Improving phytoplankton classification from hyperspectral measurements taking the SNR into account

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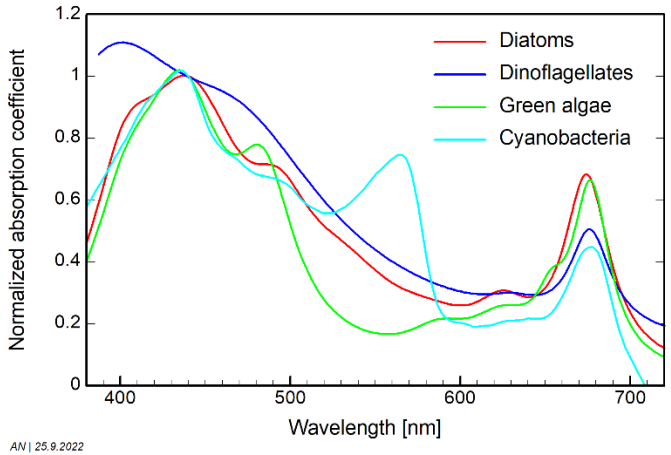
Ocean Optics XXV Conference, Quy Nhon, Vietnam, 2-7 October 2022

Maximum noise allowed for distinguishing phytoplankton groups

Simulations

- Software WASI[1,2] with Albert's bio-optical model[3] simulates remote sensing reflectance, $R_{rs}(\lambda)$
- Phytoplankton community composition is represented by 4 absorption spectra



$a^*_{dia}(440) = 0.036$ m² mg⁻¹

$a^*_{dino}(440) = 0.050$ m² mg⁻¹

$a^*_{green}(440) = 0.035$ m² mg⁻¹

$a^*_{cya}(440) = 0.033$ m² mg⁻¹

- Exchanging phytoplankton group: $|\Delta R_{rs,i,j}(\lambda)| = \left|R_{rs}(\lambda, a_i^N(\lambda)) - R_{rs}(\lambda, a_j^N(\lambda))\right|$
- Signal-to-noise ratio: $SNR^{PG}(\lambda) = \frac{R_{rs}(\lambda)}{|\Delta R_{rs}(\lambda)|}$

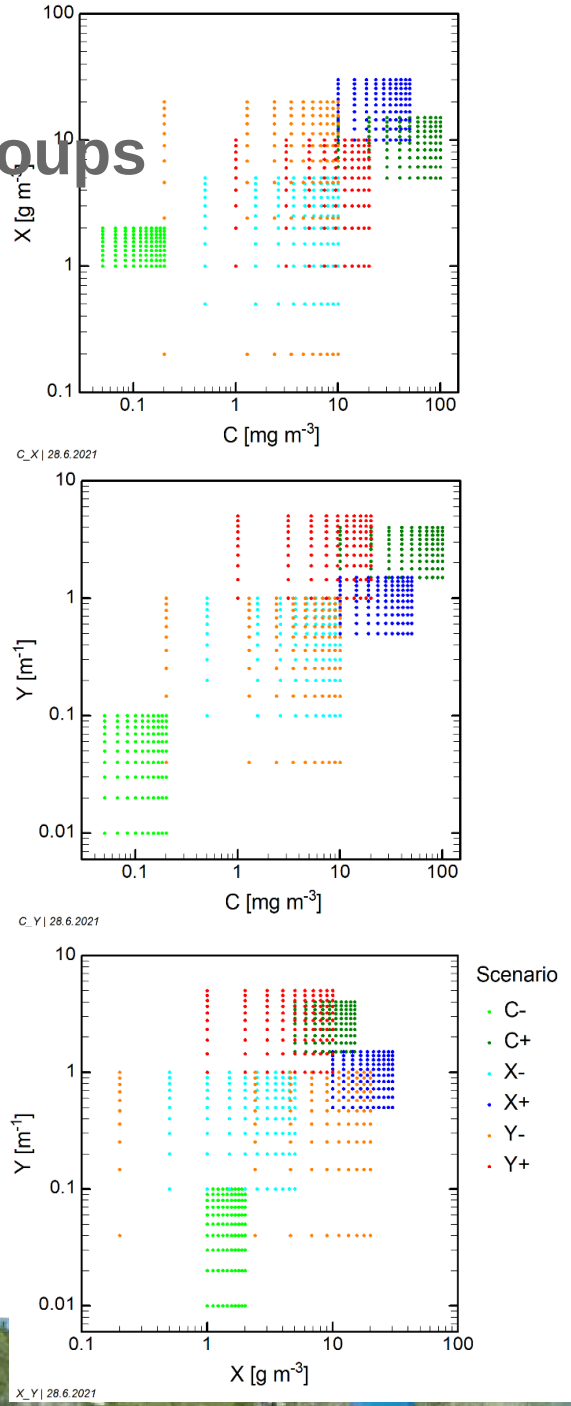
[1] Gege, P. The water colour simulator WASI: An integrating software tool for analysis and simulation of optical in-situ spectra. Computers & Geosciences 2004, 30, 523–532.
[2] WASI can be downloaded from https://ioccg.org/resources
[3] Albert, A.; Mobley, C.D. An analytical model for subsurface irradiance and remote sensing reflectance in deep and shallow case-2 waters. Opt. Express 2003, 11, 2873–2890.

