# Atmospheric Correction for Ocean Color Sensors : ADEOS/OCTS and POLDER

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## ABSTRACT

Atmospheric correction algorithms for ocean color data are presented. This paper proposes two subjects in order to achieve better atmospheric correction. One is a retrieval procedure for atmospheric aerosols by referring to both of radiance and polarization given by ADEOS/OCTS and POLDER. The other is introduction of atmospheric correction coefficients. Our atmospheric correction, which is based on radiative transfer process in an atmosphere-ocean model involving the retrieved aerosol distribution, is applied for the OCTS-ocean color data.

It is shown that retrieval of atmospheric aerosols is improved by combination use of radiance and polarization, and atmospheric correction process is progressed by using the correction coefficients.

## 1. INTRODUCTION

Atmospheric correction is the process of removal of contaminated atmospheric light from space-borne data. The Japanese satellite ADEOS was unfortunately ten-months life but provided us with valuable information of Earth environments since August 17th in 1996. ADEOS/OCTS(Ocean Color Temperature Scanner) is the second ocean color sensor in eighteen years since the first Nimbus-7/CZCS. Furthermore ocean color remote sensing is expected to progress with SeaWiFS of the USA, which was successfully launched on August 1 in 1997 [1]. At this time we focus our attention on atmospheric correction for ocean color data. Atmospheric correction is a key factor especially for ocean color analysis [2, 3], because the contribution of atmospheric light to the satellite data is about 80 to 90% in the visible wavelengths over the ocean.

Since atmospheric light is mainly due to multiple scattering by aerosols, aerosol model itself contributes greatly in atmospheric correction [4]. It is well known that atmospheric aerosols reflect the environmental change. Namely aerosol characteristics might change greatly in temporal and regional scales [5, 6, 7, 8]. Therefore the efficiency of atmospheric correction strongly depends on how we can set up an appropriate aerosol model to the satellite-image concerned. First aerosol characteristics are retrieved using both of radiance and polarization given by ADEOS/OCTS and POLDER.

Our atmospheric correction is applied for the OCTS ocean color data. Here radiative transfer process in an atmosphere-ocean model involving the retrieved aerosol distribution is simulated. We have introduced an idea of atmospheric correction coefficients, which represent the values of a ratio of the water leaving radiance to the observed radiance at the satellite [9]. Namely the atmospherically corrected images are obtained by multiplication of the calculated coefficients to the raw ocean color data. The expected chlorophyll map near the sea surface is derived through bio-optical algorithms in terms of ocean color data.

## 2. AEROSOL RETRIEVAL BASED ON ADEOS/OCTS AND POLDER DATA

It is well known that aerosols contribute greatly in the atmosphere by scattering and absorption in the visible and near infrared region of spectrum. This work partly cites aerosol retrieval using near-infrared data given by ADEOS/OCTS and POLDER. The POLDER (POLarization and Directionality of Earth Reflectance) is one of the sensors on board the satellite ADEOS, and aims to collect global-scale visible and near-infrared observations of polarized and directional solar radiance reflected by the Earth-atmosphere-surface system [10]. It is shown that aerosol retrieval can be efficiently pursued with polarization, because polarization feature strongly depends on the optical properties of particles [11].

It is found that, in the near-infrared wavelengths, a contribution of radiation out of the ocean to total radiation is negligibly small and optical thickness of the atmosphere is also small [12]. Therefore it is possible to assume that the images in the near infrared approximately represent the single scattering pattern by atmospheric constituents. Thus the measurements of OCTS- and/or POLDER- band 6 ($0.67 \mu m$) and band 8 ($0.865 \mu m$) are available to retrieve the aerosol characteristics, e.g., size and refractive index. A single scattering phase matrix is expressed by Stokes parameters (I, Q, U, V) and composed of Rayleigh scattering by molecular gases and Mie scattering by aerosols. The values of the phase matrix elements strongly depend on the characteristics of aerosols because of the uniform distribution of molecular gases. A single-mode log normal representation with two parameters, the mode radius ($\bar{r}$) and the width of the log-normal curve ($\sigma$)

is considered here for one of the most widely used size distributions. Thus it becomes our purpose to retrieve $(\overline{r}, \sigma)$ for the log-normal distribution.

It is natural to consider that several kinds of aerosols could exist together in general. In this section, we take into account heterogeneous particles for maritime aerosol models. World Meteorological Organization [13] provides a standard maritime aerosol model, which is mainly composed of oceanic (OC) and water-soluble (WS) components. Oceanic type denotes sea-salt solution in water, and water-soluble type includes water-soluble substances consisting of ammonium sulfate, calcium sulfate and organic compounds. That is, we assume now the maritime aerosols are composed of oceanic component and water-soluble one. The mixing rules of several components into a spherical shaped heterogeneous particle have been presented by several authors, e.g. Maxwell-Garnett (MG) theory, Bruggeman theory and core-mantle type [14, 15]. Since these mixing rules have been already adopted for astrophysical grains, descriptions of each theory are omitted and MG theory is employed in our present simulations. That is, a heterogeneous grain model according to Maxwell-Garnett mixing rule as small water-soluble (WS) inclusions in an oceanic (OC) matrix where the volume fraction of WS-inclusions is represented by $f$, is examined for atmospheric aerosols.

