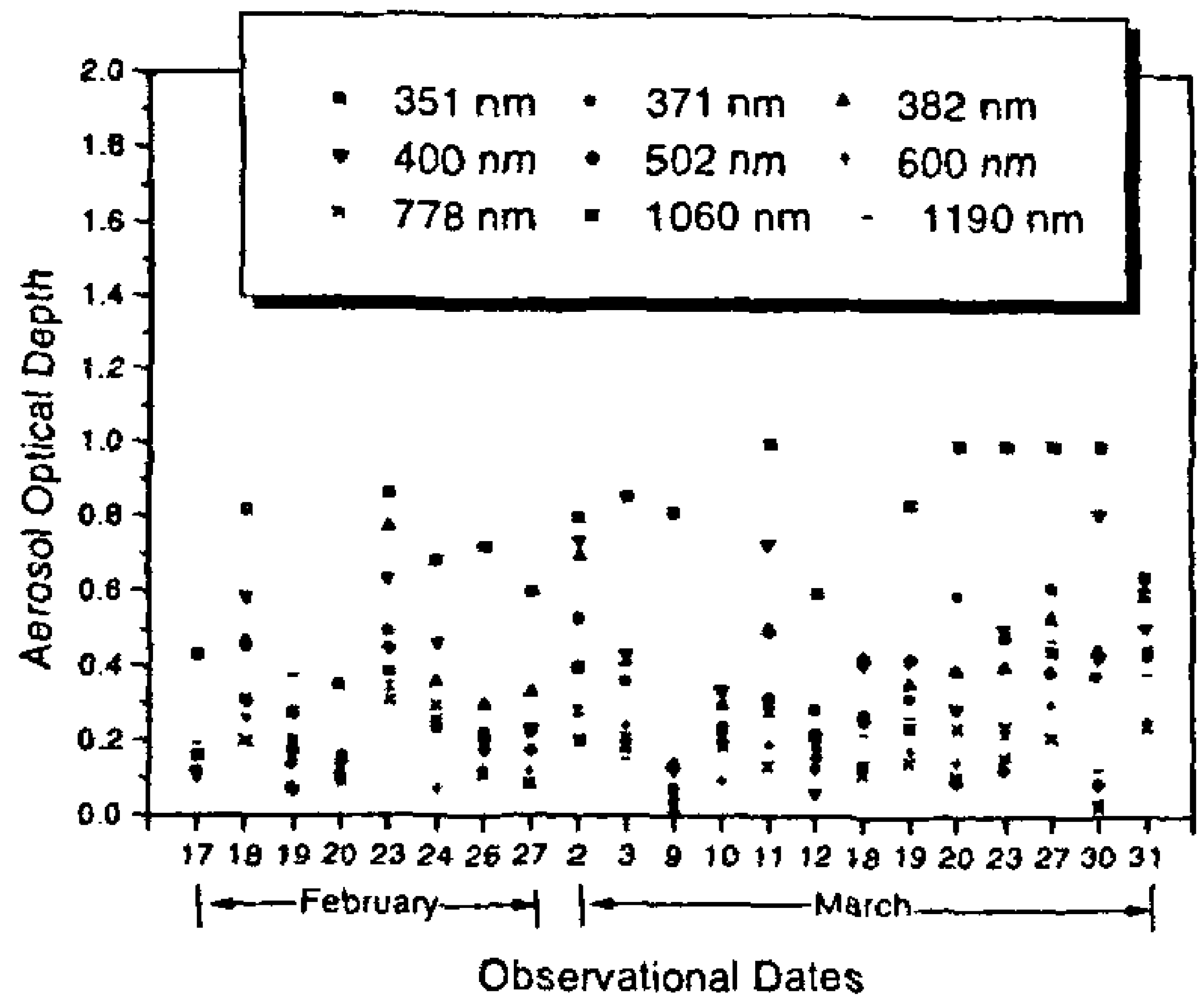

Figure 1. Daily variation in spectral dependence of AOD.

Results and discussion

The main features of AODs and corresponding ASDs inferred from the observations undertaken on cloud-free days during INDOEX–FFP 98 are presented and discussed in the following sections.

AOD variation at different wavelengths

The day-to-day variation in the AOD observed with different optical channels of the sun-photometer during the experimental period are shown in Figure 1. It is clear that the AODs are greater at smaller wavelengths and smaller at longer wavelengths as expected, suggesting abundant fine particle concentration. In addition, AODs almost at all wavelengths show increase with time, but with different slopes, which is considered to be caused by different generation and transport mechanisms associated with aerosol particles and prevailing meteorological conditions over the experimental station. This feature is clearly seen in the AOD variations at smaller wavelengths.