Maximum noise allowed for distinguishing phytoplankton groups

Scenarios

- Covered ranges: Chl-a 0.05-100 mg m^{-3} , TSM 0.2-30 g m^{-3}, aCDOM(440) 0.01-5 m^{-1}
- Concentration combinations are oriented on well-studied waters („scenarios“)
- 1000 concentration combinations per phytoplankton group per scenario

Scenario	C–	C+	X–	X+	Y–	Y+
Represents	Low chl-a	High chl-a	Low TSM	High TSM	Low CDOM	High CDOM
Example	Reef water	Finnish lakes	Lake Constance	Netherlands	Lake Garda	Lake Peipsi
C, mg m^{-3}	0.05-0.2	10-100	0.5–10	10–50	0.2-10	1–20
X, g m^{-3}	1-2	5-15	0.5-5	10-30	0.2-20	1-10
Y, m^{-1}	0.01-0.1	1.5-4	0.1-1	0.5-1.5	0.04-1	1-5



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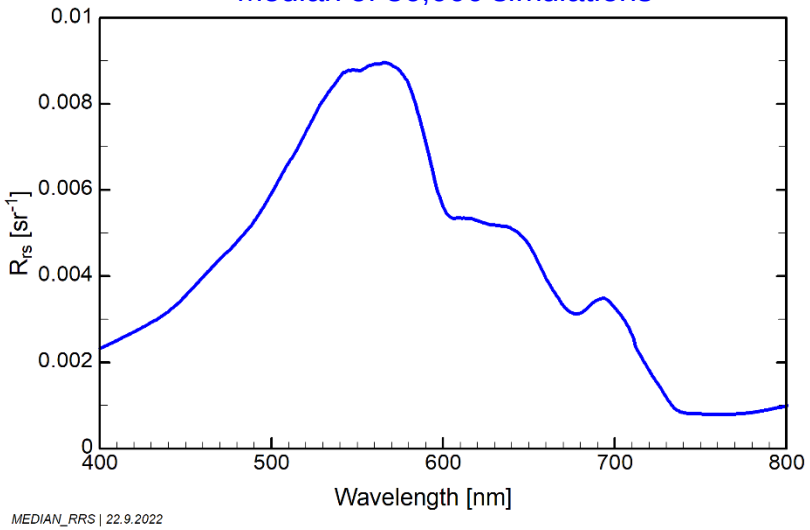
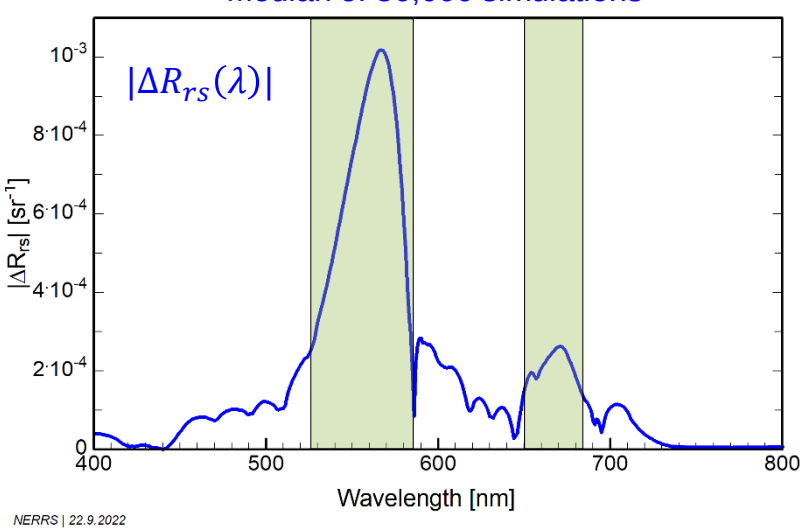
Result of simulations

