Detection of Asian Dust Air-mass based on Short Wavelength Observation of SeaWiFS

H. Fukushima, Y. Hagihara, and Y. Hoshikuma,
School of High-Technology for Human Welfare, Tokai University,
Numazu, 410-0395 Japan
hajime@fksh.fc.u-tokai.ac.jp

S. Ohta
Graduate School of Engineering, Hokkaido University
Sapporo, 060-8628 Japan
ohta@eng.hokudai.ac.jp

I. Uno
Research Institute for Applied Mechanics, Kyushu University
Fukuoka, Japan
Kasuga, Fukuoka, 816-8580 Japan
iuno@riam.kyushu-u.ac.jp

Abstract: To detect dust-loaded air-mass over land and ocean, we propose an index, which is essentially the difference in Rayleigh-corrected reflectance between 412 and 443 nm bands of SeaWiFS. Radiative transfer simulations are conducted to show that the index is linearly related to the optical thickness of modeled dust-contaminated aerosol while showing insensitivity against non-absorbing model aerosols. Asian SeaWiFS data set of 2001 spring is used to produce daily composite imagery of the index, which compares well with TOMS Aerosol Index and with predicted aerosol optical thickness predicted by CFORS chemical weather forecast.
Keywords: mineral dust, aerosol index

1. Introduction

Mineral dust-rich aerosol, such as with Saharan dust or Asian dust particles, is important in terms of its effect on radiation budget as well as its role as a source of micro-nutrient in the oceanic phytoplankton ecosystem. To know the spatial distribution and its temporal variability, satellite observation of dust aerosol is of great importance.

We define here an index for Asian dust aerosol, using two "blue" bands of Sea-viewing Wide Field-of-view

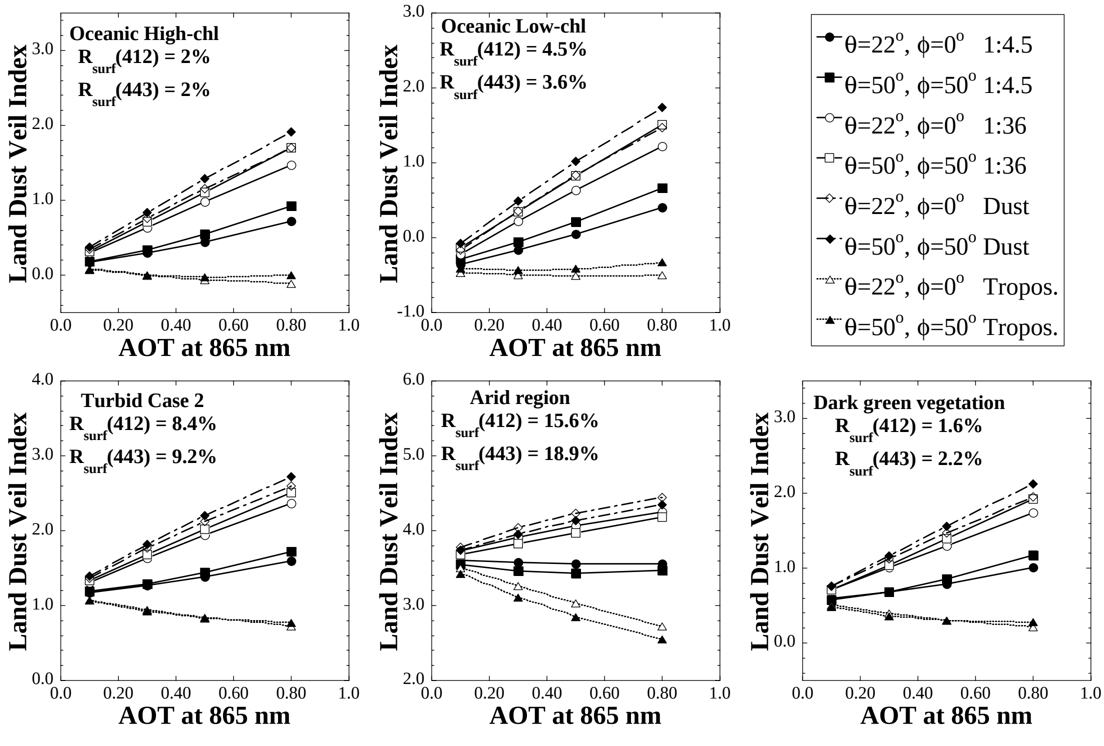

Figure 1. Dust Veil Index (*DVIR*) against optical thickness of modeled aerosols with different dust loadings. RT simulation was conducted assuming uniform aerosol vertical distribution between 0 - 3 km altitude.

