

# ATMOSPHERIC CORRECTION OF NIMBUS-7 DATA BASED ON THE MULTIPLE SCATTERING CALCULATION

Sonoyo MUKAI  
Kanazawa Institute of Technology  
Nonoichi, Ishikawa 921  
Japan  
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## Abstract

In order to get the clear images of the Earth surface, various noise should be removed from the original remote sensing data. One of the important noise is the blurring effect of the images due to the multiple light scattering in the Earth atmosphere, what one calls atmospheric effect. Here we evaluate the atmospheric effect based on the multiple scattering calculation in an atmosphere-ocean model. In calculation of the intensity of radiation, reflection at the ruffled sea surface is considered as well as the multiple scattering in the atmosphere.

We find that the atmospheric correction of NIMBUS-7 data provides us with valuable and intrinsic information on resources and/or environment of the ocean. For example, we can detect the abundant fishery area by using an image of chlorophyll density distribution.

## 1. Introduction

Here we treat with the atmospheric correction of the NIMBUS-7 data based on the multiple scattering calculation. Remote sensing data give a fruitful information on the Earth environment and resources. The presence of the intervening atmosphere between the sensor and the Earth surface, however, makes blurred intrinsic situations of the surface, what one calls atmospheric effect. Atmospheric correction is the subtraction of this atmospheric effect from the remote sensing data.

Since such atmospheric effects are caused by the light scattering by the constituent particles in the atmosphere, evaluation of the atmospheric effect requires the determination of the reflected intensity of solar radiation from the atmosphere. We shall show here how to calculate the multiple scattering and then how to make an atmospheric correction on remote sensing data.

## 2. Multiple scattering

For the atmospheric correction of remote sensing data, the multiple light scattering problem in the Earth's atmosphere-ocean model should be solved first. In calculation of the intensity of radiation in the model, an ocean surface with waves described by the slope distribution given by Cox and Munk(1954) is taken into account. Reflection at the ruffled sea surface is considered as well as the multiple scattering in

the atmosphere based on the superposition method (Mukai 1977).

In the atmosphere, Rayleigh scattering by molecules and Mie scattering by aerosols are taken into account, where the ratio of the molecular scattering cross section to the total scattering one is denoted by  $f_g$ .

The equation of radiative transfer for an atmosphere-ocean model can be written as

$$\mu \partial I(\tau, \Omega) / \partial \tau = I(\tau, \Omega) - \int_{4\pi} P(\Omega, \Omega') I(\tau, \Omega') d\Omega' / 4\pi, \quad (1)$$

together with boundary conditions

$$I^-(0, \Omega) = \pi F \delta(\Omega - \Omega_0), \quad (2)$$

$$I^+(\tau_1, \Omega) = \int_{2\pi} K(\Omega, \Omega') I^-(\tau_1, \Omega') \mu' d\Omega' / \mu, \quad (3)$$

where the optical depth,  $\tau=0$  and  $\tau = \tau_1$ , represent the top and bottom of the atmosphere and  $I^+$  and  $I^-$  represent the intensity of the upward and downward radiation at level  $\tau$ .

In eq.(3), the function  $K$  denotes the bidirectional reflectance of a ruffled sea surface, which is derived from Cox and Munk as mentioned above.

Now let us introduce  $S^*$  and  $T^*$  as the scattering and transmission functions, which are related to the reflected and transmitted intensities as follows:

$$I^+(0, \Omega) = S^*(\tau_1; \Omega, \Omega_0) F / 4\mu, \quad (4)$$

$$I^-(\tau_1, \Omega) = T^*(\tau_1; \Omega, \Omega_0) F / 4\mu + \pi F \delta(\Omega - \Omega_0) e^{-\tau_1/\mu}. \quad (5)$$

It has been shown that the radiation field in the atmosphere-ocean system can be computed from that of the standard atmosphere in terms of the superposition method (Mukai and Ueno 1978), where  $S$  and  $T$  denote the scattering and transmission functions for a standard atmosphere given by Chandrasekhar (1950). We can formulate the following equations:

$$S_0^*(\Omega, \Omega_0) = S(\tau_1; \Omega, \Omega_0), \quad (6)$$

$$T_0^*(\Omega, \Omega_0) = T(\tau_1; \Omega, \Omega_0) + 4\pi \delta(\Omega - \Omega_0) \mu e^{-\tau_1/\mu}, \quad (7)$$

$$J_n(\Omega, \Omega_0) = \int_{2\pi} K(\Omega, \Omega') T_{n-1}^*(\Omega', \Omega_0) d\Omega' \quad n \geq 1, \quad (8)$$

$$S_n^*(\Omega, \Omega_0) = \int_{2\pi} T(\tau_1; \Omega, \Omega') J_n(\Omega', \Omega_0) d\Omega' / \mu' / 4\pi + e^{-\tau_1/\mu} J(\Omega, \Omega_0), \quad (9)$$

