	<p><b>SENTINEL-3 L2 PRODUCTS AND ALGORITHM DEFINITION</b></p> <p><b>OLCI Bright Waters AC</b> (mesotrophic to high turbidity)</p>	<p>Document Ref: S3-L2-SD-03-C08-ARG- ATBD_BWAC Issue: v2.1 Date: 01/07/2010 Page 1 of 40</p>
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# **OLCI Bright Waters AC** (mesotrophic to high turbidity).


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## Algorithm Theoretical Basis Document

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**Title: OLCI Bright Waters AC (mesotrophic to high turbidity).**

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#### FROM 2.0 To 2.1

PAGE	SECTION	COMMENTS
-	-	Replaced OLCI with OLCI throughout
-	-	CDR RID-167: Changed title and clarified glint throughout
-	8.0 + throughout	Closed CDR RID-21: - Error/uncertainty estimate: Further information added to Section 8 - missing links to sections: - ATBD could be further clarified: some work has been undertaken.
9	2.0	CDR RID-100: Use of MERIS vs OLCI bands addressed


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## Acronym and Abbreviations

$\Delta_{\phi}$	Sun-sensor viewing azimuth difference	degrees
$\lambda$	Wavelength	nm
$\theta_v$	Sensor viewing zenith angle (the satellite “look angle”)	degrees
$\theta_s$	Solar zenith angle	degrees
$\rho$	Fresnel reflectance at normal incidence	dimensionless
$\rho_a$	Multiple scattering aerosol reflectance	dimensionless
$\rho_{as}$	Single scattering aerosol reflectance	dimensionless
$\rho_g$	Reflectance due to sun glitter	dimensionless
$\rho_r$	Rayleigh reflectance	dimensionless
$\rho_{ra}$	Reflectance due to Rayleigh-aerosol interaction	dimensionless
$\rho_t$	Top of atmosphere reflectance	dimensionless
$\rho_w$	Water reflectance (above surface)	dimensionless
$\tilde{\rho}$	Fresnel reflectance for sun and sky irradiance	dimensionless
$\tau_{oz}$	Ozone optical thickness	$m^{-1}$
$\tau_{wv}$	Water vapour optical thickness	$m^{-1}$
$\tau_r$	Rayleigh optical thickness	$m^{-1}$
$a$	Total absorption coefficient	$m^{-1}$
$a_{bb}^*$	Sediment absorption to backscatter ratio	dimensionless
$a_p$	Combined (phytoplankton, detritus, sediment and gelbstoff) absorption coefficient	$m^{-1}$
$a_s$	Particulate specific absorption	$m^{-1}$
$a_w$	Water absorption coefficient	$m^{-1}$
$b$	Total scattering coefficient	$m^{-1}$
$bb$	Total backscattering coefficient	$m^{-1}$
$bb_p$	Particulate (phytoplankton, detritus and sediment) backscattering coefficient	$m^{-1}$
$bb_w$	Water scattering coefficient	$m^{-1}$

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$\tilde{b}$	Particulate backscattering ratio	dimensionless
$c$	Variable given in Gordon and Wang (1994)	dimensionless
$f$	Empirical factor relating IOPs to $R$	dimensionless
$f'$	Empirical factor relating IOPs to $R$	dimensionless
$F$	Empirical factor relating IOPs to $\rho_w$	dimensionless
$F'$	Empirical factor relating IOPs to $\rho_w$	dimensionless
$n_w$	Refractive index of seawater	dimensionless
$r$	Air-water reflectance for diffuse irradiance	dimensionless
$t$	Diffuse atmospheric transmittance	dimensionless
$T$	Total atmospheric direct transmittance	dimensionless
$Q$	Ratio of upwelling irradiance to radiance	dimensionless
$R$	Irradiance reflectance	dimensionless

## 1.2 Purpose and Scope

The purpose of this algorithm is to determine the correction for NIR reflectance needed for the full atmosphere correction model – applied to visible wavelengths.


## 1.3 Algorithm Identification

The algorithm is identified as SD-03-C08 in the OLCI documentation.

# 2. ALGORITHM OVERVIEW

The successful exploitation of remotely sensed water colour observations requires the development of atmospheric correction methods in coastal waters, and the determination of total suspended matter (TSM) concentrations in gravimetric units for use in mass flux studies and hydrodynamic models. By definition, Case I waters (stratified shelf seas and the deep ocean) are coloured by biogenic materials alone (phytoplankton, its pigments, dissolved organic exudates and detritus). Coastal waters are usually termed Case II because the major influence on the water colour is TSM (tidally stirred sediments or riverine fluvial muds) or Gelbstoff (yellow substances). Gelbstoff is mainly dissolved coloured organic



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material (CDOM), consisting of humic and fluvic compounds of terrestrial origin that are transported into marine waters by river/estuary systems.

With even modest concentrations of TSM ( $>2 \text{ g m}^{-3}$ ), the significant backscatter results in reflectance at near infra-red (NIR) wavelengths that negates the 'dark pixel' atmospheric correction (AC) procedures, which assume zero NIR ( $> 700 \text{ nm}$ ) water leaving reflectances. These are termed bright waters and require a modified bright pixel atmospheric correction (BWAC). In addition, when phytoplankton such as coccolithophores are abundant the water can also be highly reflective (at visible and NIR wavelengths) due to backscatter from detached coccoliths and the BWAC is also mandatory. Very high concentrations of any phytoplankton particles will also give significant backscatter and again the BWAC will be required to correct for the resultant NIR reflectance. Gelbstoff modulates effect on the atmospheric correction dark water, as it primarily absorbs due to its dissolved nature, but Case II algorithms are needed for the retrieval of the concentrations of gelbstoff and other optically active components of the water such as TSM and chlorophyll-a (Chl-a).

Explicitly there are only two differences between the MERIS bands and the OLCI bands in terms of the BWAC, band 15 centred at 781.25 nm vs. 778.75 nm and band 16 centred at 862.5 nm vs. 885.0 nm. In addition, tables have been generated for OLCI band 21 (1020 nm). This algorithm has been shown to be robust to changes in modelled pure water to  $\pm 10\%$ . Since the changes in water absorption are considerable less than this over the band differences between the current nominal OLCI bands and those of MERIS the algorithm will perform identically with both sensors, and such wavelength changes are accounted for in Section 3.15 (except were the 1020nm band is chosen). For mesotrophic and moderately turbid waters the algorithm will perform seamlessly between sensors.

## 2.1 Objectives

The algorithm estimates the contribution of particulates and low glint / bubbles in the NIR atmospheric correction channels. The simple purpose is to return the Top Of Atmosphere (TOA) reflectance's corrected for these in-water influences so that further processing can be preformed for identification of aerosol type, using the clear water ocean atmospheric correction or potentially a land atmospheric correction over extremely turbid waters.

## 3. ALGORITHM DESCRIPTION

### 3.1 Theoretical Description

The algorithm exploits the differing spectral slopes of sediments, scattering phytoplankton, bubbles and aerosols to determine their relative contributions to the top of atmosphere reflectance. The in water part of this approach has been termed the NIR similarity spectrum.

### 3.2 Reflectance Model

The hydrological optics depends on the inherent optical properties (IOPs) of the TSM, which varies according to wavelength ( $\lambda$ ). Parameterisation of reflectance for waters dominated by TSM involves knowledge of three IOPs and their spectral properties: particulate specific absorption,  $a_s(TSM, \lambda)$ ; particulate specific scattering,  $b_s(TSM, \lambda)$ ; particulate backscattering ratio,  $\tilde{b}$ . The sensitivity of these IOPs with regard to sediment type has been investigated, under laboratory conditions, using measurements of reflectance with a spectroradiometer above a 2m depth tank (Bale *et al.*, 1994). The tank depth simulated optically deep pure water at NIR wavelengths that have an attenuation coefficient of  $1.53 \text{ m}^{-1}$  at 700 nm and  $0.20 \text{ m}^{-1}$  at 865 nm.

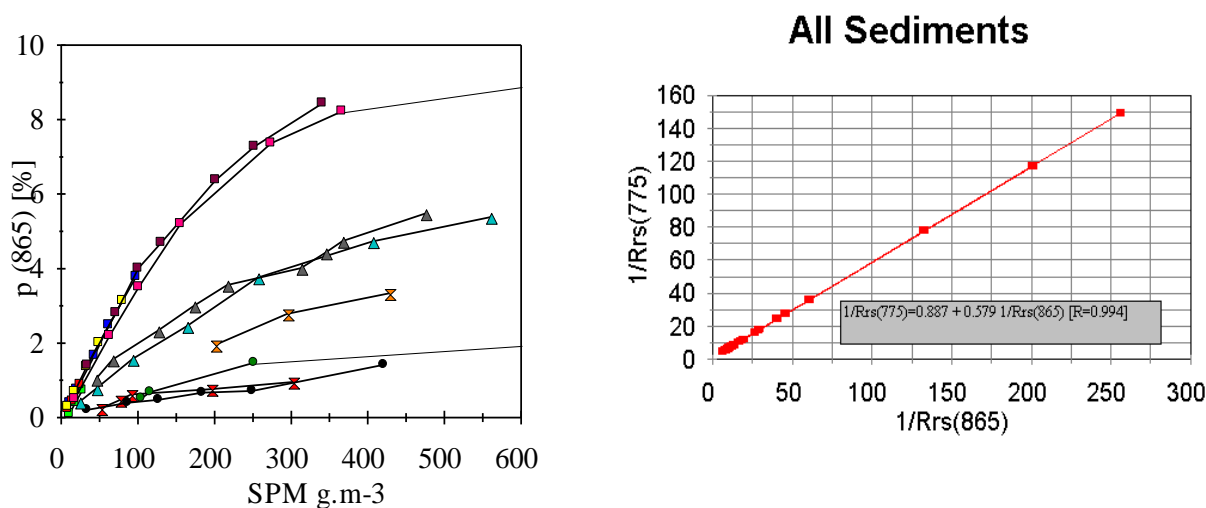



Figure 1: Reflectance of selected sediments in tank experiments

Figure 1(left) shows the relationship between reflectance and TSM for sediments collected around the UK (primarily east and south coasts). The reflectance shows high variation between sediment types, but

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each curve shows a non-linear relationship between sediment concentration and reflectance. Figure 1(right) shows the relationship between the reciprocal of sediment concentration and the reciprocal of remotely sensed reflectance. It can be observed that this is a quasi-linear within relationship. This relationship can be explored further by considering the theoretical relationship with reflectance,  $\rho_w(\theta_s, \theta_v, \Delta\phi)$ , expressed as:

$$\rho_w = \pi \Re \frac{f(\theta_s, \theta_v, \Delta\phi)}{Q(\theta_s, \theta_v, \Delta\phi)} \left( \frac{bb_w + bb_{pds}}{a_w + a_{pds}} \right) \quad (1a)$$

or alternatively:

$$\rho_w = \pi \Re \frac{f'(\theta_s, \theta_v, \Delta\phi)}{Q(\theta_s, \theta_v, \Delta\phi)} \left( \frac{bb_w + bb_p}{a_w + a_p + bb_w + bb_p} \right) \quad (1b)$$

Where  $\Re$  is defined as:

$$\Re = \left[ \frac{(1 - \rho)(1 - \tilde{\rho})}{n_w^2} \right] \quad (2)$$


$n_w$  is the refractive index of seawater,  $\rho$  is the Fresnel reflectance at normal incidence,  $\tilde{\rho}$  is the Fresnel reflectance for sun and sky irradiance,  $r$  is the air-water reflectance for diffuse irradiance; these reflectances are dependent on the sea state for which wind speed is taken as a proxy.

