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Chapter 9

Correction of the Sunglint Contamination on the SeaWiFS Aerosol Optical Thickness Retrievals

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Abstract

For ocean color remote sensing, the measurement of radiances affected by sun glint has to be avoided or masked out. SeaWiFS has a capability of operationally tilting the sensor 20° away from nadir to minimize sun glint contamination, however, sun glint is still a factor near the subsolar point. In this chapter, results are presented which give the effect of the sun glint contamination on the retrievals of ocean bio-optical and atmospheric products. It was found that, although the sun glint contamination has a minor effect on the retrieved ocean bio-optical products, the effect on the retrieved atmospheric products is significant, e.g., aerosol optical thickness. A sun glint correction scheme implemented in the SeaWiFS data processing is described. It was found that the sun glint correction significantly improves the derived atmospheric products in the region of the subsolar point.

9.1 INTRODUCTION

In ocean color remote sensing, the radiance measured at the top of the ocean-atmosphere system can be written as,

$$\begin{aligned} L_t(\lambda) \;&= L_r(\lambda) \;+\; L_a(\lambda) \;+\; L_{ra}(\lambda) \\ &+\; T(\lambda)\, L_g(\lambda) \;+\; t(\lambda)\, L_{wc}(\lambda)\,, \\ &+\; t(\lambda)\, L_w(\lambda) \end{aligned} \tag{1}$$

where $L_r(\lambda)$, $L_a(\lambda)$, and $L_{ra}(\lambda)$ are the radiance contributions from multiple scattering of air molecules (Rayleigh scattering), aerosols, and Rayleigh-aerosol interactions, respectively (Gordon and Wang 1994b). $L_g(\lambda)$ is the specular reflection from the direct sun (sun glint) radiance, $L_{wc}(\lambda)$ is the radiance at the sea surface resulting from sunlight and skylight reflecting off whitecaps on the surface (Gordon and Wang 1994a), and $L_w(\lambda)$ is the water-leaving radiance. $T(\lambda)$ and $t(\lambda)$ are the atmospheric direct and diffuse transmittance at sensor viewing direction, respectively.

As there are usually no meaningful retrievals in the sun glint contaminated regions, measurement of radiances affected by sun glint, $L_g(\lambda)$, have to be avoided or masked out. SeaWiFS has the capability of operationally tilting the sensor 20° away from nadir to minimize sun glint contamination. Sun glint is still a factor, however, near the subsolar point. The SeaWiFS processing steps compute $L_g(\lambda)$ from the Cox and Munk (1954) model with the input of sea surface wind speed. A mask is applied to areas where the glint radiance is greater than a predetermined threshold. Although the regions with the most significant sun glint contamination are masked out, there is still some residual sun glint contamination surrounding the mask. The sun glint contamination is particularly evident in the SeaWiFS derived atmospheric products, e.g., aerosol optical thickness. It is important, therefore, to develop a correction scheme for removing the effects of sun glint contamination. The ocean pigment concentration, however, is usually less affected by sun glint contamination because the bio-optical algorithm uses a two band ratio value in the derived water-leaving radiances (Fraser et al. 1997).

In this chapter, the SeaWiFS sun glint mask from Cox and Munk (1954) is briefly described. Then, a sun glint contamination correction scheme and its implementation in the SeaWiFS data processing are proposed. Next, evaluations of the National Center for Environmental Prediction (NCEP) wind speed data are given, which are used in the SeaWiFS data processing in comparison with *in situ* measurements. Finally, some comparison results are presented with and without sun glint corrections.

9.2 THE SeaWiFS SUN GLINT MASK

It is convenient to rewrite the sun glint radiance $L_g(\lambda)$ as

$$L_g(\lambda) \;=\; F_0(\lambda)\, T_0(\lambda)\, L_{GN}, \tag{2}$$

where $F_0(\lambda)$ and $T_0(\lambda)$ are the extraterrestrial solar irradiance (adjusted for the Earth–sun distance variations) and the atmospheric direct transmittance at the solar direction, respectively. The normalized sun glint radiance, L_{GN}, would be the value of sun glint radiance if there were no atmosphere and the solar irradiance $F_0(\lambda) = 1$. Note that, for a given pixel, the L_{GN} value depends on the solar and viewing geometry, the sea surface wind speed, and the wind direction.

