# 5.5 AEROSOL TYPE CLASSIFICATION WITH SEAWIFS FOUR-CHANNEL RADIANCE DATA

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## 1. Introduction

Aerosols directly and indirectly affect the Earth's climate, since they scatter and absorb radiation and also alter the cloud microphysical properties. Despite the significance of such aerosol climate effects, the accurate evaluation of the aerosol radiative forcing have not yet been clarified due to our poor knowledge of aerosol properties on a global scale (IPCC, 2001).

A classification of aerosol types is important for improving the estimation of aerosol radiative forcing, since the aerosol climate effects considerably differ from one type to another. The most important aerosol types are soil dust, carbonaceous, sulfate, and sea salt aerosols. Their representative particle size and radiation absorptivity are quite different. Soil dust aerosol particles, for example, are large in size and significantly absorb shortwave radiation, while sulfate aerosol particles are small in size and are non-absorbing. Carbonaceous aerosols are more complicated in their chemical and optical properties, but they are commonly recognized as a strongly absorbing aerosol with the inclusion of soot particles. These four aerosol types, therefore, are classified with their particle size and absorptivity of radiation.

A two-channel algorithm has already shown the Ångström exponent as a particle size index together with the aerosol optical thickness (Nakajima and Higurashi, 1998; Higurashi and Nakajima, 1999; Mishchenko et al., 1999). Herman et al. (1997) was successful in using TOMS UV radiances to detect absorbing aerosols, such as soil dust and biomass burning aerosols, which strongly absorb UV and blue radiation, as also shown by Dubovik et al. (2001) with AERONET data analysis.

In this paper, we propose a new algorithm combining these ideas proposed in the past. It retrieves the aerosol optical thickness, Ångström exponent, and radiation absorptivity with four channel satellite-received radiances in UV-NIR spectral region and classifies the aerosols into the above four aerosol types using the retrieved results. The algorithm is applied to SeaWiFS data during the Asian Atmospheric Particle Environmental Change Studies (APEX), a project of the Japan Science and Technology Corporation, conducted together with the International Asian Aerosol Characterization Experiment (ACE-Asia) in the region around Japan and the East China Sea.

## 2. Four-channel algorithm

The new algorithm assumes two aerosol optical models, that is, absorbing and non-absorbing aerosol models for the inversion process to obtain a set of aerosol optical thickness and Ångström exponent values for each aerosol model. The refractive index for each model is referenced to sulfate of WCP-55 (1983) for the non-absorbing model and to Sokolik et al. (1993) for the absorbing model. The wavelength-averaged values of the refractive index for SeaWiFS channels are shown in Table 1. The size distribution is a bimodal log-normal function as same as that used by Higurashi and Nakajima (1999). This first step is almost the same as that of the two-channel algorithm of Higurashi and Nakajima (1999) to derive the aerosol optical thickness and effective radius. We use spectral radiances in channels 6 and 8 of the SeaWiFS satellite-borne imager with the center wavelengths at 670 and 865nm, respectively. Here we define the Ångström exponent as the slope of a log-linear regression line to the spectral optical thickness calculated at wavelengths of 368, 500, 675, 862, and 1050nm.

In the second step of our algorithm, we test the blue radiation absorptivity of aerosol particles in the SeaWiFS channels 1 and 2, of which the center wavelengths are 412 and 443nm, respectively. The difference in the apparent aerosol reflectance between channels 1 and 2 for the absorbing model is smaller than that for the

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Table 1. Wavelength-averaged values of the refractive index in SeaWiFS channels.

| | Absorbing model | | | | Non-absorbing model | | | |
|---|---|---|---|---|---|---|---|---|
| Channel No. | 1 | 2 | 6 | 8 | 1 | 2 | 6 | 8 |
| Real part | 1.5 | 1.5 | 1.5 | 1.5 | 1.438 | 1.434 | 1.428 | 1.425 |
| Imaginary part | 0.012 | 0.008 | 0.005 | 0.005 | 9.99E-9 | 9.97E-9 | 1.72E-8 | 1.95E-7 |

non-absorbing model as confirmed by several numerical simulations. We, therefore, can select a suitable aerosol optical model by comparing the difference in the blue channel radiances observed and calculated with the aerosol optical thickness and Ångström exponent retrieved in the first step.

We have classified the aerosols into the following four types based on the retrieved Ångström exponent and blue-spectral radiative absorptivity. We divided the aerosols into large particles and small particles according to the Ångström exponent value assuming a boundary value of 0.8. The resulting classified aerosol types are the 'Soil dust aerosol' as the absorbing aerosol with a small Ångström exponent, 'Carbonaceous aerosol' as the absorbing aerosol with a large Ångström exponent, 'Sulfate aerosol' as the non-absorbing one with a large Ångström exponent, and 'Sea salt aerosol' as the non-absorbing one with a small Ångström exponent. Although we label these four types as 'Soil dust', 'Carbonaceous', 'Sulfate', and 'Sea salt', these types should be regarded as optically equivalent aerosol types mimicking the realistic aerosols, which should have more complicated optical properties and chemical compositions.

