Remote sensing and validation of high CDOM waters

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This presentation

Part I:

- Presentation of our AERONET-OC station in Lake Vänern)

Part II:

- Remote Sensing research in the Baltic Sea

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Rymdstyrelsen
Swedish National Space Agency

Long-term operation (16 years) of the AERONET-OC site Pålgrunden for the validation of multi-mission ocean/water colour satellite data products

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Strömbeck Consulting

JRC EUROPEAN COMMISSION

UNIVERSITY OF TARTU Tartu Observatory 1632

NASA

NASA AERONET-OC

- AERONET-OC is a sub-network of NASA AERONET
- Radiometers measure the radiance emerging from the sea or inland waters (i.e., the water-leaving radiance) as well as atmospheric properties.
- Used for satellite validation of highest quality.
- The network consists of CE-318 (9-channel) and 318-T (12-channel) sun-photo-meters (Cimel Electronique, Paris, France) .
- Operated on offshore platforms such as lighthouses, oil rigs and oceanographic towers.
- Automated measurements comprise sky, sun and water surface and ensures radiometric data collected at specific viewing angles.

AERONET vs. AERONET-OC

Measurements of spectral Aerosol optical thickness (AOT) and the Ångström exponent ($\boldsymbol{\alpha}$) using CIMEL sun-photometers.

Measurements of AOT and the Ångström exponent ($\boldsymbol{\alpha}$), as well as normalized water-leaving radiance, L_{wn} and remote sensing reflectance, R_{RS}.

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Standardization

- AERONET-OC is based on standardization of instruments, calibration, processing and distribution.
- All calibrations, measurements and calculations are done using the same protocols and methods, thus providing site-independent data of high quality.
- Annual pre- and post-calibrations are performed at Goddard Space Flight Center of the National Aeronautics and Space Administration (GSFC, NASA).
- All sun-photometers in the network are intercalibrated against the same instrument.
- Normalized water-leaving radiances are provided at three data levels (Zibordi et al., 2022).

Available data quality levels

- **Level 1.0** is the rawest quality of data and is provided close to real-time on the AERONET-OC web site.
- **Level 1.5** data, also accessible in almost real-time, includes automatic data screening (not affected by clouds, stong waves or superstructure perturbations).
- The final data level, the so-called **Level 2.0**, implies the existence of pre- and post-field instrument calibrations and the application of strict automated quality checks (Zibordi et al., 2022).

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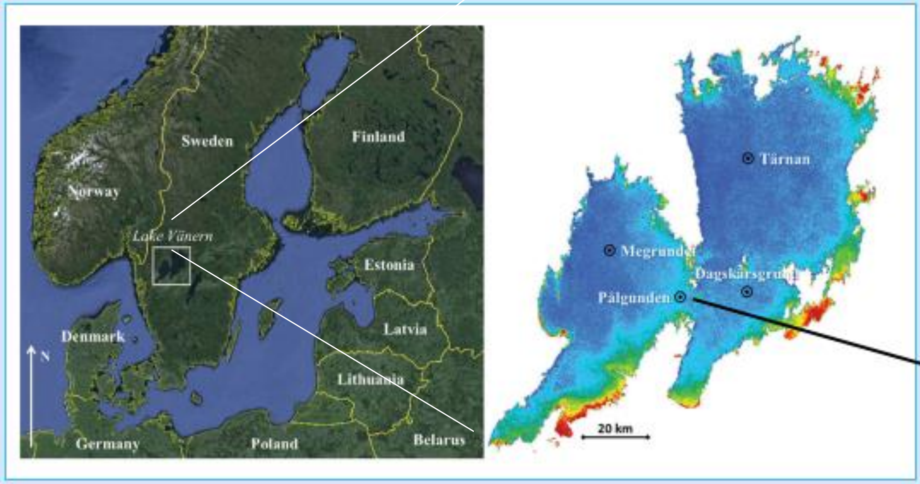
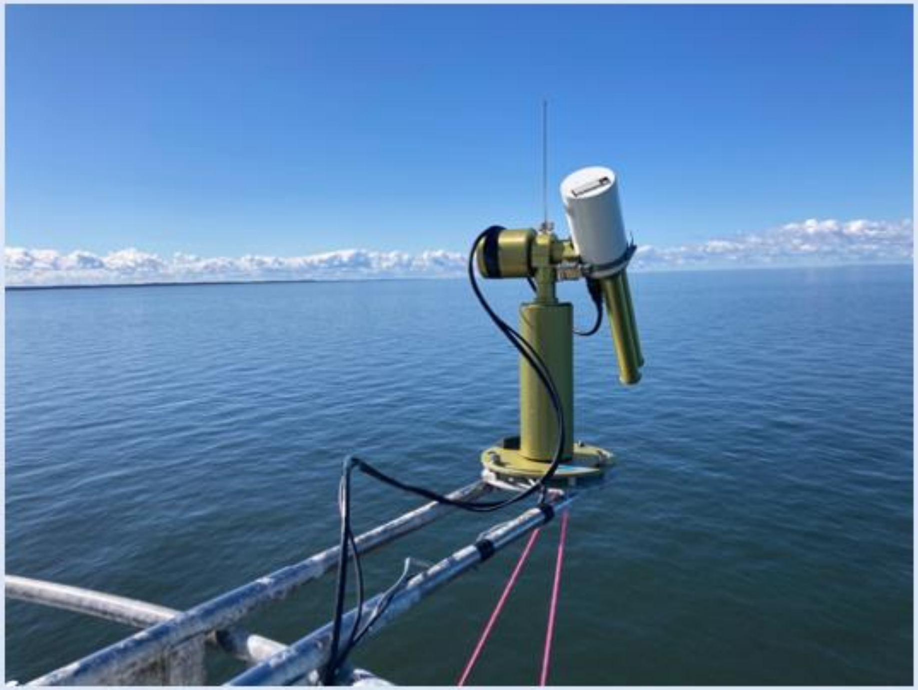
AERONET-OC Site *Palgrunden* deployed at the Pålgrunden light house, Lake Vänern





Photos: Niklas Strömbeck, site manager

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Advantages of new CIMEL CE318-T vs former CE318

- CE318-T has been deployed at *Palgrunden* since 2019.
- Wavelength **bands** matching those of **OLCI** Sentinel-3.
- More **sensitive optics**, allowing for more accurate measurements.
- Potential for programming a **higher number of measurements** per hour (at least 6 per hour, compared to 2 per hour with CE-318); more frequent measurements keep birds away
- Faster microprocessor and larger memory.
- Built-in **GPS** for accurate position and time determination.
- Data transmission using **GSM** (instead of satellite)
- Completely new and more developed user interface.

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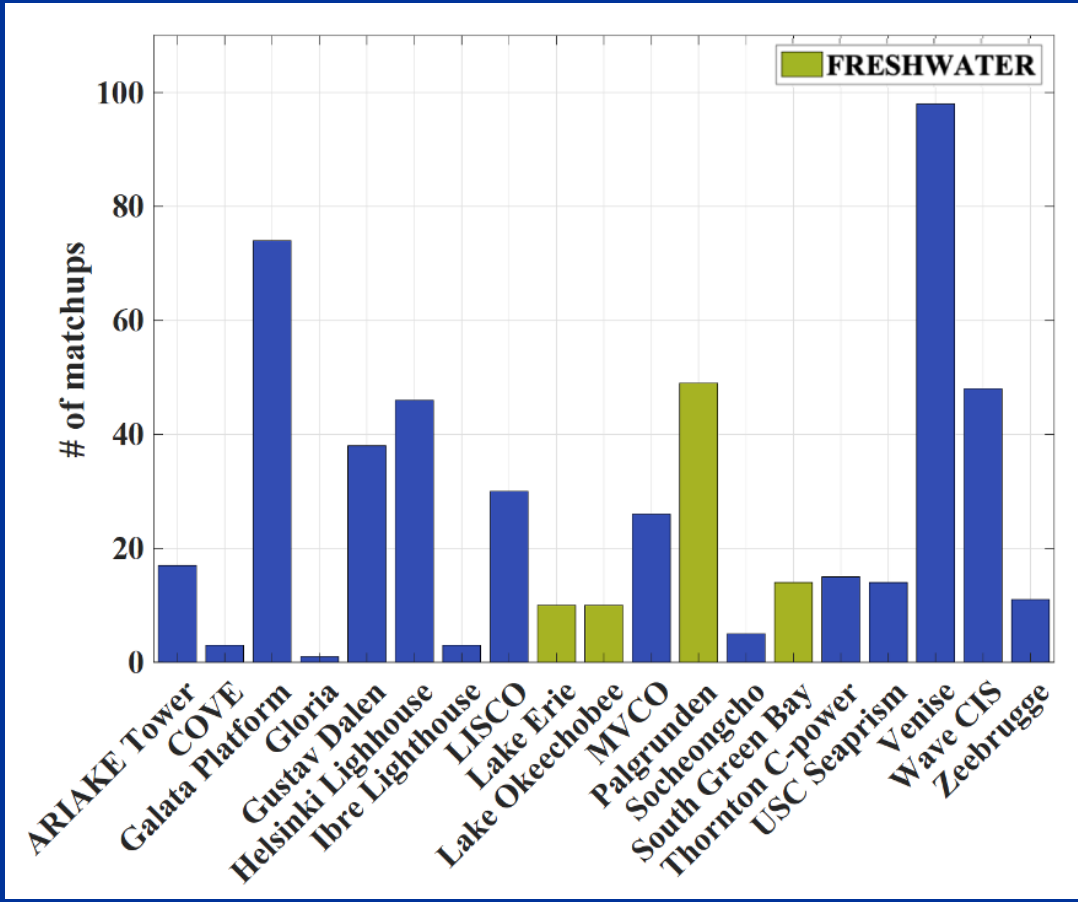
Relevance of AERONET-OC site *Palgrunden*

- The site has been operational since **2008**
- *Palgrunden* is one of only a few **high latitude** AERONET-OC stations
- and one of only six sites deployed in **freshwater** environments (it was the first freshwater site)
- Additionally, it is deployed in a **high CDOM** environment ($a_{CDOM}(440) \sim 1\ m^{-1}$)
- It contributes substantially to the validation of ocean colour processors in optical **case 2** waters.

POLYMER match-ups for case 2 waters



Pahlevan *et al.*, 2021

Example: distribution of valid AERONET-OC matchups for the AC processor POLYMER.