The SeaWiFS normalized sun glint radiance, L_{GN}, is computed based on the assumption that the wind-ruffled sea surface consists of a collection of individual facets obeying the slope statistics derived by Cox and Munk (1954). As an approximation, the normalized sun glint radiance is computed with a further assumption that the wind-ruffled surface slope distribution is independent of the wind direction. The input for the sun glint radiance computation are, at the pixel-by-pixel level, the solar and sensor viewing geometry, as well as the surface wind speed. The computed L_{GN} value is used as the sun glint mask and is applied to areas where the glint radiance is greater than a predetermined threshold.

In the SeaWiFS data processing, pixels having a normalized glint radiance $L_{GN} \geq 0.005$ are masked, and there is no further data processing for retrieving ocean and atmosphere products (McClain et al. 1995). There are also no corrections applied for pixels with a glint radiance of $0 < L_{GN} < 0.005$. It is likely, therefore, that there will be some effect of sun glint contamination outside the sun glint mask in the SeaWiFS products.

It has been found that there is no apparent bias in the SeaWiFS retrieved ocean optical property results around the subsolar point (e.g., water-leaving radiances and chlorophyll concentration). The derived aerosol optical thicknesses, however, are always biased high in the regions where $0 < L_{GN} < 0.005$. To improve the SeaWiFS atmospheric products, sun glint contamination needs to be corrected.

9.3 SUN GLINT CONTAMINATION

It is straightforward from (1) that, if known, the sun glint radiance can be subtracted from the sensor measured radiance. Subsequent data processing is then based on the corrected radiances using (2). Rewriting (1) yields

$$\begin{aligned}\hat{L}_t &= L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) \\ &+ t(\lambda)\,L_{wc}(\lambda) + t(\lambda)\,L_w(\lambda)\end{aligned}, \tag{3}$$

and

$$T_0(\lambda)\,T(\lambda) = \exp\left(-\left[\tau_r(\lambda) + \tau_a(\lambda)\right]\left[\frac{1}{\cos\theta_0} + \frac{1}{\cos\theta}\right]\right), \tag{4}$$

where $\hat{L}_t$ is the sun glint corrected radiance equal to $L_t(\lambda) - F_0(\lambda)\,T_0(\lambda)\,T(\lambda)\,L_{GN}$, and $\tau_r(\lambda)$ and $\tau_a(\lambda)$ are the optical thickness for Rayleigh (air molecules) and aerosols, respectively. The θ_0 and θ correspond to the solar and sensor zenith angles, respectively. It is assumed that the ozone absorption effects in (3) and (4) have been removed. The sun glint corrected radiance, $\hat{L}_t$, at the eight SeaWiFS bands can then be inserted into the atmospheric correction algorithm [replacing $L_t(\lambda)$], and data processing can be procede with corrected radiances. At the time of data processing, however, the aerosol optical thickness in (4) is unknown; therefore, an iterative scheme is proposed. The sun glint corrected radiance, $\hat{L}_t$, is first calculated with the uncorrected L_t, wind speed, and an initial guess for τ_a [used here as $\tau_a'(\lambda_i)$]. The initial $\hat{L}_t$ is then used to derive τ_a; this derived value is then used as input to derive the *final* sun glint corrected radiance and the *final* sun glint corrected aerosol optical thickness.

Based on results from some case studies, the $\tau_a'(\lambda_i)$ values are estimated through following steps:

a) The normalized sun glint radiance, L_{GN}, is computed using the Cox and Munk (1954) model;
b) Using a $\tau_a(865)$ of 0.1 (which is the global average value from SeaWiFS) in (4), $L_A = L_a + L_{ra}$ at the SeaWiFS 865 nm band in (3) can be derived and converted to the aerosol reflectance as $\rho_A = \pi L_A / F_0 \cos\theta_0$; and
c) A high $\tau_a'(\lambda_i)$ value is used for a low ρ_A value (i.e., a $\tau_a'(865)$ with values of 1.0, 0.4, 0.2, and 0.12 are used, corresponding to ρ_A of 0.001, 0.005, 0.008, and 0.01, respectively).

