OLCI Level 2

Algorithm Theoretical Basis Document

White Caps Correction

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	Name	Function	Company	Signature	Date
Prepared	S. Lavender	Project Manager	ARGANS Ltd		
Approved	O. Fanton d'Andon	OLCI Coordinator	ACRI-ST		
Released	S. Lavender	Project Manager	ARGANS Ltd	Digitally signed by Samantha Lavender DN: cn=Samantha Lavender, o=ARGANS Ltd, ou=Managing Director, email=samantha.lavender@argans.co.uk, c=GB Date: 2010.04.09 17:55:57 +01'00'	

Change record

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ESA	P. Goryl	
EUMETSAT	Hilary Wilson, Anne O'Carroll	
S3 Optical team	All OLCI team	

Table of Contents

List of Figures

1. INTRODUCTION

1.1 Acronyms and Abbreviations

ATBD	Algorithm Theoretical Basis Document
ECMWF	European Centre for Medium-Range Weather Forecasts
FOV	field-of-view
MERIS	Medium Resolution Imaging Spectrometer
NCEP	National Centers for Environmental Protection
OLCI	Ocean Land Colour Imager
OZA	Operating Zenith Angle
SeaWiFS	Sea-viewing Field-of-view Spectrometer
TOA	Top of Atmosphere

1.1 Symbols

Symbol	definition	Dimension / units
Geometry, wavelengths		
λ	Wavelength	nm
Atmosphere and aerosol properties		
$t_d(\lambda, \theta)$	Diffuse transmittance for angle θ	dimensionless
	$t_d(\lambda, \theta) = L_{TOA}(\lambda,\theta_s,\theta_v,\Delta\phi) / L_{0+}(\lambda,\theta_s,\theta_v,\Delta\phi)$	
$\rho(\lambda,\theta_s,\theta_v,\Delta\phi)$	Reflectance (π L / F_0 μ_s)	dimensionless

where the product π.L is the TOA upwelling irradiance if upwelling radiances are equal to L($\lambda,\theta_s,\theta_v,\Delta\phi$), for any values of θ_v within 0-π/2 and any $\Delta\phi$ within 0-2π.
Subscripts

t: total reflectance
w: water-leaving reflectance
wc: white cap

Miscellaneous

W	Wind speed	m/s

1.2 Purpose and Scope

The purpose of this ATBD is to define the approach to white cap correction that could be applied to OLCI.

1.3 Algorithm Identification

This algorithm is identified under reference "SD-03-C06" in the Sentinel-3 OLCI documentation.

2. ALGORITHM OVERVIEW

2.1 Objectives

The current MERIS algorithm handles white caps only on a statistical basis (uses external wind speed estimations from Weather Forecast auxiliary data) and the result only impact the quality flags; no correction is attempted. The recommended baseline implementation is the approach applied for SeaWiFS with the evolution being the use of additional channels in OLCI that could provide a correction based on radiometric estimations.

3. ALGORITHM DESCRIPTION

3.1 Theoretical Background

The measured top of the atmosphere (TOA) reflectance, $\rho_{tm}(\lambda)$, is composed of two parts; that which would be measured in the absence of whitecaps, $\rho_t(\lambda)$, and the additional reflectance from whitecaps, $t\rho_{wc}(\lambda)$, see Equation 1.

$$\rho_{tm}(\lambda) = \rho_t(\lambda) + t_d(\lambda)\,\rho_{wc}(\lambda) \qquad \text{(Eq 1)}$$

Based on previous research, Gordon and Wang (1994), the white cap normalised reflectance is linked to the wind speed and then propagated to the TOA reflectance using the atmospheric transmission; see Equations 2 and 3.

$$[\rho_{wc}]_N = 6.49X10^{-7}W^{3.52} \qquad \text{(Eq 2)}$$

$$t\rho_{wc}(\lambda) = [\rho_{wc}(\lambda)]_N t_d(\lambda) \qquad \text{(Eq 3)}$$