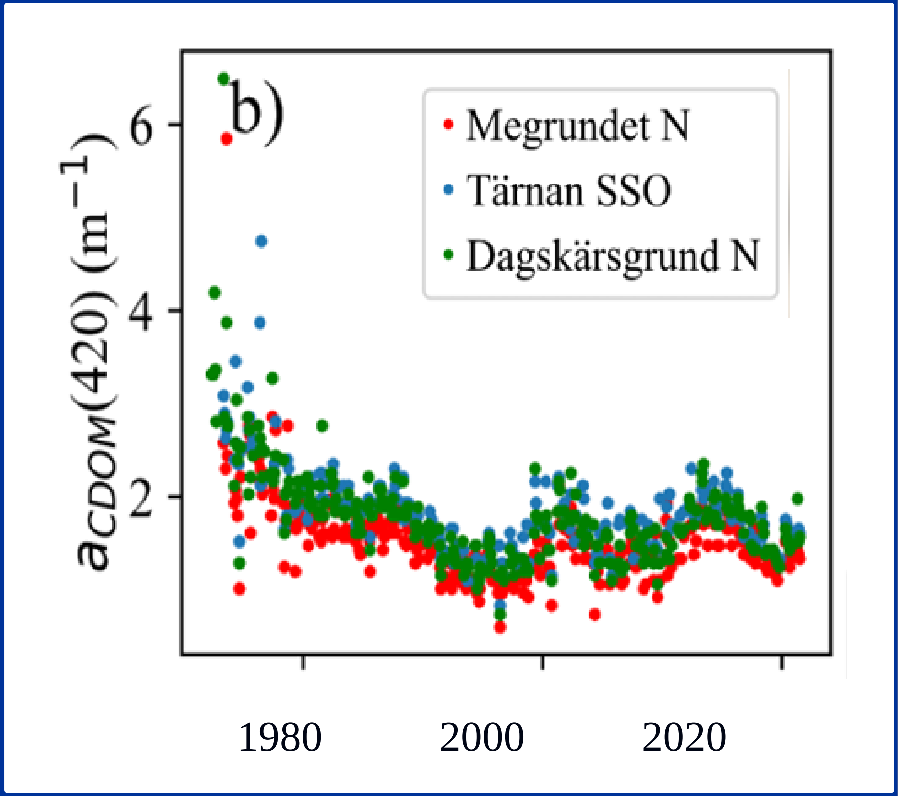
The freshwater sites are shown in light green.

Recently, two more freshwater sites have been initiated.

About 17% of the data originated from freshwater sites, approximately 50% of these measurements were from the *Palgrunden* AERONET-OC site.

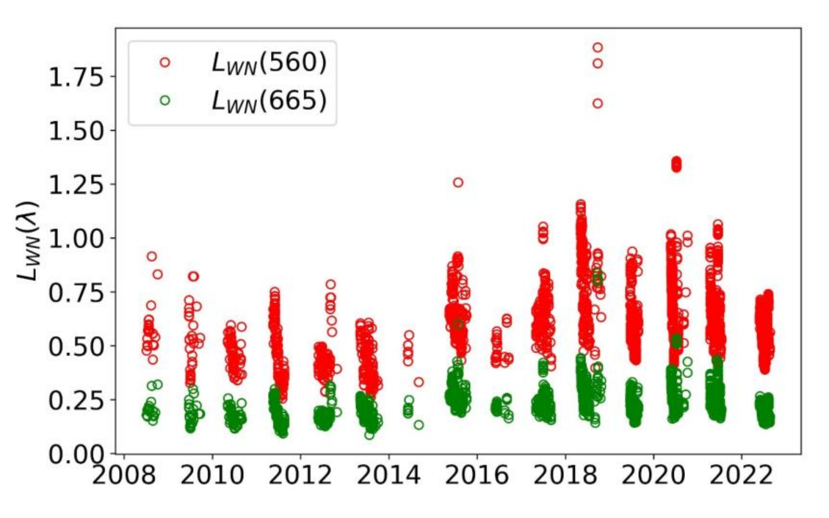
Optical Properties of Lake Vänern

- The optical properties in Vänern are dominated by a_{CDOM} while turbidity in the open lake is relatively low (Philipson et al., 2016).
- In spring, diatoms dominate while in summer the phytoplankton consists of a mix of cyanobacteria, cryptomonads, chrysophytes and dinoflagellates (https://miljodata.slu.se).



Cazzaniga *et al.*, 2023

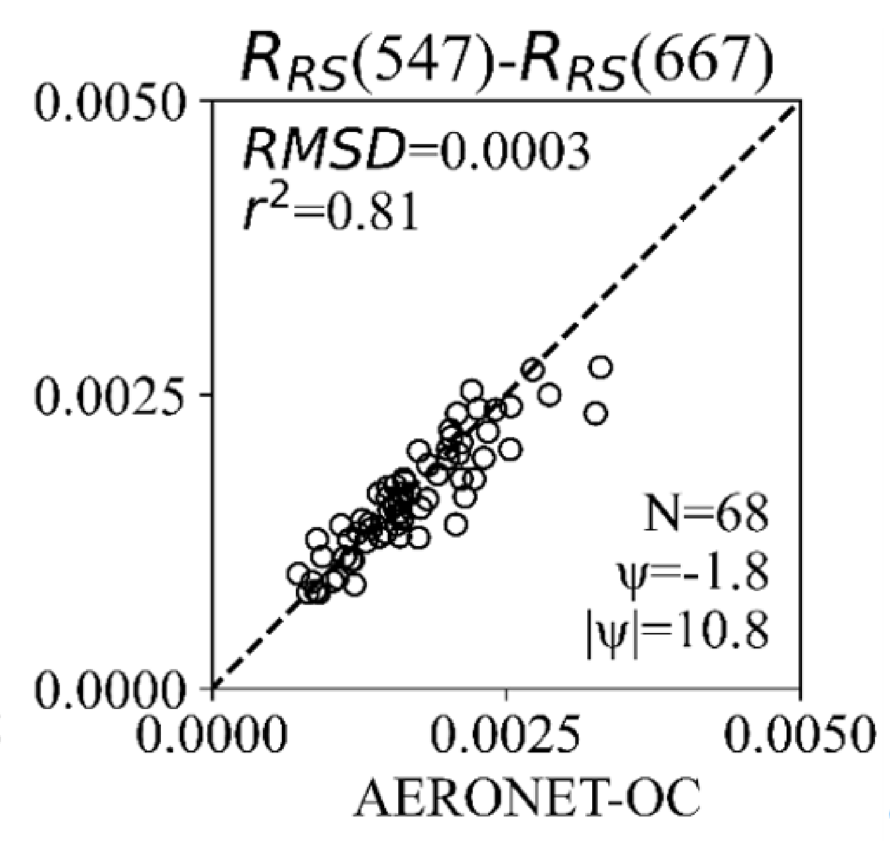
Temporal changes in Lake Vänern



An **increase** of $L_{WN}(\lambda)$ was observed in the ***in situ*** data during recent years both in the **green** and **red** spectral bands.

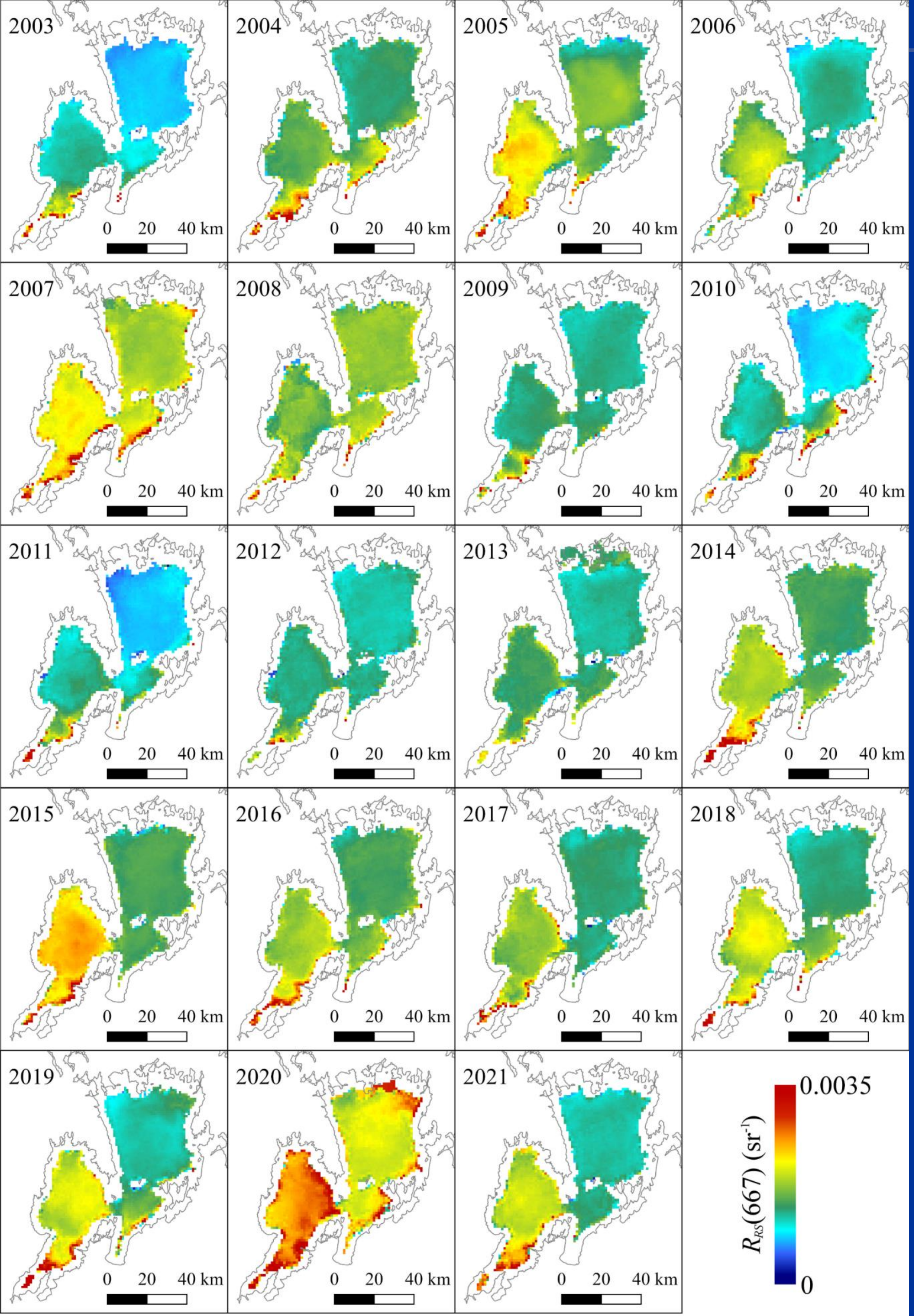
- The multi-annual time series of *in situ* data showed **clear incremental** changes over time (**2008-2022**)
- **Satellite data** was used to evaluate these changes in time
- Due to the gap between MERIS mission (2002-2012) and the launch of S3A (2016) **MODIS** data was used in this study.