The purpose of using the large $\tau_a'(865)$ values for the low ρ_A cases is to avoid the over-correction of the sun glint contamination due to uncertainties in the L_{GN} estimation. These uncertainties arise from either uncertainty in surface wind speed or limitations of the Cox and Munk model, i.e., for the cases of small ρ_A values (less than approximately 0.005 corresponding to $\tau_a <\approx 0.05$), confidence in the sun glint correction is low.

9.4 WIND SPEED DATA EVALUATION

To compute L_{GN}, the sea surface wind speed is needed. Based on a study and recommendation by Firestone et al. (1994), SeaWiFS uses the surface wind speed data provided by the National Center for Environmental Prediction (NCEP). The NCEP wind product is gridded at one degree. The SeaWiFS data processing interpolates this coarse wind data to the SeaWiFS 1 km pixel. Because the Cox and Munk model is sensitive to wind speed, some evaluations of the NCEP data were conducted. NCEP winds were compared to winds measured at the Bermuda Test Bed Mooring (BTBM). Figure 1 provides an example scatter plot for the NCEP winds versus the *in situ* buoy data. The two data sets agreed reasonably well and there was no obvious bias of the NCEP wind data. This result lends confidence to the use of the interpolated NCEP winds in the L_{GN} calculation.

9.5 RESULTS

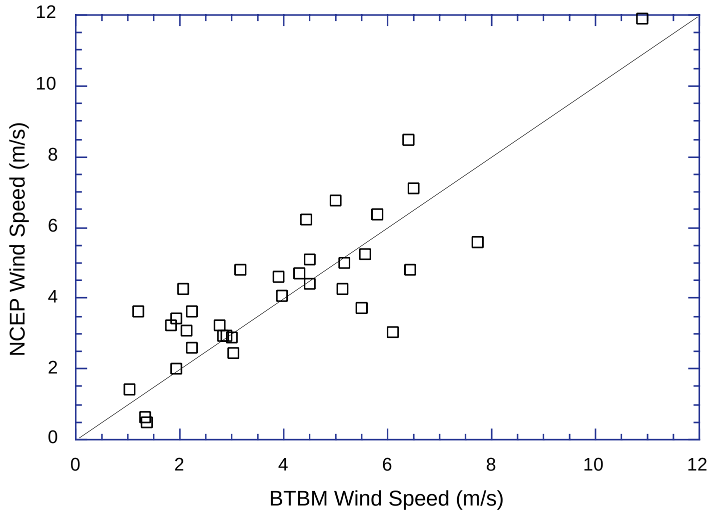

Fig. 1. The National Center for Environmental Prediction (NCEP) surface wind speed data compared with the *in situ* buoy measurements at the Bermuda Test Bed Mooring (BTBM).

