Analysis of Nephelometer Observations during EOPACE IOP-7

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Summary
Aerosol scattering measurements were conducted aboard a small boat during EOPACE IOP-7 from 25 August 1997 to 4 September 1997. Measurements were taken with a three wavelength integrating nephelometer, providing total scattering (from 7° to 170° scattering angle) and backscattering (from 90° to 170° scattering angle) at three wavelengths: blue (450 nm), green (550 nm), and red (700 nm) (Anderson et al, 1996). The measurements were obtained two meters from the surface at the bow of the boat transiting the IOP-7 propagation path. A preliminary analysis of the scattering relates the scattering to characteristics of the size distribution (Smirnov et al, 1995) and the degree of continental versus maritime influence of the mesoscale atmospheric environment. The Angstrom coefficient was observed to vary from 1.3 to 2, corresponding to a relatively broad size distribution. The Angstrom parameter is compared to that calculated from observed size distributions simultaneously measured aboard the boat. The nephelometer data are analyzed with empirical orthogonal functions to evaluate the independence of the six data channels, and to determine the utility and sufficiency of the several selected channels.

1. Introduction

Aerosol scattering is the dominant extinction mechanism in the visible wavelengths, and as such is critical to the analysis and prediction of atmospheric effects on electrooptical (EO) sensor systems. The applications of these systems are manifold in the military context, from surveillance systems required for ship safety and target identification to automated target detection and tracking subsystems of a weapon. These systems are a component of the naval commander's suite of sensors, including acoustic and electromagnetic systems. While the EO systems often have significant advantages (being a passive sensor significantly reduces the sensor vulnerability), the effects of the environment can be significant and lead to the choice of other options.

Aerosol scattering information is often extended to several wavelengths corresponding to the wavelengths of the sensors of interest. The wavelength dependence of the scattering and the size distribution of the aerosols are related, although in general, not uniquely. Various measures of the relation have been used from the very simplest such as the Angstrom coefficient (the power law dependence of the scattering on wavelength) to various modes of an assumed size distribution. A particularly successful method has been the modeling of the distribution as a combination of simpler distributions (Whitby, 1973), with coefficients relating to instantaneous wind, average wind speed, and empirical air mass characteristics as described by Gathman in the Navy Aerosol Model (NAM) (Gathman, 1983, Gathman and Davidson, 1993). This parameterization has been directly related to parameters related to Navy tactical decision aids (Goroch, 1997).

This work examines the nephelometer measurements as part of comprehensive measurements of coastal aerosol characteristics. The work described here analyzes the nephelometer data in the context of the local meteorology, and points out information available in the measurements conducted.

2. Measurements

This program measured detailed environmental and aerosol conditions in the coastal region near the shore of San Diego. The TSI three wavelength integrating nephelometer (Anderson et al., 1996) was mounted below the deck of an 11 meter boat, with a 3 meter plastic sampling tube extending to the life line at the bow. The sampling intake was

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located approximately 2 meters above the average water line. Nephelometer data included total (integrated from 7° to 170° scattering angle) and backward (integrated from 90° to 170° scattering angle) collected at 450 (blue), 550 (green), and 700 (red) nm wavelengths. The measurements were collected using the standard TSI data collection software. Meteorological measurements were collected on the bridge, approximately 3.5 meters above the surface. The met data were averaged over 1 minute intervals and saved on a laptop computer.

3. Analysis

The nephelometer data were analyzed using several techniques. The change of the size distribution can be described with the Angstrom parameter, which relates to the power law dependence of the scattering coefficient on wavelength,

$$\sigma_1 = \sigma_0 \left(\frac{\lambda_1}{\lambda_0} \right)^{-\alpha}$$

where σ is the scattering coefficient, λ is wavelength, subscripts 0 and 1 correspond to different wavelengths, and α is the Angstrom coefficient (Trakhovsky and Shettle, 1987). In the case of a Junge power law particle size distribution, the Angstrom coefficient can easily be shown to be the Junge coefficient minus one. This parameter is commonly related to atmospheric turbidity, since as the coefficient increases, the ratio of large to small particles decreases.