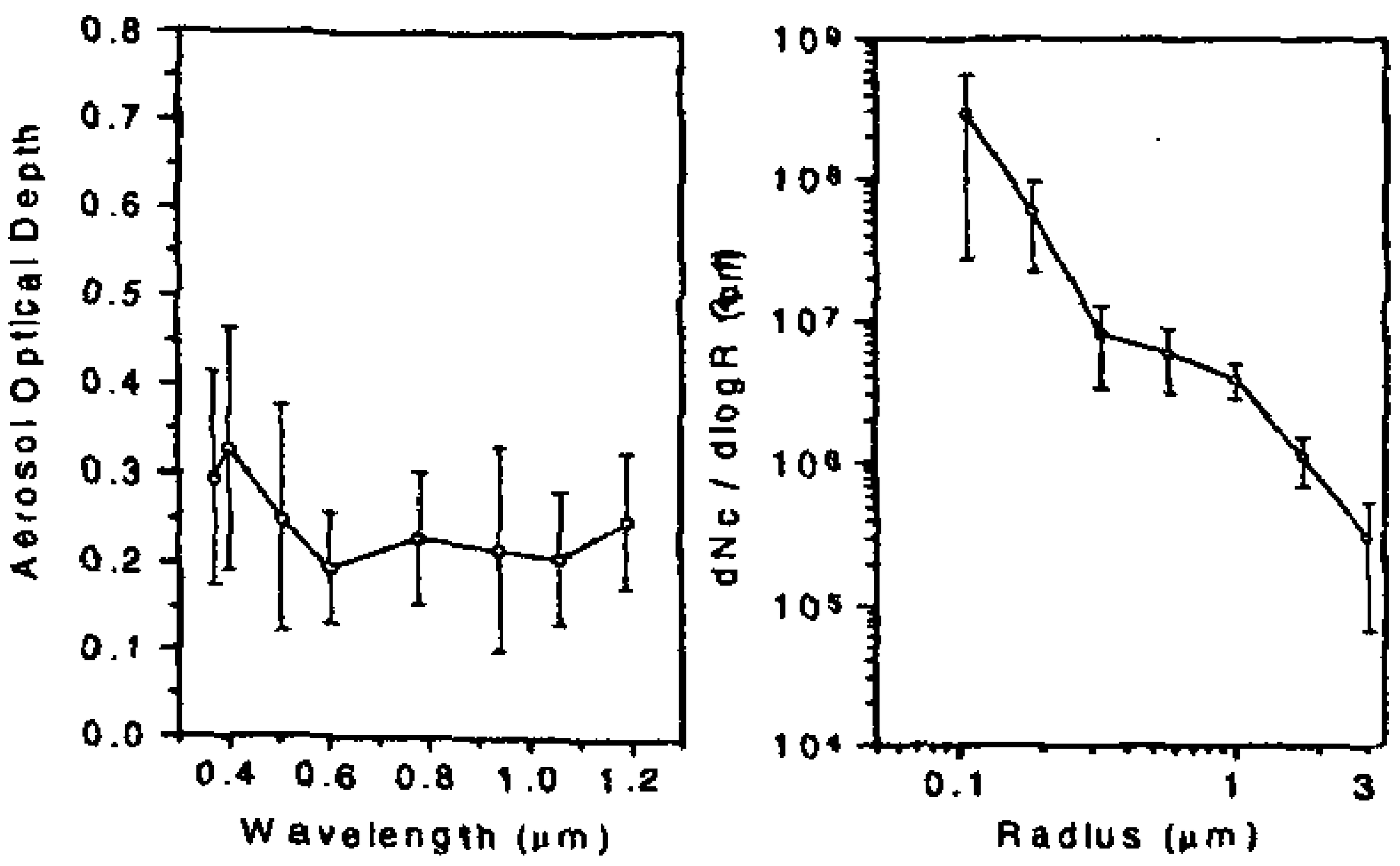

Figure 2. Wavelength variation and size distribution of sun-photometer-derived FN AODs.

Spectral AOD and size distribution

The columnar ASDs have been inverted from the spectral variation of AOD by following the constrained linear inversion scheme developed by King[5] and adopted for the data archived with the IITM radiometers at Pune[6]. The plots showing the wavelength dependence of AOD and the derived size distributions from the sun-photometer data collected for the FN, AN and FD hours are given in Figures 2–4. From these Figures, we see that the AN AODs are higher than the FN AODs and contribute more to the FD AODs. Moreover, the spectral dependence plots of AOD show almost similar behaviour with maximum value at 0.4 µm wavelength. The corresponding FN, AN and FD ASDs exhibit bimodal distribution with a primary mode at 0.1–0.2 µm followed by a secondary mode at ~ 0.8 µm. This bimodal behaviour is distinctly seen in the case of FN and FD spectra while the AN spectrum shows a shift in the secondary peak towards coarse particle size around 3 µm. Moreover, the concentration of smaller particles (radius ~ 0.1 µm) is higher in the FN ASD compared to the AN and FD ASDs. This implies that surface inversions which result in trapping of particles during the FN period and lifting of aerosol particles due to convective activity during AN period modify the ASD over the experimental site. Such short-term variations in aerosol number size spectra are often missed when the FD data sets alone are examined.