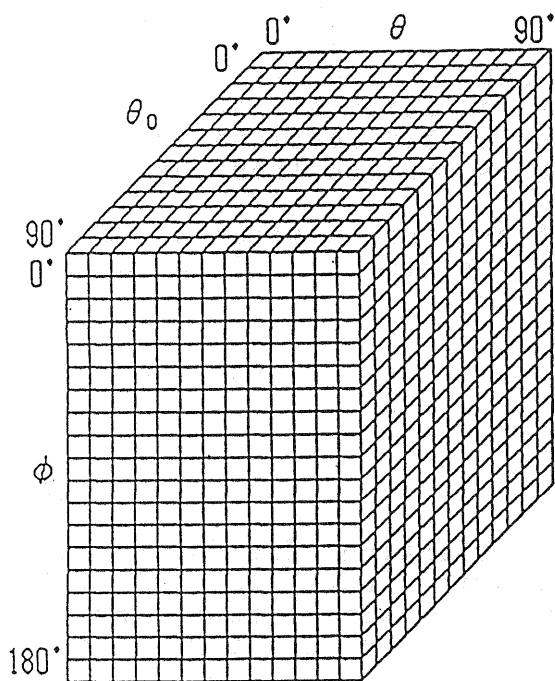
$$T_n^*(\Omega, \Omega_0) = \int_{2\pi} S(\tau_1; \Omega, \Omega') J_n(\Omega', \Omega_0) d\Omega' / \mu' / 4\pi, \quad (10)$$

$$J(\tau_1; \Omega, \Omega_0) = \sum_{n=1}^{\infty} J_n(\Omega, \Omega_0), \quad (11)$$

$$S^*(\tau_1; \Omega, \Omega_0) = \sum_{n=0}^{\infty} S_n^*(\Omega, \Omega_0), \quad (12)$$

$$T^*(\tau_1; \Omega, \Omega_0) = \sum_{n=0}^{\infty} T_n^*(\Omega, \Omega_0), \quad (13)$$

where the index  $n$  represents the number of times a photon has been reflected by the sea surface and  $\Omega$  stands for  $(\mu, \phi)$  with  $\mu$  the cosine of inclination  $\theta$  to the upward normal and  $\phi$  the azimuth (see Fig.1).



Multiple Scattering Data Base

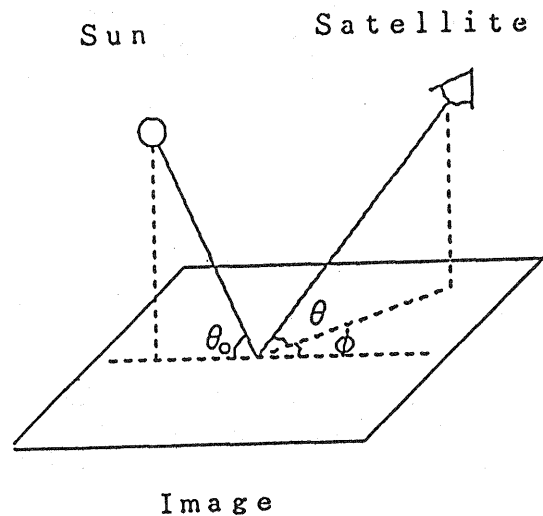


Fig.1 Diagram of M.S.D.B

### 3. Atmospheric correction

In calculation of eqs.(1)-(13), the aerosols are represented by Haze M model (Deirmendjian 1964), which corresponds fairly well to the distribution of coastal aerosols, and numerical values of optical thickness  $\tau_1$  and mixing ratio  $f_g$  are derived from Lowtran 6 code (Kneizys et al. 1983). The Lowtran 6 is a software program which calculates the atmospheric transmittance and radiance of single scattered sun light.

Specifying the parameters of Lowtran 6 code, required values are obtained (refer to Fig.2 which shows a flow chart of atmospheric correction).

The reflected intensities in eq.(4) are used for atmospheric correction of remote sensing data, so those values are stored in the multiple scattering data base (named M.S.D.B.). Using this M.S.D.B., radiance of each pixel of a remotely sensed image is corrected (see Fig.1).