Figure 1 shows plots of satellite-derived versus ground-based aerosol optical thickness data at the wavelength of 500nm. The ground-based data were derived from a PREDE skyradiometer at the Miyakojima Island site (24.733°N, 125.317°E), as one of the National Space Development Agency of Japan (NASDA) validation sites called SKYNET, sampled within 30 minutes before and after the satellite pass, and the SeaWiFS-derived data are selected within 0.5 degrees from the ground site. Both parameters derived by the four-channel algorithm show good agreement with the ground-based values.

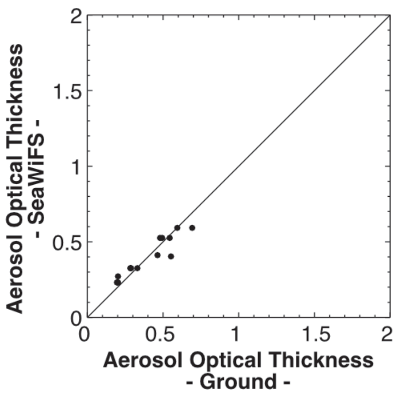


Figure 1. The correlation between satellite-derived and ground-based aerosol optical thickness.

## 3. Results

We have analyzed the SeaWiFS data in a zone of the East China Sea from 15°N to 55°N and from 110°E to 160°E from March to May 2001. Figure 2 shows the near-true color image of SeaWiFS, aerosol type and Ångström exponent on 13 April and 26 April 2001, The Asian dust was transported over Japan by a low-pressure system traveling eastward on 13 April in contrast to the case of 26 April.

The results on 26 April show the typical distribution of aerosol type and Ångström exponent in this period, that is, the area adjacent to the coast of the continent, especially over the sea of Japan, is covered by aerosols with large Ångström exponent value indicating the effect of a polluted air mass form the continent and is classified as 'Carbonaceous aerosol', while 'Sea Salt' spreads over the open sea area. In our results, carbonaceous aerosols are dominant in this region and sulfate aerosols are only found at the front southern edge of the Asian dust plume. This is consistent with the chemical sampling observation at Amami-Oshima Island (28.37°N, 128.50°E) showing that a plume of sulfate rich aerosols was first pushed out from the industrial region of the continent by a low-pressure system followed by a soil dust plume (Nakajima et al., paper 3.3 of this issue). The recent model simulations have suggested that the optical thickness of carbonaceous aerosols is as large as that of the sulfate aerosols in this region

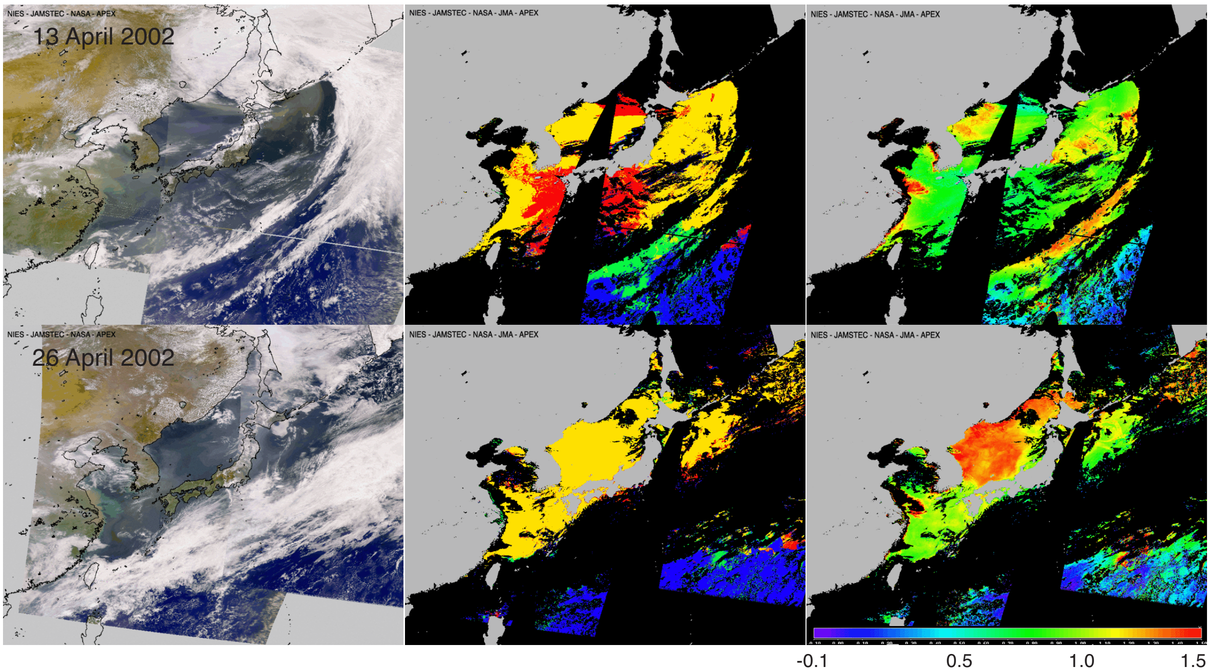


Figure 2. A near true-color image synthesized from SeaWiFS spectral radiances (left), Ångström exponent (center), and aerosol type (right) on 13 and 26 April 2001. Aerosol types are soil dust (red), carbonaceous (yellow), sulfate (green), and sea salt (blue) aerosols.