Here an efficient algorithm for aerosol retrieval is developed using a ratio of the radiance data at band 8 to that at band 6 on each pixel of an image of interest. Namely the wavelength tendency is available to retrieve aerosol characteristics. On the other hands, view angles of sun and satellite on each pixel of the image correspond to angles of incident and scattered light in point of scattering process. In other words, each pixel of the image gives each scattering angle. In our simulations, a ratio of the scattered light at band 8 to that at band 6 can be calculated for an arbitrary scattering angle if a model of atmosphere involving aerosol model is set up. Therefore we can say that a scattering angle correlates radiance of a pixel of satellite image with a simulated value of atmospheric light, and so it is possible to determine the best aerosol parameters at each pixel by comparison of observations with simulations. Thus both of spectral information and directional information of the satellite data are used to retrieve aerosol distribution.

Fig.1 presents a retrieved distribution of the optical thickness of aerosols at a wavelength of 0.55 $\mu m$ based on a ratio of band 8 to band 6 on each pixel of the OCTS image on April 26, 1997 over the Pacific Ocean near Japan. In this figure a heterogeneous model with $\{f = 0.1, (r = 0.25\mu m, \sigma = 2.2\mu m)\}$, which is named model-A hereafter, is selected as a good candidate for an aerosol model. Certainly some other grain models can also provide reasonable aerosol optical thickness. That is, model-A is one candidate to explain the OCTS-radiance data. Therefore the aerosol model-A is examined next using the polarization data simultaneously observed by POLDER. Fig.2a presents the observed polarization degree at a wavelength of $(0.67\mu m)$ on April 26 in 1997 and Fig.2b shows the simulated image using the model-A. By comparison with these two images, we found that the model-A can explain the POLDER-polarization data.

It is of interest to mention that any other grain models available to radiance data by OCTS are not impossible to interpret the polarization by POLDER. In other words model-A is an optimized aerosol model retrieved from both of OCTS and POLDER data based on scattering simulations in the polarization field. In general, it is natural to consider that not only optical thickness of aerosols but also their chemical composition and size distribution vary with pixel to pixel within an image. At any rate, such a present algorithm as both of images of radiance and polarization are interpreted by using the variation of optical thickness of one aerosol model is one approach to aerosol retrieval. Thus we can conclude that the model-A is a good aerosol model over the Pacific Ocean near Japan on April 26, 1997.

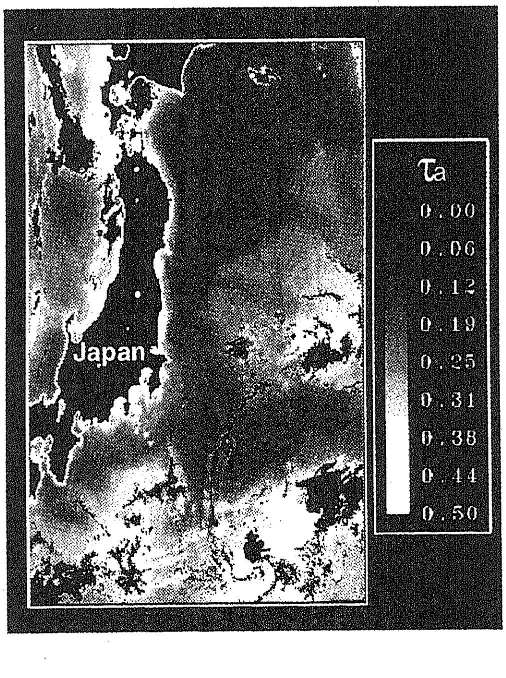

Fig. 1 A retrieved distribution of the optical thickness of aerosols at wavelength 0.55 $\mu m$ based on a ratio of band 8 to band 6 on each pixel of the OCTS image on April 26, 1997 over the Pacific Ocean near Japan, where a heterogeneous grain with $\{f = 0.1, (r = 0.25\mu m, \sigma = 2.2\mu m)\}$ is set up for an aerosol model.