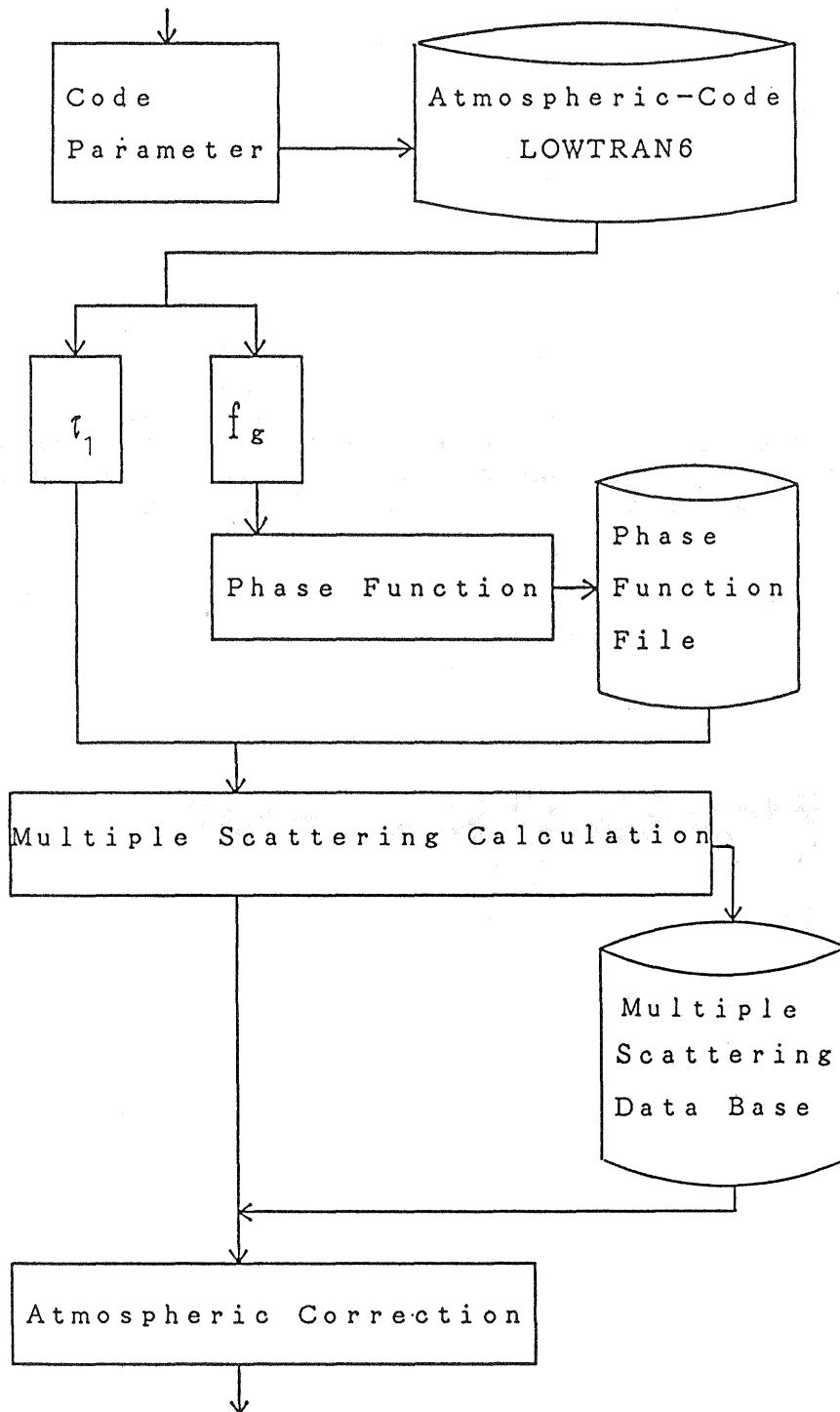


Fig.2 Flow chart of atmospheric correction

#### 4. Results and application

Our results are applied to interpret the remote sensing data given by the CZCS (Coastal Zone Color Scanner) equipped on the satellite NIMBUS-7, which has six wavelength channels of observation (i.e. ch.1,2,3,4,5 and 6 correspond to the wavelength of 0.44, 0.52, 0.55, 0.67, 0.75 and 11.5  $\mu\text{m}$  respectively) (cf.Zion 1983).

All images in this section are derived from CZCS data observed on 14th April 1981 (orbit no.12477). Note that such bright areas as land and cloud are subtracted from an original image of ch.5 and repainted in black, because we are now interested in the oceanic area.

Figs.3 and 4 show, respectively, a pre-processed image of ch.1 and a post-processed one in atmospheric correction. In comparison with each other, it is found that atmospheric correction provides us with valuable and more precise information on oceanic environment, e.g. intrinsic current situations.

In according with the algorithm by Gordon et al.(1983), the density distribution of chlorophyll is derived (Fig.5). Using this image we can detect the abundant fishery area. It is of interest to mention that the high density parts of chlorophyll in Fig.5 coincide with the real fishery in the same season.