$Q$  is the ratio of upwelling irradiance to radiance  $f$ , and  $f'$  are quasi constants for case 1 waters, all of these are dependent on the viewing geometry.

$a_w$ ,  $bb_w$  are the absorption and backscatter of water,  $bb_p$  is the combined backscatter of phytoplankton, detritus and sediment;  $a_p$  is the combined absorption of phytoplankton, detritus, sediment and gelbstoff (CDOM).

If a fixed viewing geometry and wind speed are chosen then (1a) and (1b) can be expressed as:

$$\rho_w = F \left( \frac{bb_w + bb_p}{a_w + a_p} \right) \quad (3a)$$

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$$\rho_w = F' \left( \frac{bb_w + bb_p}{a_w + a_p + bb_w + bb_p} \right) \quad (3b)$$

$F$  and  $F'$  are functions that include the terms  $Q$ ,  $\Re$  and  $\pi$  and imply geometry. Both the  $bb/a$  and the  $bb/(a+bb)$  variants of the  $f$  factor have been used in a hydro-optical modelling with the latter preferred for case 2 waters.

As the **BWAC** aims to include water with very high turbidities, and thus reflectance, the limiting values for these alternative reflectance expressions are thus important in terms of numerical stability. For a non or very low absorbing sediment, such as coccoliths, the limits are:

$$\lim_{bb_{pds} \rightarrow \infty} F \left( \frac{bb_w + bb_p}{a_w + a_p} \right) = \infty \quad \text{and} \quad \lim_{bb_{pds} \rightarrow \infty} F' \left( \frac{bb_w + bb_p}{a_w + a_p + bb_w + bb_p} \right) = F' \quad (4a,b)$$

Thus, the  $bb/(a+bb)$  variant is more useable since it provides a defined limiting reflectance of  $F'$  for high reflectance waters, which can be used as an error check for computing look-up tables (LUT's) and for their implementation.

The limit for an absorbing sediment is also of interest. Here,  $a_{bb}^*$  is defined as the specific absorption of the sediment backscatter, or the absorption to backscatter ratio, for particular sediment and in this case (3b) becomes:

$$\rho_w = F' \left( \frac{bb_w + bb_p}{a_w + bb_w + bb_p (1 + a_{bb}^*)} \right) \quad (5)$$

And the limiting value becomes:

$$\lim_{bb_{pds} \rightarrow \infty} F' \left( \frac{bb_w + bb_p}{a_w + bb_w + bb_p (1 + a_{bb}^*)} \right) = \frac{F'}{(1 + a_{bb}^*)} \quad (6)$$

This limit permits the estimation of sediment absorption from above water reflectance in tank experiments and highly turbid water where analytical and *in-situ* methods may be problematic. The

effect of the varying  $f'/Q$  is shown in Figure 2, for the tank geometry ( $\theta_s=45$ ,  $\theta_v=0$ ). It is evident that the ratio of NIR sediment reflection is dependent of the variability of the  $f'/Q$  factor.

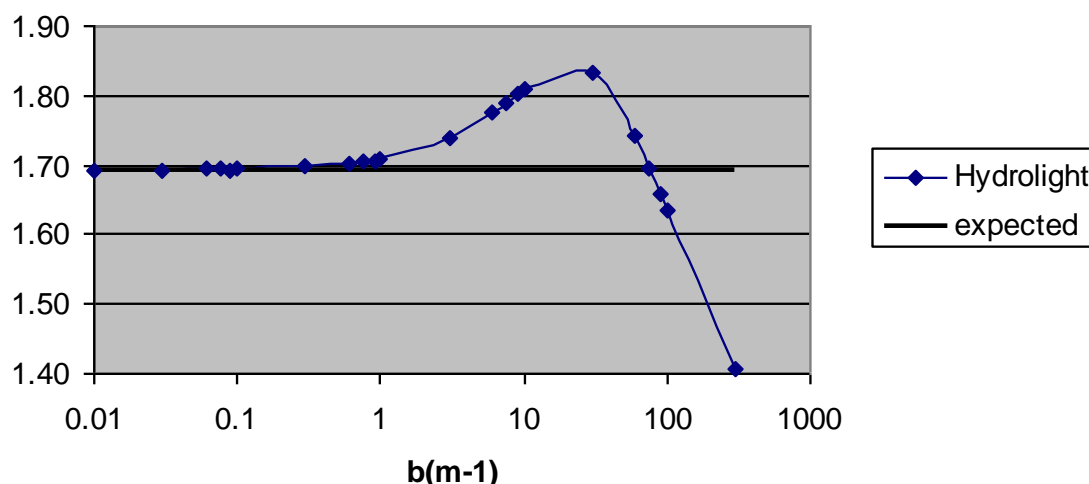


Figure 2: Effect of modelled  $f'/Q$  on  $\rho_w(773)/\rho_w(862)$

### 3.3 Implementation of the Hydrological Model

The  $F'$  values were computed using Hydrolight 3.0 (Mobley, 1995). The refractive index used was as specified in the MERIS Reference Model Document (RMD), as were the phase functions of pure water and particles. The tables were run for 4 wind speeds ( $0.25\text{ms}^{-1}$ ,  $1.00\text{ms}^{-1}$ ,  $2.75\text{ms}^{-1}$  and  $5.00\text{ms}^{-1}$ ) corresponding to sea-states recorded in the MERIS MAtchup In-situ Database (MERMAID, see <http://hermes.acri.fr/mermaid/>) metadata, and for solar angles ( $\theta_s$ ) of 0, 15, 30, 45, 60 and 75 degrees that encompasses the OLCI useful viewing geometry.  $\theta_v$  and  $\Delta_\phi$  are implicit in the Hydrolight runs and the 'quads' were set to give the following viewing geometry:

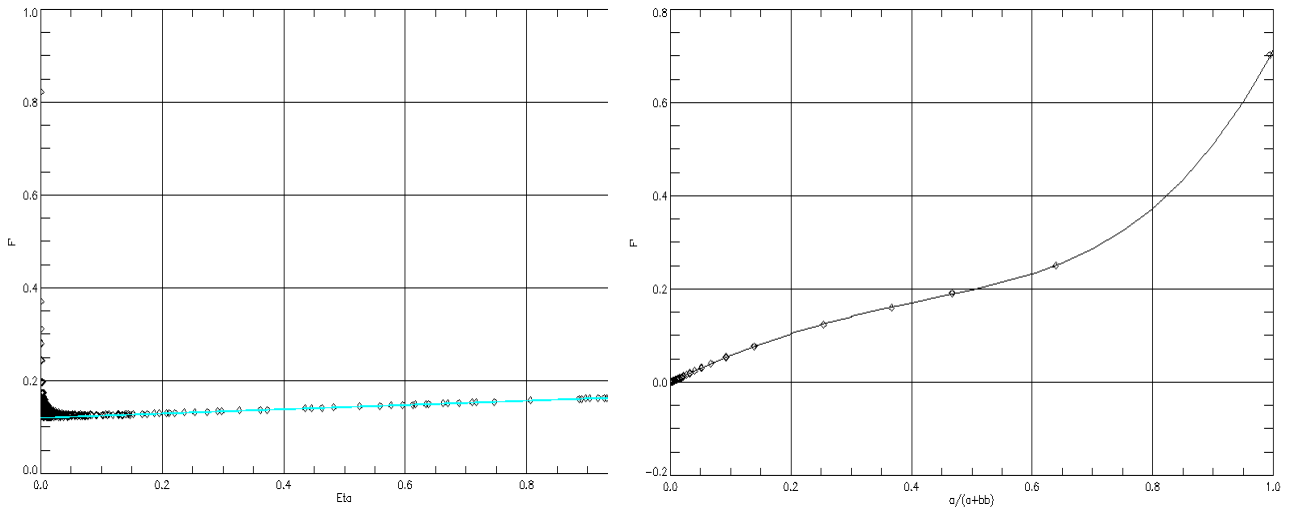
$$\theta_v = \{0, 15, 30, 45, 60\}$$

$$\Delta_\phi = \{0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180\}$$

The absorption values were run from a range of  $a_w$  values that were below the minimum found in literature, when adjusted for smile and temperature effects, and to the similar greatest value. Thereafter, a log ramp was applied to an absorption value of  $30.0\text{m}^{-1}$ . From the absorption, scattering values were calculated according to a ramp of single scattering albedo ( $\omega$ ) from zero to 0.9999 with the highest density of values at the high  $\omega$ . In all, for each band around 10,000 table runs were computed

according to the number of candidate  $a_w$  values. The  $f'$  determined from the Hydrolight runs was then fitted to  $\eta$ , where:

$$\eta = \frac{bb_w}{bb_w + bb_p} \quad (7)$$



a) Relationship between  $F'$  and  $\eta$

b) Relationship between  $F'$  and  $bb/(a+bb)$


Figure 3:  $F'$  vs.  $\eta$  and  $bb/(a+bb)$

and to  $\omega$ . The relationship with  $\eta$  proved to be linear for low turbidities,  $\eta, >0.1$  (Figure 2). The residuals from the fit to  $\eta$ , were expected to relate to  $\omega$  from previous work on case 1 waters (Morel and Gentili, 1993). However, this proved unsuccessful and instead a polynomial relationship was fitted with  $F'$  being a function of  $bb/(a+bb)$ .

Thus for any viewing geometry,  $F'$  can be expressed as:

$$F' = A0 + C \cdot \eta + \sum a_i \{bb/(a+bb)\}^i \quad (8)$$

where  $A0$  and  $C$  are the linear coefficients for  $\eta$ , and  $a_i$  represents the coefficients of a 4<sup>th</sup> order polynomial. The  $F'$  factors are provided as LUTs containing the polynomials for each band, based on wind speed and viewing geometry, with the terms vary slowly and so simple nearest neighbour lookup being sufficient. The polynomials obtained are dependent of the value of the total absorption, rather than the value of the  $a_w$  and  $a_p$ , as such this methodology enables the application tables to account for the effects of smile and temperature. As such the tables that are used are applicable to both MERIS and OLCI since for the BWAC bands the differences in wavelengths are within the MERIS 'smile'.

