

SHORT COMMUNICATION

Effect of a waveband shift on chlorophyll retrieval from MERIS imagery of inland and coastal waters

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A chlorophyll-retrieval algorithm for use with imagery from the Medium Resolution Imaging Spectrometer (MERIS) aboard ENVISAT relying on wavebands centred at 665, 705 and 775 nm was described in a previous paper (Gons et al. 2002, J. Plankton Res., 24, 947–951). The present study reexamined the performance for the current nominal setting to 708.75 nm of the previously envisaged 705 nm band. Validation of the algorithm with revised coefficients gave the same standard error of estimate for the inland and coastal waters as in the original work. The algorithm has been transcribed for direct application with the MERIS level-2 standard product ‘water-leaving reflectance’. By this correction, chlorophyll estimation will generally improve, especially for high concentrations.

The Medium Resolution Imaging Spectrometer (MERIS) onboard the European environmental remote sensing satellite ENVISAT came into orbit in March 2002. The mission of MERIS includes quantifying distributions of phytoplankton in the open oceans and coastal waters as well as quantifying distributions of vegetation on the land surface (Rast *et al.*, 1999). The MERIS level-2 standard product ‘water-leaving reflectance’ is defined by $R_w(\lambda) = \pi L_w(\lambda)/E_d(\lambda)$, where $L_w(\lambda)$ and $E_d(\lambda)$ are upward radiance corrected for air–water interface reflection and downward irradiance just above the water surface, respectively, and λ denotes wavelength. The originally planned MERIS setting included bands 7, 9 and 12 to be centred at $\lambda = 665, 705$ and 775 nm respectively. We reported the potential use—for both inland and marine waters—of an algorithm to retrieve chlorophyll *a* (Chl *a*) and the uncorrected

pigment (Chl *a-u* = Chl *a* + phaeopigment/1.7), based on this setting (Gons *et al.*, 2002). Before launch, the mean wavelength of the bands 7, 9 and 12 over the five MERIS cameras was characterized as 664.3, 708.1 and 778.15 nm respectively. Even though alterations can be made with the instrument in orbit, the current setting is likely to apply throughout MERIS’ lifetime (<http://envi-sat.esa.int/dataproducts/meris/>).

In the algorithm development, chlorophyll retrieval from MERIS data was emulated using spectral subsurface irradiance reflectance $R(0, \lambda)$ at 664, 704 and 776 nm from shipboard spectroradiometry (Gons, 1999). In short, this algorithm exploits the reflectance ratio of bands 9 and 7—here denoted R_M —as a measure of Chl *a* absorption with due correction for absorption by water and band 12 to derive the total backscattering coefficient (b_b). In particular, band 9’s current deviation of 4–5 nm from 704 nm can

be expected to significantly influence Chl *a* retrieval according to the unadapted algorithm, because the absorption coefficient of water increases by >10% in this interval (Buiteveld *et al.*, 1994). Less important is the 2 nm shift for band 12 for which the pure water absorption coefficient changes by <1.5%. This latter effect on b_b retrieval is small, and hence the effect on Chl *a* retrieval can be neglected in the present reexamination of the algorithm.

The effect on Chl *a* retrieval of the shift in MERIS band 9 was tested using the same data as those of Gons *et al.* (2002), spanning Chl *a* concentrations *in situ* from 1 to 185 mg m⁻³. MERIS data for the bands 7, 9 and 12 in the current setting were emulated using shipboard-derived $R(0,\lambda)$ in the 664, 708 and 776 nm bands respectively. Thus, the only change was the replacement of the 704 nm waveband by that at 708 nm.

The algorithm needs calibration of two parameters, namely the Chl *a*-specific absorption coefficient, denoted a^* , and an empirical constant close to unity, denoted p . It was examined first how Chl *a* retrieval is affected when the current ratio R_M —emulated from the shipboard data for the wavebands of 708 and 664 nm—is used with the original values $a^* = 0.0146 \text{ m}^2 \text{ (mg of Chl } a)^{-1}$ and $p = 1.063$. The retrieved values (mg m⁻³) for the algorithm with current [C] and original [O] ratio appeared to be very strongly and linearly correlated according to $[C] = 1.06[O] - 5.3$ ($n = 205$; $r^2 > 0.998$; SE = 1.5). The greatest difference in retrieved value was 11 mg m⁻³ and occurred for Chl *a* = 170 mg m⁻³. Differences <2 mg m⁻³ occurred over a broad interval of 55–107 mg m⁻³ of Chl *a* measured *in situ*. In the lower range of Chl *a* concentrations, the absolute difference was <9 mg m⁻³, but of course relative differences became large.

Thus, it appeared that the algorithm is rather insensitive to this waveband shift even without correcting for the changed absorption coefficient of water. This conclusion certainly holds true for midrange Chl *a* concentrations, in which instance the rather broad reflectance peak in the red-to-near-infrared spectral region is located near 705 nm. Therefore, the reflectance of band 9, and thus R_M , changes little if at all by a band shift from 704 to 708 nm. In the case of high or low Chl *a* concentration, band 9 is located further down either slope of the reflectance peak. Then, the same band shift involves appreciable changes in reflectance, with either increase or decrease of retrieved Chl *a*.

