# VARIABILITY OF THE TRENDS OBSERVED FROM SEAWIFS-DERIVED SUB-MICRON AEROSOL FRACTION OVER EAST ASIAN SEAS BASED ON DIFFERENT CLOUD MASKING ALGORITHMS

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**ABSTRACT:** Monthly-mean aerosol parameters derived from the 1998-2004 SeaWiFS observations over East Asian waters are analyzed. SeaWiFS GAC Level 1 data covering the Northeast Asian area are collected and processed by the standard atmospheric correction algorithm released by the SeaWiFS Project to produce daily aerosol optical thickness (AOT) and Ångström exponent imageries. Monthly mean AOT and Ångström exponent values are extracted from the daily composite images for six study areas chosen from the surrounding waters of Japan. A slight increasing trend of Ångström exponent is found and interpreted as about 4-5% increase in submicron fraction of aerosol optical thickness at 550nm. Two cloud screening methods, including the standard cloud masking method of SeaWiFS and the one based on the local variance method, are applied to the SeaWiFS data processing, in an attempt to inspect the influence to the observed statistical uptrend which probably induced by different cloud mask algorithms. The variability comes from the different cloud masking algorithms are discussed.

**KEY WORDS:** Anthropogenic effect, cloud mask, aerosol remote sensing

## 1. INTRODUCTION

East Asian area is supposed to be one of the strongest source regions of anthropogenic aerosols due to the rapid growing economy. In addition, natural aerosols, e.g., yellow dust, biomass burning products, further enhance the complexity of aerosols in this region. Temporal and spatial variability of aerosol loadings in East Asia are poorly understood, especially the areas over ocean. Since aerosols play an important role in Earth's radiation budget. Knowledge of aerosol property will effectively help to improve the accuracy of radiative forcing.

SeaWiFS observed aerosol data are used in this paper to study the temporal variability of aerosols above ocean in East Asia. A slightly increasing trend of Ångström exponent is observed from the 7 years time series data and sub-micron fraction of aerosol is estimated. Different cloud mask algorithms are applied in processing the satellite data and their influence are discussed.

## 2. DATA PROCESSING

SeaWiFS, launched in 1997, has generated more than 8 years global aerosol (over the ocean) and ocean color data simultaneously. It has 8 bands, centered at 412, 443, 490, 510, 555, 670, 765 and 865nm, with bandwidth 20nm for the first six and 40nm for the last two NIR bands.

SeaWiFS Global Area Coverage (GAC) data are processed with SeaWiFS Data Analysis System (SeaDAS 4.8), which employs Gordon and Wang's [1994] method for atmospheric correction. Local variance method is used to mask the cloud pixels, with the threshold of 0.02 for the 3*3 local variance of AOT at 490nm, which is less strict compared to the SeaWiFS standard cloud mask algorithm, reserving enough data even under moderately turbid atmospheric condition. The standard cloud algorithm which masks cloud when Rayleigh-corrected reflectance at 865nm exceeds 2.7%, seems a little too strict since it also masks out pixels with high aerosol loadings but not cloud.

For SeaWiFS atmospheric correction and aerosol retrieval, a set of 12 non-absorptive or weakly absorptive aerosol models, including oceanic, maritime, coastal and tropospheric models with different relative humidity (RH), is adopted in the calculation of aerosol lookup tables. Two most appropriate aerosol models and their weight are chosen by comparing the modeled value with SeaWiFS measurement at the two NIR bands. The AOT and Ångström exponent are then retrieved based on the two aerosol models, their weight and the SeaWiFS measurement [Gordon and Wang, 1994].

The target region of the present analysis is focused on the Asian Pacific, which is supposed to be under the significant influence of natural and anthropogenic aerosols from Asian continent. We selected 5 sub-areas in this region as examples to study the temporal variability of aerosols. They are 1.Okhotsk-North Japan, 2.Sea of Japan, 3.East China Sea, 4.South of Japan and 5.East of Japan, as shown in Figure 1. We also processed data for sub-area 6, the East of Iwo Island, which is located far away from the mainland of East Asia, as a reference and supplement.