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### 3.4 Atmospheric Model

For the basic AC, the total reflectance at the top of the atmosphere can be written as:

$$\rho_t(\lambda) = \rho_r(\lambda) + \rho_a(\lambda) + \rho_{ra}(\lambda) + T \cdot \rho_g(\lambda) + t \cdot \rho_w(\lambda) \quad (9)$$

Where  $\rho_r(\lambda)$  is the Rayleigh scattering reflectance,  $\rho_a(\lambda)$  is the aerosol scattering reflectance,  $\rho_{ra}(\lambda)$  is the reflectance resulting from the interaction of  $\rho_r(\lambda)$  and  $\rho_a(\lambda)$ ,  $\rho_g(\lambda)$  is the sun glint,  $t$  is the total diffuse atmospheric transmission and  $T$  is the total atmospheric direct transmission. If data are screened for sun glint, then the  $\rho_g(\lambda)$  term can be ignored. In the CZCS approximation, the term  $\rho_{ra}(\lambda) + \rho_a(\lambda)$  was approximated by the single scattering approximation  $\rho_{as}(\lambda)$ . Equation (9) thus becomes:

$$\rho_t(\lambda) = \rho_r(\lambda) + \rho_{as}(\lambda) + t \cdot \rho_w(\lambda) \quad (10)$$

In Case I waters, the term  $t \cdot \rho_w(\lambda_{NIR})$ , which is the NIR water reflectance at the satellite level is assumed to be zero. The term  $\rho_r(\lambda_{NIR})$  can be calculated and thus the term  $\rho_{as}(\lambda_{NIR})$  determined. Given 2 wavebands in the NIR it's possible to extrapolate  $\rho_{as}(\lambda)$  using:

$$\varepsilon_{as}(\lambda_{NIR}(1), \lambda_{NIR}(2)) = \rho_{as}(\lambda_{NIR}(1)) / \rho_{as}(\lambda_{NIR}(2)) \quad (11)$$

Which is used to calculate either  $c$  or the Angström exponent,  $n$ , where:

$$n = \ln[\varepsilon_{as}(\lambda_{NIR}(1), \lambda_{NIR}(2))] / \ln[\lambda_{NIR}(1) / \lambda_{NIR}(2)] \quad (12)$$

$\rho_w(\lambda)$  is calculated as:

$$\rho_w(\lambda) = [\rho_t(\lambda) - \rho_r(\lambda) - \rho_{as}(\lambda_{NIR}(2)) \cdot (\lambda / \lambda_{NIR}(2))^n] / t \quad (13)$$

The diffuse transmission can be approximated as:


$$t = \exp\{-(\tau_r \cdot 0.5 + \tau_{oz} + \tau_{wv}) / [1/\cos(\theta_v) + 1/\cos(\theta_s)]\} \quad (14)$$

and the direct transmission is approximated as:

$$T = \exp\{-(\tau_r + \tau_{oz} + \tau_{wv} + \tau_a) / [1/\cos(\theta_v) + 1/\cos(\theta_s)]\} \quad (15)$$

Where  $\tau_r$  is the Rayleigh optical thickness,  $\tau_{oz}$  is the ozone optical thickness,  $\tau_{wv}$  is the water vapour optical thickness,  $\tau_a$  is the aerosol optical thickness and  $[1/\cos(\theta_v) + 1/\cos(\theta_s)]$  is an approximation of the path length.

In Case II waters,  $\rho_w(\lambda_{NIR})$  is no longer zero and the observed  $\varepsilon(\lambda_{NIR}(1), \lambda_{NIR}(2))$  becomes:

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$$\varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)] = \{\rho_{as}[\lambda_{NIR}(1)] + t \cdot \rho_w[\lambda_{NIR}(1)]\} / \{\rho_{as}[\lambda_{NIR}(2)] + t \cdot \rho_w[\lambda_{NIR}(2)]\} \quad (16)$$

This epsilon can be expressed as:

$$\varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)] = \varepsilon_{as}[\lambda_{NIR}(1), \lambda_{NIR}(2)] + t \cdot \{\rho_w[\lambda_{NIR}(1)] - \varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)] \cdot \rho_w[\lambda_{NIR}(1)]\} / \rho_{as}[\lambda_{NIR}(2)] \quad (17)$$

Equation (3) shows that the ratio  $\rho_w(\lambda_{NIR}(1))/\rho_w(\lambda_{NIR}(2))$  will always be greater than unity, given  $a_w(\lambda_{NIR}(1)) > a_w(\lambda_{NIR}(2))$ . If the OLCI NIR bands are used then the value of  $\rho_w(\lambda_{NIR}(1))/\rho_w(\lambda_{NIR}(2))$  will be approximately 2, and  $\varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)]$  will be close to 1. Equation (16) may thus be approximated as:

$$\varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)] = \varepsilon_{as}[\lambda_{NIR}(1), \lambda_{NIR}(2)] + 0.5t / \rho_{as}[\lambda_{NIR}(2)] \quad (18)$$

If the NIR reflectance is not taken into account, equation (18) shows that any NIR water leaving reflectance will result in the observed  $\varepsilon[\lambda_{NIR}(1), \lambda_{NIR}(2)]$  being greater than the true  $\varepsilon_{as}[\lambda_{NIR}(1), \lambda_{NIR}(2)]$ .

This will result in an overestimation of the Angström exponent or c parameter in bright waters. The overestimation will then result in an overestimation of the extrapolated  $\rho_{as}(\lambda)$  and therefore underestimate or create negative values for the resultant  $\rho_w(\lambda)$  with the error being greater at shorter wavelengths. In areas of moderately high particles, where the atmospheric correction doesn't actually fail (negative  $\rho_w(\lambda)$  values), the blue / green ratio will be increased and result in anomalously high retrievals of biogeochemical parameters. In multiple scattering algorithms (e.g. Gordon & Wang, 1994 or Antoine & Morel, 1998) the erroneous estimation of  $\varepsilon(\lambda_{NIR}(1), \lambda_{NIR}(2))$  will result in the choice of the incorrect atmosphere model, with similar but less predictable results.

In order to solve this problem in bright waters, it's necessary to solve a coupled hydrological and atmospheric optical model in the NIR (700 - 900 nm) that provides estimates of  $\rho_{as}(\lambda)$  that can be used in either a single scattering or multiple scattering model.

It should be noted that if a similar architecture to MERIS is adopted for OLCI then the gaseous absorption is pre-corrected and (15) becomes:

$$t = \exp\{-\{\tau_r \cdot 0.5\} / [1/\cos(\theta_r) + 1/\cos(\theta_s)]\} \quad (19)$$

The direct transmission is not required, where there is an a prior correction for glint upstream.

### 3.5 Interactions with Water Vapour Determination

Figure 4 shows the relative gaseous transmission for the MERIS bands. At present, similar simple integrated values are not available for OLCI. However, the wavelengths are identical for the bands where water vapour is significant; band 10 and band 18. The 900nm water vapour band isn't shown



since it's off scale (0.737). It can be seen that that both  $\rho_w(709)$  and  $\rho_w(885)$  are influenced by errors in the retrieval of water vapour transmission.

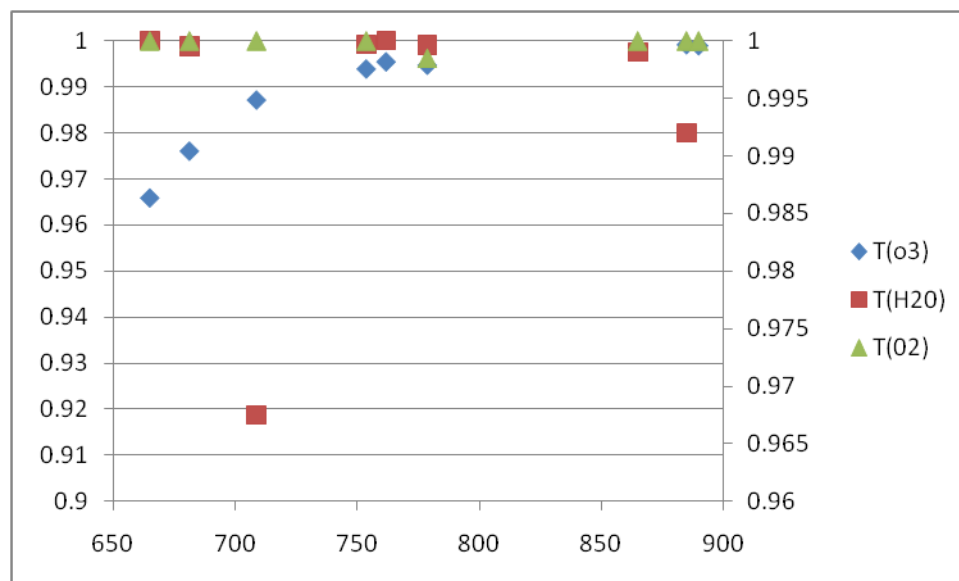



Figure 4: MERIS Gaseous Transmission

Figure 5 shows the effects of the water vapour retrieval error over the Rio de la Plata in MERIS processed MEGS 8.0 (without vicarious NIR correction). The water vapour in Figure 5a is significantly elevated over the high sediment region as is the driving TOA band ratio (Figure 5b). The BWAC for MERIS does produce adequate retrievals if NIR reflectance (Figure 5c), however since the final alpha is over estimated (Figure 5d) it's probable that  $\rho_w(885)$  is overestimated.

It's proposed that the water vapour should be recalculated before the full iterative calculation of the BWAC, see Sections 3.22 and 3.23, since at this point the theoretical surface albedo ratio required by the water vapour retrieval / transmission algorithm is known (see OLCI ATBD 04).