Where W is the wind speed (m/s measured at 10m above the surface), $t(\theta_s, \lambda)$ is the diffuse transmittance between the sun and pixel and $t(\theta_v, \lambda)$ is the diffuse transmittance between the pixel and sensor with the inputs being the solar and sensor zenith angles respectively. The calculation of diffuse transmittance is described within ATBD SD-03-C07 (atmospheric correction over clear waters). Moore et al. (2000) varied the coefficients within Equation 2 to give Equation 4 and also noted a spectral dependency (Equation 5):

$$\rho_{wc}(412) = 3.4X10^{-6}W^{2.55} \qquad \text{(Eq 4)}$$

$$\rho_{wc}(860) = 0.22\{1 - exp[-4.2\rho_{wc}(412)]\} \qquad \text{(Eq 5)}$$

The spectrum of foam reflectance has also been determined in the laboratory (Whitlock et al. 1982), as well as for foam generated in the surf zone (Frouin et al. 1996). Whitlock's laboratory experiments showed a decrease in reflectance with increasing wavelength beyond approximately 800 nm. However, Frouin reported a much larger decrease in reflectance than Whitlock at the longer wavelengths: a 40% decrease at 870 nm, 50% at 1020 nm and 95% at 1650 nm relative to the reflectance at 440 nm. The difference between the laboratory and field measurements is thought to be due to the stronger absorption properties of water at longer wavelengths acting on light reflected from submerged bubbles forced into the water by large waves (Frouin et al. 1996).

The pre-2009 approach implemented for SeaWiFS and MODIS had the Gordon & Wang (1994) correction reduced by 75% as suggested by Howard Gordon, and the Frouin et al. (1996 revised, see Table 1) spectral dependence algorithm applied, see Equations 6 and 7 (taken from SeaDAS v5.0 whitecaps.c). A windspeed threshold was applied that prevented over estimation.

If W > 8 m/s then W = 8 m/s (Eq 6)

$$\rho_{wc}(\lambda) = awhite(\lambda) * 0.4 * (6.94 * 10^{-7}) * W^{3.52} \quad \text{(Eq 7)}$$

Where *awhite* is a wavelength dependent factor to address the decreasing reflectance versus wavelength (see Table 1), 0.4 is a wavelength independent "albedo modifier" and the final (wind speed dependant) component is the Monahan and O'Muircheartaigh (1980) power function.

Table 1: SeaDAS v5.0 MODIS/Aqua sensor-specific atmospheric correction data

MODIS Wavebands [nm]	White-cap albedo, WA (Frouin, May 1999)
412	1.0
443	1.0
469	1.0
488	1.0
531	1.0
551	1.0
555	1.0
645	0.889225
667	0.889225
678	0.889225
748	0.760046
859	0.644950
869	0.644950
1240	0.0
1640	0.0
2130	0.0

3.2 OLCI Baseline Implementation

In 2009, reprocessing 2 of SeaWiFS stated that the result was a nearly constant whitecap correction (see http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/whitecap/). Therefore, a revised whitecap correction was developed that used a fractional coverage model (less prone to over estimation), the wind speed threshold was increased to 12 m/s and the multiplicative reduction factor (0.4) was eliminated. Therefore, the revised formulation of Equation 7 is given by Equation 8 (Stramska and Petelski, 2003):

$$\rho_{wc}(\lambda) = 4.18 * 10^{-5}(W - 4.93)^3 \qquad \text{(Eq 8)}$$

Figure 1 shows the comparison of the different methods. Stramska and Petelski (2003), displayed as red squares, has two limits applied:

Wind speed<5 m/s set white cap (W) = 0

Wind speed>12 m/s set wind speed as 12 m/s

Therefore, below 5 m/s no white cap correction is applied and above 12m/s a maximum value is applied; the flagging is described in ATBD SD-03-C05.

