Radiometric measurement requirements to derive information on phytoplankton community composition from satellite

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IEEE IGARSS 2021, Brussels, Belgium, 11–16 July 2021

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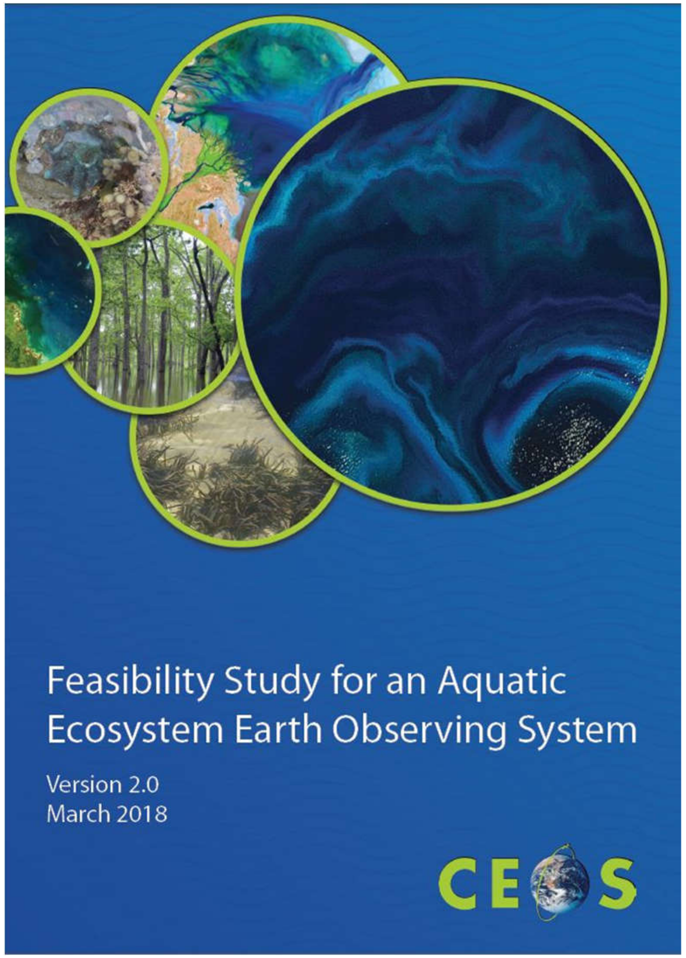
Introduction

CEOS study[1]

- requirements for satellite system dedicated to inland and coastal waters
- sensitivity analysis for spectral and radiometric requirements with focus on chl-a

Sensitivity analysis has been complemented for phytoplankton classification

- assessment of the potential of multi- and hyperspectral sensors
- design of new sensors



[1]https://ceos.org/document_management/Publications/Feasibility-Study-for-an-Aquatic-Ecosystem-EOS-v.2-hi-res_05April2018.pdf

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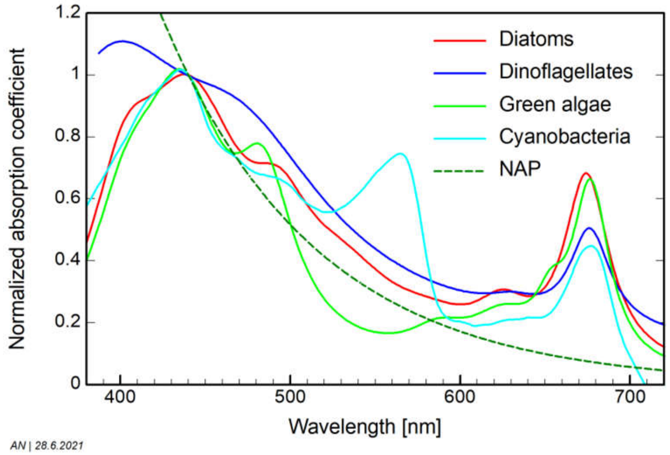
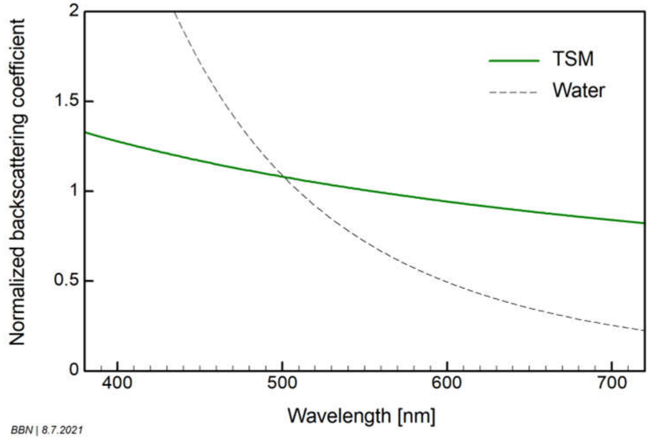
Simulations at bottom of atmosphere: modeling