With scattering measurements at three wavelengths, three Angstrom coefficients can be obtained for each pair of wavelengths. The similarity of these pairs indicates how closely the particle distribution adheres to the power law distribution.

A combination of log normal distributions provides a somewhat more realistic assessment of the size distribution (Fitzgerald, 1991; Pruppacher and Klett, 1980). The Navy Aerosol Model (NAM), has been successfully used to describe marine aerosols as a combinination of log normal distributions (Gathman, 1983; Gathman and Davidson, 1993). The coefficient of the smallest radius aerosol mode is physically related to the maritime or continental characteristic of the air mass, and is generally termed the air mass parameter (AMP). Nephelometer measurements have been used to retrieve the air mass parameter (Goroch, 1997; Littfin and Goroch, 1997).

It has been proposed that large particles (>1 micron diameter) can dominate the nephelometer measurements. Since most of the large particle scattering contribution is in the forward direction, the ratio of total scattering to backscattering provides some information on the potential for such contamination.

4. Variation of nephelometer observations

The preliminary analysis of the EOPACE IOP-7 nephelometer data has been conducted for the first 5 days of the experiment. The data sets were selected from the periods during which the boat was on the IOP-7 propagation path, offshore from the Coronado strand. The scattering coefficients for two days, 26 and 27 August, 1997 were found to demonstrate an interesting contrast in observations. Both days were characterized by negligible wind and calm seas. Meteorological observations reported elsewhere show the two days to be quite similar in terms of stability and mesoscale features.

The nephelometer total and backward scattering cross sections are shown in Figures 1 and 2. Both runs were conducted at approximately the same time of day, from 0500 to 0700 local. The scattering increases during this interval for both days. Each day has a maximum toward the end of the day. The scattering on the 27th however is significantly greater than that on the 26th. An examination of the two figures also shows there are differences in the relationships both between the scattering and backscattering, and among the different colors.

The most evident feature of both days is the large peak occurring toward the end of the data collection event. Figures 3 and 4 show the scattering and the ship track, with several locations identified on both the ship track and the backscatter plots. On both days, the ship changed from an outbound to an inbound track at the same time as the scattering showed an anomalous peak. It is expected that this peak corresponds to local contamination when the vessel is either stopped or changing course.

The air mass parameter (AMP) was retrieved using the procedure described earlier (Goroch, 1997). The air mass parameter is shown in figures 5 and 6 for retrieval techniques using each of three pairs of total scattering values, and from the combination of all three values. The AMP is consistently greater on the 27th than on the 26th , consistent with the observed increased scattering. Since the AMP retrieval artificially removes the large mode aerosol, this may indicate a problem with the scaling of the

