A SPECTRAL WEIGHTING FUNCTION FOR IMPROVING PHYTOPLANKTON CLASSIFICATION

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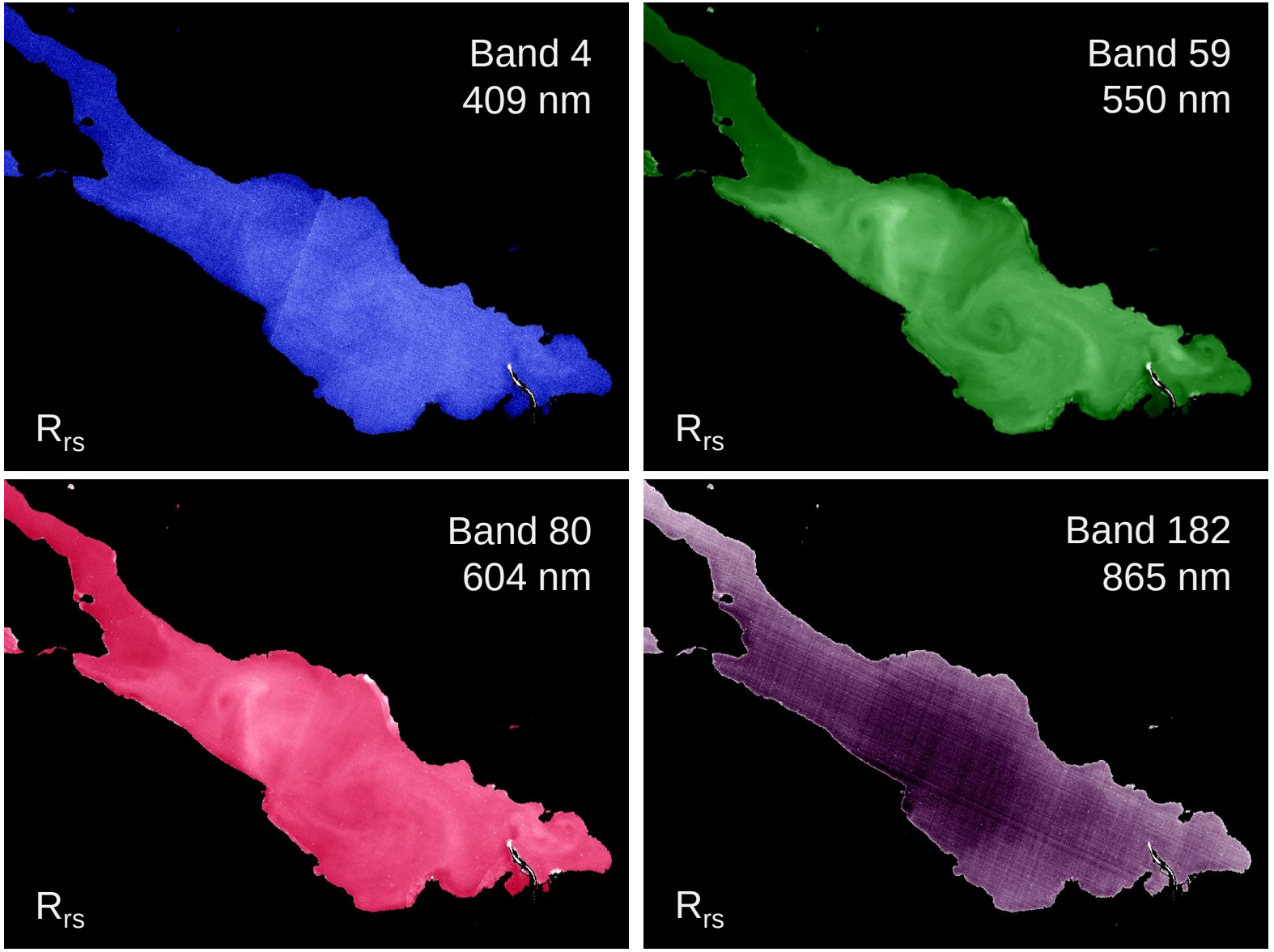
DLR

Outline

- Noise in satellite images
- Spectral weighting
- Maximum noise allowed for distinguishing phytoplankton groups
- Example from Lake Constance for DESIS
- Conclusions

DESIS image from Lake Constance, 14 August 2021



Noise

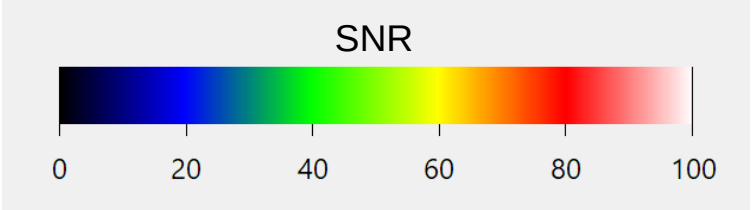
Signal-to-noise ratio for averaging 9 x 9 pixels