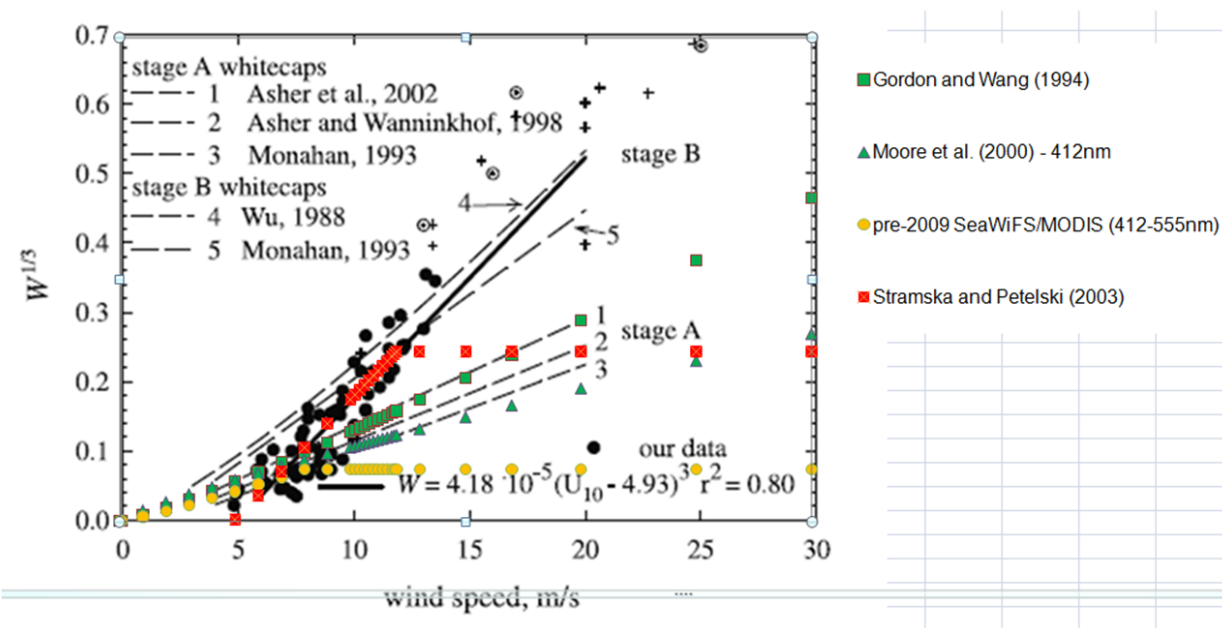

Figure 1: Underneath is Figure 4 from Stramska and Petelski (2003) with the Stramska and Petelski (2003) data as solid black dots, the Ross and Cardone (1974) data as pluses, and Nordberg et al. (1971) data by crosshair-circles. In colour are a wider set of glint correction techniques (see legend).

3.1 OLCI Evolution

Alternatively, there is the possibility to use waveband O21 (1020 nm) for the white cap correction. If it's assumed that the water-leaving reflectance is zero then the residual signal in the SWIR will be the white cap correction once glint is removed / or if it's negligible. From Frouin et al. (1996) it's calculated to be 50% of the 440 nm signal.

3.2 Algorithm Validation

Boat et al. (2009) undertook extensive measurements of the whitecap coverage in the North Atlantic and Norwegian Sea. They stated that the Stramska and Petelski (2003) wind speed relationship agrees well with the North Atlantic relationships above a wind speed of 10 m/s. At low wind speeds Stramska and Petelski (2003) underestimate, but the difference is small (range of 0.06 % to 0.2% at 7 m/s).

4. ASSUMPTIONS AND LIMITATIONS

The baseline OLCI implementation is Equation 8, which is what the NASA Ocean Biology Processing Group (OBPG) is moving towards. Linked to the development/validation of the glint correction is the possibility of a correction using OLCI band 21.

The white cap correction would be applied before the atmospheric correction, but needs the atmospheric transmission as an input. Therefore, the diffuse transmittance will need to be without the aerosol optical thickness included because otherwise it would require an iterative loop with the atmospheric correction. An alternative is to select a climatological value. Stramska and Petelski (2003) state that, from their point of view, that within ocean colour atmospheric correction it's better to underestimate the effect of whitecaps than to overestimate it.

Minimum windspeed limit on white cap correction is set to a value of 5.0 m/s.

Maximum windspeed limit on white cap correction is set to a value of 12.0 m/s.

5. INPUT DATA

Diffuse transmittance: t_d [dimensionless]

Wind speed: W [m/s]

6. ERROR BUDGET

An error model will (ideally) be based on probability density functions (PDFs) provided for the input variables (t_d and W), which will be propagated through the white cap equation (Equation 9) to obtain an output PDF. An alternative is a sensitivity analysis where the input variables are varied by ±5% and the variation in the output analysed (see the sun glint ATBD, SD-03-C09).

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