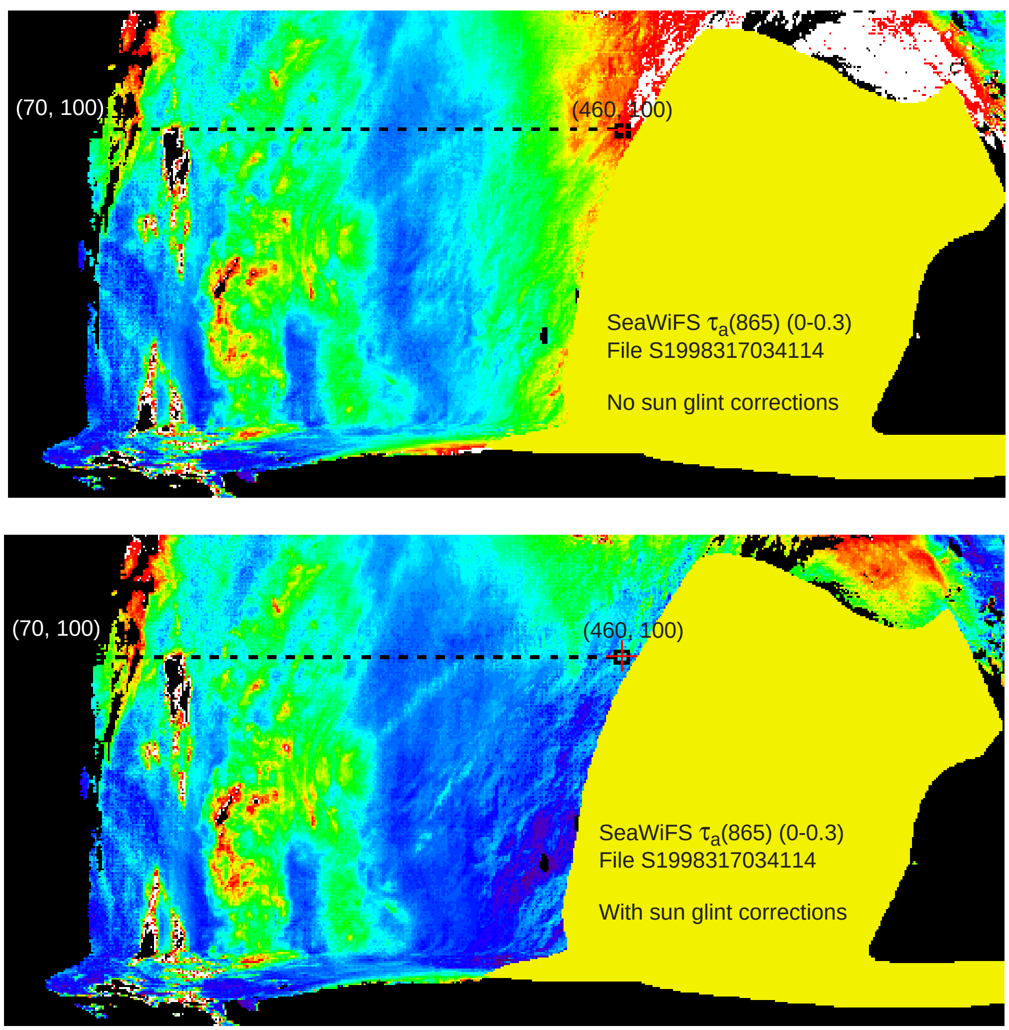

Fig. 2. The SeaWiFS derived aerosol optical thickness $\tau_a(865)$ for cases of without (top panel) and with (bottom panel) the sun glint corrections.