The data archived with the spectroradiometer in the 0.4–0.7 µm wavelength region are also examined for aerosol optical and physical properties. Figures 5–7 depict spectral distribution and associated ASDs obtained for the FN, AN and FD data sets. As in the case of the sun-photometer, the spectroradiometer data also show higher concentration of smaller particles during the FN period while the concentration of larger particles in the secondary mode of the size spectrum during the AN period is not clearly seen. This may be because of a difference in the range of scanning wavelengths covered by both radiometers. It may be noted, however, that the high spectral resolution data of the spectroradiometer yield fine-scale variations in AOD and associated size distributions as opposed to the conventional sun-photometers.

Short-term trend in AOD variations

The variations observed in the AOD at the 0.5 µm wavelength during the study period are plotted in Figure 8. An increasing trend in AOD is evident from the plot. A similar trend is then seen in the aerosol columnar content data obtained with the argon-ion lidar from radiometric observations at the experimental site. Hence this feature confirms the enhancement of aerosol loading over the experimental site during the study period.

Environmental effects of aerosol optical properties

The sun-photometer used in the present study was also operated at Thiruvananthapuram, a south-western coastal station, during the intercomparison of several experiments conducted (5–10 January 1998) prior to the INDOEX–FFP 98 programme. AODs and ASDs were obtained from

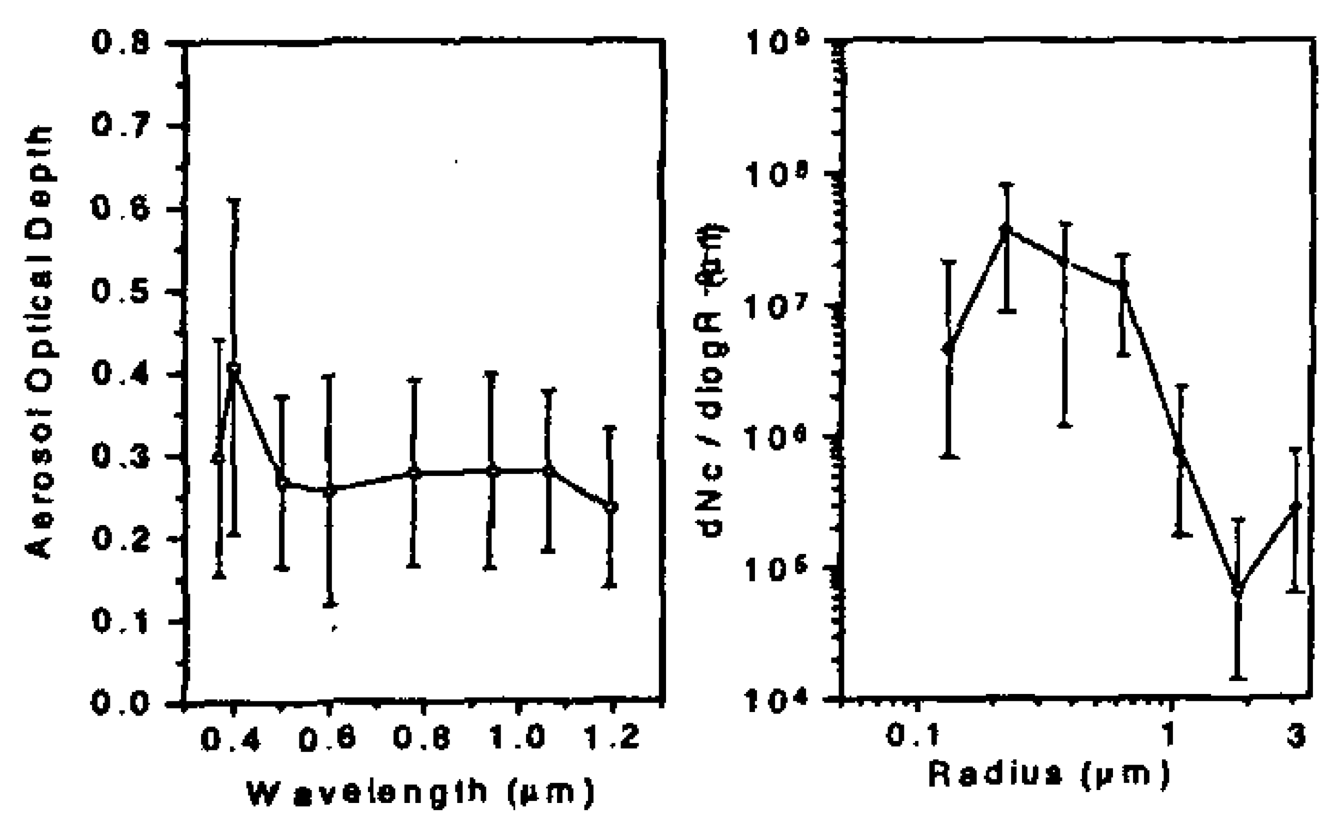

Figure 3. Same as Figure 2 but for AN AODs.