Validation of MODIS reflectance difference: $R_{RS}(547)$ - $R_{RS}(667)$ vs. AERONET-OC data



Cazzaniga e*t al.*, 2023

MODIS $R_{RS}(\lambda)$ showed **good agreement** at several spectral bands.
The **best** agreement was shown by the green - red reflectance difference:
$R_{RS}(547)$ - R_{RS} (667).



Changes in $R_{RS}(\lambda)$ in Lake Vänern (2004-2021)

Remote sensing reflectance is an Essential Climate Variable (ECV).

$R_{RS}(\lambda)$ in red (and green) centre-wavelengths shows periodical changes between 2002 and 2021 with clear minima occurring between 2010-2013.

Also, there are clear differences between the western and eastern basin of Lake Vänern.

Significant correlations were found between $R_{RS}(\lambda)$ and turbidity, and also between $R_{RS}(\lambda)$ and total phytoplankton biovolume.

Cazzaniga *et al.*, 2023

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Conclusions

- We have set up and sustained fiducial refence measurements of remote sensing reflectance in Lake Vänern (high CDOM waters) since 2008.
- The data has contributed to multiple studies of various ocean colour processors and atmospheric correction models.
- The validated satellite products can be used to assess long-term trends in ocean colour data.
- $R_{RS}(\lambda)$ is an Essential Climate Variable (ECV) and was shown to be related to biovolume and turbidity in lake Vänern.

Bio-optical studies and remote sensing of coastal waters

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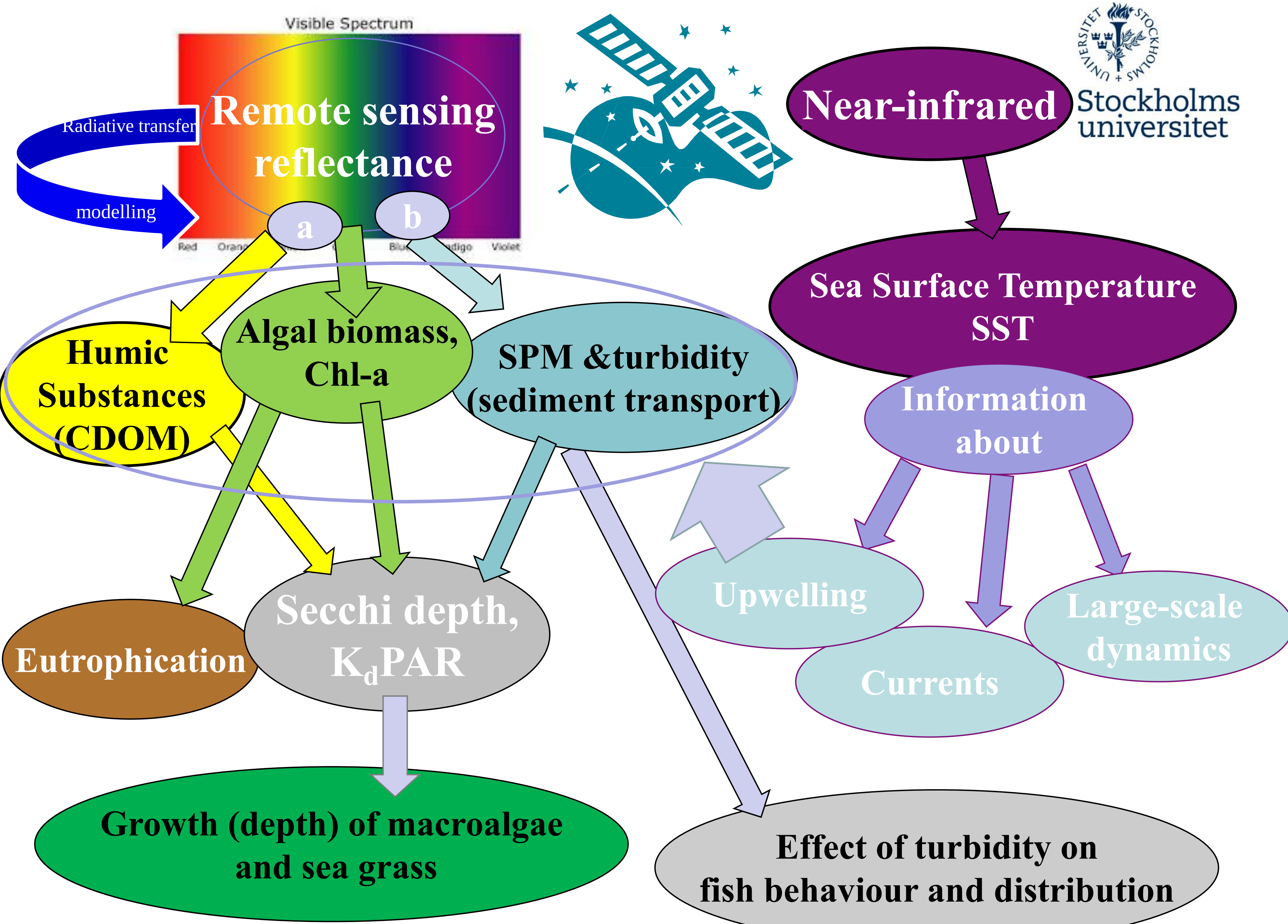
Structure of this part

- Remote sensing of coastal waters in a nutshell
- Important factors influencing Baltic Sea Optics
- Satellite validation
- Optical mooring deployment at Station B1 (SW of Askö)
- Results from our remote sensing research

Marine remote sensing and ecology



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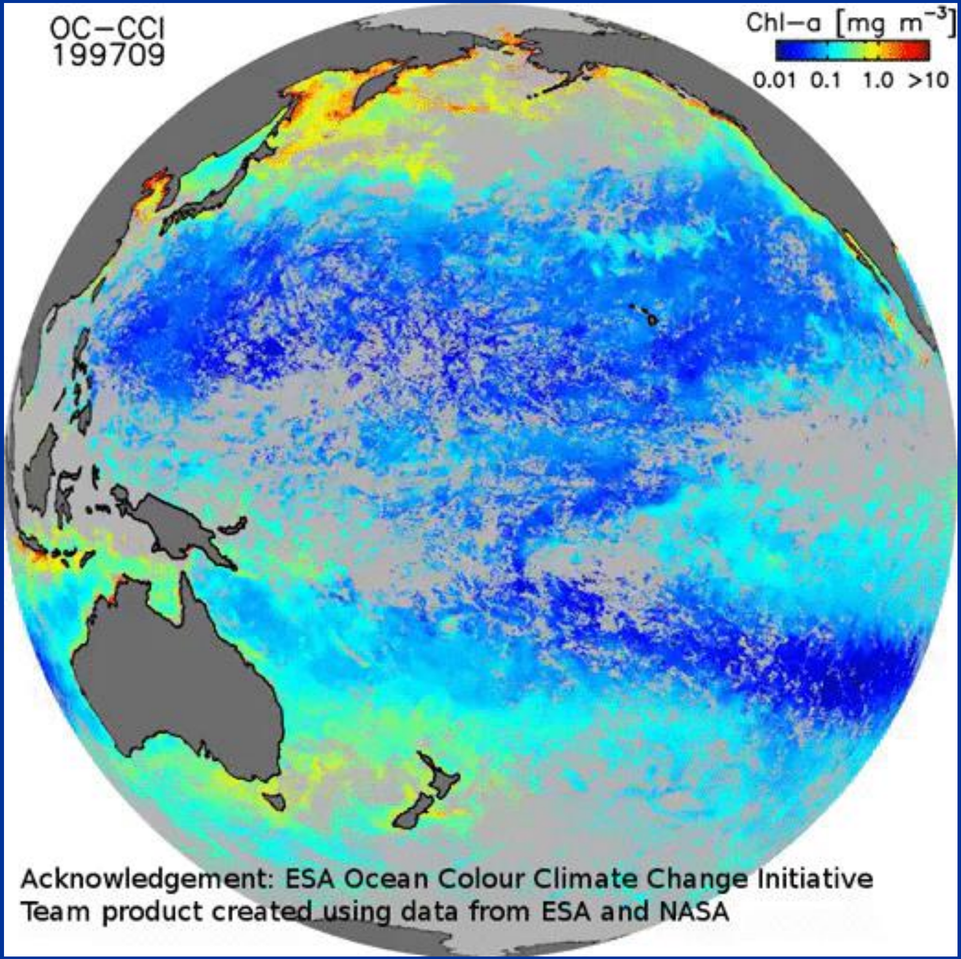


Patterns of phytoplankton distribution in the World Ocean obtained from ESA's Ocean Color Climate Change Initiative OC-CCI (merged satellite products from NASA (SeaWiFS, MODIS) and ESA (MERIS), daily images;
4 km spatial resolution. Note: the methods strictly only apply to clear ocean waters.