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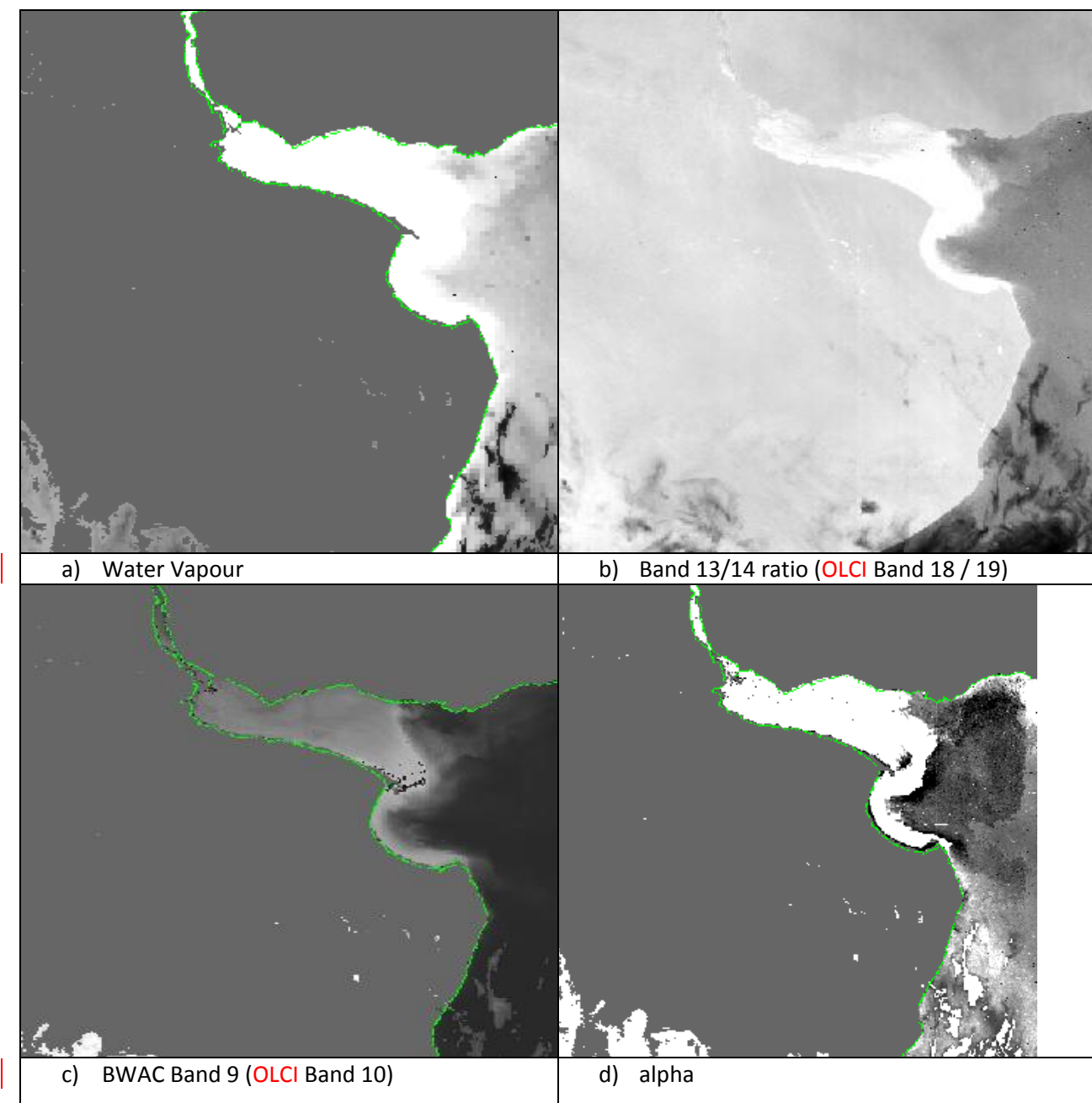


Figure 5: Influence of high reflectance on water vapour and alpha

### 3.6 Pure Water Absorption

Figure 6 shows the absorption of pure water from a number of sources. Although there is good agreement in the 680-700nm range, there is considerable disagreement at wavelengths greater than 700nm and especially at the OLCI 781 nm and 865 nm bands. For the BWAC, the final choice of values (Kou et al, 1993) was determined by observed similarity spectra in the NIR (Ruddick et al 2006) from Wetlabs technical reports. In the visible region, the values of Pope and Fry (1997) were chosen. In the region where the Pope and Fry (1997) and Kou *et al.* (1993) overlapped, the values were combined by giving a weighed window towards the visible for the Pope and Fry (1997) values and toward the NIR for the Kou *et al.* (1993) values. Both absorption and error estimates were combined and the full table is supplied in the current MERIS RMD. Both the Kou *et al.* (1993) and Pope and Fry (1997) values are estimated at a temperature of 22°C.

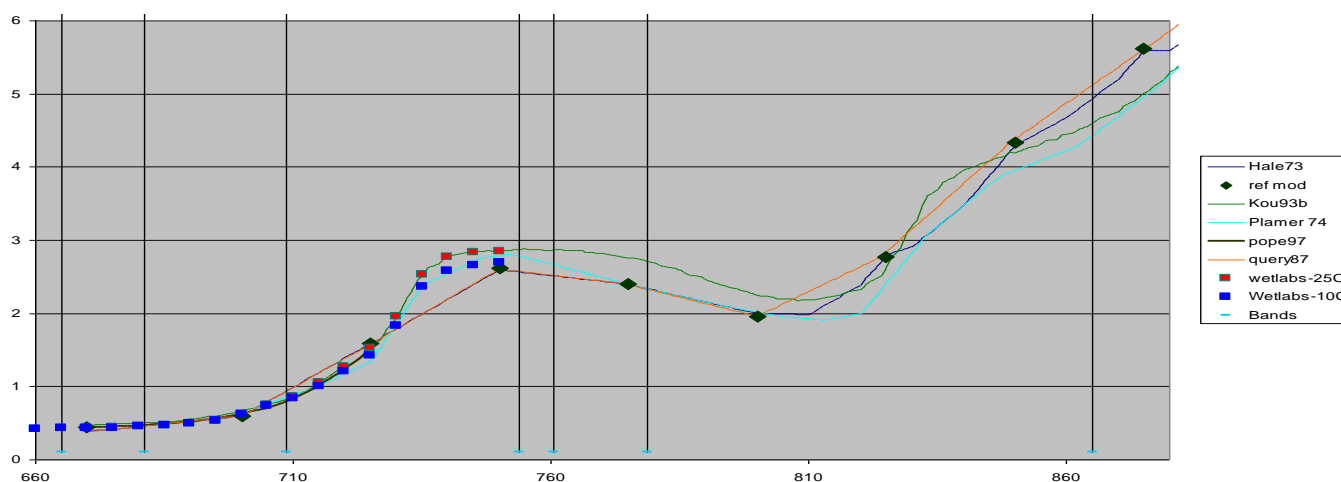


Figure 6: Variation in water absorption from literature

It should also be noted that both the Kou *et al.* (1993) and Pope and Fry (1997) absorption values are estimated at a temperature of 22°C. Temperature effects are more difficult to determine, but Wetlabs provide good figures up to 750nm and a set of Gaussian decompositions that can enable extrapolation. At wavelengths higher than this there are only brief technical reports.

Figure 7 shows one illustration and similar data are in qualitative agreement. In brief, all the NIR bands are to some extent influenced by temperature, but the greatest magnitude is at 753nm that will make interpretation of data from this band difficult without temperature correction. Preliminary coefficients for the variation of absorption with temperature are provided in the MERIS RMD.

From measures taken by Wetlabs to correct the hyper-spectral AC instrument, salinity effects have been determined and found to be at least an order or magnitude less than temperature effects. They may be influenced by instrument artefacts since it's difficult to discriminate between changes in absorption due to salinity and those caused by changes in the refractive index of water.

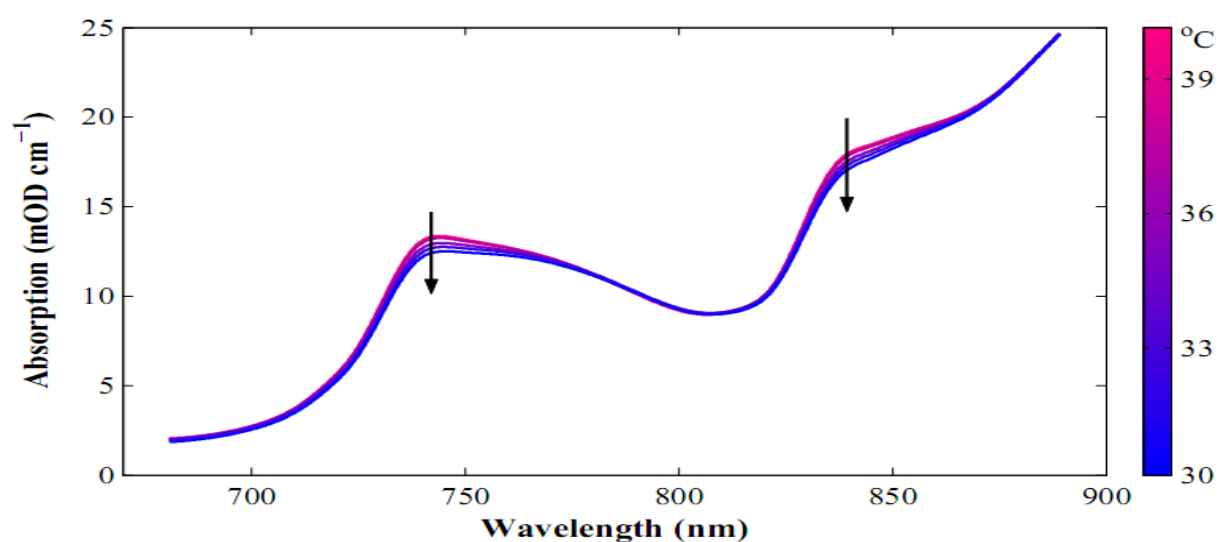



Figure 7: Temperature dependence of water absorption

Band	$\lambda(\text{nm})$	$da_w/dT$	$a_w(T=5)$	$a_w(T=15)$	%Change
7	665.000	0.00017	0.4254	0.4271	-0.40
8	681.250	0.00015	0.4767	0.4782	-0.32
9	708.750	0.00180	0.7885	0.8065	-2.24
10	753.750	0.00894	2.7153	2.8047	-3.19
11	760.625	0.00568	2.7705	2.8273	-2.01
12	778.750	0.00055	2.6857	2.6912	-0.20
13	865.000	0.00394	4.5489	4.5883	-0.86

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14	885.000	-0.00488	5.6423	5.5935	0.87
15	900.000	0.00049	6.3975	6.4024	-0.08

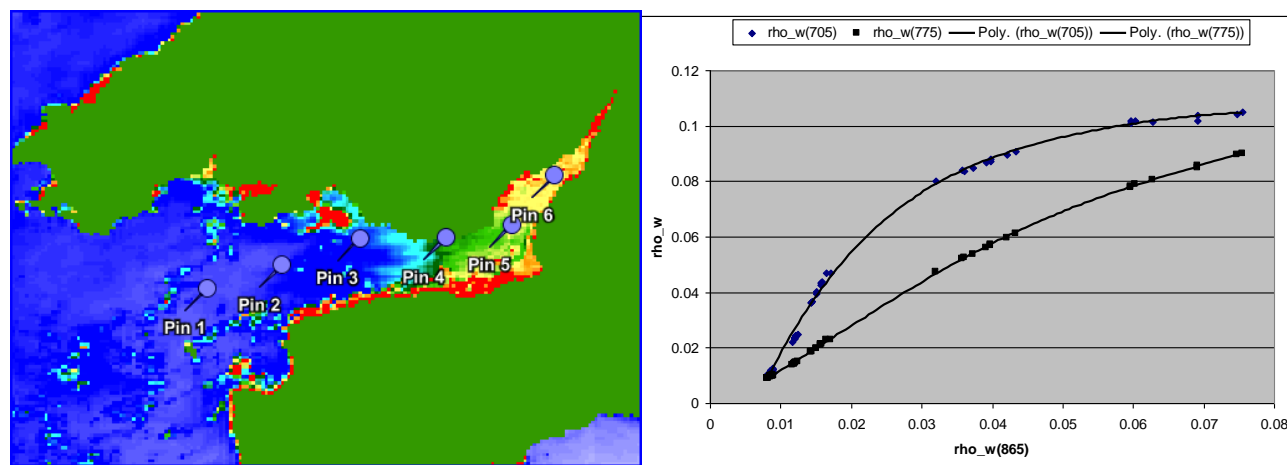
### 3.7 Pure Water Scattering

Values for pure water backscatter are chosen according to the RM for seawater. There is a change in seawater backscatter according to salinity, and sensitivity to this will be examined in a later ATBD release. This is only expected to affect case 1 waters and may require flagging in mesotrophic lakes; the current  $F'$  formulation permits this change of  $bb_w$ .