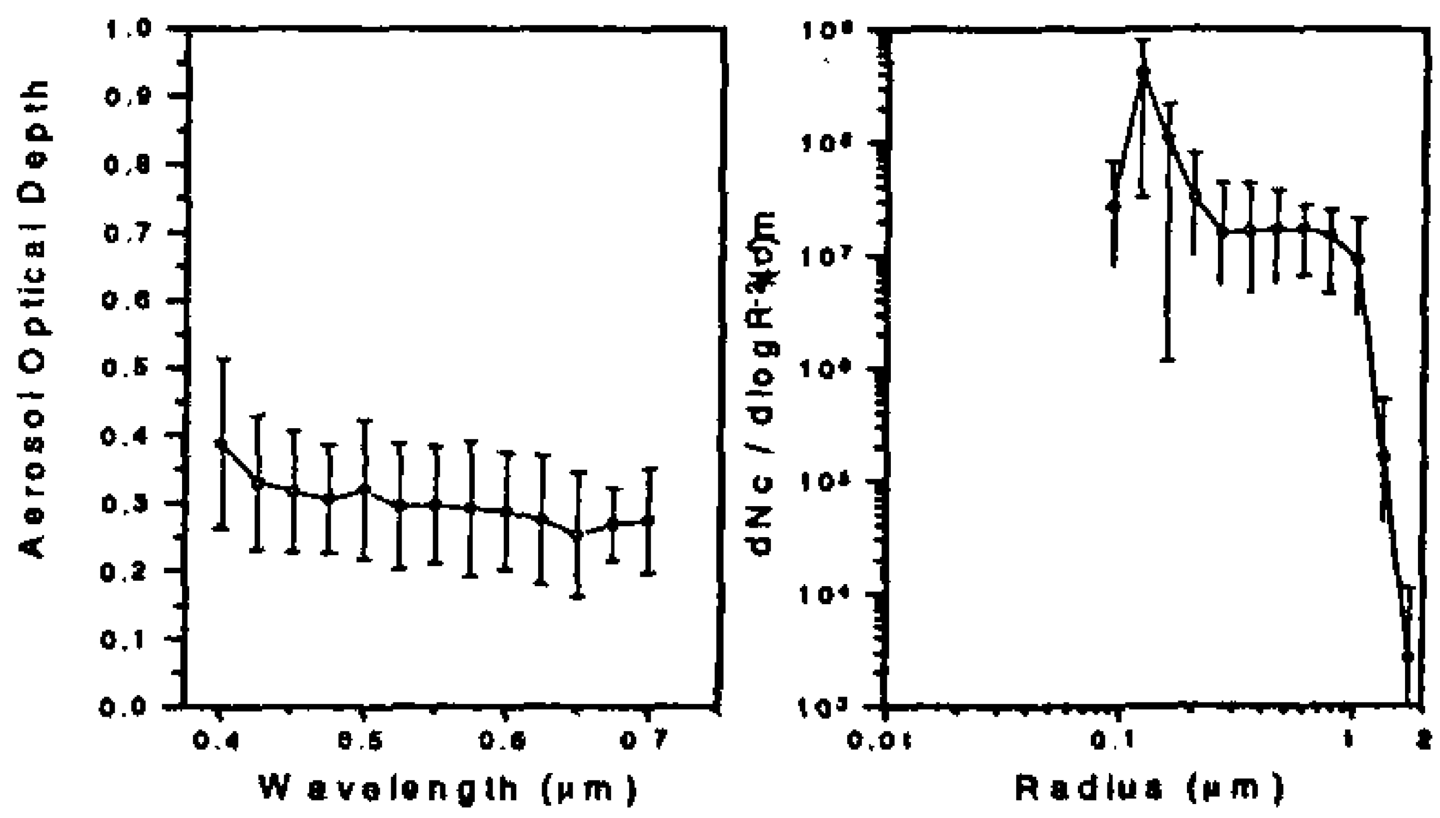

Figure 5. Same as Figure 2 but for the spectroradiometer data.