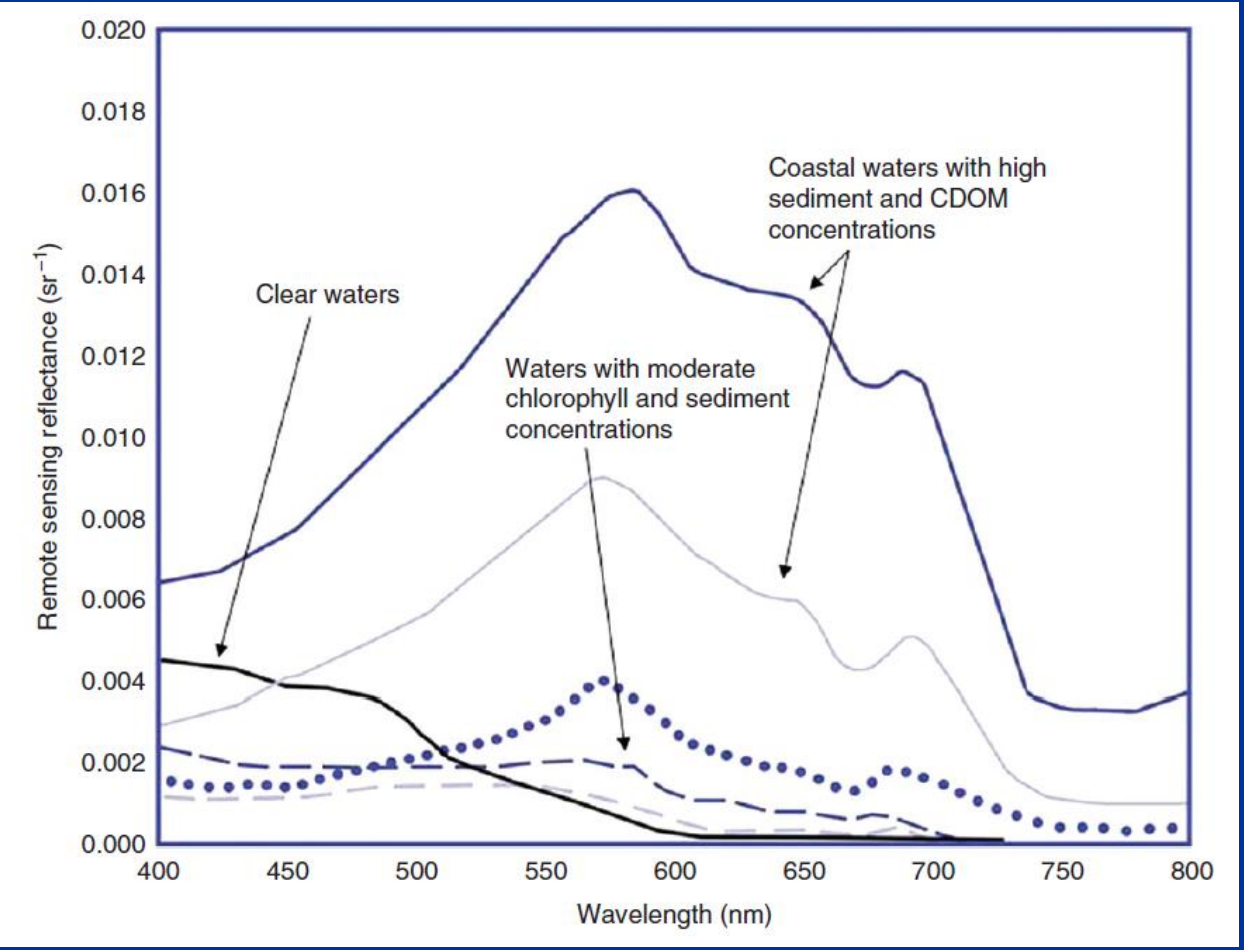
Important factors influencing Baltic Sea Optics

- Permanent salinity stratification - surface layer with brackish water.
- Relatively high CDOM (coloured dissolved organic matter) absorption compared to other seas and oceans with increasing gradient towards the northernmost and easternmost gulfs.
- Two major phytoplankton blooms per year:
  - Spring bloom with mostly diatoms and dinoflagellates
  - Specific Baltic Sea Summer blooms of filamentous nitrogen-fixing cyanobacteria; some of them are toxic.
- Frequent upwelling 10-20 km off the coast during summer - brings nutrient-rich bottom waters up into the surface mixed layer, stimulating primary production.
- Eutrophication- makes water more murky due to algal growth.

Surface accumulations of the filamentous cyanobacteria *Nodularia spumigena* *(Searcher cruise 1999)*

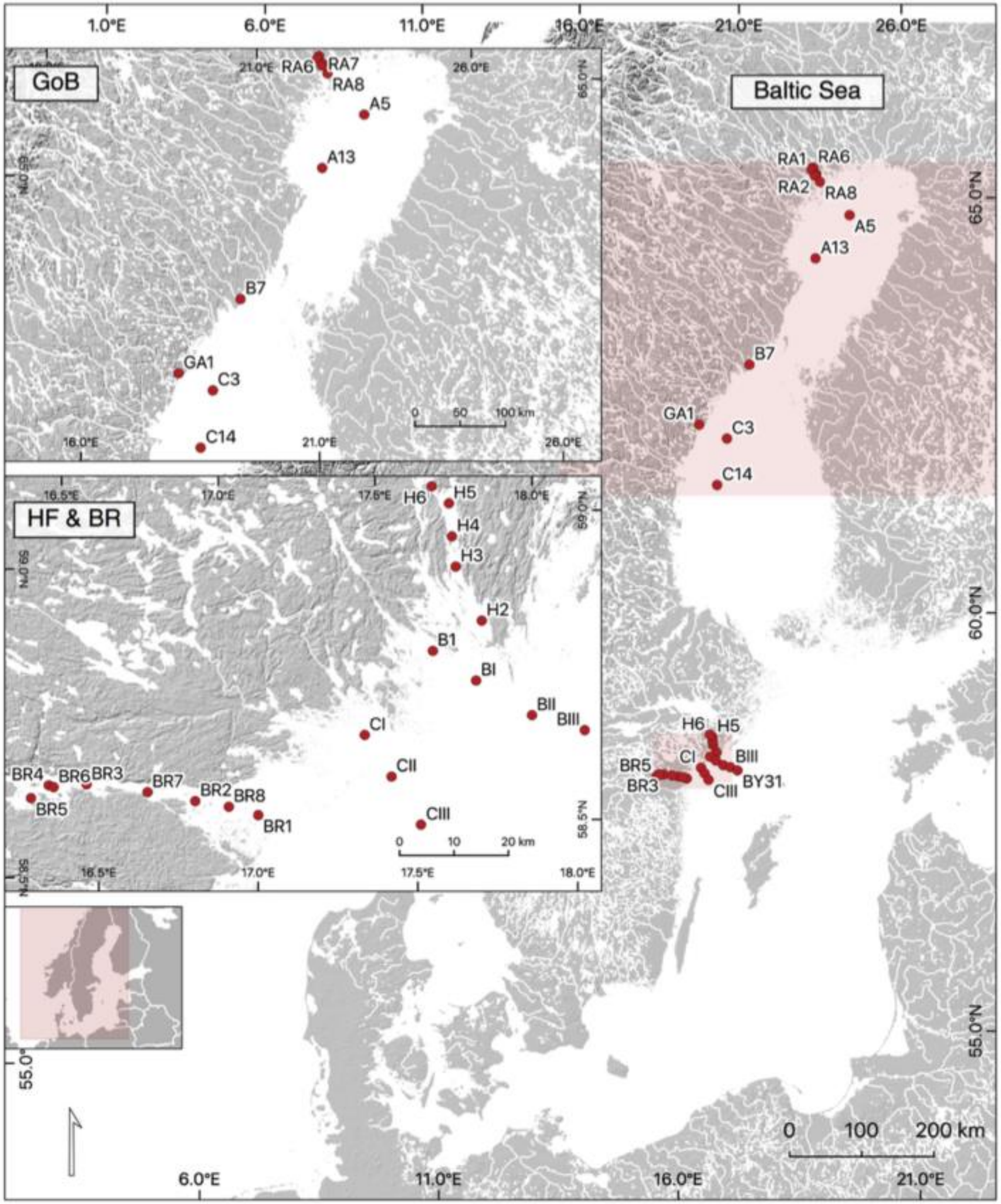
Nodularia spumigena in the NW Baltic proper, Sentinel-2A L1C, 2015-08-13 enhanced True Colour, © European Union (Kyryliuk, 2019)

Examples of different remote sensing reflectance spectra (water spectra)