- Bio-optical model[1] simulates remote sensing reflectance, $R_{rs}(\lambda)$
- Phytoplankton community composition is represented by 4 absorption spectra[2]





$a^*_{dia}(440)$ =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

$a^*_{NAP}(440)$ = 0.027 m² g⁻¹

$b^*_{b,NAP}(555)$ = 0.011 m² g⁻¹

$b_{b,phy}$ = 0 (retrieval based solely on phytoplankton absorption)

- Impact of chl-a concentration, C: $|\Delta R_{rs,C}(\lambda)| = |R_{rs}(\lambda, 1.3C) - R_{rs}(\lambda, C)|$
- Impact of 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: $SNR^{BOA}(\lambda) = \frac{R_{rs}(\lambda)}{|\Delta R_{rs}(\lambda)|} + \frac{\rho L_{sky}(\lambda)}{E_d(\lambda)|\Delta R_{rs}(\lambda)|}$

[1]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.

[2]Courtesy M. Hieronymi, HZG Geesthacht, Germany, for the cyanobacteria spectrum

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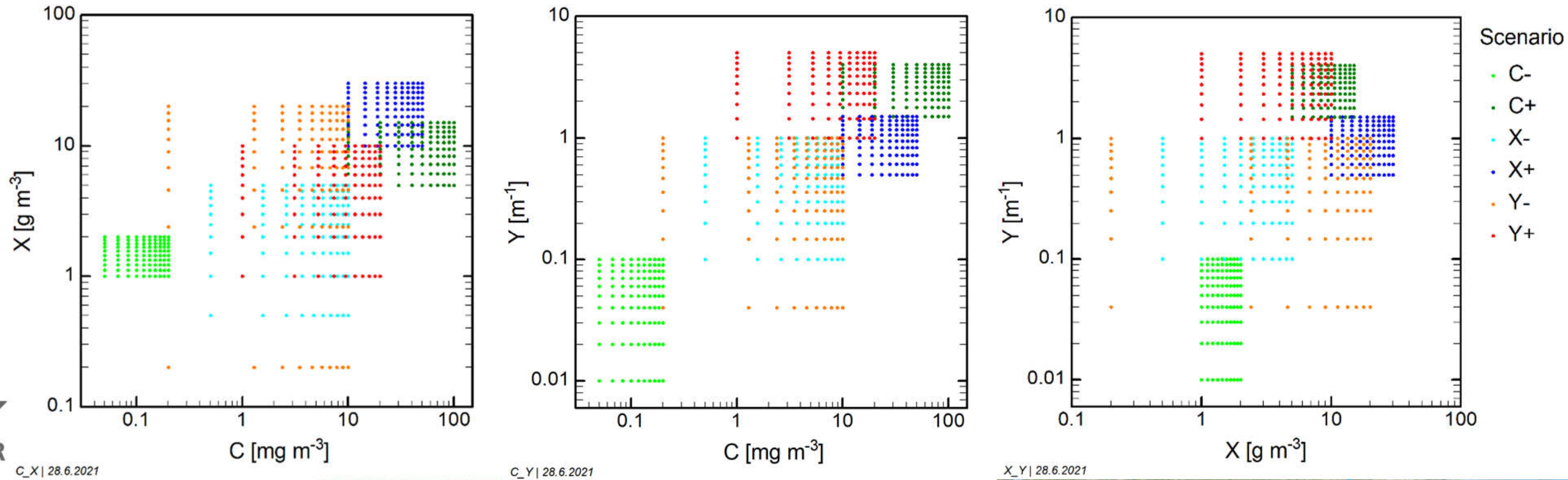
Simulations at bottom of atmosphere: scenarios