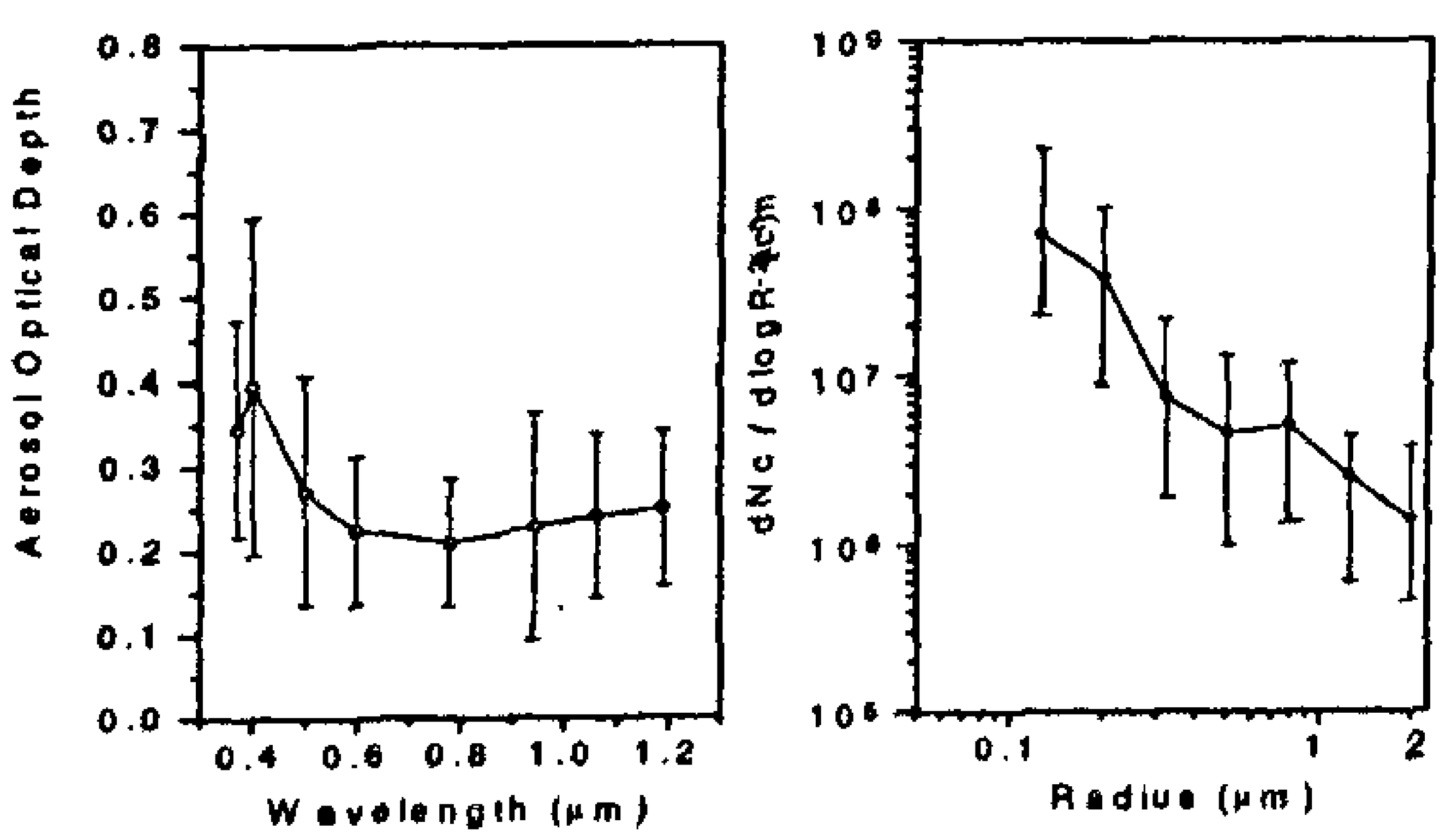

Figure 4. Same as Figure 2 but for FD AODs.