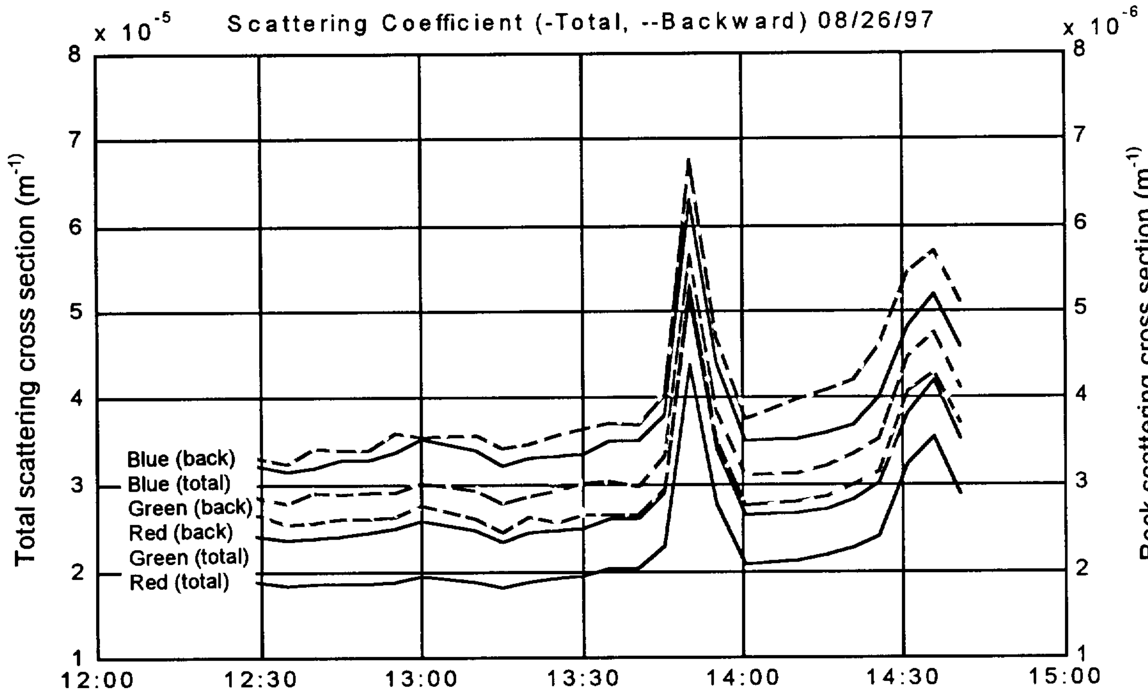

Figure 1. Nephelometer total and backward scattering cross sections during 26 Aug 98 ship event. Note the backscattering cross section scale is on the right.

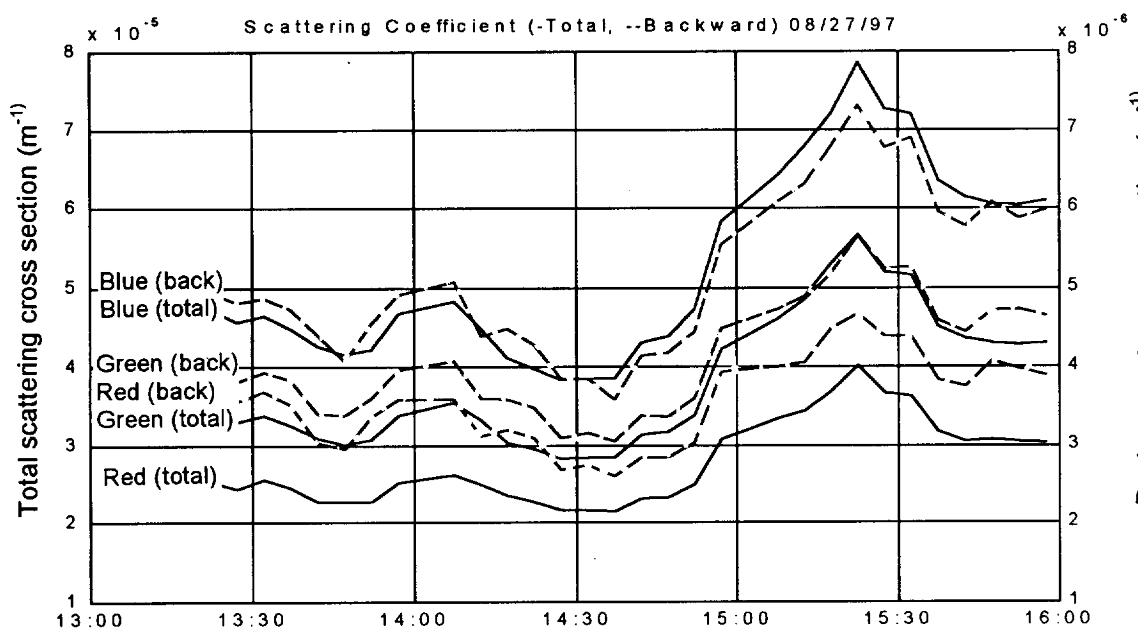

Figure 2. Nephelometer total and backward scattering cross sections during 27 Aug 98 ship event