SNR after atmospheric correction (Level-2 data):

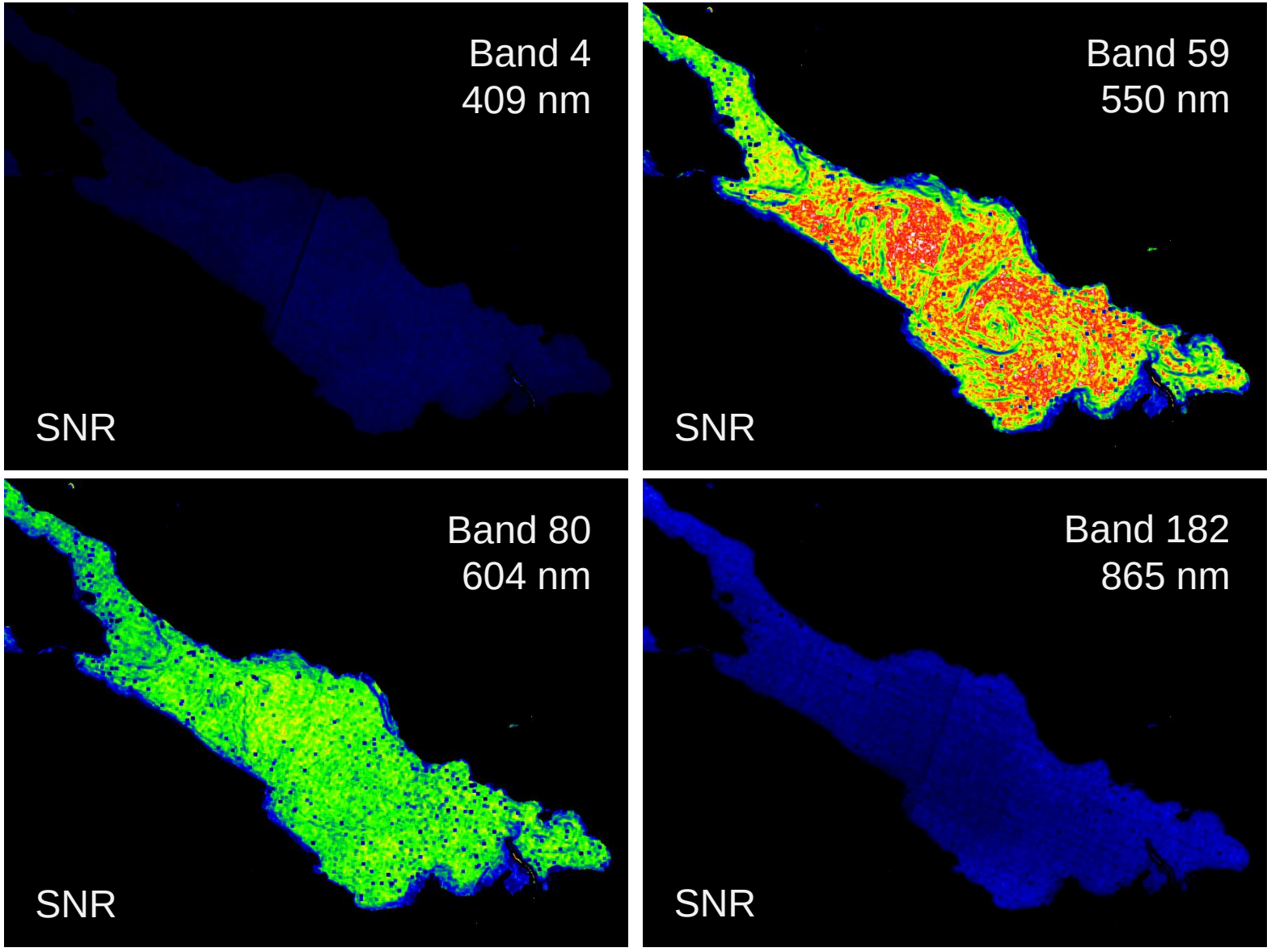
$$SNR = \frac{R_{rs}}{StdDev(R_{rs})}$$

Small-scale variability reduces the SNR.

The **maxima in the image** represent measurement noise (photon noise, sensor noise).