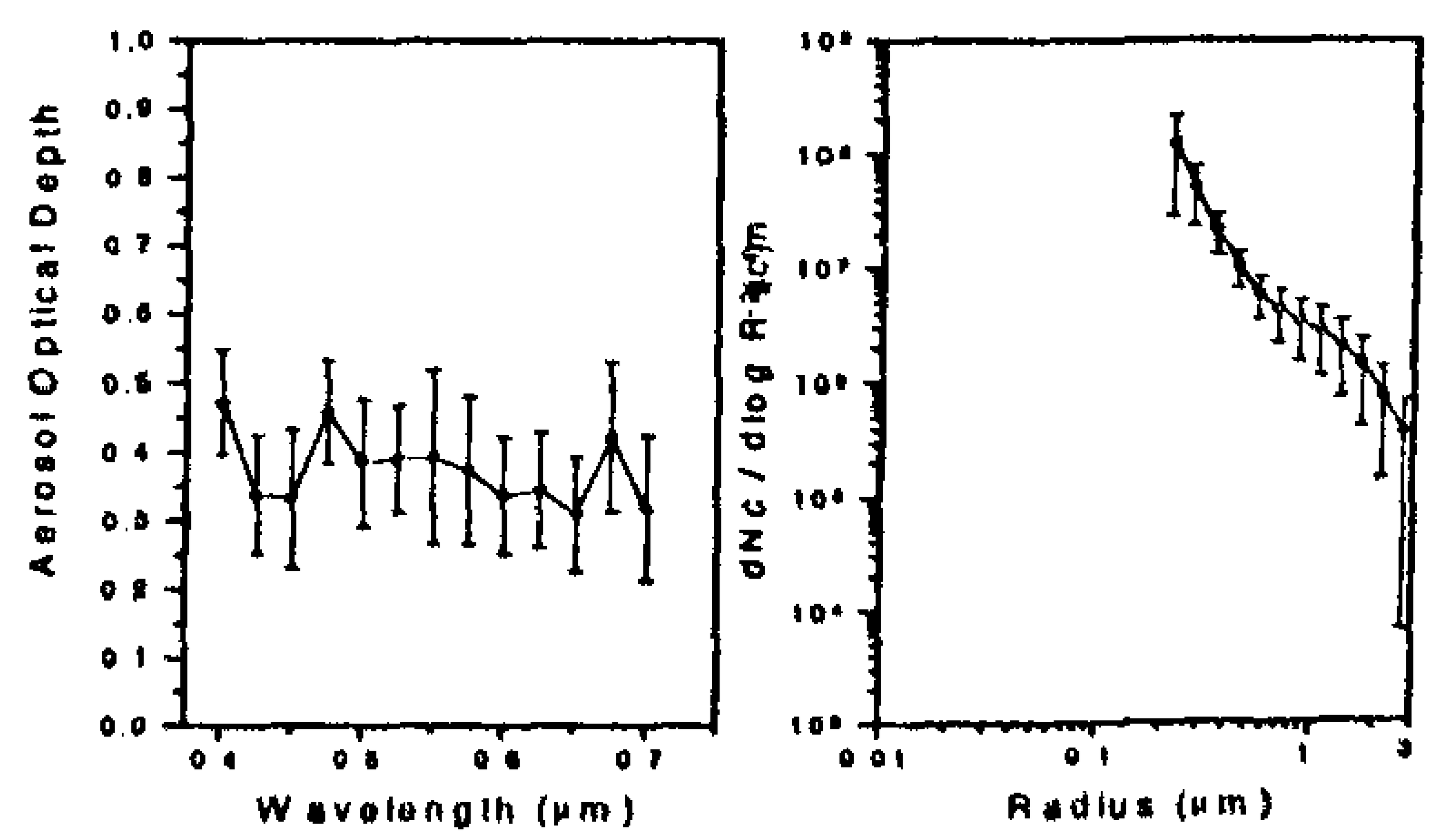

Figure 6. Same as Figure 3 but for the spectroradiometer data.

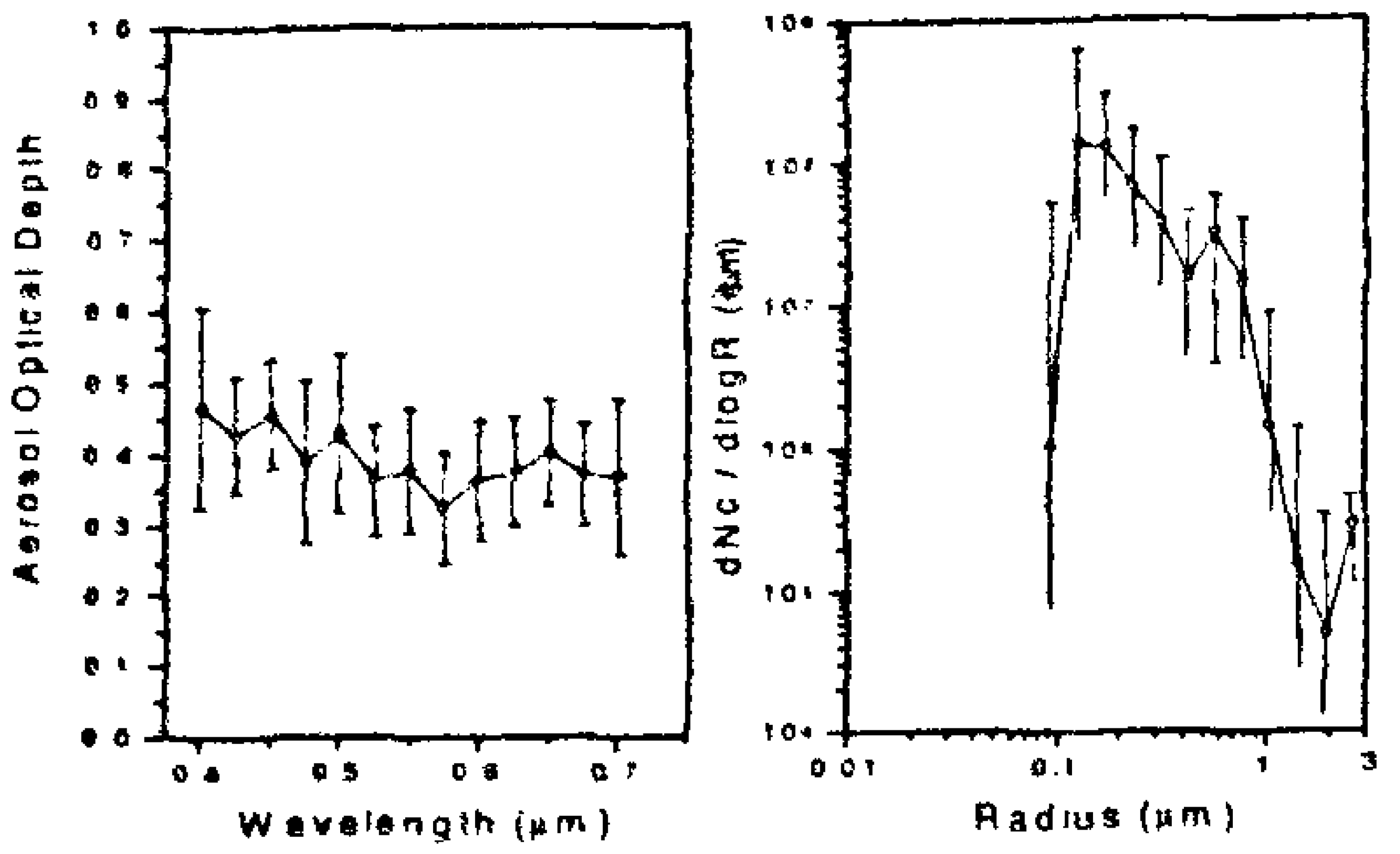

Figure 7. Same as Figure 4 but for the spectroradiometer data.