### 3.8 Sediment Absorption

NIR sediment properties at high concentrations are difficult to determine. In order to provide a preliminary set of coefficients to drive the **BWAC**, the equation for the limiting reflectance described in Section 3.2. was used on a MERIS image of the Severn estuary. Figure 9 shows a set of points along the Severn estuary plotted against scaled TOA 708.75nm reflectance; the image was ICOL processed in order to remove any adjacency effects. The data points were extracted from MEGS, and were Rayleigh and gaseous absorption corrected. The atmosphere was assumed to be homogenous over the area and a simple AC was performed by extrapolating the points to zero reflectance and assuming that this intercept was the true  $\rho_{as}$ . The value for alpha was obtained from the Level 2 image for pin 1 and pin2. This  $\rho_{as}$  was subtracted from all the pin points and the saturation radiance obtained by fitting a Gompertz curve to Figure 9b. The absorption obtained is given in the MERIS RMD, and showed a weak exponential decline with wavelength.

This exercise will be completed on further images and complemented by Mie modelling. Specifically this needs to be done for white scatters.



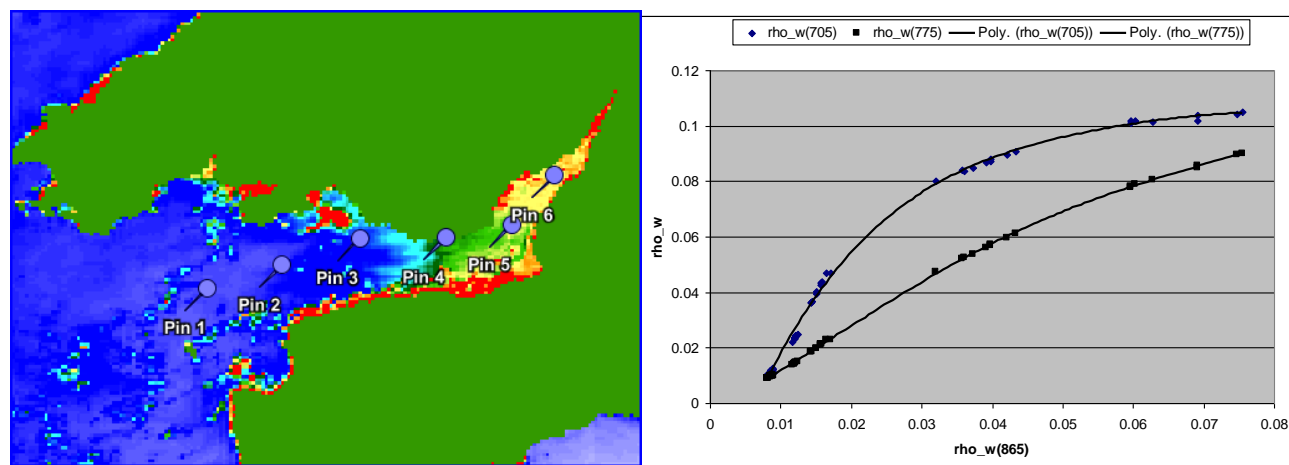
a) Severn estuary pin set

b) reflection saturation at the Severn estuary pin set

Figure 8: Reflectance saturation - Severn Estuary

### 3.9 Particulate IOPs

NIR sediment properties at high concentrations are difficult to determine. In order to provide a preliminary set of coefficients to drive the **BWAC**, the equation for the limiting reflectance described in Section 3.2 was used on a MERIS image of the Severn estuary. Figure 9a shows a set of points along the Severn estuary against scaled TOA 708.75nm reflectance; the image was ICOL processed in order to remove any adjacency effects. The data for the points were extracted from MEGS and were Rayleigh and gaseous absorption corrected. The atmosphere was assumed to be homogenous over the area and a simple AC was performed by extrapolating the points to zero reflectance and assuming that this intercept was the true  $\rho_{as}$ . The value for alpha was obtained from the level 2 image for pin 1 and pin2. This  $\rho_{as}$  was subtracted from all the pin points and the saturation radiance obtained by fitting a Gompertz curve to Figure 9b. The absorption obtained is given in the MERIS RMD, and showed a weak exponential decline with wavelength.



a) Severn estuary pin set

b) reflectance saturation at the Severn estuary pin set

Figure 9 Reflectance saturation - Severn Estuary

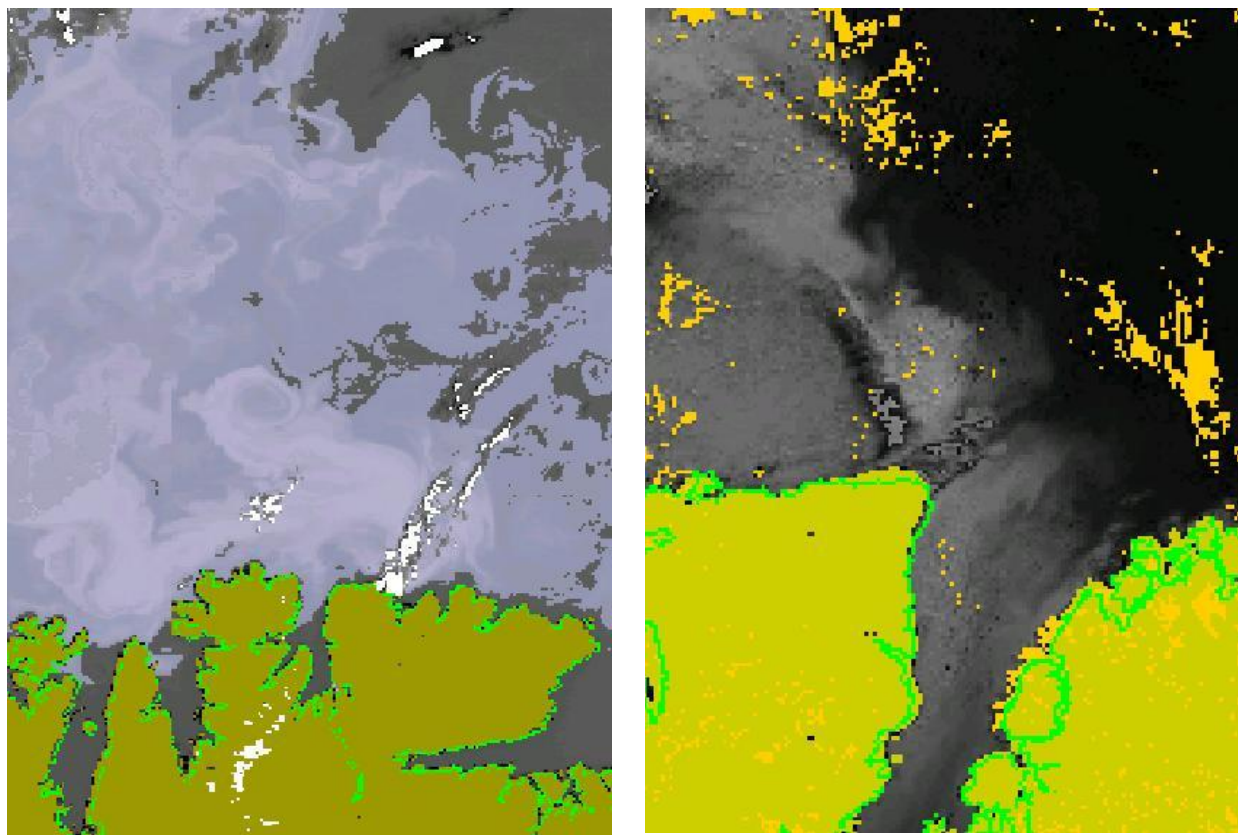
This exercise will be completed on further images and complemented by Mie modelling. Specifically this needs to be done for white scatters.

### 3.10 Flagging of Scattering Provinces

High sediment waters (HSW) are defined as having saturating reflectance at band 708.75nm and potentially higher, conversely Low sediment waters are defined as having a usable reflectance at 708.75nm.

Although white scatterers such a *coccolithophores* rarely have saturation reflectance at they have significantly different scattering properties, since they do not have the levels of associated CDOM.





a) Barents sea coccolithophores bloom      b) Amazon Plume

Figure 10: White scatterer flag

The white scatterers are detected by simple top of atmosphere log ratio flag and threshold where the flag is:

$$\ln\{[t_d(709)/t_d(620)][\rho_{rc}(620).a_w(620)]/[ \rho_{rc}(709).a_w(709)]\}/\ln\{620/709\}$$

The current flag threshold is 4.8, although this would need final adjustment when the final band set of OLCI is available. The flag has been implemented for the MERIS and Figure 10 shows a comparison of the flag output for highly reflective coccolithophores bloom in the Barents Sea (a) compared with a highly reflective scene over the Amazon plume (b). The assertion of the flag is shown as purple in the Barents. It can be seen that the flag is not asserted in the coastal waters of the Barents Sea and never asserted in the Amazon plume. Figure 11 shows the comparative 709/781 similarity slope for two scattering areas, the Barents Sea and the Severn estuary. Although the data range is different, the coccolithophores



maintain a linear slope up to a  $\rho_{rc}(709)$  of 0.02. This reflectance range will also encompass whitecaps and bubbles.

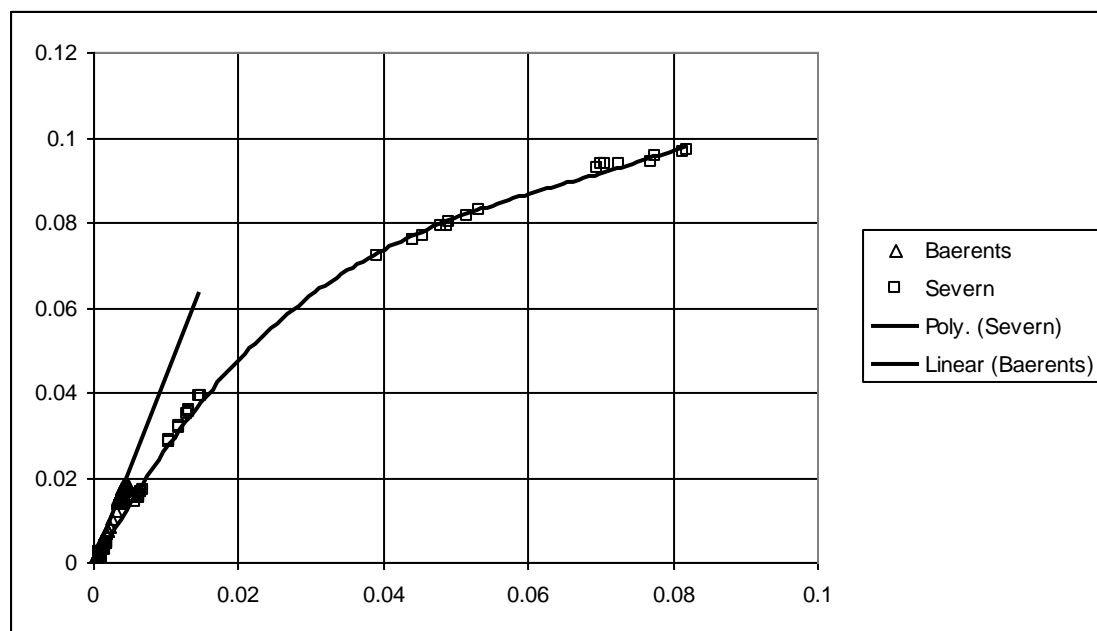


Figure 11: Comparative scattering in Severn Estuary and Barents Sea

### 3.11 Chlorophyll Fluorescence and absorption

Preliminary data from hyper-spectral radiometer measurements, where there is a strong fluorescence peak, indicate there is potential contamination of the 708.75nm band by the fluorescence signal. However, quantitative analysis of these results awaits an adequate stray-light correction scheme for these instruments. At present we assume that the Gaussian formulation of Gordon (1979) is appropriate.