DESIS image from Lake Constance, 14 August 2021

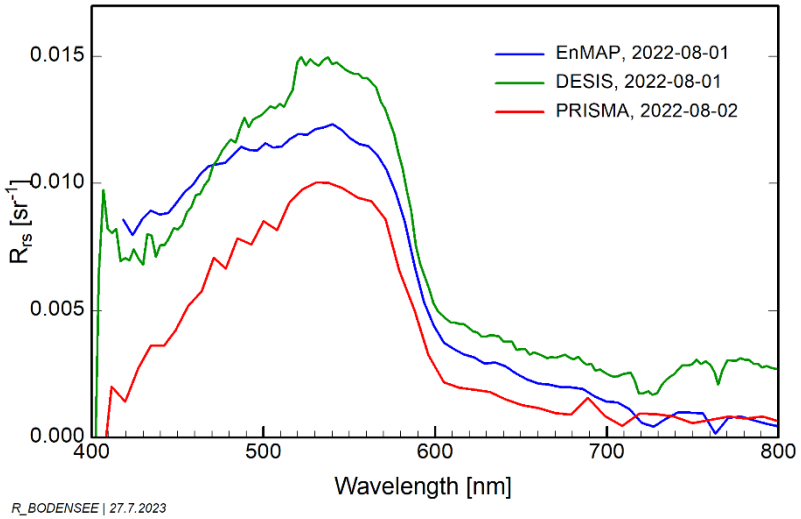


Peter Gege, DLR, 2 August 2023

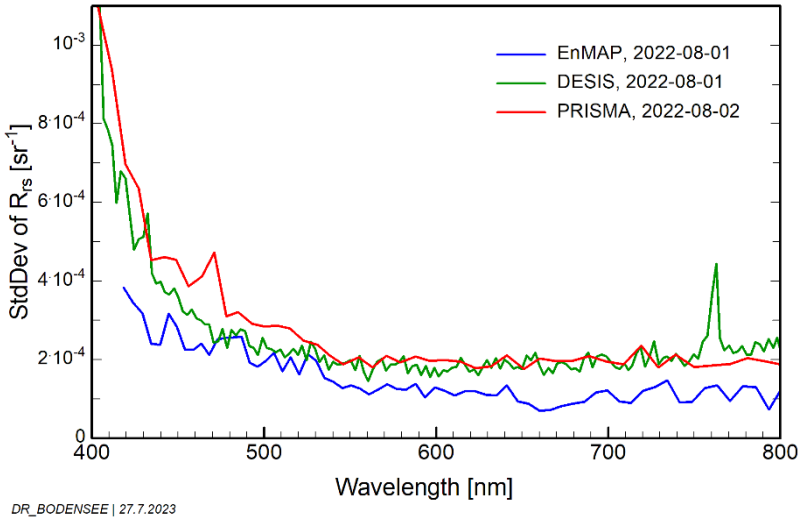
Noise

Comparison of single image pixels with highest SNR of Lake Constance, averaging 9 x 9 pixels

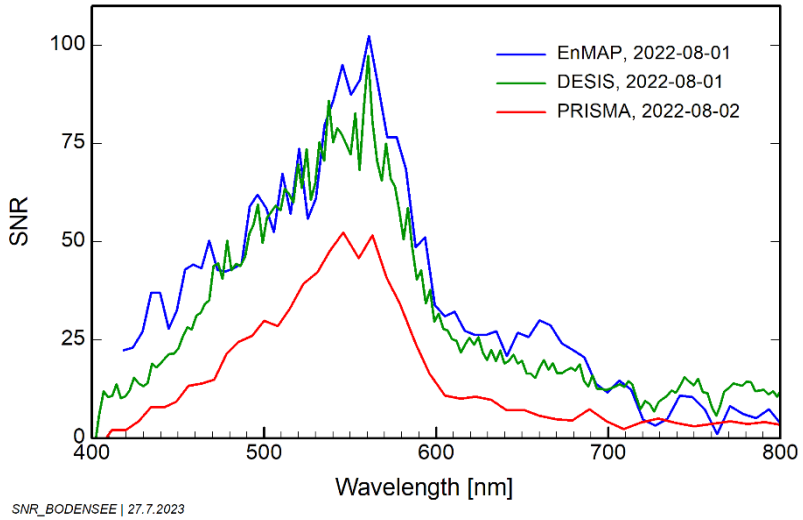
Lake Constance, 1-2 August 2022



Lake Constance, 1-2 August 2022



Lake Constance, 1-2 August 2022



Atmospheric correction:

- ACOLITE for PRISMA
- PACO for DESIS and EnMAP

Spectral weighting

Application during inverse modelling

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:

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

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

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

Measure of data quality

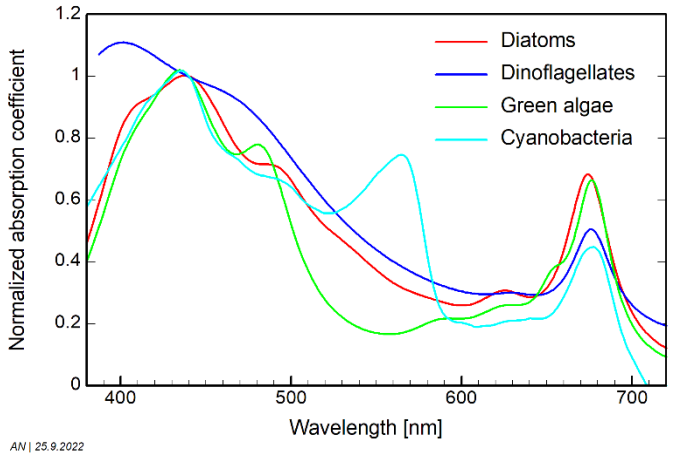
Measure of information content

[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.

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



$a^*_{dia}(440) = 0.036$ m^2 mg^{-1} from WASI database

$a^*_{dino}(440) = 0.050$ m^2 mg^{-1} from WASI database

$a^*_{green}(440) = 0.035$ m^2 mg^{-1} from WASI database

$a^*_{cya}(440) = 0.033$ m^2 mg^{-1} provided by M. Hieronymi (HEREON)

- 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: $SNR^{required}(\lambda) = \frac{R_{rs}(\lambda)}{|\Delta R_{rs}(\lambda)|}$

[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

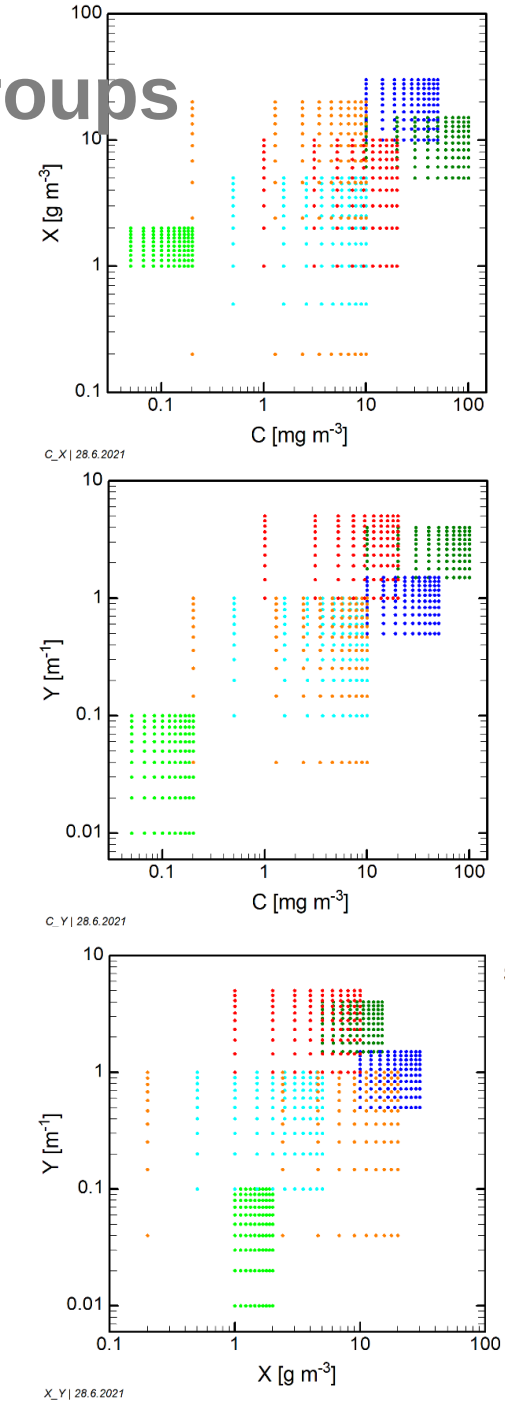
[3] Albert, A.; Mobley, C.D. An analytical model for subsurface irradiance and remote sensing reflectance in deep and shallow case-2 waters. Opt. Express 2003, 11, 2873–2890.