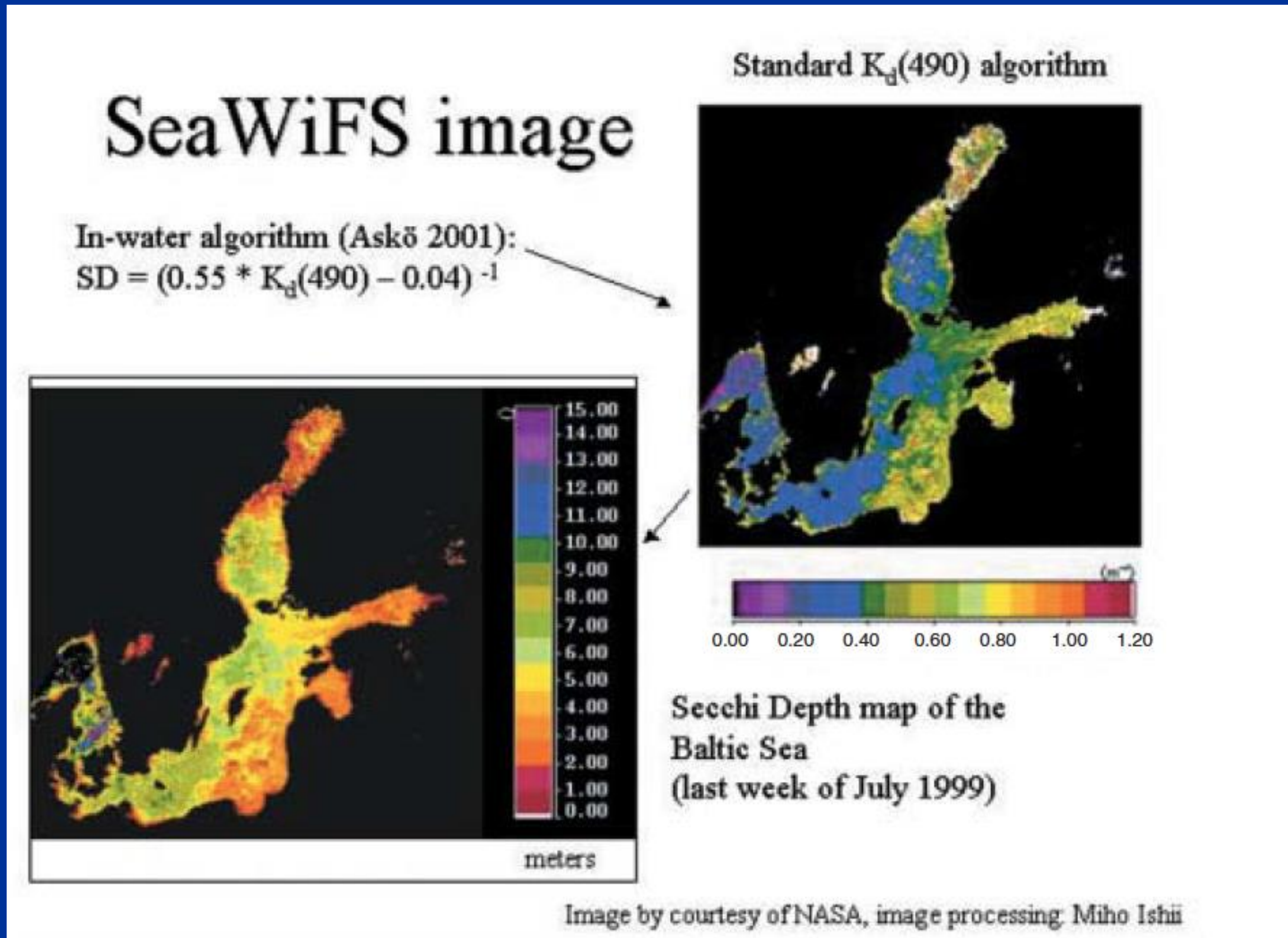


Hoepffner and Zibordi, 2009

Validation on Limanda

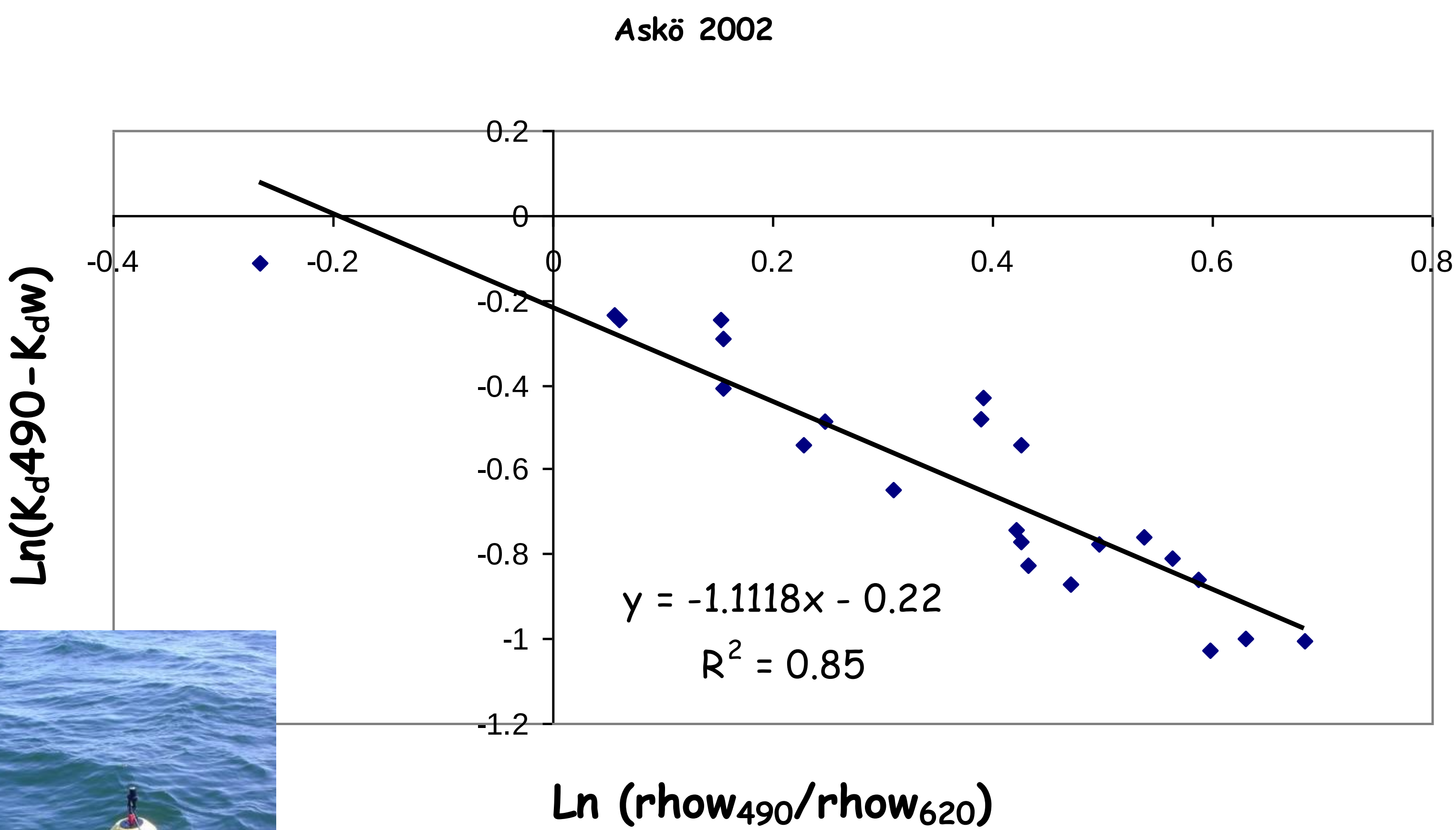


Optical transects in the Baltic proper (HF & BR) and monitoring stations in the Gulf of Bothnia (GoB) for the validation of satellite data



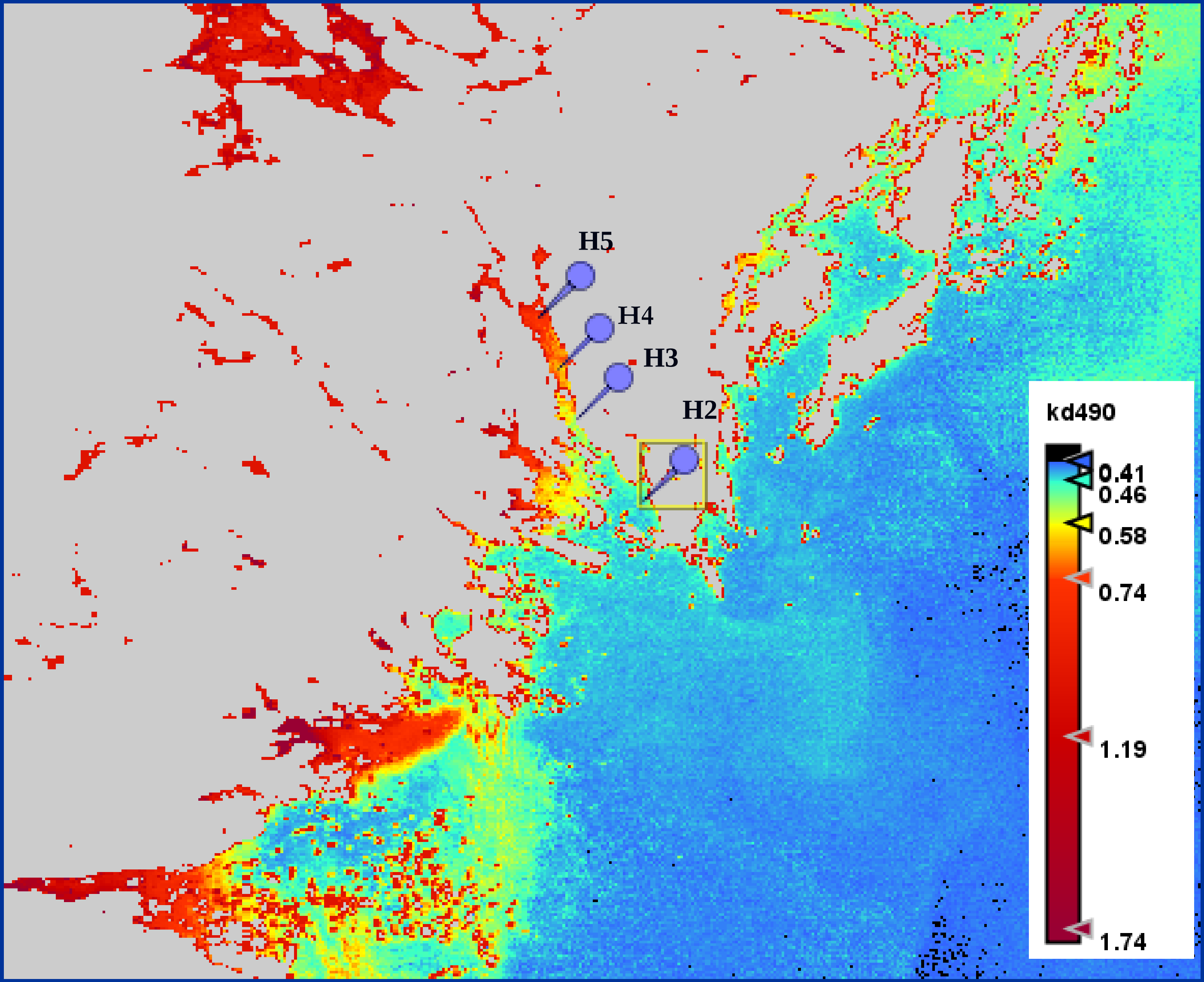
Kratzer, S., Håkansson, B., and Sahlin, C., 2003, Assessing Secchi and photic zone depth in the Baltic Sea from Space, Ambio, 32(8), 577-585.