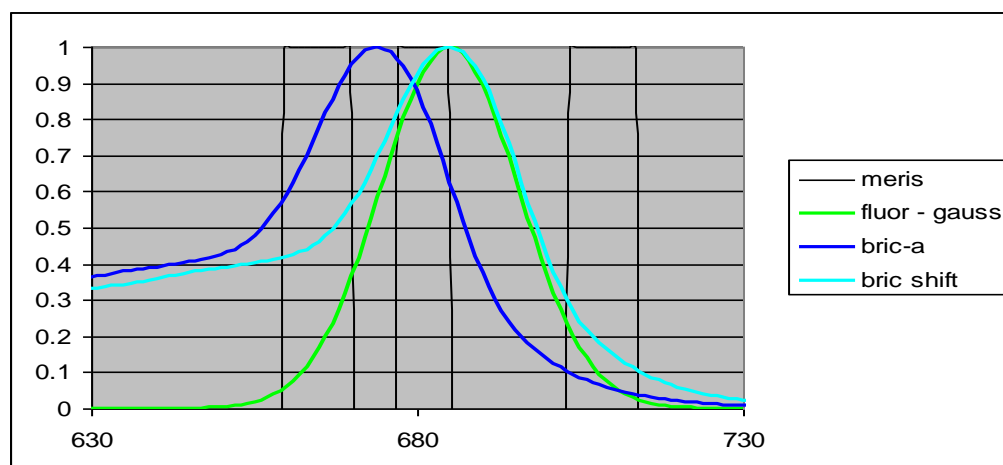
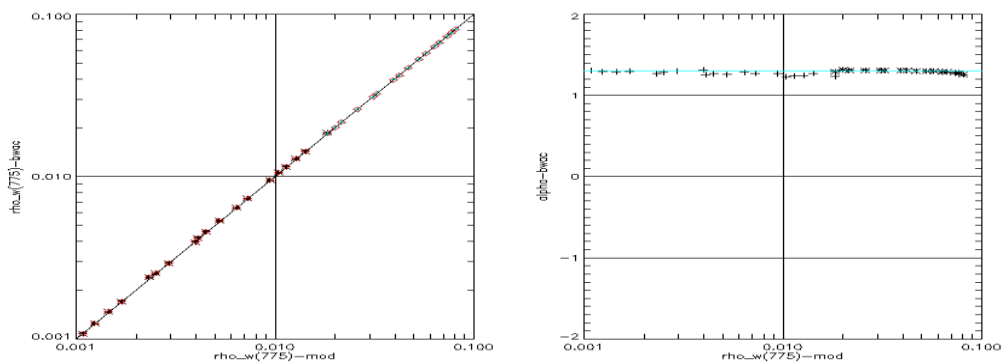


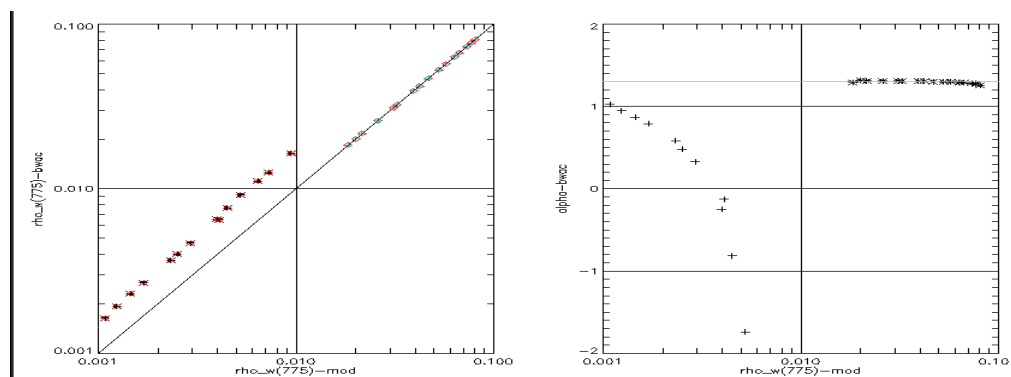
Figure 12: Chlorophyll fluorescence and absorption for MERIS / OLCI bands

Figure 12 shows the normalised chlorophyll fluorescence and absorption parameters described in the MERIS RMD. The absorption curve is from Bricaud *et al.* (1998) and the fluorescence curve is from the standard Gaussian in the RMD. Also shown for reference is the shifted absorption curve, since this may better match the chlorophyll fluorescence shown *in vivo*. It can be seen that there is significant overlap at the 708.75nm band. The extra reflectance at 708.75nm, due to fluorescence rather than particle scattering, results in an overestimate of  $\rho_w(NIR)$  and the consequent error in the BWAC.

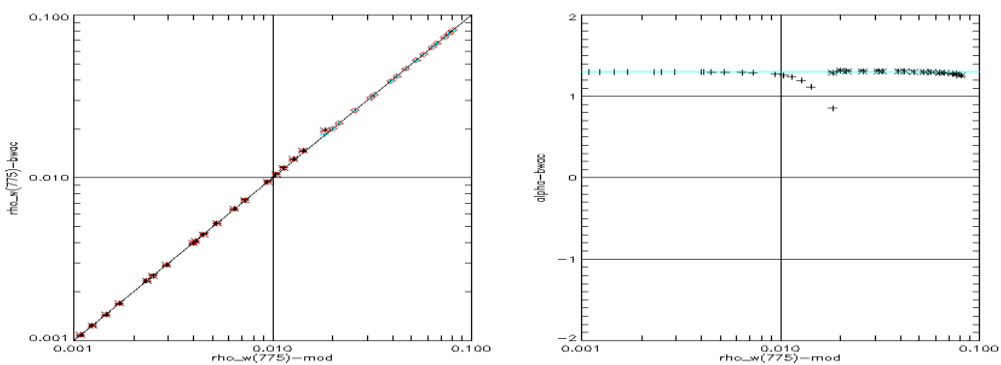
The effect can be corrected by using the first estimate of  $bb_p(708.75)$  derived in Section 3.22; the BWAC low band set solution. It's assumed that there is no fluorescence and thus the corrected reflectance  $\rho'_w(\lambda)$  is equal to  $\rho_w(\lambda)$  and that initially  $a_p(670)$  is zero. The solution is iterated until the relative change in  $\rho_f(685)$  is less than 0.01%. If  $\rho_f(685) \leq 0$  then the calculation is terminated since fluorescence correction is unnecessary. The  $bb_p(708.75)$  estimated from the fluorescence corrected reflectance is then returned to the BWAC. The iterative procedure typically takes around 5 iterations.



a) The nominal **BWAC** Correction – without natural fluorescence




b) The nominal **BWAC** Correction – with natural fluorescence



c) The **BWAC** Correction – with the fluorescence corrections and natural fluorescence

Figure 13: Effects of natural fluorescence on **BWAC**

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– row is calculated using the Angström exponent as..

$a_p(670)$  is estimated as follows:

$$bb_p(670)=bb_p^*(670).bb_p(709)/bb_p^*(709) \quad (F1)$$

$$a(670)=a_p(670)+a_w'(670)+bb_p(670).a_{bb}^*(670) \quad (F2)$$

$$F'=F'(670, \vartheta_v, \vartheta_s, \Delta\Phi, a(670), bb_w(670), bb_p(670)) \quad (F3)$$

$$a_p(670)=[bb_p(670)+bb_w(670)].[F'/\rho'_w(670)-1]-a_w'(670)-bb_p(670).a_{bb}^*(670) \quad (F4)$$

$\rho'_w(685)$  is estimated as follows:

$$bb_p(685)=bb_p^*(685).bb_p(709)/bb_p^*(709) \quad (F5)$$

$$a_p(685)=a^*_p(685).a_p(670)/a^*_p(670) \quad (F6)$$

$$a(685)=a_w'(685)+a_p(685)+bb_p(685).a_{bb}^*(685) \quad (F7)$$

$$F'=F'(685, \vartheta_v, \vartheta_s, \Delta\Phi, a(685), bb_w(685), bb_p(685)) \quad (F8)$$

$$\rho'_w(685)=F'.[bb_p(685)+bb_w(685)]/[bb_p(685)+bb_w(685)+a(685)] \quad (F9)$$

The fluorescence is estimate as follow, assuming  $K(\lambda) \approx a(\lambda)$  :

$$\rho_f(685)=\rho_w(685)-\rho'_w(685) \quad (F10)$$

$$\rho_f(\lambda)=\rho_f(685).Lfn(\lambda).EO(685).a(685)/Lfn(685).EO(\lambda).a(\lambda) \quad (F11)$$

where  $Lfn(\lambda)$  is the normalised fluorescence spectra derived from the Gaussian, and since  $EO(\lambda)$  is a constant, the fluorescence spectrum that is adjusted for  $EO(\lambda)$ ,  $\rho fn(\lambda)$  can be used.

The fluorescence corrected reflectance  $\rho'_w(\lambda)$  is derived as:

$$\rho'_w(\lambda)=\rho_w(\lambda)-\rho_f(\lambda) \quad (F12)$$

From this a new estimate of  $bb_p(709)$  is calculated according to Section 3.20 and iteration resumes at (F1).

Table 1 shows provisional values for the relative fluorescence height and for the chlorophyll specific absorption.

Band	$L_{fn}(\lambda)$	$\rho_{fn}(\lambda)$	$a_p(\lambda)$
670	0.1884	0.1810	0.3129
685	0.9135	0.9135	0.2053
709	0.1448	0.1514	0.0176

Table 1 Fluorescence height and phytoplankton absorption

### 3.12 Glint and Whitecaps

If uncorrected for at the pre-correct stage, both glint and white caps will propagate into the BWAC solution as an aerosol with an erroneous alpha. This is a limitation of the current iterative solution.

### 3.13 Solution Overview

Compared to the original implementation of the BWAC (e.g. Lavender *et al.* 2005) where TSM was used as a state variable, the OLCI algorithm is implemented in terms of the IOPs and the parameterisation as described in the previous sections. The solution relies on providing estimates from a low band set {709nm, 781nm, 865nm} and a high band set {781nm, 865nm, 885nm}. For the initial estimates, the first 2 wavelengths of the band sets are used.