Median of 36,000 simulations



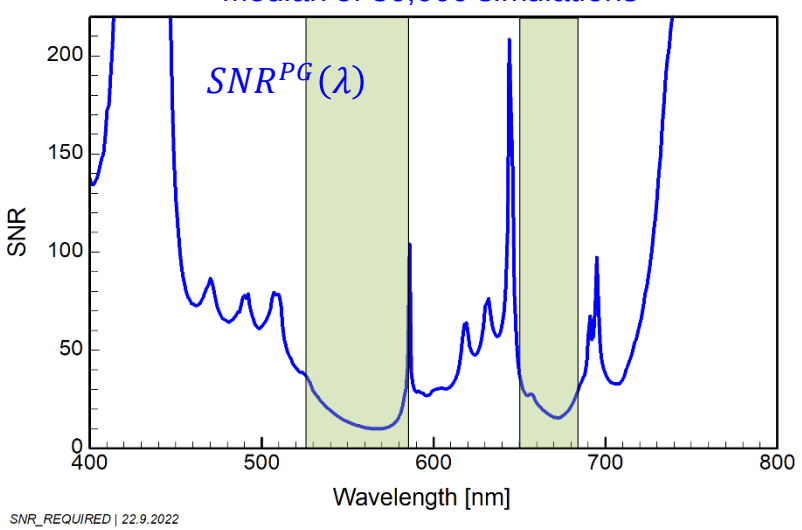
MEDIAN_RRS | 22.9.2022

Median of 36,000 simulations



NERRS | 22.9.2022

Median of 36,000 simulations



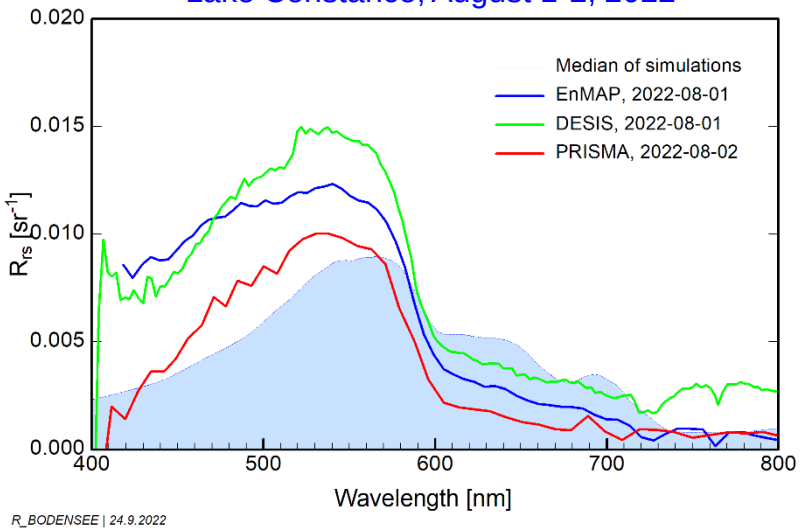
SNR_REQUIRED | 22.9.2022

- Maxima of $|\Delta R_{rs}|$ / Minima of SNR at
  - 525 – 585 nm
  - 650 – 682 nm
- These ranges provide most information about phytoplankton group
- Average $|\Delta R_{rs}|$ / SNR in these ranges:
  - $6.7 \cdot 10^{-4}$ sr^{-1} / 18:1
  - $2.1 \cdot 10^{-4}$ sr^{-1} / 22:1