K_d490 algorithm using bands at 490 nm and 620 nm



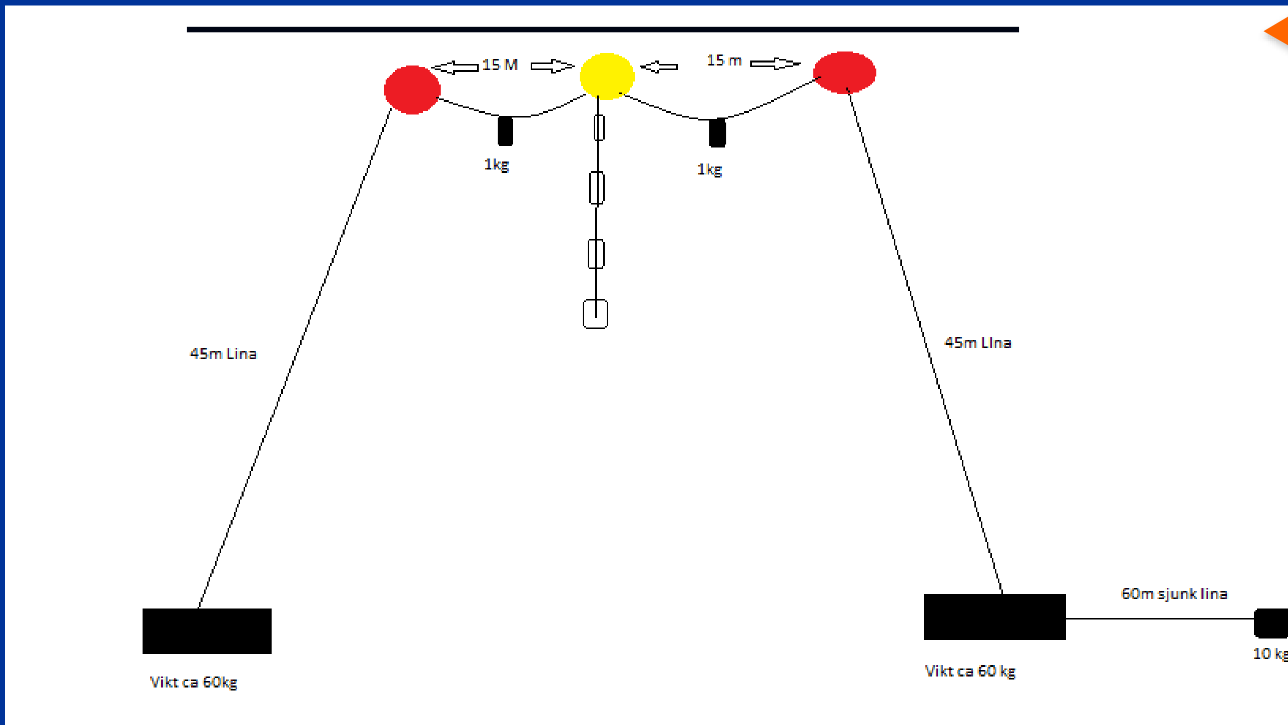
490 nm: MERIS channel 3; 620 nm MERIS channel 6.

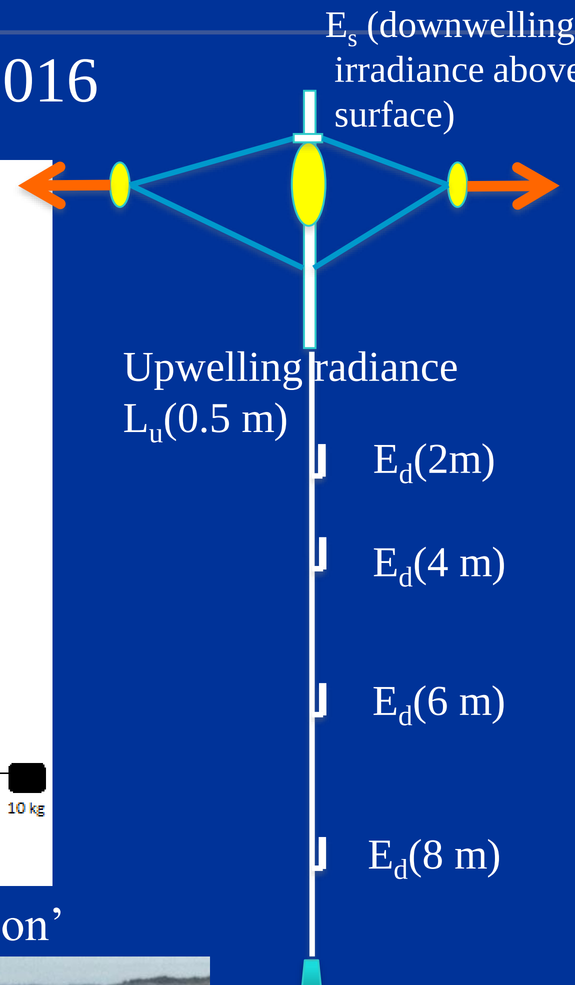
MERIS $K_d(490)$ image (300 m resolution)



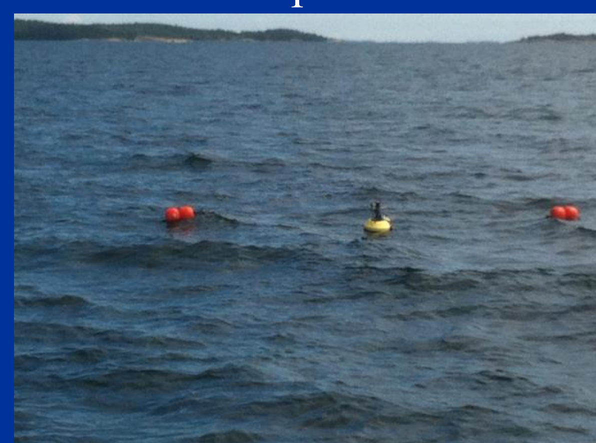
22 August, 2002, Kratzer *et al.*, 2008

TACCS mooring deployment 11-22 June 2016



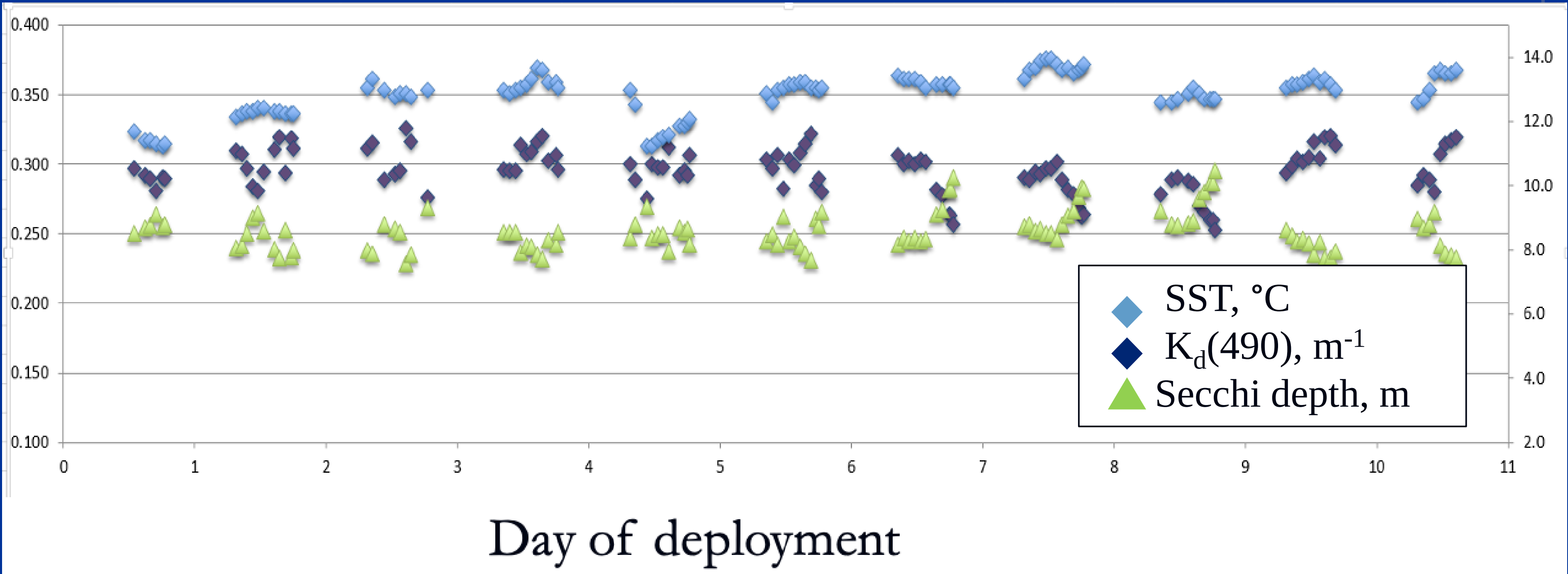


Two point mooring: TACCS held so that it floats in ‘normal position’



Bio Optika

Time series of SST, K_d(490) and Secchi depth at station B1 during 11-22 June 2016