### 3.14 Prerequisites

In the current MERIS processor the reflectance is pre-corrected for gaseous absorption, and thus the Rayleigh corrected reflectance is calculated from the glint and absorption corrected TOA reflectance,  $\rho_t(\lambda)$ :

$$\rho_{rc}(\lambda) = \rho_t(\lambda) - \rho_r(\lambda) \quad (S1)$$

For OLCI this not assumed, although desirable, the reflectance is corrected for gaseous absorption using the following diffuse transmission term:

$$t = \exp[-(\tau_{oz} + \tau_{ww})/\cos(\theta_v)] \quad (S2)$$

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### 3.15 Smile and Temperature effects

The smile effect (across the field-of-view the characteristics of the optics and slight misalignments of the sub-systems generally induce small variations of the spectral channels central wavelength, see OLCI ATBD C04), and is corrected as follows.

$$a_w'(\lambda') = a_w(\lambda) + K\lambda a * (\lambda - \lambda') + KTa * (22.0 - T) \quad (S2)$$

Where  $\lambda$  is the nominal wavelength of the standard water absorption,  $\lambda'$  is the actual MERIS wavelength and  $K\lambda a$  is the rate of change of water absorption with wavelength;  $T$  is the observed temperature, 22.0 is the standard laboratory temperature for which the tables are provided and  $KTa$  is the rate of change of absorption with temperature. At present, it's assumed that there is no interaction between  $K\lambda a$  and  $KTa$ . It's also assumed that  $bb_w$ ,  $bb_p$  and  $a_p$  have low sensitivities relative to wavelength. At present it's not known if there is will be a similar smile effect in the design of the OLCI; however at this point it's wise to include this as a potential correction. Temperature effects are significant in the 5-10 degree range and a simple monthly climatology is sufficient to correct for the major global water temperatures.

### 3.16 Choice of IOPs

The IOPs of  $bb_p^*(\lambda)$ , and  $a_{bb}^*(\lambda)$  are chosen according the white scatterers flag described in Section 3.10, and a simple table is provided for each scattering type. The dimensions of this table should not be fixed to allow for the detection of future scattering types.

### 3.17 Initial Estimates


The atmospheric path reflectance in the NIR can be solved simply if an Angström exponent is known and the shape of the water reflectance is known. The solution can be defined in terms of  $Kw$ , the TOA ratio of water reflectance at 2 bands ( $\lambda_1, \lambda_2$ ), and  $Ka$  the ratio of path radiance, related to the Angström exponent, but other atmosphere models could also be used. The ratios are defined as:

$$Kw = [\rho_w(\lambda_2) * t(\lambda_2)] / [\rho_w(\lambda_1) * t(\lambda_1)] \quad (I1)$$

$$Ka = (\lambda_2 / \lambda_1)^\alpha \quad (I2)$$

$$\rho_w(\lambda) = F'(\lambda, \vartheta_w, \vartheta_s, \Delta_\phi, a(\lambda), bb_w(\lambda), bb_p(\lambda)) * a(\lambda) / [a(\lambda) + bb_p(\lambda) + bb_w(\lambda)] \quad (I3)$$

$$a(\lambda) = a_w'(\lambda') + a_{bb}^*(\lambda) * bb_p(\lambda) \quad (I4)$$

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From (S5) and (S6) it can be seen that  $K_w$  is dependent on  $F'$  and  $bb_p(\lambda)$ . For the low band estimate,  $bb_p(781)$  is set to 0.001 and for the high band estimates  $bb_p(781)$  is set to 0.5; both compatible with case 1 waters. At the other wavelengths  $bb_p(\lambda)$  is determined from  $bb_p^*(\lambda)$ .

Given  $K_w$  and  $K_a$  it is possible to determine  $\rho_{as}(\lambda)$ , from a simple difference equation:

$$\rho_{as}(\lambda_1) = (\rho_{rc}(\lambda_1) - K_w * \rho_{rc}(\lambda_2)) / (K_a - K_w) \quad (I5)$$

In terms of practical implementation it should be noted that when  $K_a \approx K_w$ , then the  $\rho_{as}(\lambda_1)$  is undefined, since the atmospheric and water reflectance are identical. The water reflectance is simply estimated as:

$$\rho_w(\lambda_1) = (\rho_{rc}(\lambda_1) - \rho_{as}(\lambda_1)) / t(\lambda_1) \quad (I6)$$

### 3.18 Band Choice

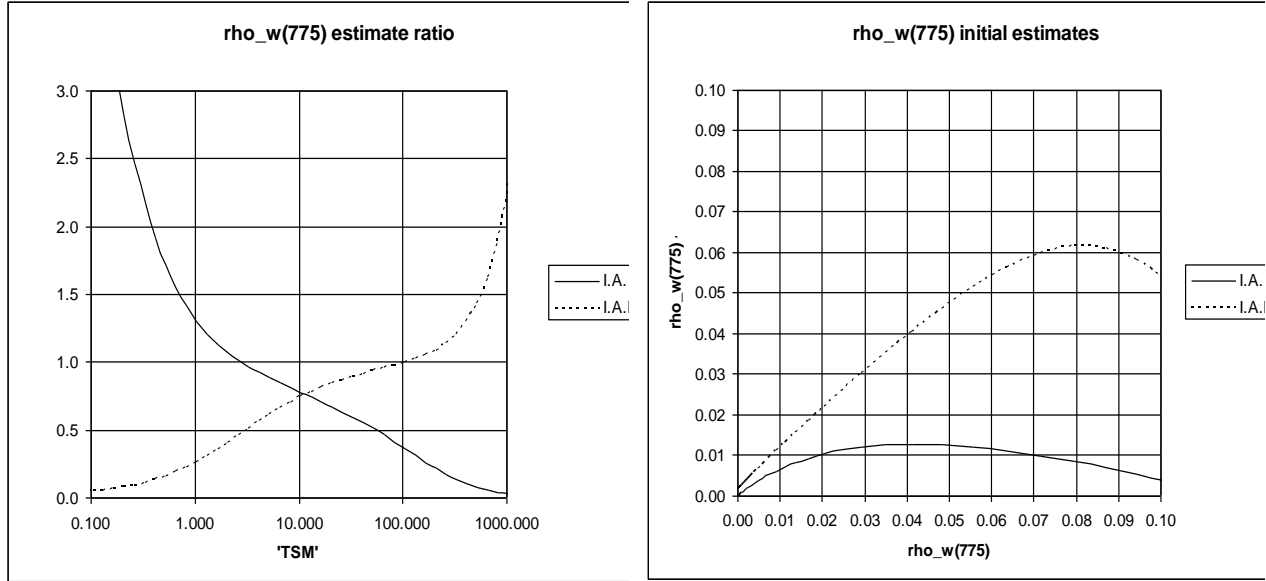
Figure 14a shows the relationship between TSM and the ratio of the true value of  $\rho_w(781)$  and the initial estimate of  $\rho_w(781)$ . The setting of the initial values of  $bb_p(781)$  gives mild overestimates for the low band estimates up to a value of around  $10 \text{ mg.m}^{-3}$  and matching underestimates for the high band estimate; this crossover point matches the applicability of the two iterative procedures and Figure 14b shows the corresponding reflectance estimates. The band choice is based on the high band estimate, since at high turbidities the low band estimate may become zero and is potentially affected by errors in the estimation of water vapour absorption.

The current thresholds are:

$$\rho_w(781) < 0.15 \rightarrow \text{Use low band set only}$$

$$\rho_w(781) > 0.02 \rightarrow \text{Use high band set only}$$

The level of overlap is chosen for computational efficiency and could be broadened.



a) Initial estimates vs. Nominal TSM

b) actual and initial estimates of  $\rho_w(781)$

Figure 14 BWAC Initial Estimates

### 3.19 Radiometric Threshold

The threshold is based on the number of **OLCI** counts, and on the low band  $\rho_w(709)$  estimate. The test is only applied when the high band estimate is less than 0.15, since depending of the sediment absorption at high turbidities the  $\rho_w(709)$  may be zero or negative.

The threshold is calculated as:


$$\min_{\rho_w(709)} = \pi * [n\_bit\_709.mean\_gain(709)] / [e0(709).cos(\theta_s)] / t_d(709) \quad (S3)$$

where  $mean\_gain(709)$  is the average gain over all the cameras,  $e0(709)$  is the TOA solar irradiance and  $n\_bit\_709$  is the desired threshold in **OLCI** counts. Both  $mean\_gain(709)$  and  $e0(709)$  should be in the same radiometric units. It is also assumed the **OLCI** gain will show low variability, since the purpose of this flag is to avoid unnecessary computation and to remove noise where the BWAC, so that the BWAC is not activated on pixels where  $\rho_w(709, 781, 865)$  are below the sensor noise.

### 3.20 Determination of $bb$ from $\rho_w(\lambda)$

The determination of  $bb_p$  as a function of  $\rho_w(\lambda)$  is non trivial in computational terms and is required for both the high and low band estimates.



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Given:

$$\rho_w(\lambda) = F \cdot a(\lambda) / [a(\lambda) + bb_w(\lambda) + bb_p(\lambda)] \quad (S4)$$

$bb_p$  can be inverted as :

$$bb_p(\lambda) = [\rho_w(\lambda) \cdot a(\lambda)] / [F' - \rho_w(\lambda)] - bb_w(\lambda) \quad (S5)$$

In Case 1 waters this does not present a problem since  $\rho_w(\lambda) < F'$ , and the can be iterated since  $a(\lambda) = aw'(\lambda) + a_{bb}^*(\lambda) * bb_p(\lambda)$ , convergence is simple achieved using  $\Delta bb_p(\lambda)$  as a convergence criteria.

Highly turbid Case 2 waters present a problem, since  $\rho_w(\lambda)$  can be  $>$  or equal  $F'$ , as a result there is either an arithmetic error, where the denominator above becomes zero or a negative  $bb_p(\lambda)$  is determined. In this case an estimate of  $bb_p(\lambda)$  is obtained  $F$ , where:

$$F = F' \cdot a(\lambda) / [a(\lambda) + bb_w(\lambda) + bb_p(\lambda)] \quad (S6)$$

and:

$$bb_p(\lambda) = [\rho_w(\lambda) \cdot a(\lambda)] / F - bb_w(\lambda) \quad (S7)$$

This is iterated using the above relationship for  $a(\lambda)$ , and convergence is achieved when  $F' > \rho_w(\lambda)$ . Thereafter the Case 1 iterative method is used.

### 3.21 Optional water vapour correction

Determine  $bb(781)$  from step I6 above using the equations in Section 3.20.