Noise allowed for distinguishing phytoplankton groups

Scenarios

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

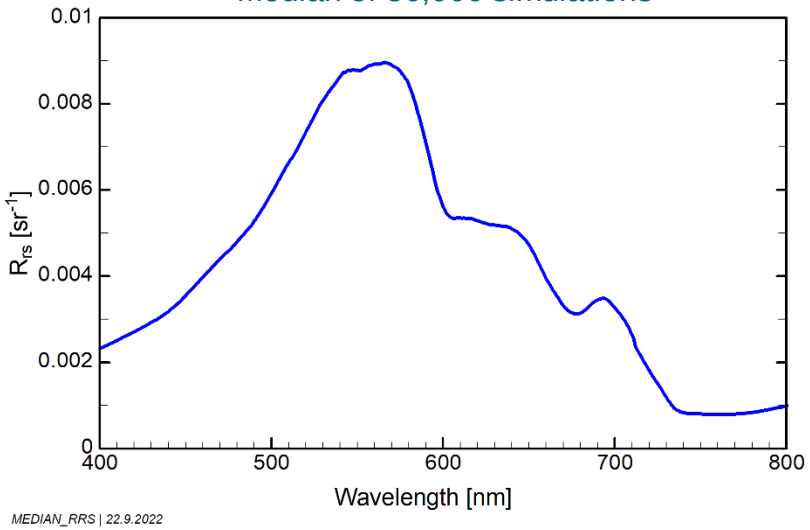
Scenario	C−	C+	X−	X+	Y−	Y+
Represents	Low chl-a	High chl-a	Low TSM	High TSM	Low CDOM	High CDOM
Example	Reef water	Finnish lakes	Lake Constance	Netherlands	Lake Garda	Lake Peipsi
C, mg m^{-3}	0.05-0.2	10-100	0.5–10	10−50	0.2-10	1−20
X, g m^{-3}	1-2	5-15	0.5-5	10-30	0.2-20	1-10
Y, m^{-1}	0.01-0.1	1.5-4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