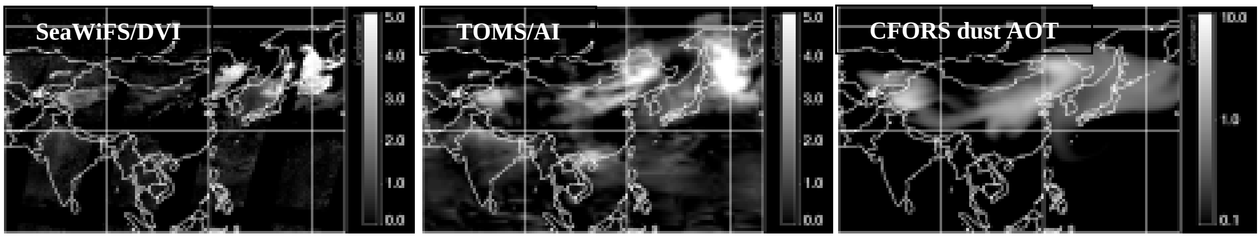

Figure 2. Image comparison for April 10, 2001: (a) SeaWiFS/DVI, (b) TOMS_AI, and (c) CFORS-predicted dust AOT

Sensor (SeaWiFS). Then our scheme is applied to Asian low-resolution SeaWiFS data obtained in spring (March through May) in 2001. We will show several image examples and compares them with TOMS Aerosol Index (AI) [1], as well as with the aerosol optical thickness (AOT) of dust predicted by Chemical weather FORecast System (CFROS) [2].

2. Dust Veil Index (DVI) for SeaWiFS

1) Definition of Base Index

The empirical dust veil index in its raw form is defined as

$$DVIR = [\ \{\rho_T(443) - \rho_{CR}(443)\} - \{\rho_T(412) - \rho_{CR}(412)\}\ ] \times 100[\%]$$

where ρ_T stands for the total reflectance, and ρ_{CR} is the elevation corrected Rayleigh reflectance. The symbol λ means observed SeaWiFS band centered at λ [nm].

The rationale for this formula is as follows. Firstly, $\rho_T - \rho_{CR}$ can be seen as the sum of the aerosol reflectance and the ground reflectance. When we have dust aerosol, the aerosol reflectance in 412 nm will be more diminished than in 443 nm due to the enhanced absorption that arises from larger absorption of dust particles. This effect is also enhanced from the larger interaction between dust particles and air molecules in shorter wavelength band. Hence, we anticipate larger *DVIR* value when aerosol is more absorptive.

2) Radiative Transfer Simulation of Base Index

We conducted radiative transfer simulation to study the behavior of *DVIR* under different conditions. First, we define dust-loaded aerosol model, which has bi-modal size distribution with one mode for large mineral particles and the other for background small tropospheric particles. We have assumed wavelength dependent imaginary refractive index for dust particles based on the absorption measurements of soil particles sampled from few meter depth ground at Gansu province in China. While we mostly assumed mode radius of 2μm for mineral particles, larger mode radius of 4 μm with larger standard deviation was also used in consideration to such a case where the place (or pixel) is closely located to the dust source. We varied volume mixture ratio of tropospheric to dust particles from 1:4.5 to 1:36. We also assumed five different land covers, namely ocean waters with high or low chlorophyll-a concentration, turbid coastal water, arid region, and dark green vegetation. The spectral reflectance at 412 nm and at 443 nm for these land cover conditions were determined by sampling Rayleigh-corrected SeaWiFS pixels in the areas where *DVI* records low values and where we are likely to have low AOT. The reflectance values are applied to Lambertian ground surface.

Results are shown in Figure 1 where uniform aerosol vertical distribution over 0 to 3 km altitude was assumed. Simulations were conducted for mixed aerosol cases, dust particles with 4μm mode radius only, and tropospheric small particles only. The solar zenith angle was assumed to be 30^{o}, while satellite zenith angle θ and relative azimuth angle ϕ were chosen so that they are typical values at scan center or at scan edge of SeaWiFS.

It is obvious that DVI is enough sensitive against dust-loaded airmass, showing almost linear dependency on AOT and also dependency on the dust amount over variable mixture ratio. On the other hand, the index has no or negative sensitivity for "tropospheric aerosol only" case. The difference in scan geometry affects the DVI value but not much. Very interestingly, while the index value over varying AOT shows similar pattern and range (less range for "arid region" case), the absolute value includes "bias", which is apparently caused by difference in ground reflectance between 412 nm and 443 nm.