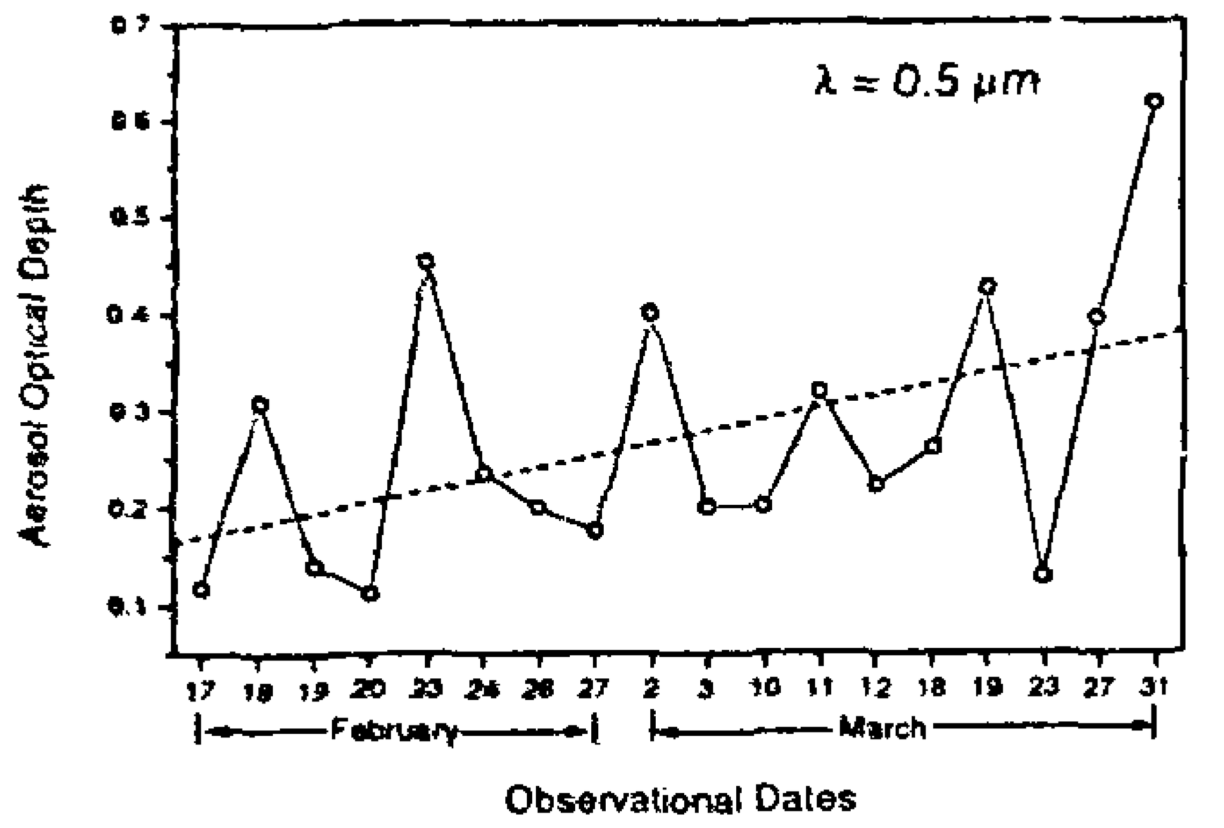

Figure 8. Day-to-day variation in AOD observed during the INDOEX–FFP 98. Dashed line indicates short-term trend.