As a measure of aerosol abundance, AOT at eight visible and near-infrared wavelengths is derived first. Ångström exponent, an indicator of aerosol size distribution, was then calculated based on the definition

$$\alpha(490,865) = \ln(\tau_a 490 / \tau_a 865) / \ln(865/490) \cdot \quad (1)$$

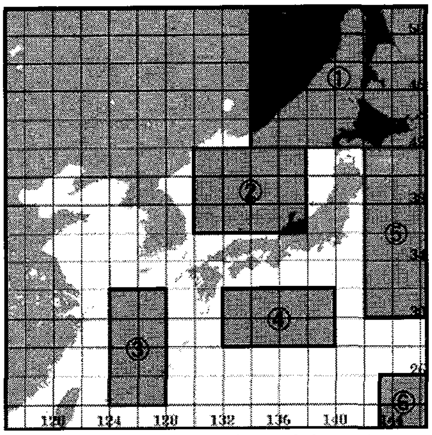

Fig.1. Geographic location of the sub-areas.

## 3. RESULT

Seven years mean value of AOT and Ångström exponents for each sub-area are calculated and plotted in Fig.2, processed with the local variance method. To check the possible influence to the statistical result due to the cloud mask method, satellite data are also processed with the SeaWiFS standard cloud mask algorithm, and plotted in Fig.2 as a comparison. It is evident that the standard method apparently lowers the AOT value, but not largely increase Ångström exponent simultaneously. It can be explained by the over-strictness of the standard method, which masks out those pixels with larger aerosol optical thickness but not cloud.

Fig. 3 provides the time series of monthly mean AOT and Ångström exponent for each sub-area, with the local variance method. It is interesting to observe a slightly increasing trend of Ångström exponent from the monthly mean data, with a mean slope of 0.0146 per year for the first 5 sub-areas. The uptrend is consistent with the result of *Sobajima et al* [2004] who used the AVHRR data from NOAA-11 and NOAA-14, while they found a rapid increase in Ångström exponent during 1998-2000, which is different from the steady and gradual increase we found here. We also noticed in Fig. 3 that no apparent trend in AOT is observed over this period. This differs from the result of Sobajima *et al.*, where they reported a rapid increase in annual mean AOT at 500nm in East Asian ocean over 1989-1990 to 1999-2000 [*Sobajima et al*,2004]. We also noticed that a decrease of Ångström exponent and AOT has appeared after year 2004, with the reason remaining unclear.

Since Ångström exponent is an indicator of aerosol size distribution, this uptrend can be related to the increasing fraction of small aerosol particle in this area. An empirical relationship was adopted to estimate the sub-micron fraction (SMF) of AOT at 550nm from $\alpha(450,700)$,

$$SMF = -0.0512\alpha^2 + 0.5089\alpha + 0.02, \quad (2)$$

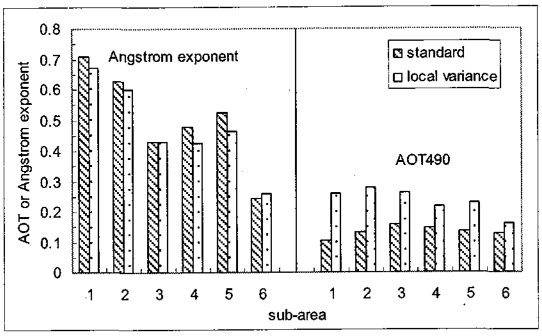

Fig 2. Averaged angstrom exponent and AOT for 6 sub-areas and 2 cloud mask methods. "standard": SeaWiFS standard method; "local variance": local variance method.

which was originally obtained from C-130 measurements conducted throughout the ACE-Asia campaign [*Anderson et al*, 2005]. Here SMF represents the fraction of AOT caused by actual aerosol that exists at low-RH aerodynamic diameters smaller than 1 μm. The retrieved monthly mean SMF time series is listed in Table 1 for each sub-area, as well as the mean increasing slopes per year of Ångström exponent. From the annual mean slope of 0.0067 for SMF, an estimate of about 4~5% increase of sub-micron particle fraction above the ocean in East Asia over 7 year would be reached.

Table 1. The uptrend (slope) of Ångström exponent and SMF for each sub-area and each cloud mask algorithms.

| | Ångström slope per year | | SMF slope per year | |
|---|---|---|---|---|
| | Standard | Local-variance | Standard | Local-variance |
| 1 | 0.0076 | 0.0147 | 0.0033 | 0.0065 |
| 2 | 0.0079 | 0.0144 | 0.0035 | 0.0065 |
| 3 | 0.0118 | 0.0165 | 0.0055 | 0.0077 |
| 4 | 0.0106 | 0.0114 | 0.0049 | 0.0053 |
| 5 | 0.0071 | 0.0161 | 0.0032 | 0.0074 |
| 6 | 0.0057 | 0.0092 | 0.0027 | 0.0045 |

Time series of monthly mean AOT and Ångström exponent with the SeaWiFS standard method are plotted in Fig. 4. The trends of Ångström are still observable, although it is depressed. The reason is perhaps related to the over-strictness of this cloud mask method, which decrease the representative capability of turbid atmosphere which has higher reflectance.

