

The Atmospheric Correction of ROCSAT-1 OCI Imagery— Part I: OCITRAN-1

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(Manuscript received 28 September 1999, in final form 10 November 1999)

ABSTRACT

The atmospheric aerosol effect makes an important contribution to the total radiance in the visible and infrared bands, observed by the Ocean Color Imager on the ROCSAT-1 satellite. For better interpretations of OCI data, an accurate aerosol effect correction is necessary. In this study the concept of clear water is adopted to determine the aerosol effect as part of the atmospheric effect correction model, OCITRAN-1. A clear water area is chosen to assess the aerosol condition and remove the aerosol effect. Two SeaWiFS image sets were used to test the accuracy of the OCITRAN-1 model by comparing its result with those obtained by the SeaDAS model. The comparison shows a reasonable consistency between the estimates generated by these two models in low chlorophyll concentration areas, but the water leaving radiance derived by OCITRAN-1 is significantly greater than that derived by SeaDAS, especially when the chlorophyll concentration is higher than 2.0 mg/m³. Therefore, the aerosol effect correction of OCITRAN-1 is most suitably applied in ocean areas of low chlorophyll concentration.

(Key words: OCI, Atmospheric correction, Aerosol effect)

1. INTRODUCTION

The Coastal-Zone Color Scanner (CZCS) on Nimbus-7, launched in 1978, was the first operational sensor for ocean color monitoring. The CZCS consisted of four visible bands at 443, 520, 550 and 670nm and one near IR band at 750nm. In its ten-year-life period, the CZCS provided about 66,000 informative ocean color images (Evan and Gordon, 1994). Following the success of CZCS, several other ocean color sensors and projects have been designed to study ocean color, such as the SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and MODIS (Moderate Resolution Imaging Spectroradiometer) of the U.S.A. (Salomonson et.al., 1989),

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OCTS (Ocean Color and Temperature Scanner) of Japan (Kawamura, H. and the OCTS Team, 1998), and OCI (Ocean Color Imager) of R.O.C. The SeaWiFS sensor launched in 1997 consists of six visible bands at 412, 443, 490, 512, 555 and 670nm, and two near IR bands at 765 and 865nm. The SeaWiFS was designed for collecting global ocean color images and for estimating global chlorophyll concentrations. One of the main goals of SeaWiFS is to collect ocean information that can be used to analyze global change (Gregg et al., 1993). As one of the ocean color sensors, the OCI on ROCSAT-1 satellite, launched in January 1999, has six channels, 443, 490, 512, 555, 670 and 865nm, which are similar to SeaWiFS. ROCSAT-1 is a low-earth orbit science satellite at an altitude of 600 km with an inclination of 35 degrees and an orbital period of 97 minutes. The main goal of this study is to establish a precise radiance model for OCI imagery.

The radiative transfer theory suggests that the OCI sensor channels in the visible and infrared regions could be significantly affected by the constitutions of the atmosphere molecules and aerosols. Therefore, an accurate atmospheric correction model has to be applied to the OCI images. Because the SeaWiFS and OCI sensors have similar channels and applications, this research will use the SeaWiFS images as test data for investigating the atmospheric correction model, OCITRAN-1, developed by this study.

2. METHODOLOGY

The total radiance observed by the OCI sensor could be analyzed into several factors: atmospheric molecular and aerosol scattering, water leaving radiance and sun glint radiance (see also Fig. 1). Previous studies of ocean color using the CZCS data have suggested that the total radiance (L_t) observed by satellites could be seen as the summation of Rayleigh scattering (L_r), aerosol scattering (L_a) and the water leaving radiance which affected by the atmosphere (tL_w). Because the OCI could not efficiently avoid the sun glint effect (L_g), this factor should be added in. So, the factors in total radiance can be written as follows:

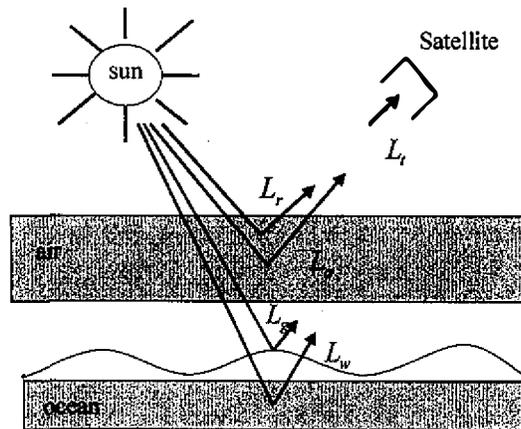


Fig. 1. Schematic representation of the solar radiance transformation.

$$L_r(\lambda) = L_r(\lambda) + L_w(\lambda) + L_g(\lambda) + t(\lambda)L_w(\lambda), \quad (1)$$

where $t(\lambda)$ is the diffuse transmittance from the sea surface to the sensor (Gordon et al., 1983),

$$t(\lambda) = \exp\left[-\left(\frac{\tau_r(\lambda)}{2} + \tau_{oz}(\lambda)\right)\left(\frac{1}{\cos\theta}\right)\right], \quad (2)$$

where $\tau_r(\lambda)$ and $\tau_{oz}(\lambda)$ are the Rayleigh optical thickness and the ozone optical thickness, respectively. θ is the satellite azimuth angle, and λ is the wavelength.

Past studies have showed that the water leaving radiance is significantly smaller than the atmosphere contributed radiance (Rayleigh and aerosol scattering) in optically thick atmospheric conditions (Gordon and Wang, 1992). Consequently, in applications of OCI data to marine environmental monitoring, it is crucial to devise an accurate process to remove the atmospheric effect when extracting the water leaving radiance.

The main goal of this study is to establish a preliminary atmospheric correction model for OCI data. The flowchart of the atmospheric correction of OCITRAN-1 model is shown in Fig. 2. The radiance amounts contributed by different mechanisms are modeled in Equation 1. In addition, the computation regarding the atmospheric aerosol scattering is discussed in detail below.

In this study, the Rayleigh scattering is computed by the method proposed by Gordon et al. (1988). The influences of the optical thickness of ozone, water vapor and oxygen are calculated item by item. And, a Gaussian distribution model is used to model the sea surface slope and to compute the sun glint effect (Viollier et al., 1980). The algorithm of Rayleigh scattering computation is discussed by Liu et al. (1999).

In modeling of atmospheric aerosol effect for OCI images, the concept of clear water (Gordon and Clark, 1981), which was used in the CZCS data, is employed in this study. The CZCS included four visible bands at 443, 520, 550, 670 and one infrared band at 750nm. Some channels are similar to the channels of the OCI sensor. Gordon et al. (1983) proposed that the radiance of the single aerosol scattering could be expressed as

$$L_a(\lambda) = \frac{\omega_a(\lambda)\tau_a(\lambda)F_0(\lambda)p_a}{4\pi\cos\theta}, \quad (3)$$

where

$$p_a = P(\chi^-) + [\rho_n(\theta_0) + \rho_n(\theta)]P(\chi^+)$$

$$\cos\chi^\pm = \pm\cos\theta\cos\theta_0 - \sin\theta\sin\theta_0\cos(\phi - \phi_0)$$