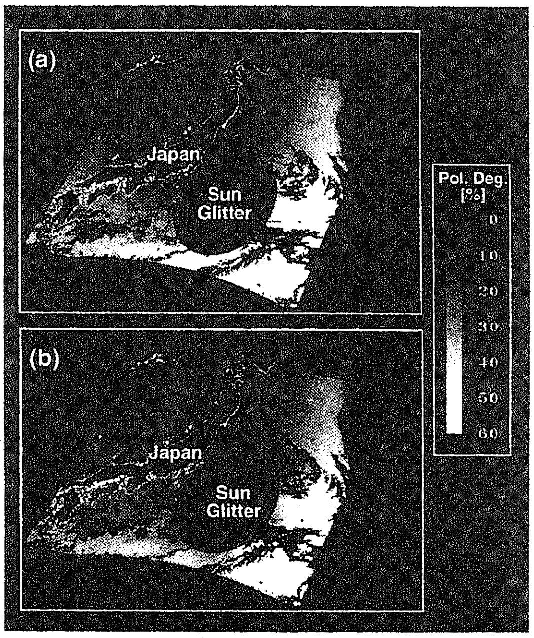

Fig. 2 Polarization degree at a wavelength of $(0.67 \mu m)$.
a: POLDER data observed on April 26, 1997 over the Pacific Ocean near Japan.
b: simulated results using the same aerosol model as Fig.1.

### 3. ATMOSPHERIC CORRECTION

Our atmospheric correction is based on multiple scattering calculations. Therefore radiative transfer problem in an atmosphere-ocean model involving the retrieved aerosol model has to be numerically solved to obtain the values of atmospheric correction coefficients $C$. The value of $C$ is obtained from a ratio of the water leaving radiance to the observed radiance at the satellite. The $C$-values depend on the place of each pixel in a satellite image as well as wavelength. Atmospherically corrected images are obtained by multiplication of $C$-values to the raw satellite data.

In our present calculations, the model-A is employed for an aerosol model. The sea surface is simulated by multiple facets whose slopes vary according to the isotropic Gaussian distribution with respect to wind speed [16]. Wind speed is assumed to be $5m/sec$ as a typical value for a clear day. Several ocean models have been prepared. For example, one of them is a completely diffused model, namely upward radiance out of the ocean is represented by Lambert's law. Multiple scattering for the atmosphere-ocean model is solved by the adding-doubling method.

Chlorophyll density distribution near the sea surface is derived through bio-optical algorithms for ocean color data as follows;

$$Chlorophyll = 0.2818[(Rad_{0.520}+Rad_{0.565})/Rad_{0.490}]^{3.497}, \tag{1}$$

where $Rad$ represents the radiance after atmospheric correction at wavelengths of 0.490, 0.520 and 0.565 $\mu m$ [17, 18]. Fig. 3 represents the expected chlorophyll map in units of $\mu g/l$. From this figure we found that our treatment provides the intrinsic streams of Kuroshio (warm current) and Oyashio (cold current) in the Pacific Ocean. That is, the characteristic flow pattern of the sea surface in the late spring is clearly displayed, for example tidal front goes up to Sendai Bay and typical eddies are appeared off Sanriku coast etc.

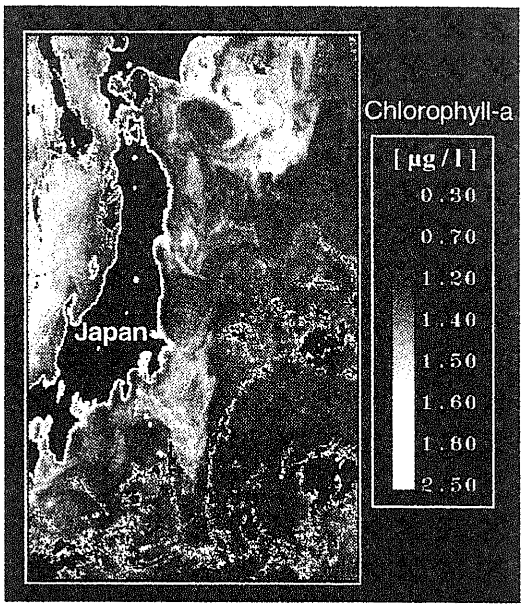

Fig.3 Expected chlorophyll map near the sea surface in units of $\mu g/l$ from the OCTS data on April 26, 1997.

### 4. DISCUSSIONS

It is found that an efficient atmospheric correction for ocean color data is pursued due to improved aerosol retrieval by combination of POLDER and OCTS, and employment of atmospheric correction coefficients.

It is natural to consider that several kinds of aerosol components exist together with. But it is difficult to determine the mixing structure of each components. At any rate, from present work, we can say that such a Maxwell-Garnett mixing rule as small water-soluble (WS) inclusions in an oceanic (OC) matrix is available to interpret the space-borne data, and polarization information is useful to improve the aerosol retrieval.

## ACKNOWLEDGMENTS

POLDER data was distributed by CNES in France. This work was partially supported by NASDA (PSPC-20170), and also by scientific research funds from the Ministry of Education, Science and Culture of Japan (07640579).

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