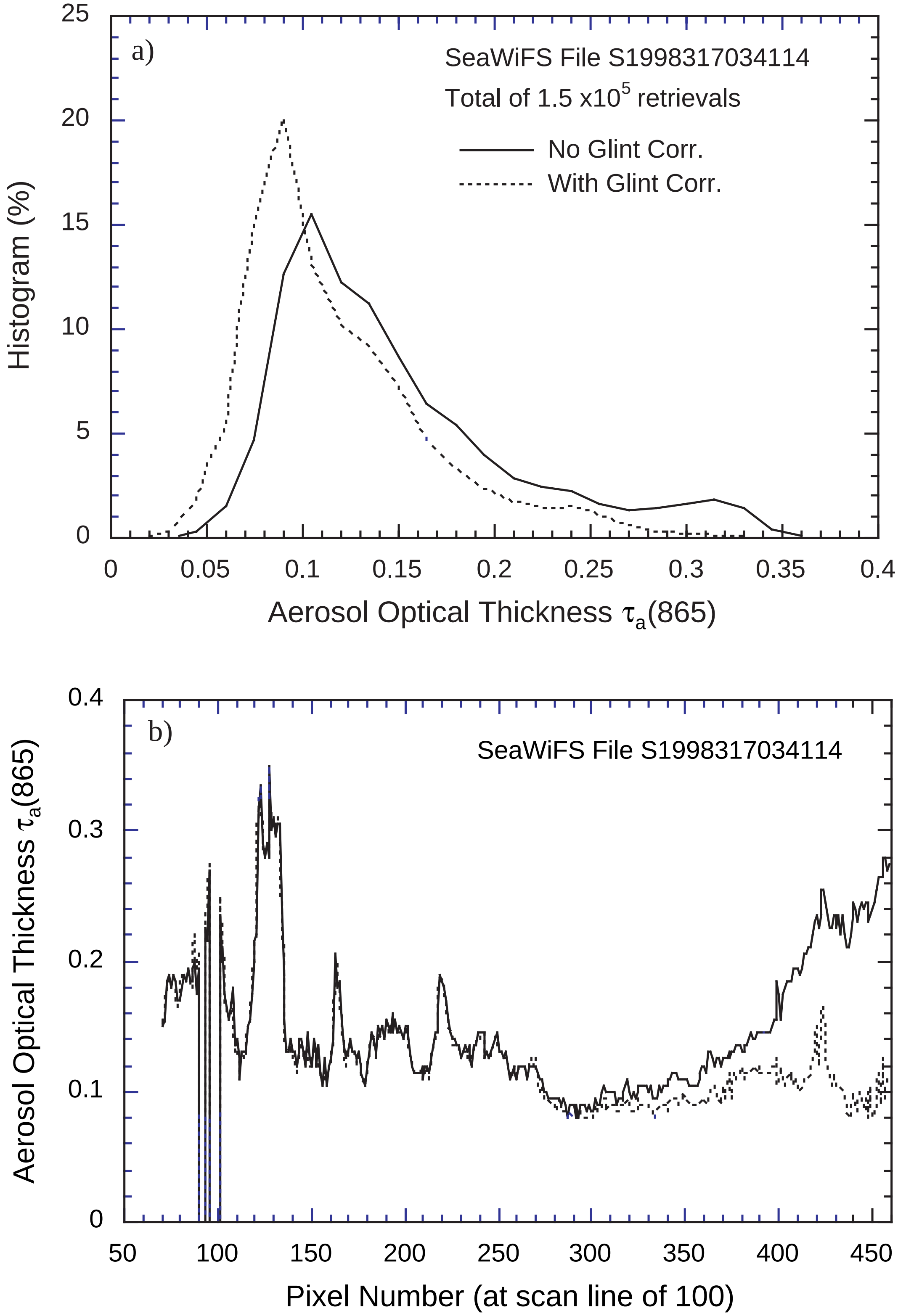

Fig. 3. A quantitative comparison in the SeaWiFS derived $\tau_a(865)$ values for cases of with and without sun glint contamination corrections: **a)** histograms from results in Fig. 2, and **b)** data from pixels 70–460 at scan line 100 (dashed line in Fig. 2).

To assess the efficacy of the proposed sun glint correction scheme, some case studies were conducted. Figure 2 provides an example of the SeaWiFS $\tau_a(865)$ images for cases with and without sun glint corrections. SeaWiFS data (file name `S1998317034114`) was acquired on 13 November 1998 along the west coast of Australia at the location around $-24°$ of latitude and 120° of longitude. The image in the top panel was processed without the sun glint correction, while the bottom image was processed with the correction applied. The value of $\tau_a(865)$ is scaled from 0–0.3. The sun glint mask (right side part of image, grey-white color) in Fig. 2 is clearly seen. In comparing two $\tau_a(865)$ images, it can be seen that the derived aerosol optical thickness is reduced around the area outside of the glint mask when the correction is applied. Figures 3a and 3b show results of a quantitative comparison of these two images. Figure 3a compares the histograms from the two cases, while Fig. 3b compares a specific scan line (dashed lines in Fig. 2). Figure 3a shows that, with the sun glint corrections, the large $\tau_a(865)$ values, which correspond to the sun glint contamination regions, are much reduced. The sun glint contamination effects are clearly seen in Fig. 3b where the $\tau_a(865)$ is obviously biased, increasing as the pixel numbers increase (close to the glint mask region) for cases without the sun glint corrections. The $\tau_a(865)$ values are much more reasonable with the sun glint contamination correction applied.

The effects of sun glint contamination on the ocean optical products were also studied. It was found that there is almost no effect on the SeaWiFS retrieved ocean products, e.g., normalized water-leaving radiances and chlorophyll concentration.

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