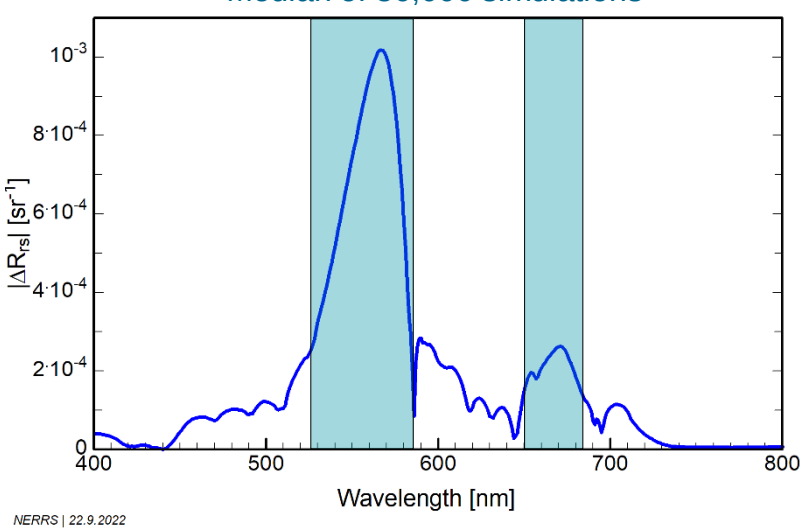
Results

Allowed noise for distinguishing phytoplankton groups

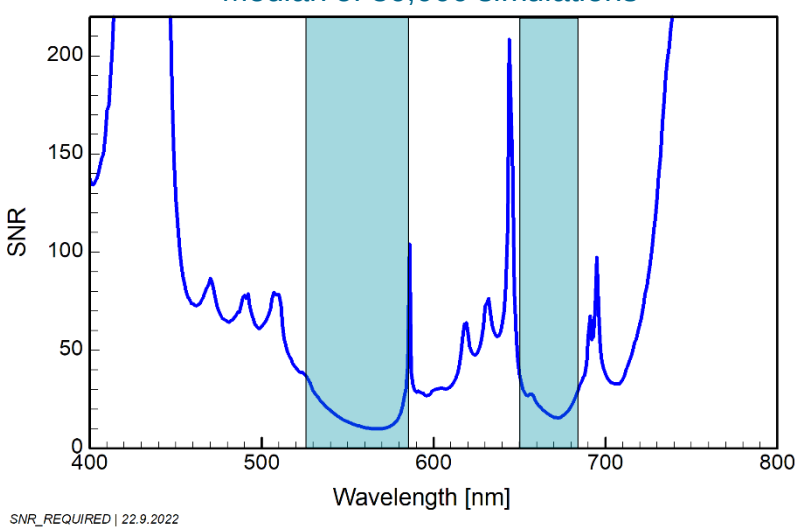
Median of 36,000 simulations



Median of 36,000 simulations



Median of 36,000 simulations

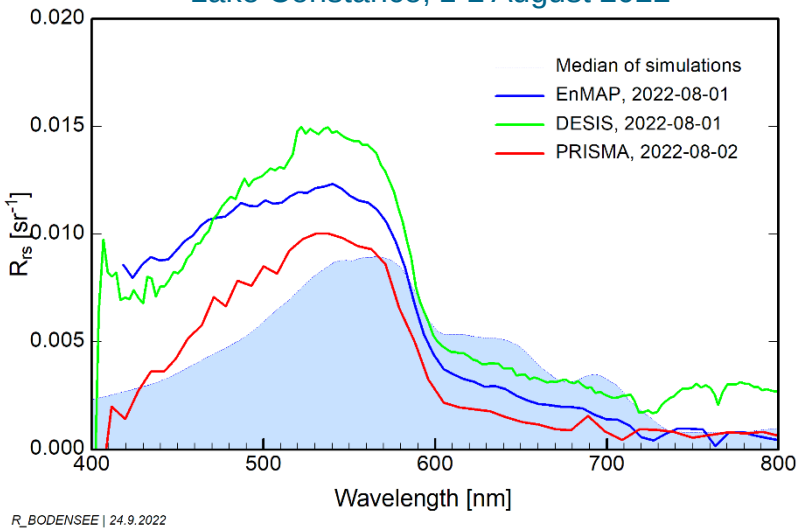


- Maxima of $|\Delta R_{rs}|$ / Minima of SNR at
  - 525 – 585 nm
  - 650 – 682 nm
- These ranges provide most information about phytoplankton group
- Average $|\Delta R_{rs}|$ / SNR in these ranges:
  - $6.7 \cdot 10^{-4}$ sr^{-1} / 18:1
  - $2.1 \cdot 10^{-4}$ sr^{-1} / 22:1