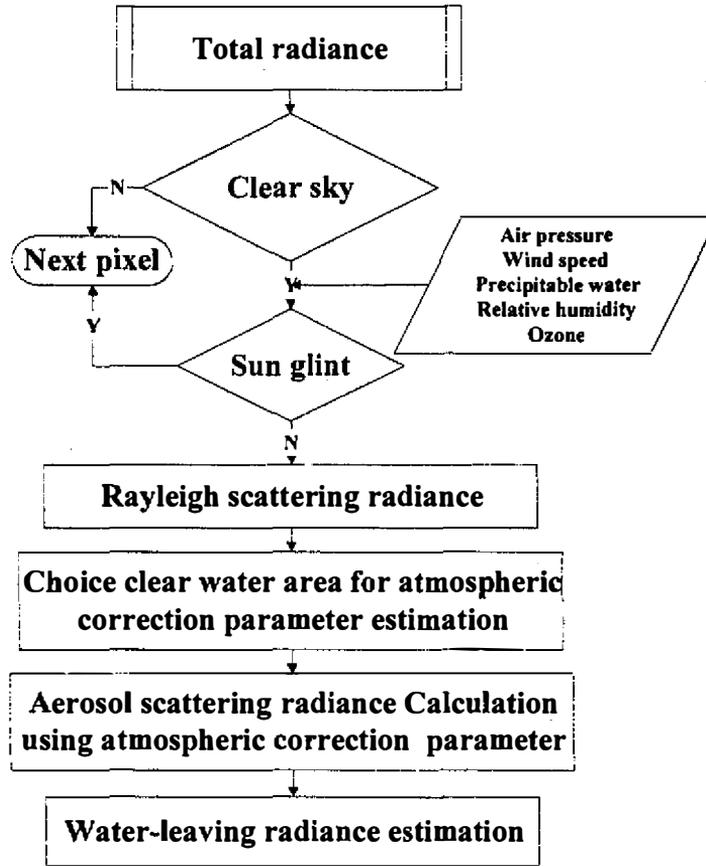


Fig. 2. Flowchart of the atmospheric correction of OCITRAN-1 model.

where p_a is the amount of photons scattered by the atmosphere and transferred into the sensor, $P(\chi^\pm)$ is the aerosol scattering phase function, χ^\pm is the scattering angle, and ρ_n is the Fresnel reflectance for an incident angle on the flat sea surface. ω_a is the single scattering albedo, τ_a is the aerosol optical thickness, λ is wavelength, θ_0 is the solar zenith angle, and θ is the zenith angle of sensor. F' is the instantaneous extraterrestrial solar irradiance F_0' reduced by two trips through the ozone layer; that is,

$$F_0'(\lambda) = F_0(\lambda) \exp[-\tau_{oz}(\lambda)(1/\cos\theta + 1/\cos\theta_0)]. \tag{4}$$

By dividing two arbitrary aerosol radiance equation in different channels, the following equation can be obtained,

$$\frac{L_a(\lambda_2)}{L_a(\lambda_1)} = \varepsilon(\lambda_2, \lambda_1) \frac{F_0'(\lambda_2)}{F_0'(\lambda_1)} = S(\lambda_2, \lambda_1), \tag{5}$$

where ε is the atmospheric correction parameter, defined as

$$\varepsilon(\lambda_2, \lambda_1) = \frac{\omega_a(\lambda_2)\tau_a(\lambda_2)\rho_a(\theta, \theta_0, \lambda_2)}{\omega_a(\lambda_1)\tau_a(\lambda_1)\rho_a(\theta, \theta_0, \lambda_1)}. \quad (6)$$

So, the water leaving radiance observed by satellite is equal to

$$t(\lambda_i)L_w(\lambda_i) = L_t(\lambda_i) - L_r(\lambda_i) - S(\lambda_i, \lambda_n)[L_t(\lambda_n) - L_r(\lambda_n) - t(\lambda_n)L_w(\lambda_n)], \quad (7)$$

where $i=1,2,3\dots n$, and is the sensor band index. For CZCS and OCI, the values of n are taken as 4 and 6, respectively.