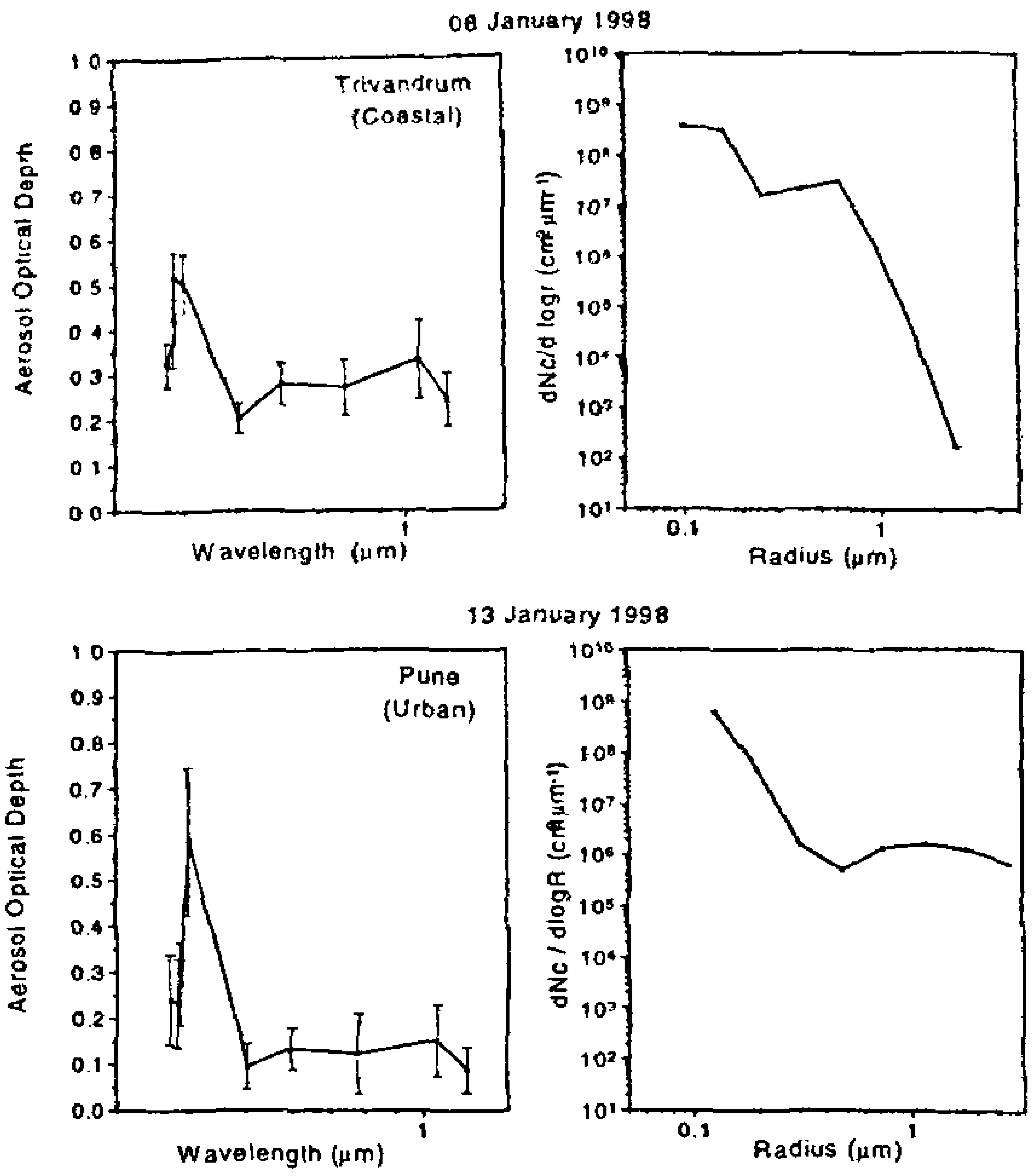

Figure 9. Comparison of aerosol optical properties between different environments.

the data collected on 6 January 1998. These parameters were examined in contrast to such information available at Pune with the same instrument just after a week. The spectral variations in AOD and the derived ASDs over coastal Thiruvananthapuram and urban Pune are compared in Figure 9. Although the AODs show similar variation with wavelength at both stations, they are higher over Pune as expected. Also, the ASD shows bimodal distribution with a primary peak around 0.1 μm at both stations. The concentrations of coarse-mode particles which constitute the secondary peak in the size spectrum, however, are greater at Thiruvananthapuram than at Pune. This is in accordance with the properties of aerosol particles present over the experimental stations. Although the particle concentration is low, the ASD over Pune shows broader secondary peak, indicating contributions from different sources at the experimental station and higher concentrations of accumulation-mode particles.

Conclusions

The present study emphasizes that the information on both continental and marine AODs and ASDs is essential for a detailed understanding of the optical state of aerosols in the ITCZ. Thus, the results of the study indicate the following main features:

The sun-photometer observed average AOD in the 0.37–1.19 μm wavelength region shows: (i) variation of FD optical depth between 0.21 and 0.40 while that of FN and AN optical depths between 0.19 and 0.33, and 0.23 and 0.41, respectively; (ii) bimodal ASD for FD, FN and AN observations; and (iii) increasing trend in daily variation of AOD at 0.5 μm.

The spectroradiometer determined average AOD in the 0.4–0.7 μm wavelength region shows (i) variation of FD optical depth between 0.32 and 0.47, while that of FN and AN optical depths between 0.25 and 0.39, and 0.31 and 0.47, respectively, and (ii) bimodal ASD for FD, FN and AN observations.

The AODs and ASDs measured with the sun-photometer over Pune and Thiruvananthapuram near-simultaneously indicate higher depths and lower concentration of coarse-mode aerosol particles over Pune in contrast to Thiruvananthapuram where the coarse-mode particles dominate the aerosol size spectrum.

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