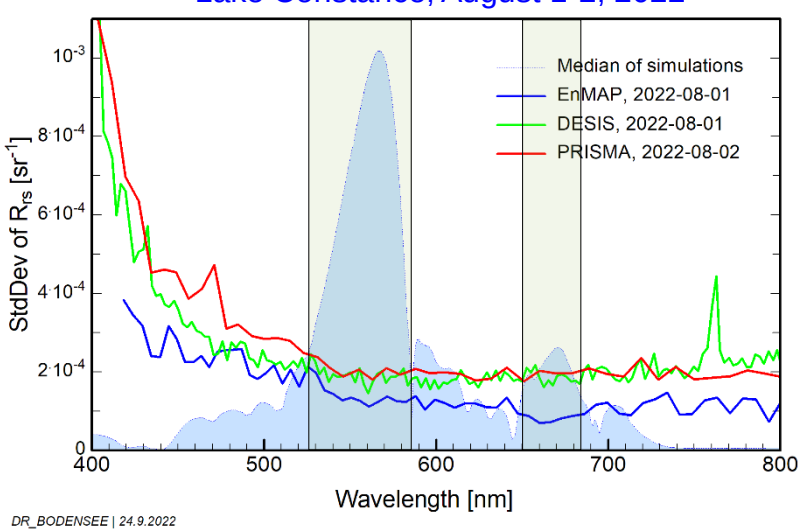
Maximum noise allowed for distinguishing phytoplankton groups

Comparison with real data

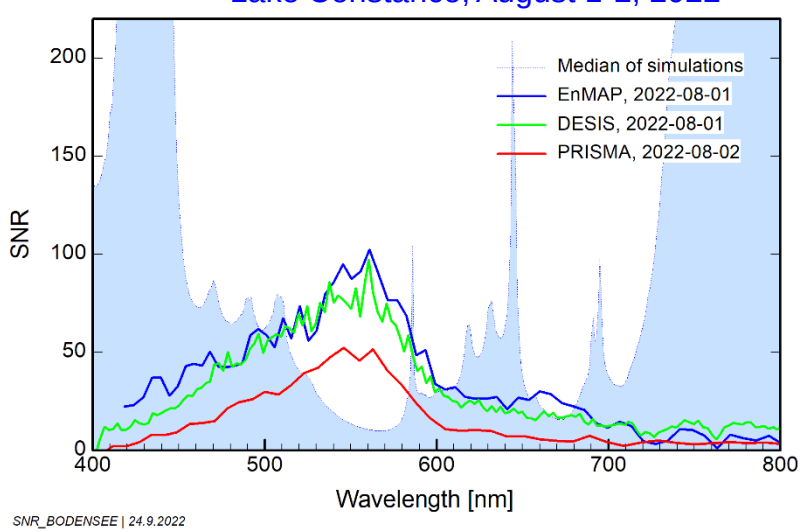
Lake Constance, August 1-2, 2022



Lake Constance, August 1-2, 2022



Lake Constance, August 1-2, 2022



Note: The shown EnMAP spectra are preliminary results from the still ongoing commissioning phase.

- R_{rs} is comparable to the median of the simulations
- Image noise is below the required $|\Delta R_{rs}|$ / SNR approximately at the wavelengths from the previous slide
  - 525 – 585 nm
  - 650 – 682 nm