Determine  $\rho_w(\lambda)$ , with  $\lambda = 885, 890$


$$bb_p(\lambda) = bb_p^*(\lambda) \cdot bb_p(781) / bb_p^*(781) \quad (W1)$$

$$a(\lambda) = aw'(\lambda) + a_{bb}^*(\lambda) * bb_p(\lambda) \quad (W2)$$

$$\rho_w(\lambda) = F'(\lambda, \vartheta_w, \vartheta_s, \Delta\phi, a(\lambda), bb_w(\lambda), bb_p(\lambda)) * a(\lambda) / [a(\lambda) + bb_w(\lambda) + bb_p(\lambda)] \quad (W3)$$

Determine the surface albedo ratio as:

$$\rho_w(885) / \rho_w(890) \quad (W5)$$

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### 3.22 Low Band Solution

The iterative solution is initialised with an alpha and  $\rho_w(709)$  from the initial estimates above.  $bb_p(709)$  is calculated according to Section 3.20. This estimate is corrected for the natural fluorescence of chlorophyll described in Section 3.11 and convergence is based on the relative error of the estimated bb:

$$\text{abs}(bb_{p,iter-1} - bb_{p,iter})/bb_{p,iter} < \text{tol} \quad (\text{L1})$$

the tolerance is around 0.001, and the BWAC fails if  $\text{iter} > 30$ . The  $bb_p(709)$  estimated at this point the natural fluorescence is applied according to Section 3.11. From the new estimate of  $bb_p(709) - \rho_w(781)$ ,  $\rho_w(865)$  are calculated according to the IOPs:

$$bb_p(\lambda) = bb_p^*(\lambda) \cdot bb_p(709) / bb_p^*(709) \quad (\text{L2})$$

$$a(\lambda) = a_w'(\lambda) + a_{bb}^*(\lambda) \cdot bb_p(\lambda) \quad (\text{L3})$$

$$\rho_w(\lambda) = F'(\lambda, \vartheta_w, \vartheta_s, \Delta_\phi, a(\lambda), bb_w(\lambda), bb_p(\lambda)) \cdot a(\lambda) / [a(\lambda) + bb_p(\lambda) + bb_w(\lambda)] \quad (\text{L4})$$

The estimated  $\rho_{as}(\lambda)$  is determined as:

$$\rho_{as}(\lambda) = \rho_{rc}(\lambda) - \rho_w(\lambda) \cdot t(\lambda) \quad (\text{L5})$$

If either of these  $\rho_{as}(\lambda)$  are  $\leq$  to zero then this is treated as an exception and the BWAC has failed. The alpha corresponding to the  $\rho_{as}(\lambda)$  is calculated as:

$$\alpha = \ln(\rho_{as}(781) / \rho_{as}(865)) / \ln(781/865) \quad (\text{L6})$$

Optionally the value of alpha can be constrained at this stage such that  $\rho_{as}(412) \leq \rho_{rc}(412)$ . The difference equation in Section 3.17 is used to determine  $\rho_{as}(709)$ , where Kw and Ka are:


$$Kw = [\rho_w(781) \cdot t(781)] / [\rho_w(709) \cdot t(709)] \quad (\text{L7})$$

$$Ka = (781/709)^\alpha \quad (\text{L8})$$

A new estimate of  $\rho_w(709)$  is obtained from the  $\rho_{as}(709)$  estimated by the difference equation as:

$$\rho_w(709) = (\rho_{rc}(709) - \rho_{as}(709)) / t(709) \quad (\text{L9})$$

An estimate of  $\rho_w(709) \leq$  zero is treated as an exception and the BWAC fails. The procedure then proceeds to the next iteration. On successful completion  $\rho_w(781, 865, 885)$  are calculated according to (L2, L3, L4) and  $bb_p(781)$  is preserved in order to estimate TSM.

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### 3.23 High Band Solution

The iterative solution is initialised with an alpha and  $\rho_w(865)$  from the initial estimates above.  $bb_p(865)$  is calculated according to Section 3.20 and convergence is based on the relative error of the estimated bb:

$$\text{abs}(bb_{p,iter-1} - bb_{p,iter})/bb_{p,iter} < \text{tol} \quad (\text{H1})$$

The tolerance is around 0.001, and the BWAC fails if  $\text{iter} > 60$ . From the new estimate of  $bb_p(865)$  -  $\rho_w(781)$ ,  $\rho_w(885)$  are calculated according to the IOPs:

$$bb_p(\lambda) = bb_p * (\lambda) \cdot bb_p(709) / bb_p(709) \quad (\text{H2})$$

$$a(\lambda) = a_w'(\lambda) + a_{bb}^*(\lambda) * bb_p(\lambda) \quad (\text{H3})$$

$$\rho_w(\lambda) = F'(\lambda, \vartheta_w, \vartheta_s, \Delta_{\oplus}, a(\lambda), bb_w(\lambda), bb_p(\lambda)) * a(\lambda) / [a(\lambda) + bb_p(\lambda) + bb_w(\lambda)] \quad (\text{H4})$$

The estimated  $\rho_{as}(\lambda)$  is determined as:

$$\rho_{as}(\lambda) = \rho_{rc}(\lambda) - \rho_w(\lambda) \cdot t(\lambda) \quad (\text{H5})$$

If either of these  $\rho_{as}(\lambda)$  are  $\leq$  to zero then this is treated as an exception and the BWAC has failed. The alpha corresponding to the  $\rho_{as}(\lambda)$  is calculated as:

$$\alpha = \ln(\rho_{as}(781) / \rho_{as}(865)) / \ln(781/865) \quad (\text{H6})$$

Optionally the value of  $\alpha$  can be constrained at this stage such that  $\rho_{as}(412) \leq \rho_{rc}(412)$ . The difference equation in Section 3.17 above is used to determine  $\rho_{as}(865)$ , where Kw and Ka are:


$$Kw = [\rho_w(885) * t(885)] / [\rho_w(865) * t(865)] \quad (\text{H7})$$

$$Ka = (885/865)^\alpha \quad (\text{H8})$$

A new estimate of  $\rho_w(865)$  is obtained from the  $\rho_{as}(865)$  estimated by the difference equation as:

$$\rho_w(865) = (\rho_{rc}(865) - \rho_{as}(865)) / t(865) \quad (\text{H9})$$

An estimate of  $\rho_w(865) \leq$  zero is treated as an exception and the BWAC fails. The procedure then proceeds to the next iteration. On successful completion  $\rho_w(709, 781, 885)$  are calculated according to (H2, H3, H3) and  $bb_p(781)$  is preserved in order to estimate TSM.

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### 3.24 Practical consideration

The algorithm requires LUTs and is performed on a pixel-by-pixel basis.

### 3.25 Sensitivity and Noise

Certain very high sediment waters or extreme atmosphere types could return anomalous results. Both of these could be classified as cloud / land because of their high absolute reflectance. Lavender *et al.* (2005) showed that for SeaWiFS a non-unique solution to the inversion problem became more problematic at TSM concentrations greater than circa  $50 \text{ g m}^{-3}$ . The use of the upper band set improves this, and the expected performance is around  $500 \text{ g m}^{-3}$  before ambiguity occurs.


Results (e.g. Bale *et al.*, 1994) show that although the exact value of TSM iterated within the turbid water correction procedure may vary according to sediment properties, the relationships between the remote sensed reflectances are robust and independent of sediment type.

### 3.26 Product Blending

Where there is an estimate from both band sets the output is a simple arithmetic average. This may be upgraded in future to blend the data according to the final reflectance values. Note, both  $bb_p(781)$  is also an average for subsequent estimates of TSM.

## 4. FLAGS AND POTENTIAL PRODUCTS RESULTING FROM BWAC PROCESSING

- BWAC Failure
- TSM Load
- Case II sediment dominated waters
- Chlorophyll absorption at 665nm
- Chlorophyll fluorescence

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## 5. POTENTIAL FOR ‘QUICKLOOK’ GENERATION

The initial estimates for the high band shown in Figure 14b indicate that the high band estimate is quasi-linear over a wide range of sediment. Since the Rayleigh optical thickness is low in the NIR the transmission can be set to 1 and the high band initial estimate can be used a quicklook for relative TSM load.

## 6. FURTHER EVOLUTION

The present BWAC is capable of separating the spectral signature of atmospheric aerosols and water reflectance due to sediment. Potentially, both the spectral signatures of white-caps and glint can be accommodated into the model.


A number of preliminary iterative algorithms that extend the current 3 band solution to 4 bands (to account for glint) have been tested. However, these have proved unstable when tested with simulated data with noise. As such it will be necessary to use iterative non-linear minimisation techniques to explore these solution methods further. This means a substantive change in the algorithm, which at present has been implemented in MEGS 8.0 and has proved functional.

A second problem remains the lack of field radiometric data for the 1020nm band. It’s planned to use the SEN3EXP ‘MERIS OLCI mode’ test orbits to develop the BWAC algorithms further when this is available in the near future. Again, collaboration with the ESA WaterRadiance Project will be important since it’s necessary to obtain estimates of IOPs at the 1020nm band.

A number of robust minimisations techniques can be used in place of the iterative techniques currently used. These will be tested and implemented if substantive problems are found when the sediment absorption characteristics are evaluated.

## 7. ASSUMPTIONS AND LIMITATIONS

At present glint is not accounted for and is assumed pre corrected. It’s also assumed that the OLCI will be calibrated to +/- 1%.


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## 8. ERROR BUDGET

Figure 13a shows the forward simulation of the BWAC using the MERIS calibration factors and 1.5 bit of Gaussian noise. In the situation where the IOPs of particulates are known and without natural fluorescence the BWAC is 'highly accurate'. The error budget is dependent on the knowledge of the NIR IOPs of sediments and the range of absorption to scattering values, rather than the radiometric performance of OLCI provided that it is comparable with MERIS. At present the NIR IOPs of particulates are poorly known; however the work in progress in the Water Radiance Project, are comparable with those obtained in 3.8, obtained from TOA reflectance spectra in MERIS images. It's planned to use the results from the ESA WaterRadiance Project to test the sensitivity of the BWAC to a number of particulates. These will be used to determine and error budget on the output variables. The final reference model tables from the ESA Water Radiance project are expected to be delivered in September 2010. In the absence of this data we expect to be able to obtain parameters from two highly turbid estuaries, the Amazon plume and the Rio Formoso from collaborators in the US and Portugal.

## 9. BWAC BAND USAGE


Channel	Wavelength	Width	MERIS	BWAC Usage
O_1	400	15		YS-Conc./Flag
O_2	412.5	10	M_1	YS-Conc./Flag
O_3	442.5	10	M_2	YS-Conc./Flag
O_4	490	10	M_3	
O_5	510	10	M_4	
O_6	560	10	M_5	
O_7	620	10	M_6	
O_8	665	10	M_7	709 Correction
O_9	681.25	7.5	M_8	709 Correction
O_10	708.75	10	M_9	BWAC Baseline - Flag (LSW)
O_11	753.75	7.5	M_10	BWAC LSW
O_12	761.25	2.5	M_11	
O_13	764.375	3.75		
O_14	773.75	5		
O_15	781.25	10	M_12	BWAC LSW / Baseline - Flag (HSW)
O_16	862.5	15	M_13	
O_17	872.5	5		
O_18	885	10	M_14	BWAC(HSW)
O_19	900	10	M_15	
O_20	940	20		
O_21	1020	40		BWAC(HSW)

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Note grey areas mark changed bandwidths / centres for MERIS vs. Sentinel-3 **OLCI**.

## 10. REFERENCES

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