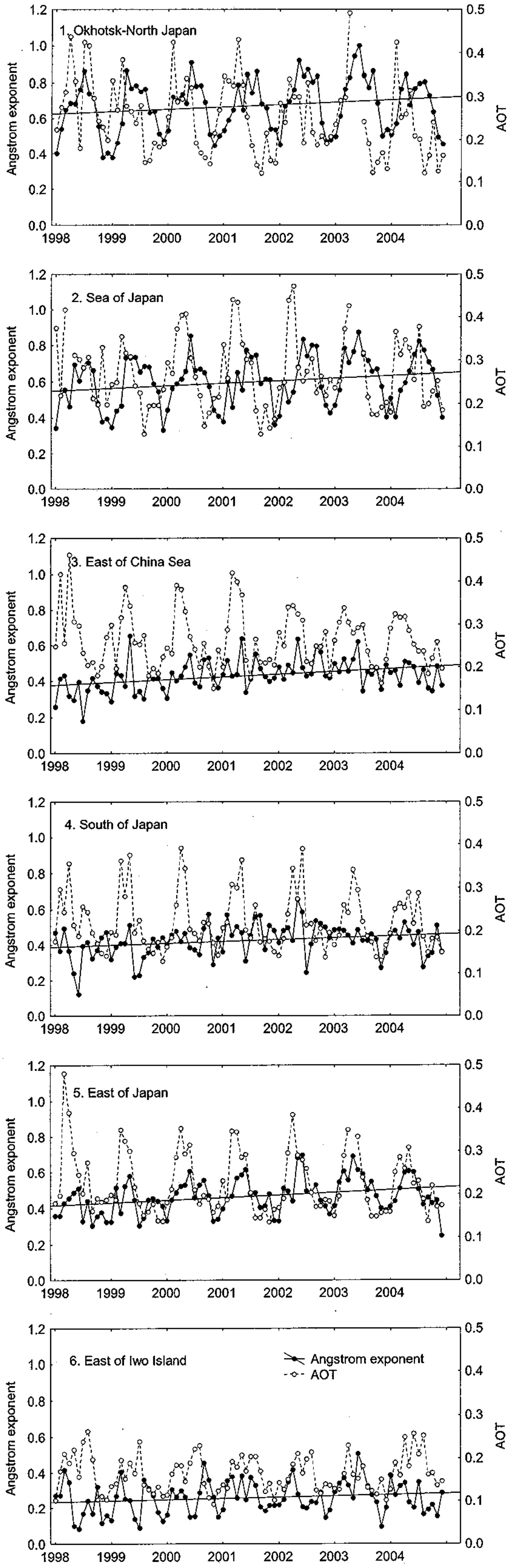

Fig 3. Time series of monthly mean AOT and Ångström exponent derived from SeaWiFS for 6 sub-areas. Data are processed with the local variance cloud mask method.