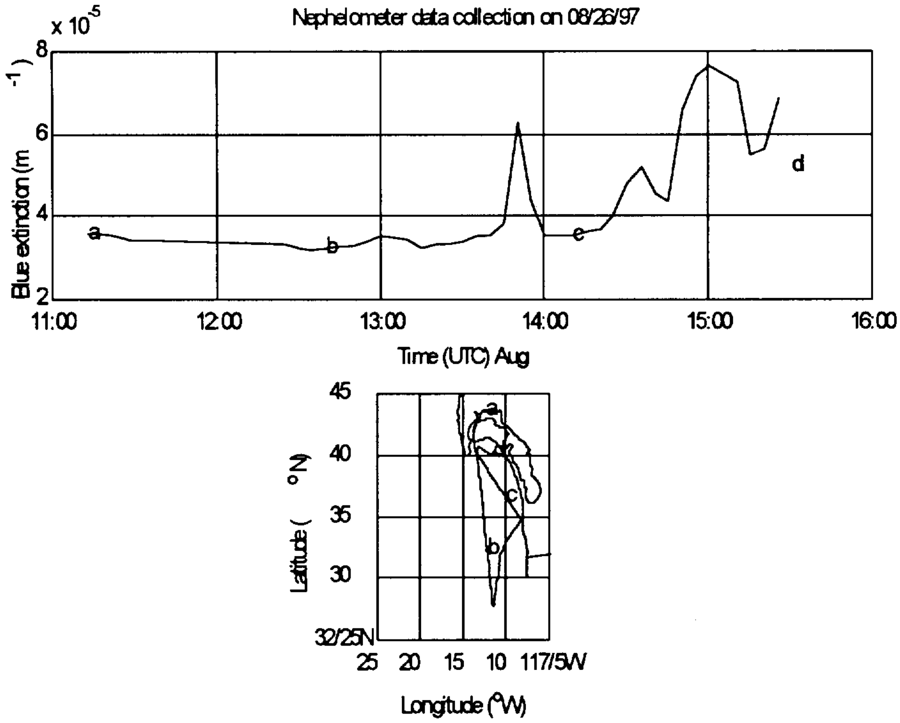

Figure 3. Ship track during 26 Aug 98 event. Ship locations are correlated to nephelometer observations above.

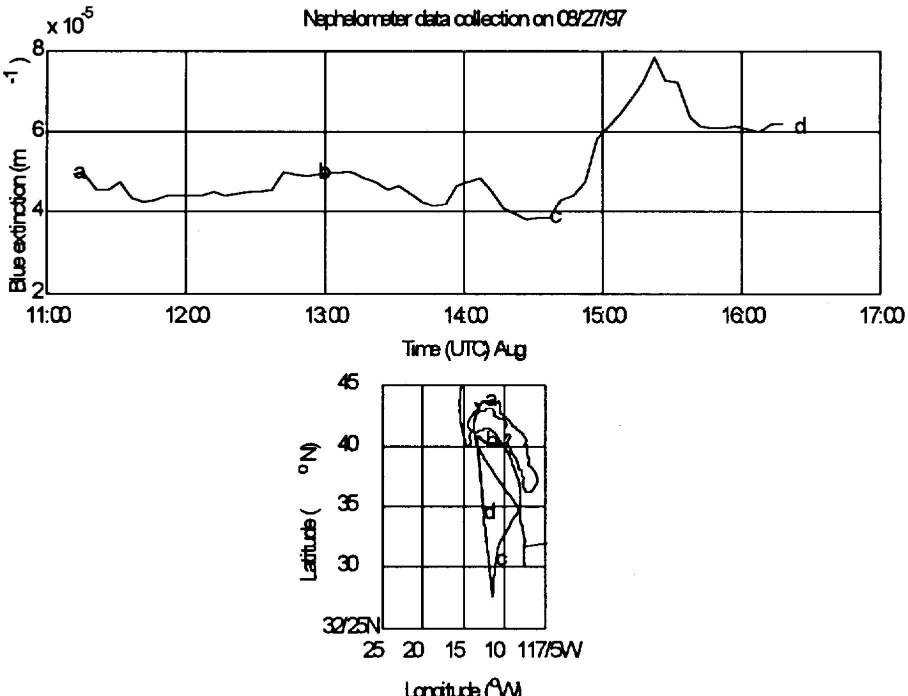

Figure 4. Ship track during 27 Aug 98 event. Ship locations are again correlated to the nephelometer observations.

