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# A spectral weighting function for improving phytoplankton classification

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**Abstract:** A spectral weighting function is presented which optimizes phytoplankton classification from hyperspectral data taking the signal-to-noise ratio of the current image into account. The improvements are illustrated using a DESIS image from Lake Constance.



## 1. Spectral weighting

The new era of hyperspectral satellite sensors such as PRISMA, DESIS or EnMAP opens promising opportunities for distinguishing phytoplankton groups (PG's) from space at a high spatial resolution around 30 m. Because only parts of the spectrum bear information about the PG, the idea of giving the information-carrying bands a higher weight during data processing is explored. Such a weighting function can be applied, in principle, to any algorithm that makes use of all available bands. The following approach is chosen:

$$w(\lambda_i) = 1 + \frac{SNR^{image}(\lambda_i)}{SNR^{PG}(\lambda_i)} \times \frac{|\Delta R_{rs}(\lambda_i)|}{|\Delta R_{rs}(\lambda_{max})|}.$$

$w(\lambda_i)$ is the weight of band $i$ centered at wavelength $\lambda_i$. The term 1 ensures that all bands are used in order to distinguish the effect of phytoplankton from that of CDOM, TSM and sunglint. Spectral weighting is expressed as the product of a factor considering data quality in terms of the signal-to-noise ratio (SNR) and a factor measuring the information content of each band concerning phytoplankton classification in terms of remote sensing reflectance differences ($\Delta R_{rs}$). $SNR^{image}$ is the average SNR of the water pixels of the actual image, $SNR^{PG}$ is the minimum SNR required for phytoplankton classification, $\Delta R_{rs}(\lambda_i)$ is the average $\Delta R_{rs}$ caused by exchanging the dominating PG, and $\lambda_{max}$ is the wavelength most sensitive to PG. $SNR^{image}(\lambda_i)$ is extracted from the actual image, the other parameters are obtained from simulation as described in the next sections.

## 2. Influence of the phytoplankton group on reflectance

Simulations were made for 6,000 concentration combinations of water constituents representing typical inland and coastal waters around the globe to determine the function $|\Delta R_{rs}(\lambda)|$. The concentrations, IOPs and algorithms are described in [1]. For each concentration combination, remote sensing reflectance, $R_{rs}(\lambda)$, was simulated for four PG's, represented by specific absorption spectra of green algae, cyanobacteria, diatoms and dinoflagellates, and for each PG pair $(a, b)$ the difference $|\Delta R_{rs}^{a,b}(\lambda)| = |R_{rs}^{a}(\lambda) - R_{rs}^{b}(\lambda)|$ was calculated. With 4 groups, 6 pairings can be realized, adding up to 24,000 simulated spectra $R_{rs}(\lambda)$ and 36,000 spectra $|\Delta R_{rs}^{a,b}(\lambda)|$. Figures 1a and 1b show their medians. $|\Delta R_{rs}(\lambda)|$ is largest from 525 to 585 nm, hence this range provides most information about the phytoplankton group in most studied conditions. The most sensitive wavelength is $\lambda_{max}$ = 567 nm.

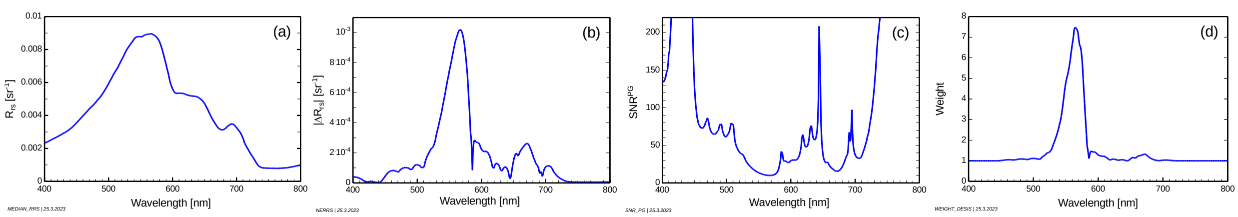


Figure 1: Median spectra of the simulations (a) $R_{rs}(\lambda)$, (b) $|\Delta R_{rs}(\lambda)|$, (c) $SNR^{PG}(\lambda)$ and weighting function $w(\lambda)$ derived for a DESIS image from Lake Constance (d).

## 3. Minimum SNR required for distinguishing phytoplankton groups

To resolve reflectance differences $\Delta R_{rs}(\lambda)$, the noise of the measurement must be below $|\Delta R_{rs}(\lambda)|$, hence the minimum SNR required for phytoplankton classification is given by $SNR^{PG}(\lambda) = R_{rs}(\lambda)/|\Delta R_{rs}(\lambda)|$. The median of the 36,000 simulations is shown in Figure 1c. For the most sensitive range, a minimum SNR near 20:1 is required. Less sensitive wavelengths and water darker than the median spectrum $R_{rs}(\lambda)$ from Figure 1a require a higher SNR.