(Takemura et al., 2001). And a numerical test has shown that our algorithm tends to classify aerosols as 'Carbonaceous aerosol' when the carbonaceous aerosols are mixed with sulfate aerosols. These results support our result that the contribution of the carbonaceous aerosols was dominant in this region.

The Asian dust plume was successfully classified as 'Soil dust aerosol' and consistent with the visual judgment in the near-true color image. It is interesting that the Ångström exponent of the dust of 0.6 is not as small as 0.3 to 0.4 of the Saharan dust plume found by Deuzé et al. (1999) and Higurashi et al. (2000), although it is smaller than the surrounding values. This result suggests that soil dust aerosols and air pollution aerosols were highly mixed in this region. As a result, the effective particle size of the polydispersion was reduced.

## 4. Conclusions

We have developed a four-channel algorithm to classify aerosols into four types of soil dust, carbonaceous, sulfate, and sea salt aerosols. This algorithm has been applied to the SeaWiFS data during the APEX-E2 / ACE-Asia in the period of March to May 2001. The retrieved aerosol optical thickness and Ångström exponent have shown good agreement with the ground-based values. The Asian dust aerosols have been successfully classified as soil dust aerosols and it was found that the East China Sea region had complicated mixtures of different types of aerosols.

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## References

Chin, M., R. B. Rood, S.-J. Lin, J.-F. M¸ller, and A. M. Thompson, Atmospheric sulfur cycle simulated in the global model GOCART: Model description and global properties, *J. Geophys. Res.*, *105*, 24671-24687, 2000.

Deuzé, J. L., M. Herman, P. Goloub, D. Tanré, and A Marchand, Characterization of aerosols over ocean from POLDER-ADEOS-1, *Geophys. Res. Lett.*, *26*, 1421-1425, 1999.

Dubovik, O., A. Smirnov, B. N. Holben, M. D. King, Y. J. Kaufman, T. F. Eck, and I. Slutsker, Accuracy assessments of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements, *J. Geophys. Res.*, 105, 9791-9806, 2000.

Herman, J. R., P. K. Bhartia, O. Torres, c. Hsu, C. Seftor, and E. Celarier, Global distribution of UV-absorbing aerosols from Nimbus 7/TOMS data, *J. Geophys. Res.*, *102*, 16911-16922, 1997.

Higurashi, A., and T. Nakajima, Development of a two channel aerosol retrieval algorithm on global scale using NOAA AVHRR, *J. Atmos. Sci.*, *56*, 924-941, 1999.

Higurashi, A., T. Nakajima, B. N. Holben, A. Smirnov, R. Frouin, and B. Chatenet, A study of global aerosol optical climatology with two channel AVHRR remote sensing, J. Climate, *13*, 2011-2027, 2000.

IPCC (the Intergovernmental Panel on Climate Change), *Climate Change 2001: The Scientific Basis*, edited by J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, and D. Xiaosu, 881pp, Cambridge Univ. Press., Cambridge and New York, 2001.

Lacis, A. A., and M. I. Mishchenko, Climate forcing, climate sensitivity, and climate response: A radiative modeling perspective on atmospheric aerosols in *Aerosol forcing of climate*, edited by R. J. Charlson and J. Heintzenberg, pp. 11-42, John Wiley and Sons, Chichester, 1995.

Mishchenko, M. K., I. V. Geogdzhayev, B. Cairns, W. B. Rossow, and A. A. Lacis, Aerosol retrievals over the ocean using channel 1 and 2 AVHRR data: A sensitivity analysis and preliminary results, *Applied Optics*, *38*, 7325-7341, 1999.

Nakajima, T., and A. Higurashi, A use of two-channel radiances for an aerosol characterization from space, *Geophys. Res. Lett.*, *25*, 3815-3818, 1998.

Sokolik, I., and A. Andronova, and T. C. Johnson, Complex refractive index of atmospheric dust aerosols, *Atmos. Environ*, *16*, 2495-2502, 1993.

Takemura, T., H. Okamoto, Y. Maruyama, A. Numaguti, A. Higurashi, and T. Nakajima, Global three-dimensional simulation of aerosol optical thickness distribution of various origins, *J. Geophys. Res.*, *105*, 17853-17873, 2000.

WCP-55, *Report of the experts meeting on aerosols and their climate effects*, edited by A. Deepack and H. E. Gerber, 107pp, World Meteorological Organization, 1983.