We can conclude that a remote sensing image processed of atmospheric correction based on the multiple scattering calculation displays more intrinsic information on the Earth surface than an original one does. Our present knowledge of the constituent particles of the atmosphere, however, is not sufficient. If such values as size and/or optical properties of aerosols in the corresponding time and place to the observation are available, a more effective atmospheric correction will be done.

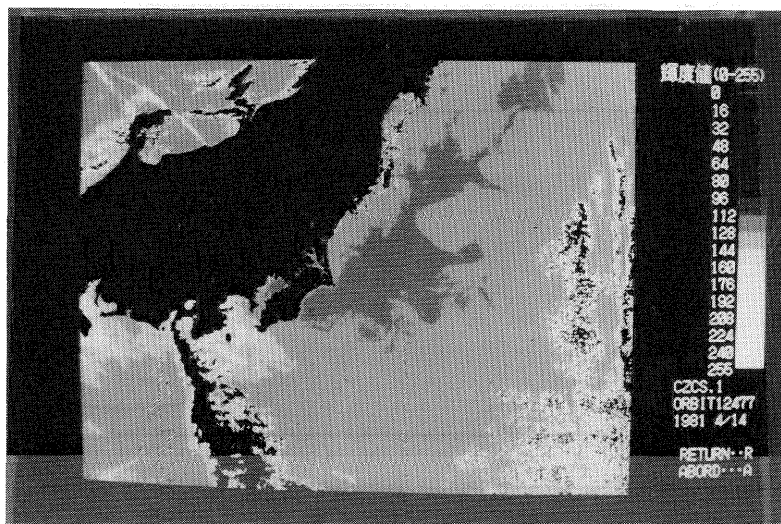


Fig.3 Original image of ch.1-CZCS data on 14th April 1981

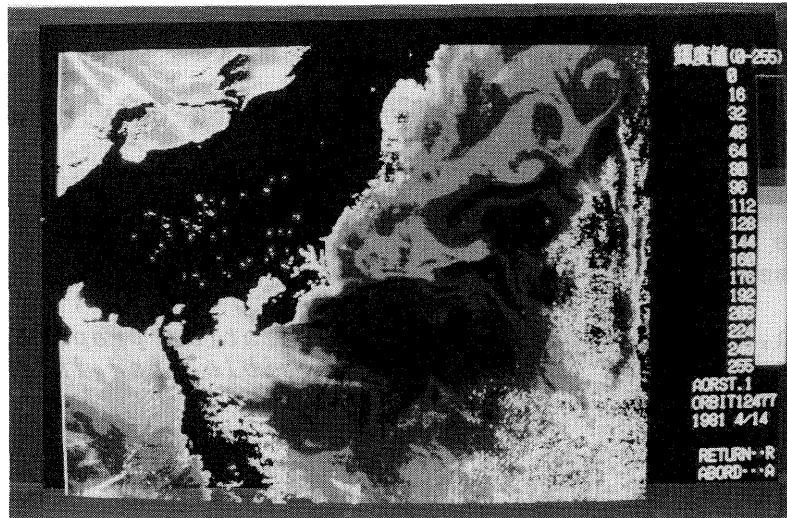


Fig.4 Atmospheric corrected image. See Figure 3 for key.

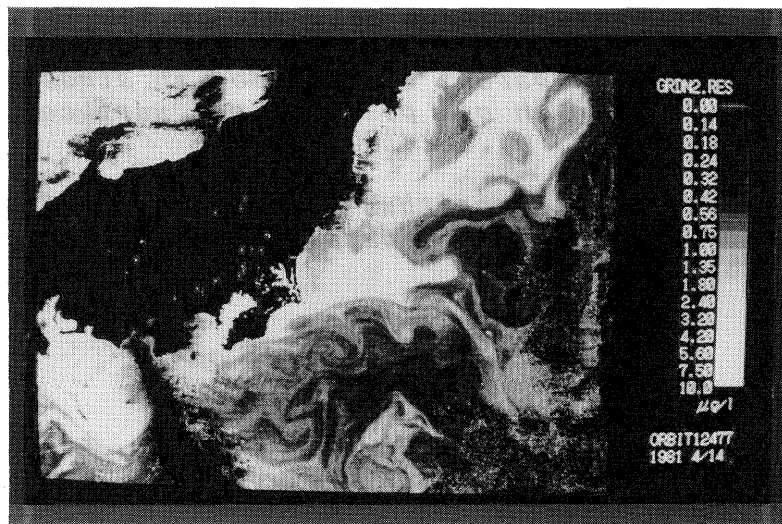


Fig.5 Chlorophyll image. See Figure 3 for key.

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