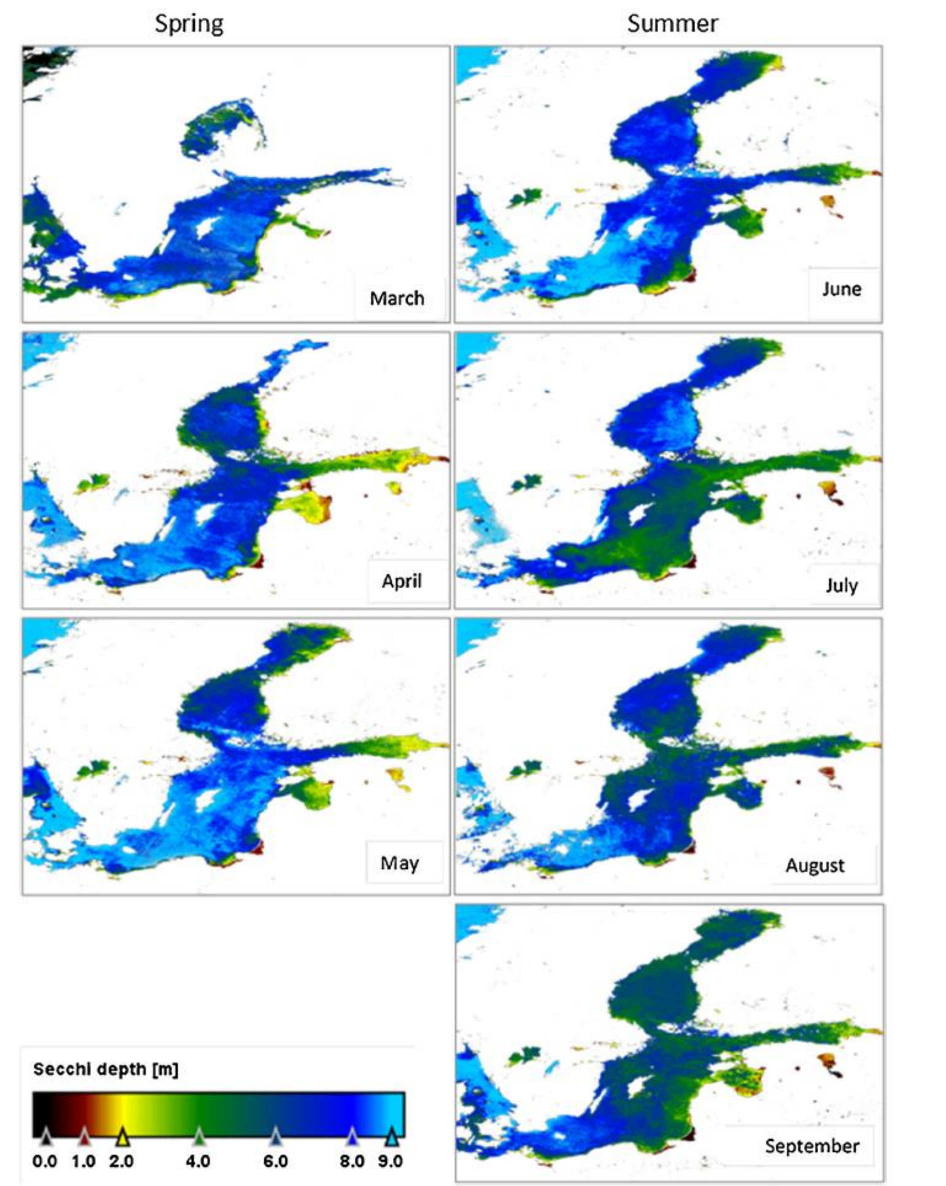


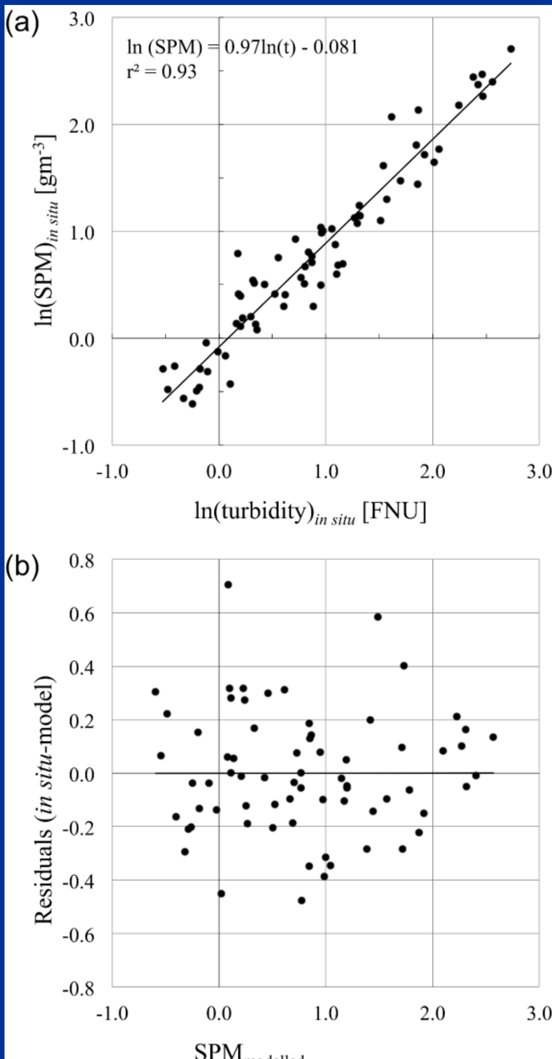
Fig. 5. Monthly means of Secchi depth algorithm (8.35, $K_d(\lambda) + c(\lambda)$, flag ice_haze) for 2010.

MERIS Secchi Depth time series over the Baltic Sea basin during 2010 Monthly means for spring (left) and summer (right).

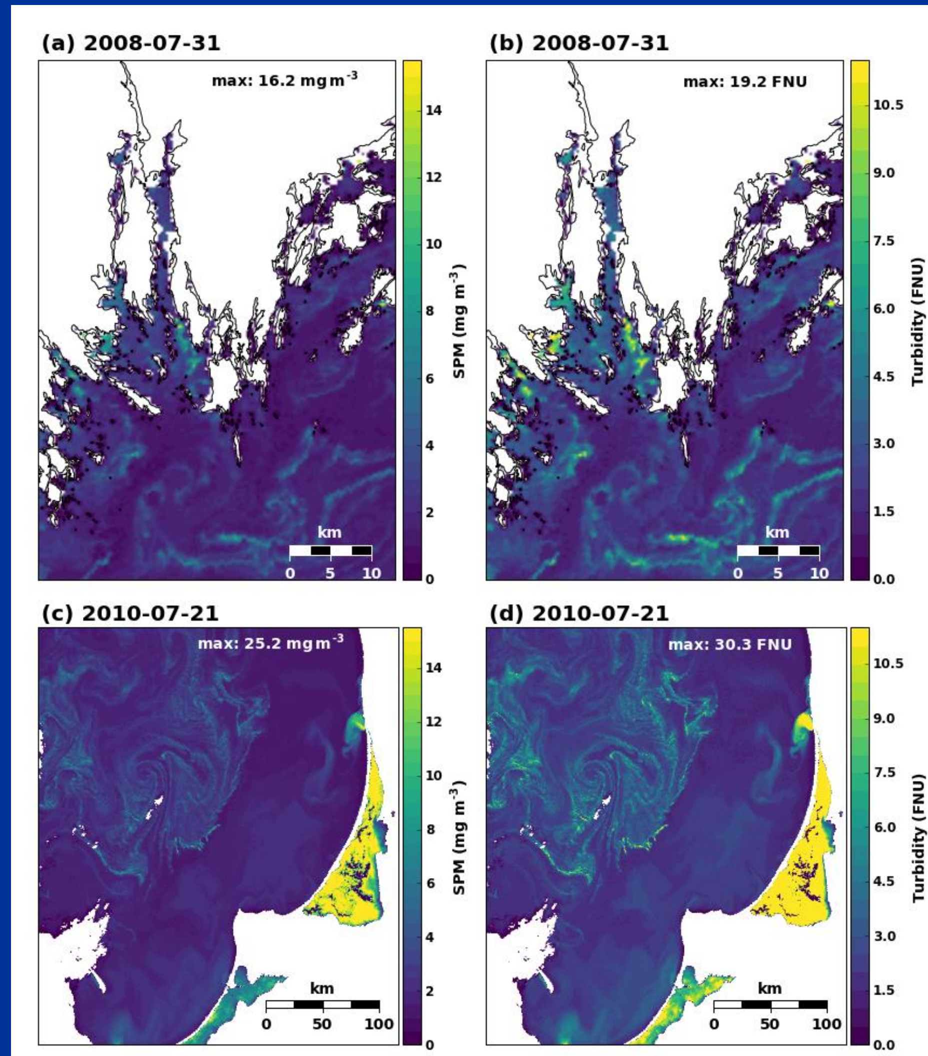
We can use apply similar methods to coastal areas using Sentinel-2 data (10 m resolution)

Alikas, K. and Kratzer, S., 2017. Improved retrieval of Secchi depth for optically-complex waters using remote sensing data. Ecological Indicators, 77, 218-227.

Coastal distribution of SPM (left) and turbidity (right)



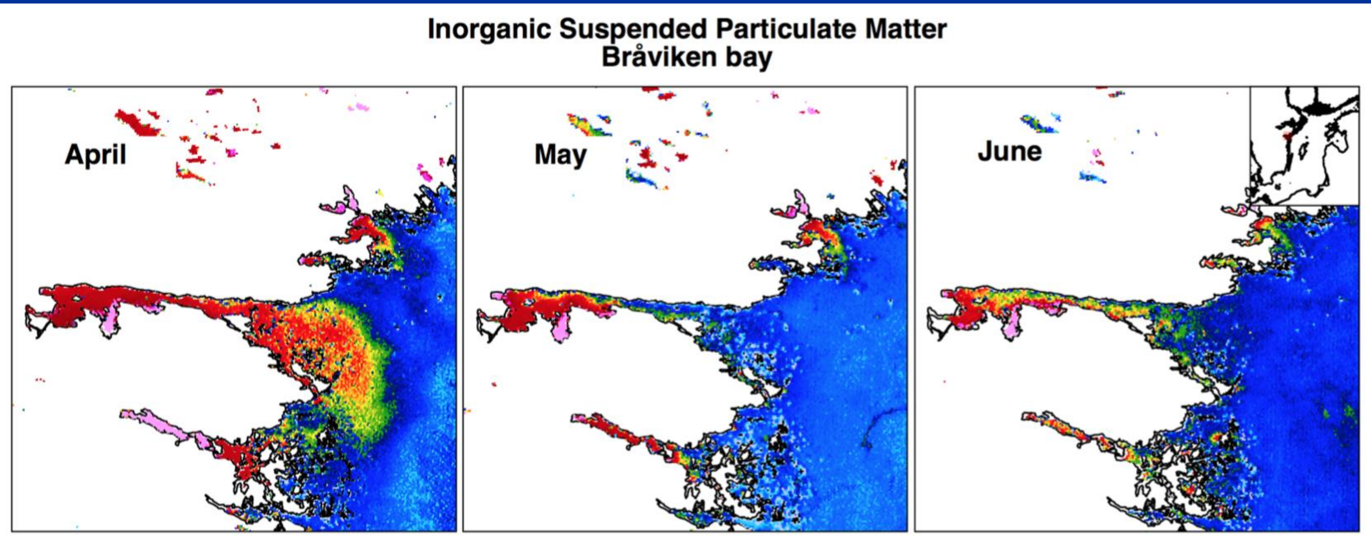
Relationship between SPM and turbidity



MERIS image NW Baltic Sea, Sweden (Askö/Landsort area)