Generally, the water leaving radiance is very small in the clear water area. The water leaving radiance observed by satellite at 670 nm could be very small and can be ignored when the pigment concentration is less than 0.25 mg/m^3 (Gordon et al., 1983). Hence, $\varepsilon(\lambda_i, \lambda_4)$ is the only unknown variable remaining in Equation (7). Moreover, $\varepsilon(\lambda_i, \lambda_4)$ is mostly changes with the optical thickness of atmospheric aerosol because the single scattering albedo, ω_a , is influenced slightly by the scattering phase function. Therefore, the relationship between τ_a and λ can be approximated as

$$\varepsilon(\lambda, \lambda_4) \approx \frac{\tau_a(\lambda)}{\tau_a(\lambda_4)} = \left(\frac{\lambda}{\lambda_4}\right)^n. \quad (8)$$

Finally, the water leaving radiance for different channels can be estimated.

Because both the OCI and the SeaWiFS sensors cover channel frequencies in both visible and infrared regions, the atmospheric correction method of the concept of clear water can be applied to the data of both two sensors. The SeaDAS model (discussed in section 4) will be used to evaluate the OCITRAN-1 estimation. This study uses the SeaWiFS images as examples to check the accuracy of aerosol radiance derived by the clear water concept. Basically, the concept of clear water assumes that the water leaving radiance at 670nm and 865nm frequencies is zero and uses this assumption to estimate the $\varepsilon(670,865)$ quantity. Then, the relationship between wavelength and ε values is used to assess the ε values at different channels. Finally, the atmospheric aerosol radiance is computed.

3. DATA

Two sets of SeaWiFS images are processed by the two following atmospheric correction models: (1) OCITRAN-1, developed in this study, and (2) the SeaDAS model. Then, the accuracy of OCITRAN-1 will be appraised by the SeaDAS result. These two SeaWiFS images

crossing the Taiwan area were acquired at 04:12 GMT, August 22, 1998 and 04:13 GMT, March 27, 1999, respectively. Both images were acquired in descending mode at about the local noontime. The ground resolution of SeaWiFS at the nadir is 1.1x1.1km, and the images are in the LAC (Local Area Coverage) format. The total radiance images at 555nm of these two images are shown in Figs. 3 and 4, respectively. The larger pixel values in Figs. 3 and 4 indicate the land or cloud area, and the lower pixel values indicate clear-sky ocean area.

4. RESULT AND DISCUSSION

SeaWiFS sensor uses eight channels in the visible and infrared spectra. Gordon and Wang (1994) used the last channels in the infrared region to establish an atmospheric correction procedure called SeaDAS. Later, this procedure was adopted as the routine operational package for radiance correction in SeaWiFS images. In this study, the SeaDAS model is employed to evaluate the accuracy of the OCITRAN-1 model. Essentially, the OCI sensor was designed to have channels similar to those of the SeaWiFS, but it lacks the 412 and 765nm channels. Unfortunately, the 765nm channel is used as the reference for atmospheric correction in the SeaDAS model. Hence, this study can not follow the SeaDAS method completely. That is why this study adopts the concept of clear water for atmospheric correcting to establish the procedure, OCITRAN-1. The OCITRAN-1 uses the lowest pigment concentration area under clear-sky in the investigation region to assess the aerosol scattering radiance and atmospheric correction parameter. Then, the parameter is assumed to be the same over the entire image for estimating the water leaving radiance and the total pigment concentration.

In order to investigate the accuracy of OCITRAN-1, the two sets of SeaWiFS images are processed by OCITRAN-1 and SeaDAS models, respectively. Then, the processed results are compared. Atmospheric correction results of two test regions, the Taiwan Strait and the northern South China Sea, are selected for comparison. Generally, the water mass in the Taiwan Strait contains higher suspended particles than the water mass of the northern South China Sea. So, the water leaving radiance in the former area is larger than that in the latter.

For the first set of SeaWiFS images, the clear-sky area in the southeast ocean area of Taiwan is selected to assess the atmospheric correction parameter, then this parameter is used to correct the atmospheric effect over the entire image. Figure 5 illustrates the water leaving radiance map of the SeaWiFS image at the 555nm channel after the atmospheric correction using OCITRAN-1. The black area in Fig. 5 indicates land or cloud area. Generally, the water leaving radiance in the Taiwan Strait is larger than $1.0 \text{ mW/cm}^2/\mu\text{m/sr}$ but about $0.2\text{-}0.8 \text{ mW/cm}^2/\mu\text{m/sr}$ in the eastern and southwest ocean area of Taiwan.