- 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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Simulations at top of atmosphere

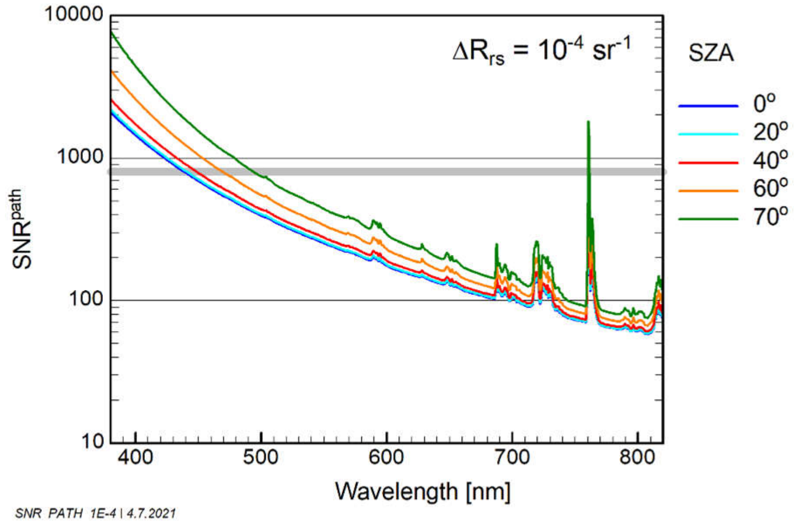
- $L^{TOA}(\lambda) = L^{path}(\lambda) + t_A(\lambda)\left[R_{rs}(\lambda)E_d(\lambda) + \rho L_{sky}(\lambda)\right]$
- $|\Delta L^{TOA}(\lambda)| = t_A(\lambda)E_d(\lambda)\,|\Delta R_{rs}(\lambda)|$
- $SNR^{TOA}(\lambda) = \frac{L^{TOA}(\lambda)}{|\Delta L^{TOA}(\lambda)|} = \frac{L^{path}(\lambda)}{t_A(\lambda)E_d(\lambda)|\Delta R_{rs}(\lambda)|} + SNR^{BOA}(\lambda)$
- Modtran-6 simulates $L^{path}(\lambda)$, $t_A(\lambda)$, $E_d(\lambda)$ and $L_{sky}(\lambda)$
- Environmental conditions: mid-latitude summer atmosphere, horizontal visibility 50 km, sun zenith angle of 40°

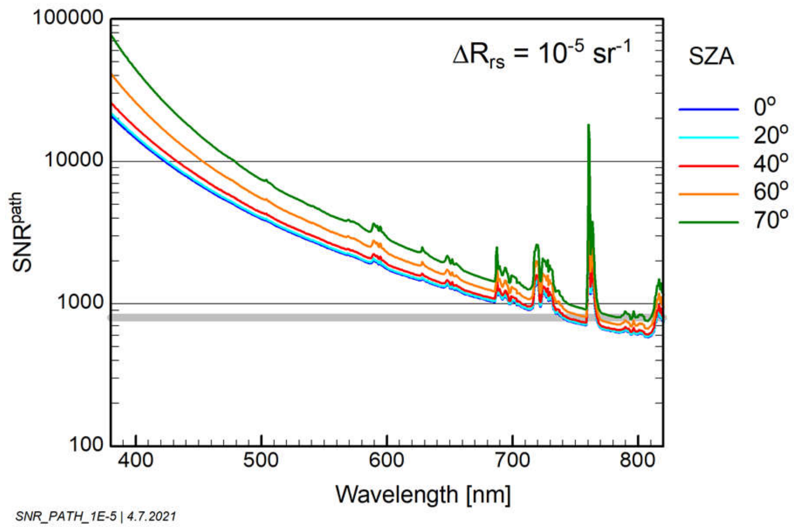
Results: SNR required at TOA due to path radiance

$$SNR^{path}(\lambda) = \frac{L^{path}(\lambda)}{t_A(\lambda)E_d(\lambda)|\Delta R_{rs}(\lambda)|}$$