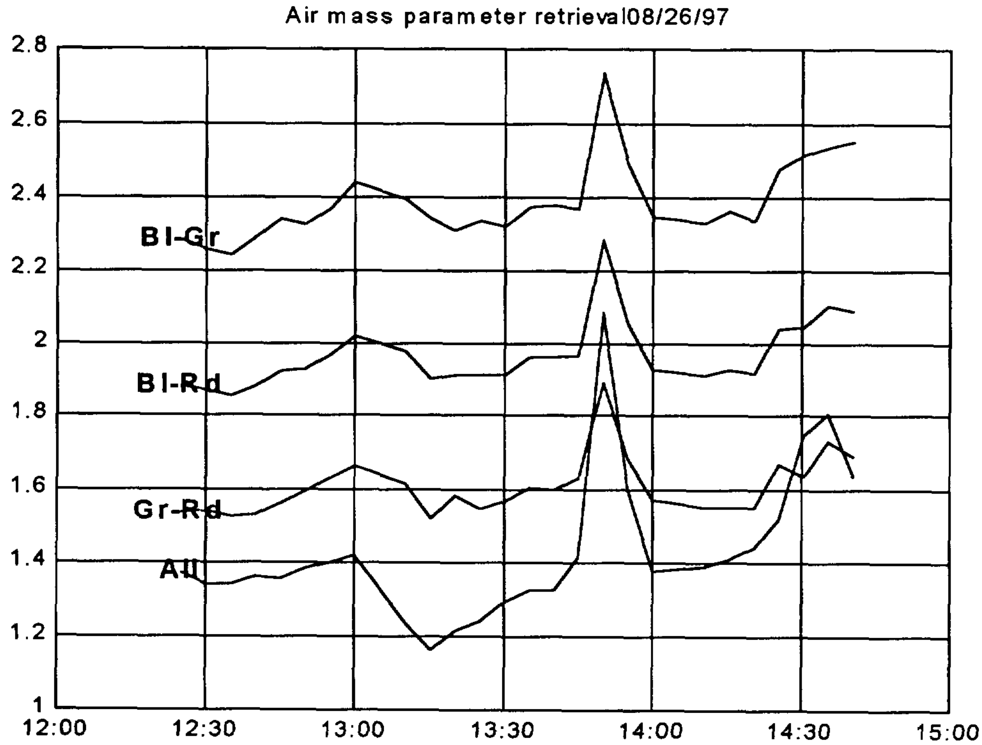

Figure 5. Air mass parameter retrieval using pairs of channels and all channels in least squares retrieval.