The clear-sky pixels in the northeastern ocean area of the Dong-Sha Island are selected in the second set of SeaWiFS images to estimate the atmospheric correction parameter. The estimated water leaving radiance is shown in Fig. 6. It is obvious that the water leaving radiance is generally less than that in the Taiwan Strait area. In most of the area, the value is less than $1.0 \text{ mW/cm}^2/\mu\text{m/sr}$, especially between the northeastern ocean area of Dong-Sha Island and the northern area of the Luzon Strait, and generally the estimated radiance values are less than $0.5 \text{ mW/cm}^2/\mu\text{m/sr}$.

Finally, the water leaving radiance of the two sets of SeaWiFS data estimated by the



Fig. 3. The total radiance image of SeaWiFS 555nm channel of 04:12 GMT, August 22, 1998. Unit in $mW/cm^2/\mu m/sr$.

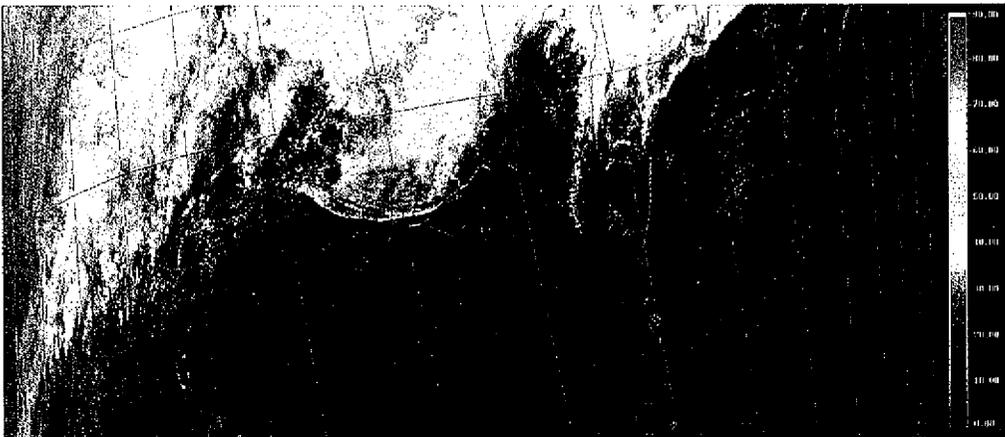


Fig. 4. Same as Figure 3, except image acquired at 04:13 GMT, March 27, 1999.

OCITRAN-1 and the SeaDAS models are compared in this study (see also Fig. 7). For the first and second sets, the correlation coefficients of two model estimations are 0.407 and 0.526 at the 490nm channel, respectively, but they are 0.699 and 0.577, respectively at the 555nm channel. Basically, the water leaving radiance estimated by OCITRAN-1 is systematically higher than the values estimated by SeaDAS. The bias would be induced by the atmospheric correction parameter assessed by clear water area, which can not be applied to the entire image. Figure 8 shows the correlation comparison of chlorophyll concentration estimated by the OCITRAN-1 and the SeaDAS models. Generally, the correlation is higher in the Taiwan Strait than in the South China Sea. The correlation varies from 0.582 to 0.625. In other words, the correlation is higher for clear water masses. The comparison also shows that the chlorophyll concentration estimated by OCITRAN-1 is clearly less than the value estimated by SeaDAS



Fig. 5. The water leaving radiance image of SeaWiFS 555nm after atmospheric correction by using OCITRAN-1 model. Image acquired on August 22, 1998. Unit in $mW/cm^2/\mu m/sr$.



Fig. 6. Same as Figure 5, except image acquired on March 27, 1999.

where the concentration is higher than $2\text{ mg}/m^3$. This result indicates that the OCITRAN-1 is more suitable for applications in ocean water with low chlorophyll concentration.