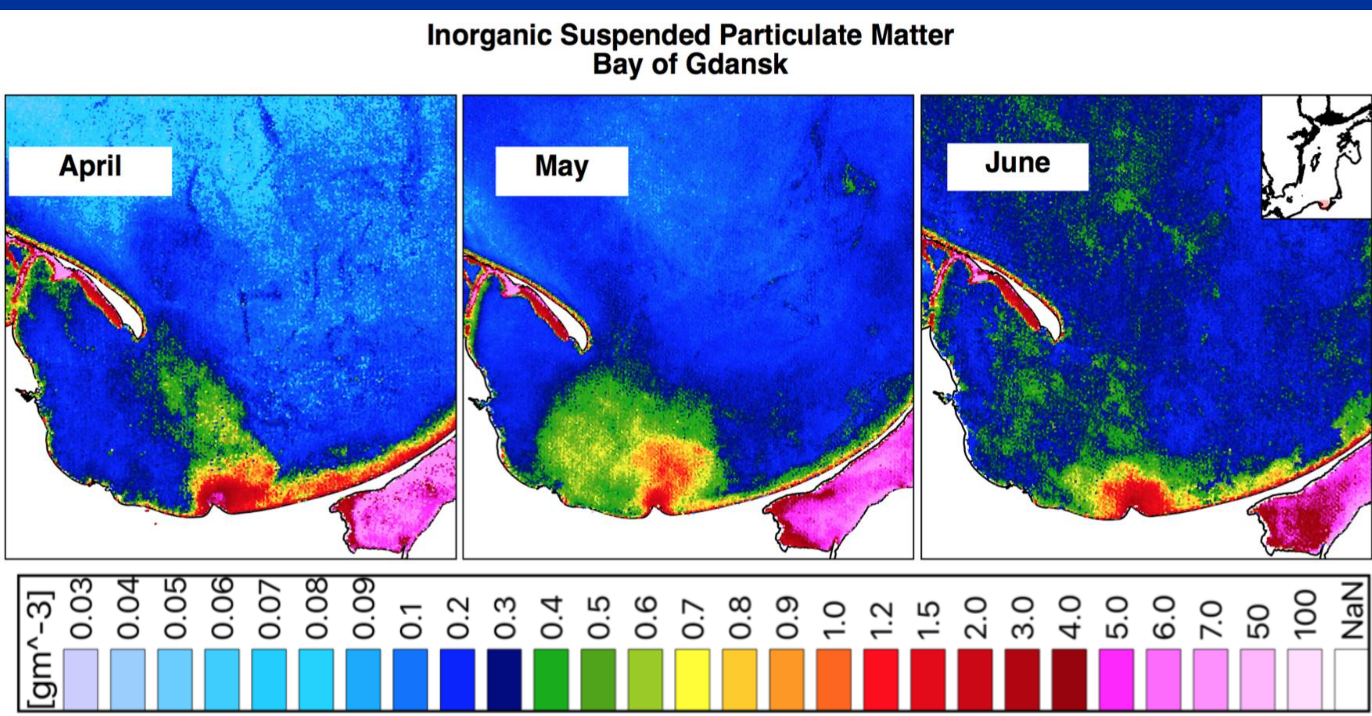
MERIS image SE Baltic Sea (Curonian Lagoon and Bay of Gdansk)

Kari et al., 2017



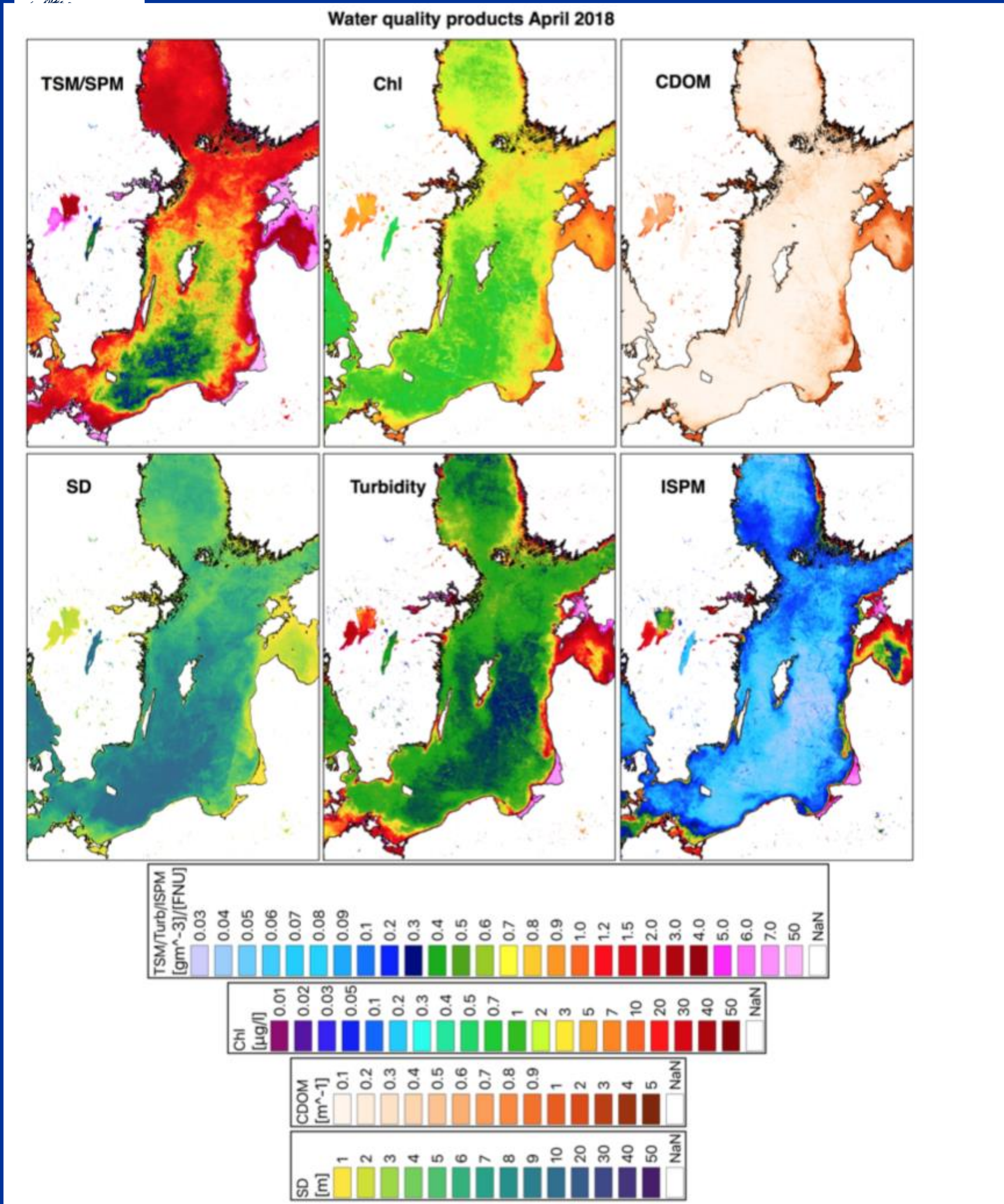
Seasonal changes

Bråviken Bay,
NW Baltic proper



Bay of Gdansk

Monthly composites (OLCI- Sentinel-3A data;© ESA);
Data processing:
PhD thesis, D. Kyryliuk 2019, DEEP, SU
Algorithm development and validation:
Kratzer et al. 2019, RSE



Ocean Colour products that we can derive reliably from Space (composite images derived from Sentinel-3 data);
Several products are based on our own regional algorithms (SPM; Secchi depth; turbidity, inorganic SPM).

Kyryliuk, D., 2019. Baltic Sea from Space:
The use of ocean colour data to improve our understanding of ecological drivers across the Baltic Sea basin – algorithm development, validation and ecological applications (PhD thesis, DEEP, SU)

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PhD training courses and workshops

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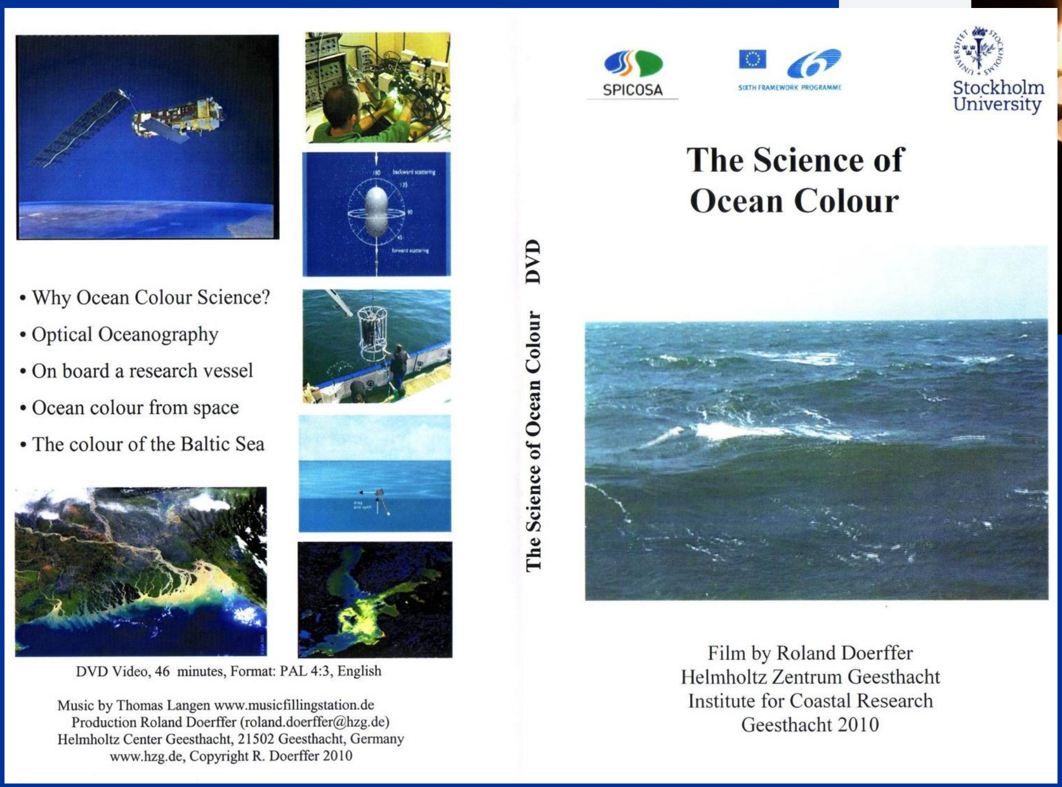
Thanks a lot to my students and our scientific collaborators!

In Memoriam of Roland Doerffer (1947- 2021)



The Science of Ocean Colour, a film by Dr. Roland Doerffer (46 min)

Download: http://www.spicosa.eu/setnet/downloads/index.htm