3) Definition of DVI

As shown in the simulation results, the index in its original form has dependency on different land cover, although the range over varying AOT stays mostly same. Taking this into consideration, we define a corrected index as

$$DVI = DVIR - DVIR\_min$$

where *DVIR_min* is the minimum for the pixel location over an appropriately long period when we can expect clear sky condition.

3. Image Analysis and Comparisons

1) Data Processing

We have collected all the SeaWiFS Level-1 GAC data of March-May 2001 that cover the Asian continent and its marginal seas. Each data was first corrected for Rayleigh

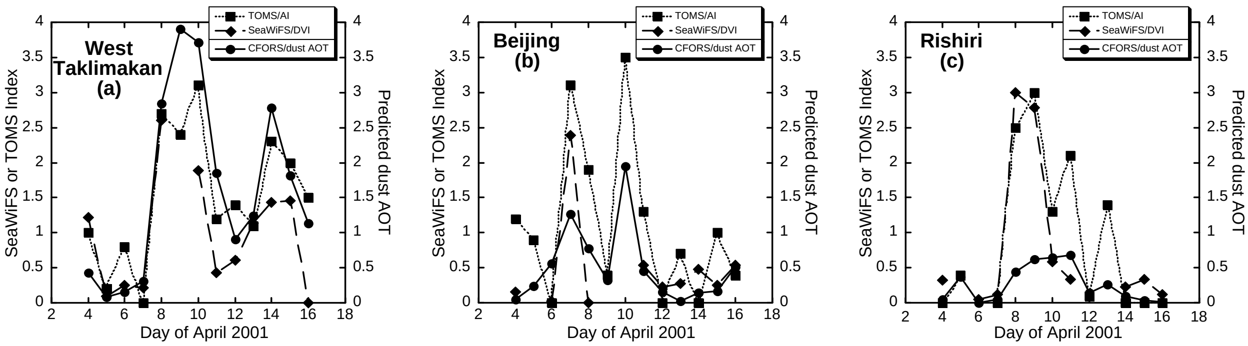

Figure 3. Time series comparison of SeaWiFS/DVI, TOMS/AI and CFORS dust AOT over two weeks in April 2001 for three locations : (a) Taklimakan Desert, (b) Beijing, and (c) Rishiri Island, Hokkaido, Japan.

reflectance using surface elevation data, and then converted into *DVIR*. During the processing, cloud screening (masking) was applied to each pixel using 412, 555 and 670 nm band data.

From the collection of the processed individual data we produced "daily *DVIR*" composite images. In the time-series data processing, *DVIR_min* value is determined by taking the location-wise minimum *DVIR* over 4 weeks satellite data (during 2 weeks prior to and after the target day).

2) Comparisons with TOMS/AI and CFORS AOT

For comparison study, we also composed similar daily composite image of TOMS/AI based on the data made available at the TOMS web page at NASA/GSFC, and partial AOT for dust aerosol predicted by CFORS [2]. An example of the image comparisons is shown in Figure 2 for April 10, 2001. Although there is general agreement in " dust distribution pattern" among the three imageries, differences are also significant. The SeaWiFS DVI image has the highest spatial distribution whereas the CFROS-predicted AOT shows smoother pattern. Another noticeable difference is a high index values at southernmost Chinese coastal area seen in both the SeaWiFS and TOMS images but not in CFORS-dust AOT. It is not shown here but CFORS AOT of carbonaceous aerosol, which is available separately, records high value at this area. Thus, DVI seems also sensitive to absorptive aerosol such as soot.

Figure 3 shows a time series comparison over the DVI, TOMS/AI and CFORS dust AOT during two weeks in April 2001 for different locations. It is interesting to observe that while all three correlate strongly with very similar value range in Taklimakan desert area (dust source), the satellite-derived index tend to record higher values than that of CFORS-predicted AOT when the location is farther from the source area. This is considered due to the nature of TOMS/SeaWiFS index, which responds more sensitive against elevated dust aerosol typically located above the cloud layer.

4. Conclusion

We have proposed a simple scheme for detecting dust airmass that based on the "blue bands" of SeaWiFS data. The radiative transfer simulation reveals the usefulness of the proposed dust veil index if the original index value is corrected for bias that arise from the surface spectral differences. Image and time series comparisons, only one example was shown in this paper, confirm the usefulness of this simple and empirical index, which features high spatial resolution.

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