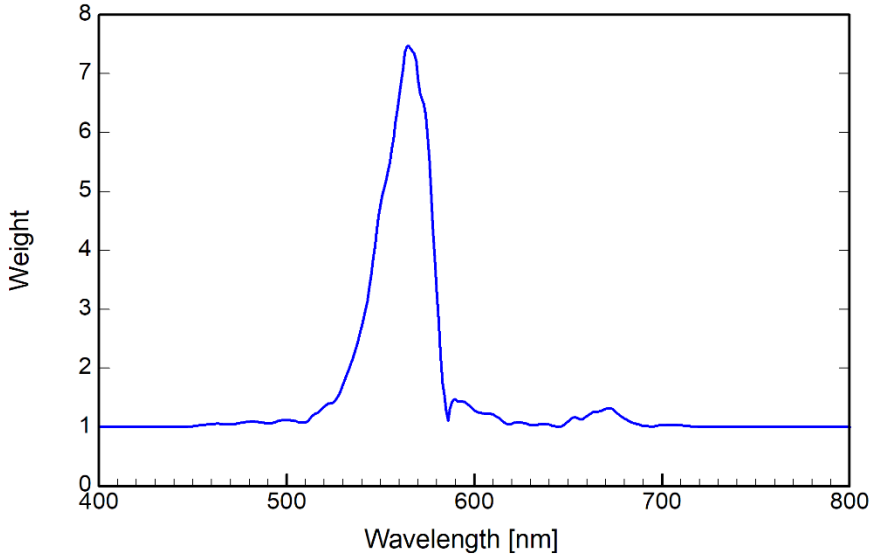
Spectral weighting

Application during inversion

Software WASI-2D[1] for inverse modelling.

Inversion minimizes Residuum Res = weighted sum of squared differences between measured and simulated R_{rs} values of each band i:

$$Res = \frac{1}{N}\sqrt{\sum_{i=1}^{N} w(\lambda_i)\left(R_{rs}^{measured}(\lambda_i) - R_{rs}^{simulated}(\lambda_i)\right)^2}.$$



Spectral weighting function w accounts for sensor noise and R_{rs} changes:

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

Measure of data quality

Measure of information content

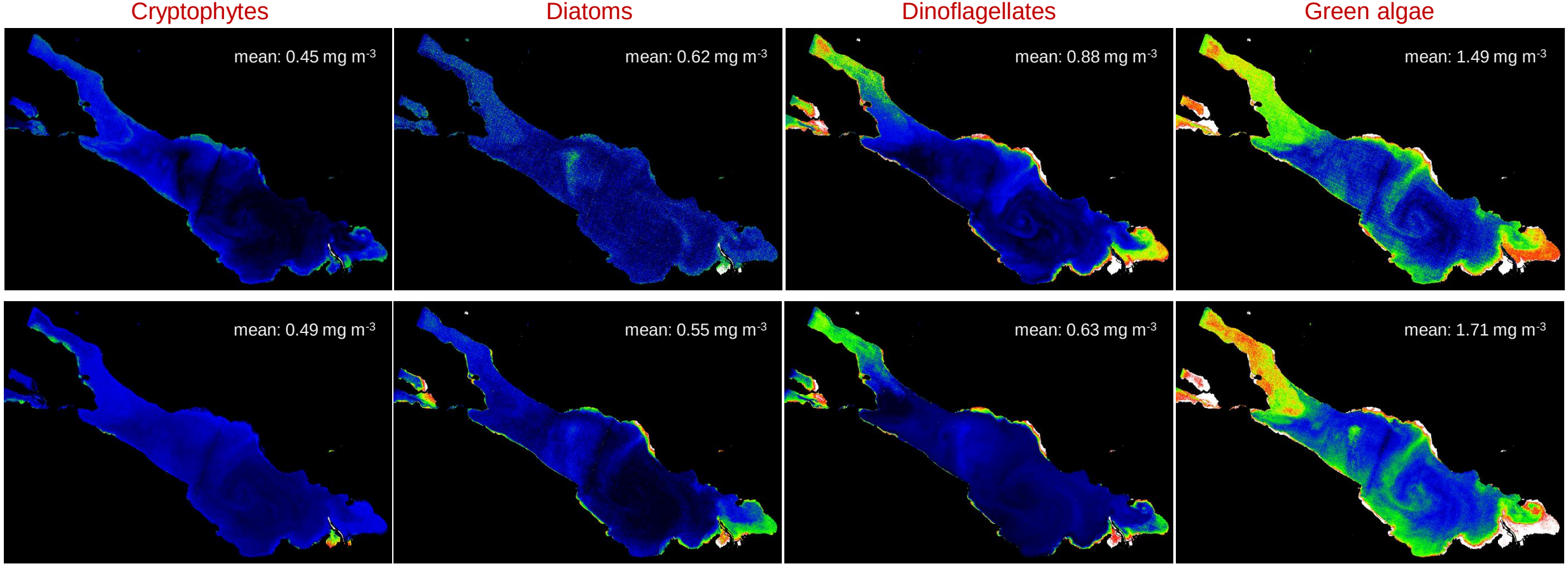
Red: from image

Blue: from simulation

[1] P. Gege. WASI-2D: A software tool for regionally optimized analysis of imaging spectrometer data from deep and shallow waters. Computers & Geosciences 2014, 62, 208-215.