## 4. Results

The impact of applying $w(\lambda_i)$ has been tested for several hyperspectral DESIS and EnMAP images. A DESIS image from Lake Constance is selected here for illustration, as it was the only one that allowed the distinction of four PG's. The standard deviation of $R_{rs}(\lambda)$ and the ratio $R_{rs}(\lambda)/stddev(R_{rs}(\lambda))$ were calculated for each water pixel from a 9 x 9 window, the ratio being the SNR. The average of the 10 pixels with lowest SNR at 560 nm was taken as $SNR^{image}(\lambda)$. This spectrum and the spectra from Figure 1a-c led to the weight function $w(\lambda_i)$ shown in Figure 1d.

Inverse modeling has been applied to the image twice: once weighting all bands equally, and once multiplying the squared differences of measurement and simulation with $w(\lambda_i)$ for calculating the least squares. Figure 2 compares the results.

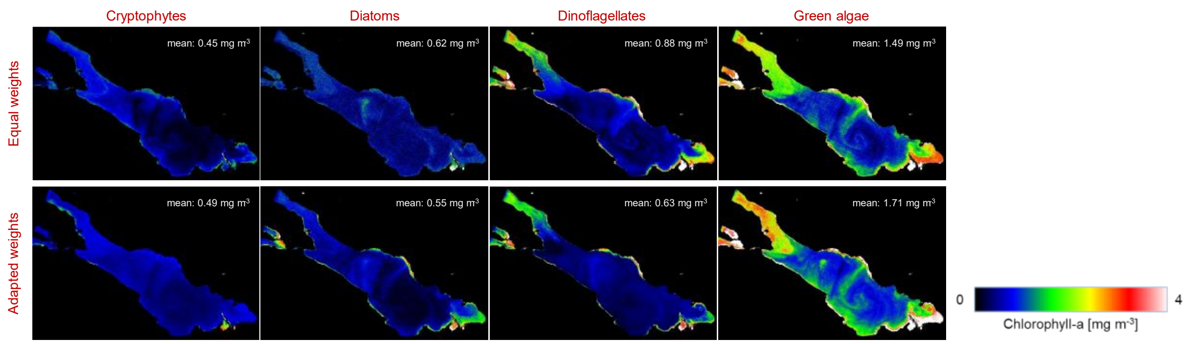


Figure 2: Phytoplankton classification for a DESIS image of Lake Constance on August 14, 2021. Upper row: all bands weighted equally. Lower row: Weighting function from Figure 1d applied.

The upper row of Figure 2 shows the chlorophyll-a concentration maps of the four PG's derived with equal weights, the lower row for applying $w(\lambda_i)$. The overall patterns and the average concentrations are similar, but the images using $w(\lambda_i)$ are less noisy. Since the noise is difficult to see in the chosen magnification, the coefficient of variation of the chlorophyll-a maps (standard deviation divided by mean of 9 x 9 pixels) is compared in Figure 3.

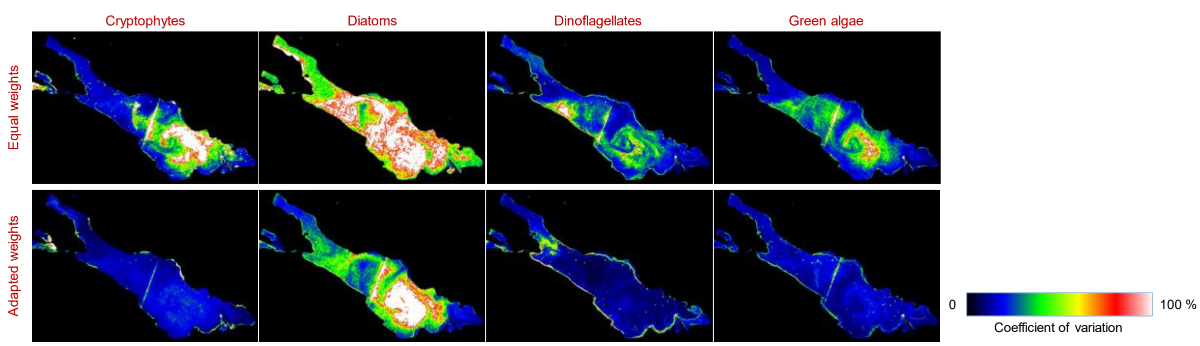


Figure 3: Coefficient of variation of the chlorophyll-a concentrations from Figure 2.

Figure 3 shows that spectral weighting reduces the coefficient of variation of all four PG's for most water pixels. Hence, spectral weighting reduces the noise of the derived concentrations, i.e. it improves the detection threshold.

## 5. Reference

[1] P. Gege and A.G. Dekker, "Spectral and radiometric measurement requirements for inland, coastal and reef waters," Remote Sensing **12**, 2247 (2020).