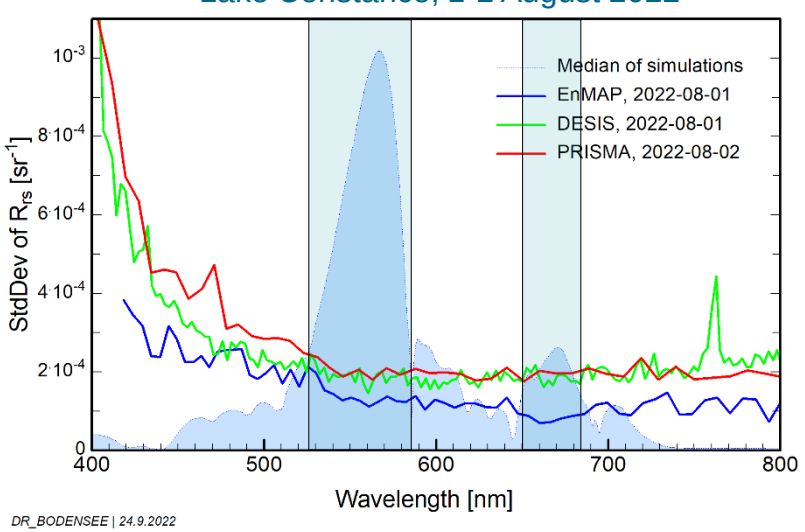
Results

Comparison of allowed and observed noise

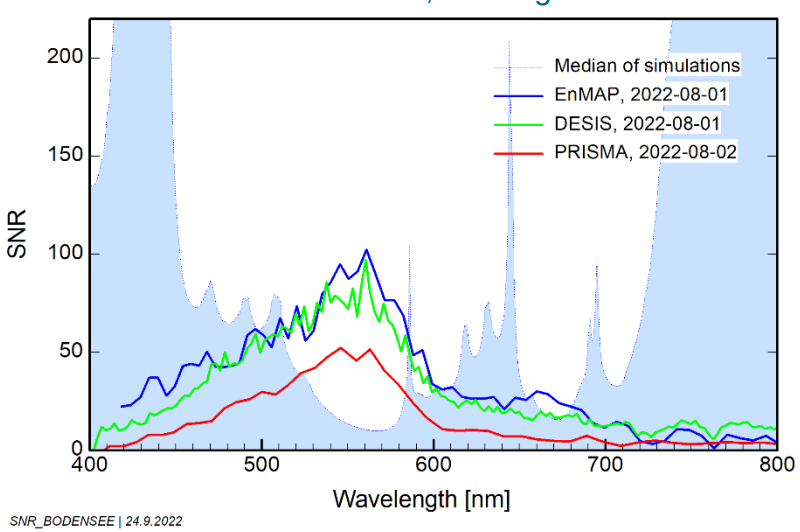
Lake Constance, 1-2 August 2022



Lake Constance, 1-2 August 2022



Lake Constance, 1-2 August 2022



- 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

Results

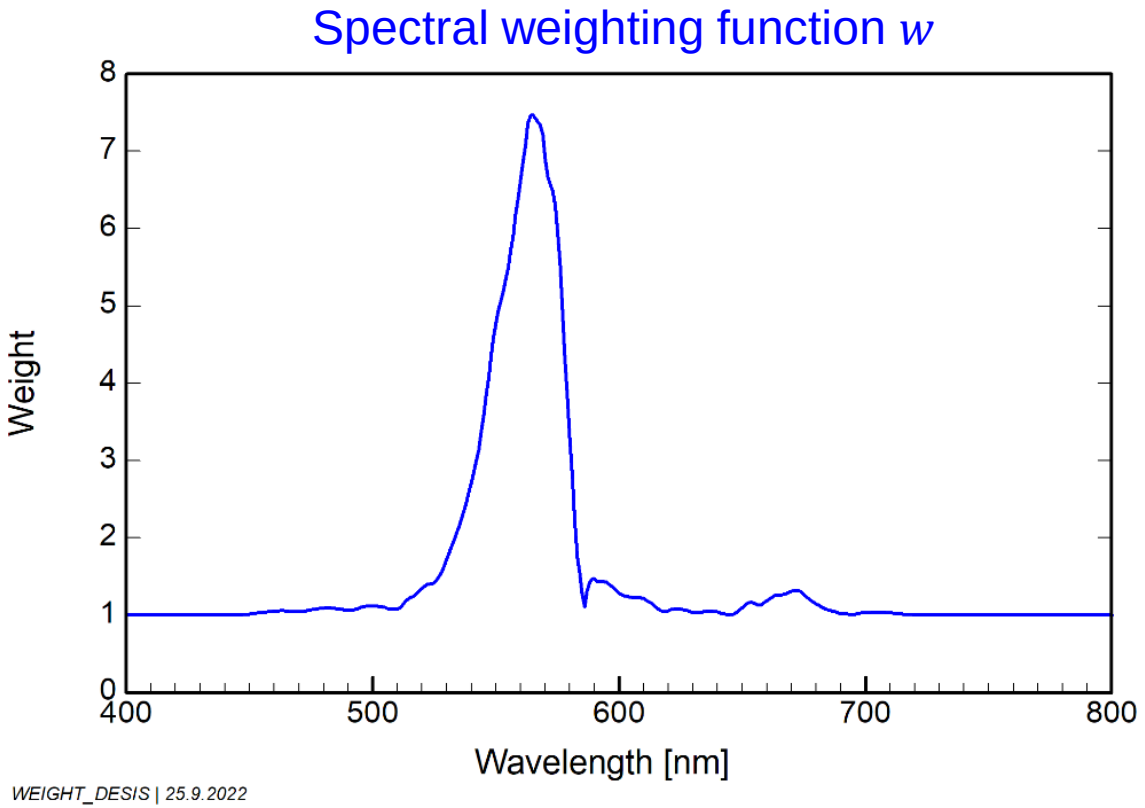
Spectral weighting function for phytoplankton classification