Minimum useable wavelength for SNR = 800[1]

$\|\Delta R_{rs}\|$	Sun zenith angle				
	0°	**20°**	**40°**	**60°**	**70°**
10^{-4} sr^{-1}	438	441	448	469	494
10^{-5} sr^{-1}	740	740	743	769	785



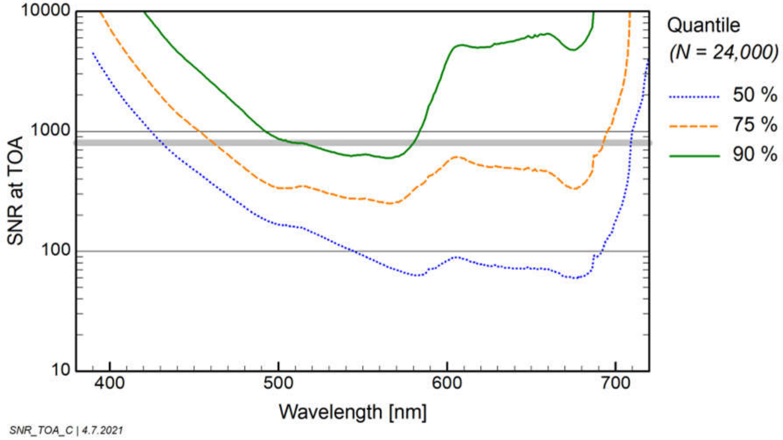


[1]Recommended by Muller-Karger et al. 2018
https://esajournals.onlinelibrary.wiley.com/doi/10.1002/eap.1682

Plots adopted from: Gege, P.; Dekker, A.G. Spectral and radiometric measurement requirements for inland, coastal and reef waters. *Remote Sensing* 2020, 12, 2247. doi:10.3390/rs12142247

Results: Measurement requirements at TOA

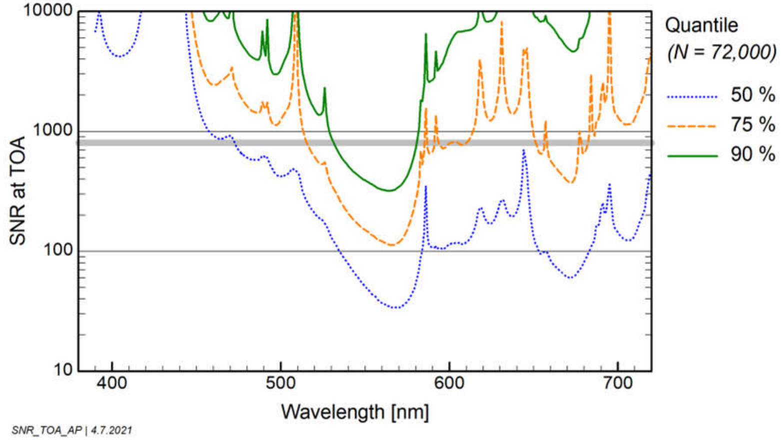
Resolve 30% change of chl-a concentration



- Useable wavelengths for SNR = 800[1]

Quantile	From [nm]	To [nm]
50 %	407	618
75 %	431	606
90 %	507	580

Resolve exchange of phytoplankton group



- Useable wavelengths for SNR = 800[1]

Quantile	From [nm]	To [nm]
50 %	440	728
75 %	515	585
	650	682
90 %	531	581

[1]Recommended by Muller-Karger et al. 2018
https://esajournals.onlinelibrary.wiley.com/doi/10.1002/eap.1682

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Summary

Required SNR at TOA

- Dominated by path radiance
- Depends strongly on wavelength; SNR > 1000 below 500 nm for $|\Delta R_{rs}| < 10^{-4}$ sr^{-1}
- Chl-a changes of 30 %: SNR > 600 above 460 nm for 75% quantile
- Phytoplankton classification: SNR > 800 above 500 nm for 75% quantile

A paper about these simulations is in preparation. It includes additionally sensor requirements (NEL).

Thank you for your attention!