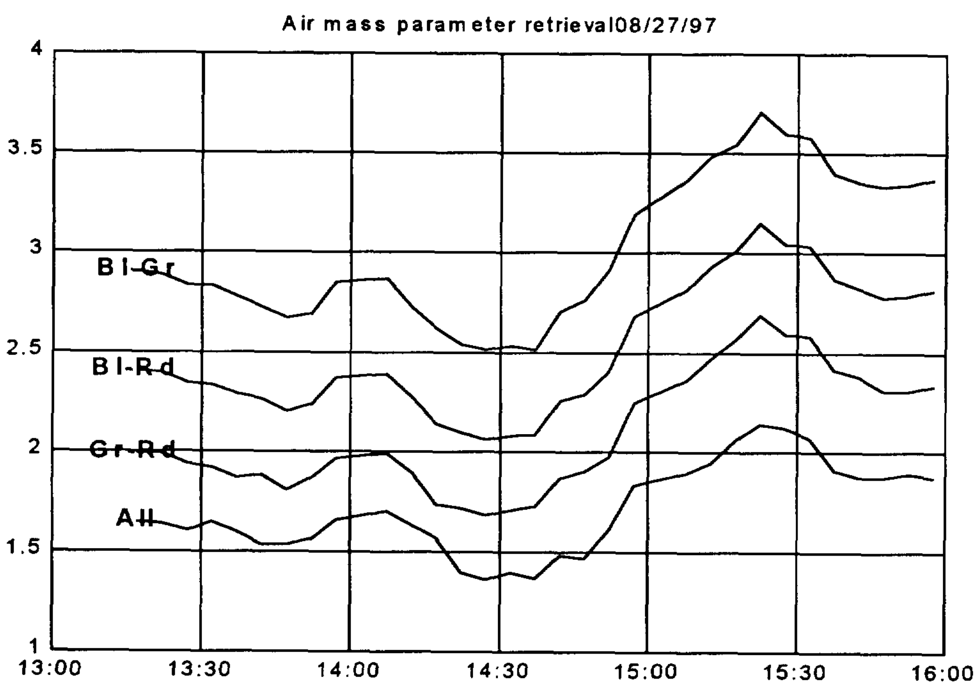

Figure 6. Air mass parameter retrieval for 27 Aug 98.

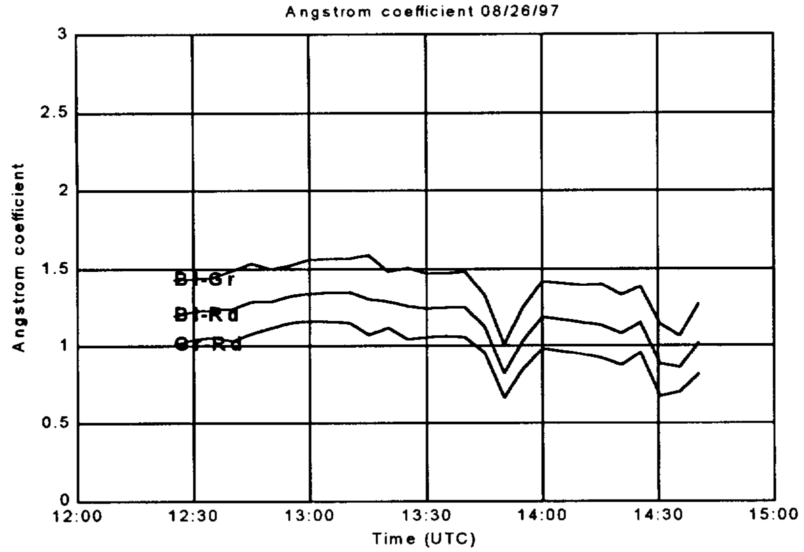

Figure 7. Angstrom coefficients calculated from pairs of scattering observations on 26 Aug 98.

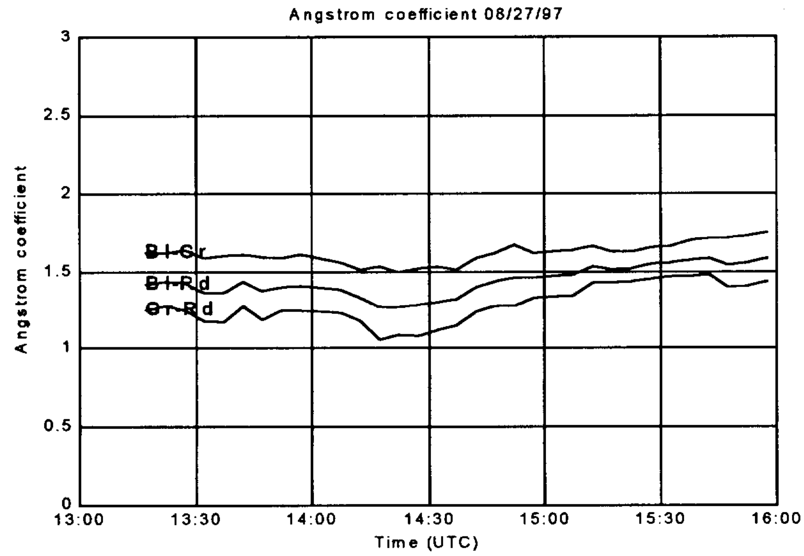

Figure 8. Angstrom coefficients calculated from pairs of nephelometer measurements on 27 Aug 97.

large aerosol component at very low wind speed. This conjecture must await analysis and comparison to detailed aerosol spectra.