5. CONCLUDING REMARKS

Although the OCI sensor does not provide the 765nm channel which SeaDAS used for the atmospheric correction reference, it consists of six channels covering the CZCS frequency range. Besides, the OCI has one extra 865nm channel, which CZCS does not include. Hence, the concept of a clear water based atmospheric correction method can be established with the OCI data.

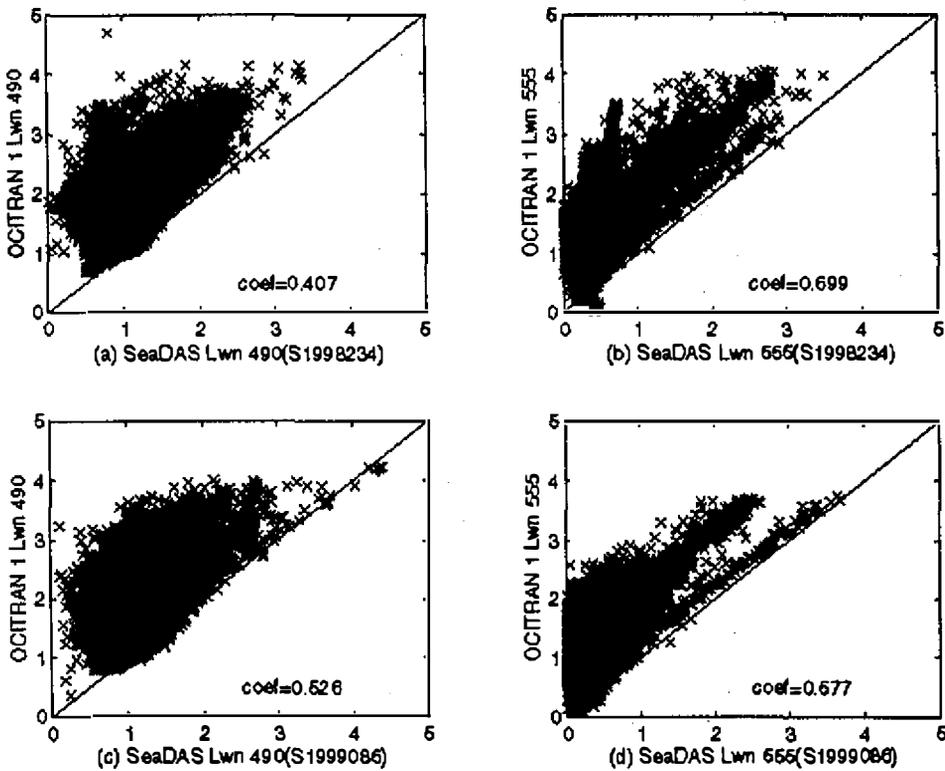


Fig. 7. Comparison of water leaving radiance estimated by OCITRAN-1 and SeaDAS model. Unit in $mW/cm^2/\mu m/sr$. (a) Data acquired on August 22, 1998 at 490nm channel, (b) same as (a), but at 555nm channel, (c) same as (a), but on March 26, 1999, (d) same as (a), but at 555nm.