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

Measure of data quality

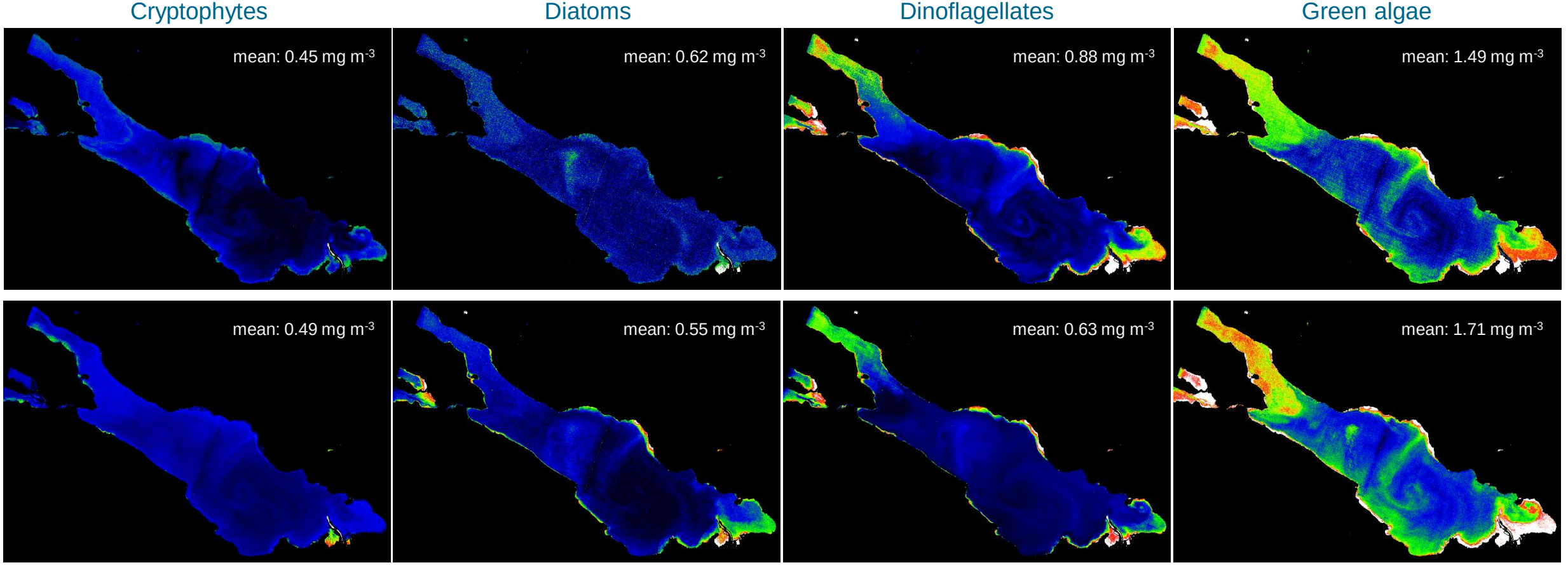
Measure of information content

- SNR^{image}: DESIS image from Lake Constance
- $SNR^{required}$: Simulations for phytoplankton groups
- $\frac{|\Delta R_{rs}|}{|\Delta R_{rs}(\lambda_{max})|}$: Simulations for phytoplankton groups



Results

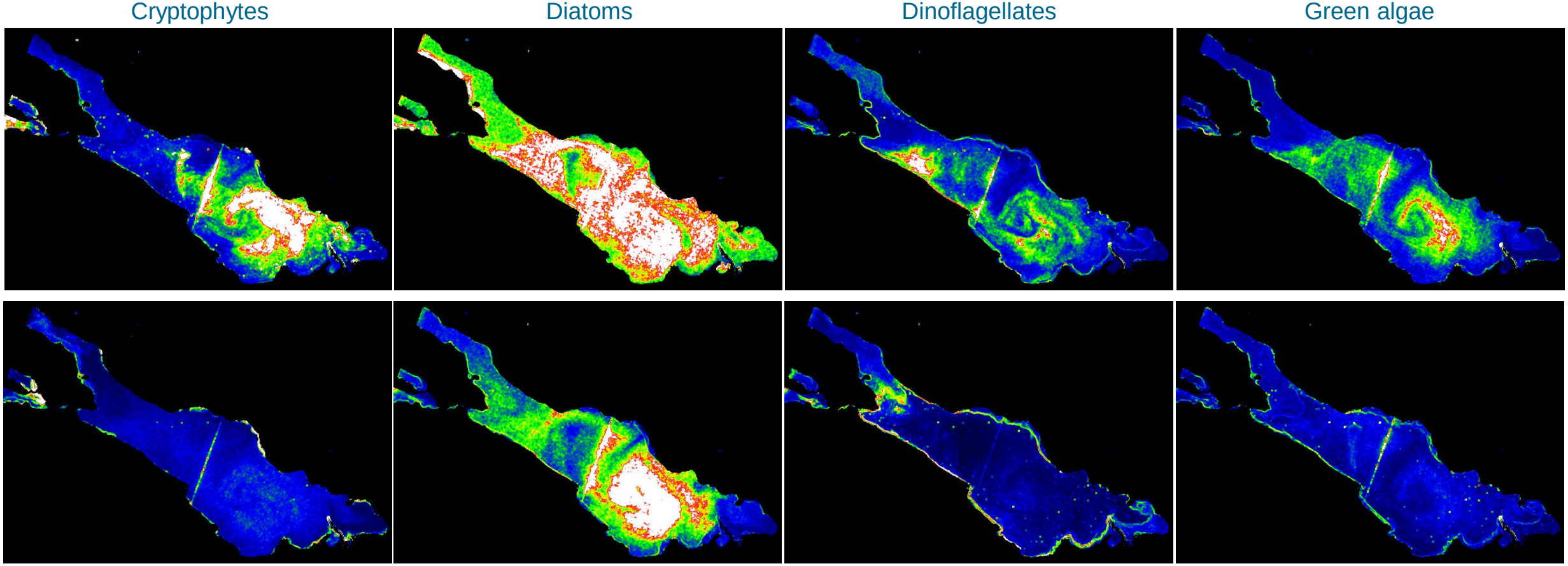
Improvement of phytoplankton classification using spectral weighting function



DESIS image from Lake Constance, 14 August 2021

Results

Improvement of phytoplankton classification using spectral weighting function



DESIS image from Lake Constance, 14 August 2021

Conclusions

- Spectral range bearing most information about phytoplankton groups is different for absorption and R_{rs}
- Spectral range bearing most information about phytoplankton groups in R_{rs}: 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

– Martin Hieronymi (HEREON) for providing an absorption spectrum of cyanobacteria
– Astrid Bracher and Mariana Sopa (AWI) for providing SIOPs of phytoplankton, NAP and CDOM from Lake Constance
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Thank you for your attention!