Angstrom coefficients were calculated from the three pairs of scattering values (figures 7 and 8). The Angstrom coefficients were similar to values expected in clean marine regions (Smirnov et al., 1995). The values on the second day were somewhat larger than the first, consistent with the increasing relative concentration of larger particles.

5. Conclusions

Aerosol scattering measurements were conducted off the Southern California coast during August 1997. Comparison of two subsequent days indicates a moderate change in aerosol conditions although the wind speeds were quite low, and temperature and humidity were similar. The scattering was related to the air mass parameter and the coefficient corresponding to the smallest particle mode was retrieved. Although the AMPs were low, consistent with a clear marine air mass, the differences between the two days were significant. The differences in the AMP were consistent with the differences in the Angstrom parameter. The Angstrom parameter was similar to the value expected from a strongly maritime environment.

Acknowledgments

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References

Anderson, T.L. et al., 1996. Performance characteristics of a high-sensitivity, three-wavelength total scatter/backscatter nephelometer. Journal of Atmospheric and Ocean Technology, 13: 967-986.

Fitzgerald, J.W., 1991. Marine Aerosols: A Review. Atmospheric Environment, Part A, 25: 533-546.

Gathman, S.G., 1983. Optical properties of the marine aerosol as predicted by the Navy aerosol model. Optical Engineering, 22(1): 57-63.

Gathman, S.G. and Davidson, K.L., 1993. The Navy Oceanic Vertical Aerosol Model. 1634, Naval Command, Control, and Ocean Surveillance Center, RDT&E Div., San Diego.

Goroch, A.K., 1997. Air mass parameter retrieval from nephelometer data in the Sea of Japan. In: K.M. Anderson and J.H. Richter (Editors), Battlespace Atmospheric Conference, NRaD - Sand Diego, CA, pp. 47-51.

Littfin, K. and Goroch, A.K., 1997. Determination of the origin of an air mass using nephelometer measurements and the Navy aerosol model,, SPIE Annual Meeting, Propagation and Imaging through the Atmosphere, San Diego, CA, pp. 06.

Pruppacher, H.R. and Klett, J.D., 1980. Microphysics of Clouds and Precipitation. Reidel, London.

Smirnov, A., Villevalde, Y., O'Neill, N.T., Royer, A. and Tarussov, A., 1995. Aerosol Optical Depth Over the Oceans: Analysis in Terms of Synoptic Air Mass Types. Journal of Geophysical Research, 100(D8): 16639-16650.

Trakhovsky, E. and Shettle, E.P., 1987. Wavelength scaling of atmospheric aerosol scattering and extinction. Applied Optics, 26: 5148-5153.

Whitby, K.T., 1973. Modeling of multimodal size distributions., Jahreskongress GAF, Vienna, Austria, pp. 136-142.

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DISCUSSOR'S NAME: G. de Leeuw

Has the AMP also been retrieved from the nephelometer data for higher AMPs? And is the error then still <1?

AUTHOR/PRESENTER'S REPLY:

In this experiment, the AMPs were all rather low. But if you refer to my reference number 6 from the SPIE 1997 Conference proceedings, you will see comparisons of AMPs as high as 9, which indicates a strong continental influence. The agreement in the November 1996 experiment shown indicates agreement within plus or minus 2 AMP units. While not quite as good as the plus or minus one for marine AMPs, it is certainly good enough agreement to use accurately for IR predictions using the Navy Aerosol Model.