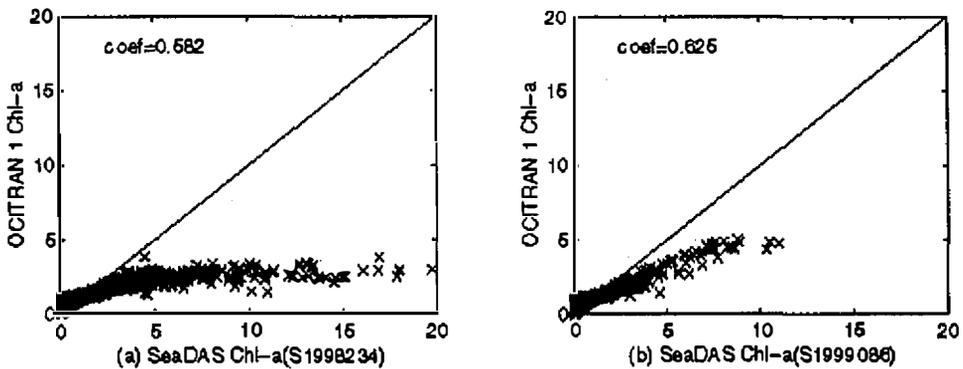


Fig. 8. Comparison of chlorophyll concentration estimated by OCITRAN-1 and SeaDAS. Unit in mg/m^3 . (a) Data acquired on August 22, 1998, (b) same as (a), but on March 27, 1999.

This study reveals that the result of OCITRAN-1 is consistent with SeaDAS in the low chlorophyll concentration areas. But, in the higher chlorophyll concentration region, the water leaving radiance is probably overestimated and chlorophyll concentration is underestimated by OCITRAN-1. This result suggests that the OCITRAN-1 is suitable for application to non-clear water masses and that further study is needed.

Acknowledgements The authors would like to thank Dr. C. R. McClain of the Goddard Distributed Active Archive Center (DAAC) funded through the NASA Earth Observing System (EOS) for providing the SeaWiFS images. This study was made possible by support from the National Space Program Office (NSPO) of the National Science Council of Taiwan, R.O.C. under grant NSC-86-NSPO-A-OCI-019-01-01 and NSC-87-NSPO-A-OCI-019-01-01.

REFERENCES

- Evans, R. H. and H. R. Gordon, 1994: Coastal zone color scanner "system calibration": A retrospective examination. *J. Geophys. Res.*, **99**, 7293-7307.
- Gordon, H. E. and D. K. Clark, 1981: Clear water radiances for atmospheric correction of coastal zone color scanner imagery. *Appl. Opt.*, **20**, 4175-4180.
- Gordon, H.R, D. K. Clark, J. W. Brown, O. B. Brown, R. H. Evans, and W. W. Broenkow, 1983: Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates. *Appl. Opt.*, **22**, 20-36.
- Gordon, H. R., J. W. Brown, and O. B. Evans, 1988: Exact Rayleigh scattering calculations for use with the Nimbus-7 coastal zone color scanner. *Appl. Opt.*, **27**, 862-871.
- Gordon H. R. and M. Wang, 1992 : Surface-roughness considerations for atmospheric correction of ocean color sensors. I: The Rayleighscattering component. *Appl. Opt.*, **31**, 4247-4260.
- Gordon H. R. and M. Wang, 1994: Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm. *Appl. Opt.*, **33**, 443-452.
- Gregg, W. W., F. C. Chen, A. L. Mezaache, J. D. Chen, and J. A. Whiting, 1993: The simulated SeaWiFS data set, version1, NASA Technical Memo. 104566 (9), S.B. Hooker and E.R. Firestone, EDS., NASA Goddard Space Flight Center, Greenbelt, Maryland, 17pp.
- Kawamura, Hiroshi and the OCTS Team, 1998: OCTS Mission Overview. *J. Oceanogr.*, **54**, 383-399.
- Liu, G. R., S. J. Huang, T. H. Kuo, W. J. Chen and C. Y. Tseng, 1999: The Atmospheric Effect Correction of the Ocean Color Imager of ROCSAT-1-Simulations and Using SeaWiFS Data as the Example. *TAO, Supplementary Issue*, 99-114.
- Salomonson, V. V., W. L. Barnes, P. W. Maymon, H. E. Montgomery, and H. Ostrow, 1989: MODIS: advanced facility instrument for studies of the Earth as a system. *IEEE Trans. Geosci. Remote Sens.*, **27**, 145-152.
- Viollier, M., D. Tanre, and P. Y. Deschamps, 1980: An algorithm for remote sensing of water color from space. *Boundary-Layer Meteorology*, **18**, 247-267.