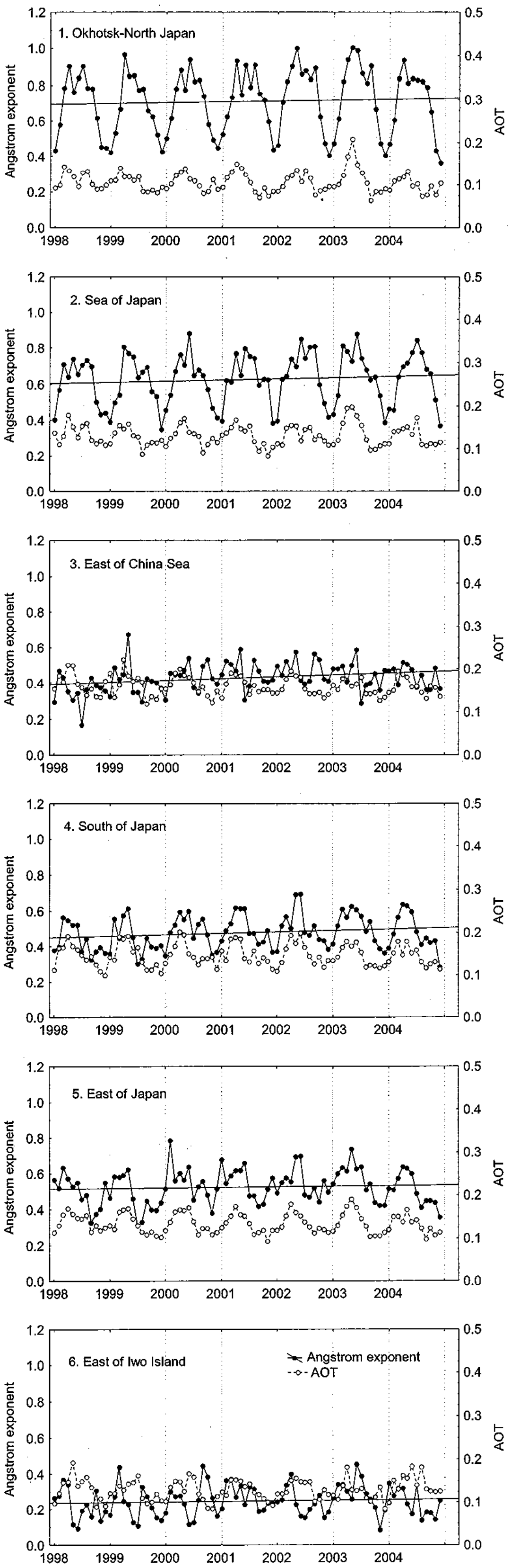

Fig 4. Same with Fig.3, but processed with the SeaWiFS standard cloud mask.

It is interesting to notice that the standard cloud mask method applied to SeaWiFS data processing reduce the mean AOT value and increase the mean Ångström exponent compared to the local variance method (Fig 1). It seems that the strict standard method masking the pixels with higher aerosol reflectance while at the same time it masking the pixels with more small particles too. In addition, it also decreases the increasing trend of angstrom exponent, which would lead to an assumption that the reduced portion of data, masked by the standard method but not the local variance method, should be accompanied with even higher increasing trend.

## 4. DISCUSSION

Ångström exponent is observed to be slightly increasing with time at East Asian Seas from the 1998-2004 SeaWiFS measurement. Is this uptrend of Ångström exponent observed here a real fact of nature or an illusion caused by the temporal degradation of the sensor? This is a crucial issue we face first. SeaWiFS project has taken comprehensive approaches, includes the pre-launch calibration, the Transfer-to-Orbit, and the post-launch calibrations, so as to provide reliable satellite measurements [Johnson et al., 1999; Barnes et al., 2000; Barnes et al., 2001; Eplee et al., 2004]. Considering the high reliability of the SeaWiFS calibration, this uptrend of Ångström exponent is turned to be related to the increase of small aerosol fraction most possibly, rather than being caused artificially by the SeaWiFS sensor, although there may exist some unknown factors which influence the calibration of sensor.

We have noticed that there seem to have a systematic under-estimation of the mean Ångström exponent itself over the ocean, compared to the published data collected from land-based aerosol observation [Aoki and Fujiyoshi, 2003]. However, part of the discrepancy is reasonable, considering the facts that the field data are collected in the continental or coastal areas where anthropogenic small aerosols commonly dominated, and the SeaWiFS data are averaged over the ocean where large maritime aerosols prevailed,. The remainder, is not clear due to possible calibration offset. There are various factors that may contribute the discrepancy, e.g., calibration, algorithm performance, cloud masking, data sampling, etc. But since what we focused on is the relative variability of Ångström xponent with time, not the absolute value itself, influence to Ångström exponent from the algorithm performance or other factors is complicated, but should be statistically the same for each year and would not induce such an increasing trend.

## 5. SUMMARY

Seven years SeaWiFS data (1998-2004) were analyzed and temporal variability of aerosol optical thickness and Ångström exponents above ocean were presented for the selected sub-areas in the East Asian area, with different cloud masking algorithm. The aerosol optical thickness at 490nm remained stable, while Ångström exponent was found to increase slightly with time except 2004. Increasing trend of small particles is evaluated in terms of sub-micron fraction of aerosol optical thickness, which is assessed to be about 4-5% increase over seven years. SeaWiFS standard cloud mask algorithm lowers the trend a little due to its over-strictness in determining the cloud.

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