The coefficients a^* and p were recalibrated for the 708 nm band replacing that at 704 nm using the same IJssel Lagoon data as in the previous calibration (Gons *et al.*, 2002). The absorption coefficient of water was changed from 0.63 m⁻¹ for 704 nm to 0.70 m⁻¹ for 708 nm (Buiteveld *et al.*, 1994). For Chl *a*, the revised

values were $a^* = 0.0161 \pm 0.0002 \text{ m}^2 \text{ (mg of Chl } a)^{-1}$ and $p = 1.062 \pm 0.006$ ($n = 114$; $r^2 = 0.96$), and for Chl *a*-u, these were $a^* = 0.0139 \pm 0.0002 \text{ m}^2 \text{ (mg of Chl } a\text{-u})^{-1}$ and $p = 1.054 \pm 0.006$ ($n = 114$; $r^2 = 0.97$). Both a^* values were ~10% higher, whilst the p values remained nearly the same as previously. Validation of the revised algorithm gave the same standard error of estimate of ~9 mg Chl *a* m⁻³ for the various inland and coastal waters of the previous study. In conclusion, MERIS band 9's shift will not detract from applicability of this simple, rapid chlorophyll-retrieval algorithm.

Finally, the algorithm is transcribed here so as to allow direct substitution of the MERIS level-2 standard product $R_w(\lambda)$ instead of $R(0,\lambda)$. In the band ratio R_M , the difference in these reflectances may be largely cancelled (see further), but the backscattering coefficient b_b is derived from reflectance at a single waveband (Gons, 1999), here written for MERIS band 12 centred at $\lambda = 778 \text{ nm}$:

$$b_b = \frac{R(0,778)a_w(778)}{0.082Q - R(0,778)} \quad (1)$$

where Q is the subsurface upward radiance to irradiance conversion factor and $a_w(778)$ is the absorption coefficient of water at this waveband. It follows from dividing by Q that

$$b_b = \frac{R_L(0,778)a_w(778)}{0.082 - R_L(0,778)} \quad (2)$$

where $R_L(0,778)$ is subsurface radiance reflectance, i.e. the ratio of upward radiance to downward irradiance at null depth. Note that upward radiance varies with nadir angle; thus, $R_L(0,\lambda)$ is valid for the specified measurement geometry only. However, for turbid waters considered here, the angular dependence over the 0–30° nadir interval will be small (Morel and Gentili, 1993).

Thus, in order to obtain values of b_b from the MERIS standard product, it is necessary to establish the conversion factor $R_L(0,\lambda)/R_w(\lambda)$. From equation (10) of Mobley (1999), it can be written as

$$\frac{R_L(0,\lambda)}{R_w(\lambda)} = \frac{1}{\pi T} \quad (3)$$

where the quantity T , accounting for bidirectional refraction and reflection at the water surface, has a value close to 0.54 (Morel and Gentili, 1996; Mobley, 1999). Hence, the factor $R_L(0,\lambda)/R_w(\lambda)$ is expected to be ~0.59. For shipboard measurements on various water, under mostly clear sky at markedly varying sun zenith angle (θ_0), this factor varied by no more than 6% over the whole 380–780 nm spectrum. Differences between the MERIS bands 7 and 9 were <1% (Table I). Indeed,

Table I: Factor $R_L(0,\lambda)/R_w(\lambda)$ for conversion of ‘water leaving reflectance’ to subsurface radiance reflectance at the wavebands 664, 708 and 778 nm computed for four stations on Lake IJsselmeer, 3 July 2001

θ_0 (degree)	F	Z_{SD} (m)	Chl a concentration (mg m^{-3})	Factor 664 nm	Factor 708 nm	Factor 778 nm
60.4	0.19	1.5	23	0.609	0.608	0.614
49.1	0.13	1.2	46	0.592	0.587	0.596
40.0	0.11	0.8	52	0.588	0.584	0.592
31.4	0.23	0.6	56	0.588	0.585	0.591

θ_0 is sun zenith angle. F is fraction of diffuse light in downward irradiance (400–700 nm). Z_{SD} is Secchi-disk depth.

the ratio R_M does not significantly change by use of $R_w(\lambda)$ instead of subsurface reflectance. For MERIS band 12, the conversion factor decreased from 0.61 to 0.59 at $\theta_0 = 60$ and 31° respectively. The mean value of 0.60 to convert $R_w(778)$ to $R_L(0,778)$ can be taken for general application, giving together with $a_w(778) = 2.69 \text{ m}^{-1}$ (Buiteveld *et al.*, 1994)

$$b_b = \frac{1.61R_w(778)}{0.082 - 0.6R_w(778)} \quad (4)$$

Following substitution of the values $a_w(664) = 0.40 \text{ m}^{-1}$ and $a_w(708) = 0.70 \text{ m}^{-1}$ for the MERIS bands 7 and 9 (Buiteveld *et al.*, 1994), and the new values of a^* and b , the equations are

$$[\text{Chl } a] = \frac{R_M(0.70 + b_b) - 0.40 - b_b^{1.06}}{0.016} \quad (5)$$

$$[\text{Chl } a\text{-}u] = \frac{R_M(0.70 + b_b) - 0.40 - b_b^{1.05}}{0.014} \quad (6)$$

where R_M has been redefined as the MERIS band-9-to-band-7 ratio of ‘water-leaving reflectance’, b_b is obtained from the MERIS band 12 according to equation (4) and the pigment concentration is in mg m^{-3} .

Compared to the previously described algorithm, the new equations will provide more accurate estimates of chlorophyll concentrations in well-mixed water, in

particular, for high algal and cyanobacterial biomass with Chl $a > 100 \text{ mg m}^{-3}$.

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