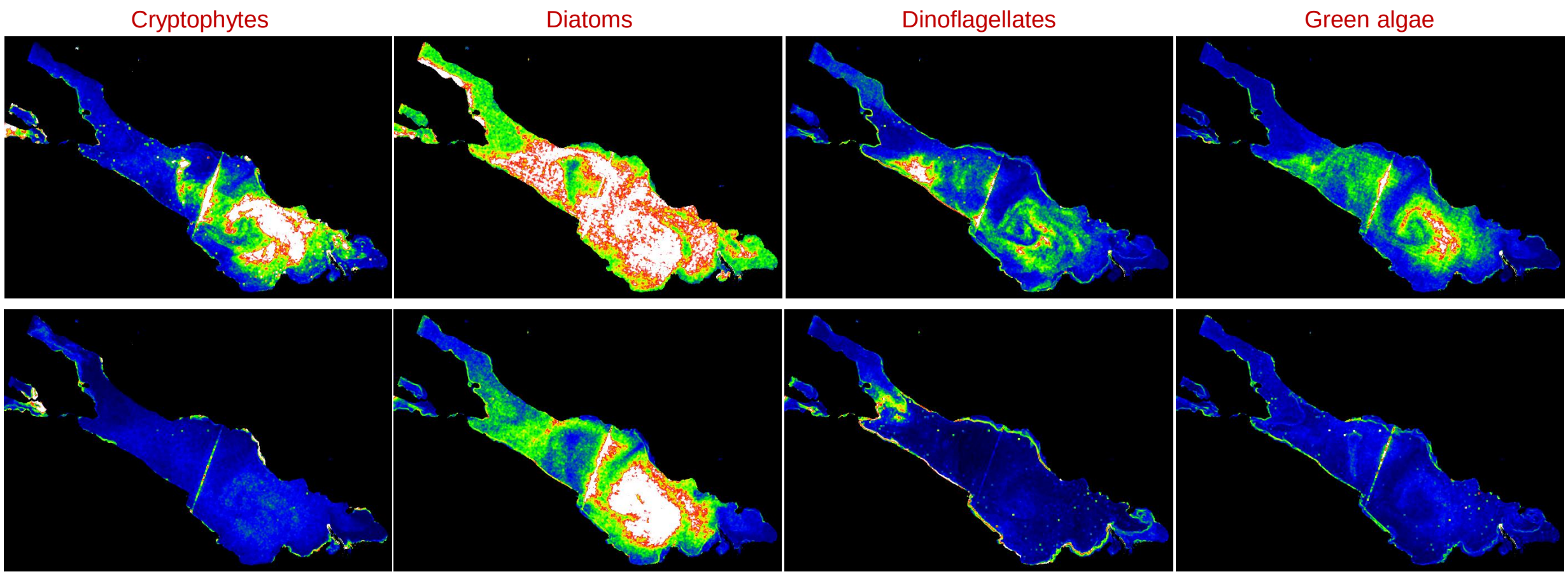
Example

DESIS 2021-08-14 Lake Constance



Example

DESIS 2021-08-14 Lake Constance



Summary

- Spectral range bearing most information about phytoplankton groups: 525-585 nm
- Required noise-equivalent $|\Delta R_{rs}|$ for phytoplankton classification (50 % of scenarios): $6.7 \cdot 10^{-4}$ sr^{-1}
- Required SNR for phytoplankton classification (50 % of scenarios): 18:1
- Spectral weighting decreases noise-induced uncertainty. Improves the detection limit

Acknowledgements

- Milad Niroumand Jadidi (FBK) for atmospheric correction of PRISMA image
- Stefan Plattner and Ian Somlai (DLR) for preparing DESIS image
- Nicole Pinnel and Raquel de los Reyes Lopez (DLR) for providing an EnMAP image
- Sebastian Fischer (DLR) and the EnMAP Mission Board for permission to show EnMAP results from the commissioning phase
- Martin Hieronymi (HEREON) for providing an absorption spectrum of cyanobacteria
- This study was partly funded by BMWK and DLR grant number 50EE1915

Thank you for your attention!