Marine optics monitoring in Greenland: benefits, challenges and future

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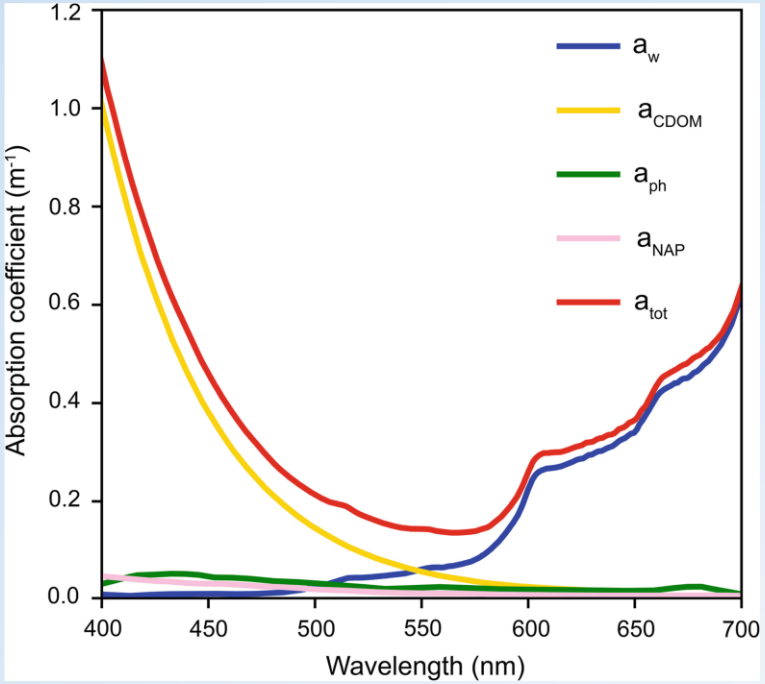
Key terms:

- **Biogeochemistry** - the study on the chemical, physical, geological, and biological processes and reactions that govern the composition of the natural environment. Biogeochemistry focuses on cycles of chemical elements, such as **carbon, nitrogen, phosphorus and silica** and their interactions with and incorporation into living things transported through earth scale biological systems in space through time.
- **Biooptic** is the scientific discipline that involves studies of the interaction of living organisms with natural light field in the environment e.g. photosynthesis, camouflage
- **Proxy** - a measured variable used to infer the value of a variable of interest
- **Inherent Optical Properties of sea water** – a physical quantity that determines the transmission of light over a distance (loss of intensity) based on properties of pure water and constituents within
- **Optically significant constituents of sea water** – dissolved and particulate material contained in sea water impacting spectral properties and magnitude of IOP,s

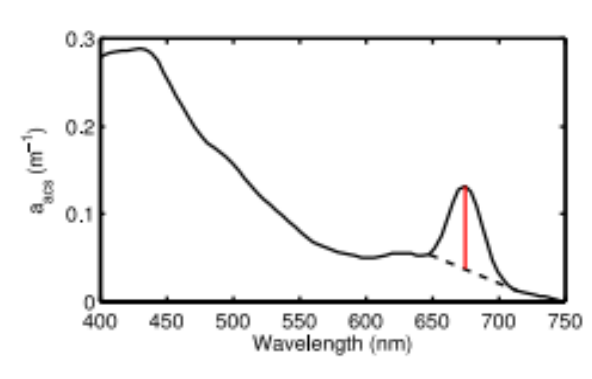
Inherent Optical Properties - IOPs - attenuation coefficient, c(λ), absorption coefficient, a(λ), scattering coefficient, b(λ)

$$\frac{dL(\lambda)}{dr} = -cL(\lambda) \qquad c(\lambda) = a(\lambda) + b(\lambda)$$



Opticaly Significant Constituent contributing to:

- absorption coefficient – water, dissolved inorganic salts, colored dissolved organic matter, suspended particles, photosynthetic pigments contained in autotrophs (phytoplankton)
- scattering coefficient – water, suspended particles

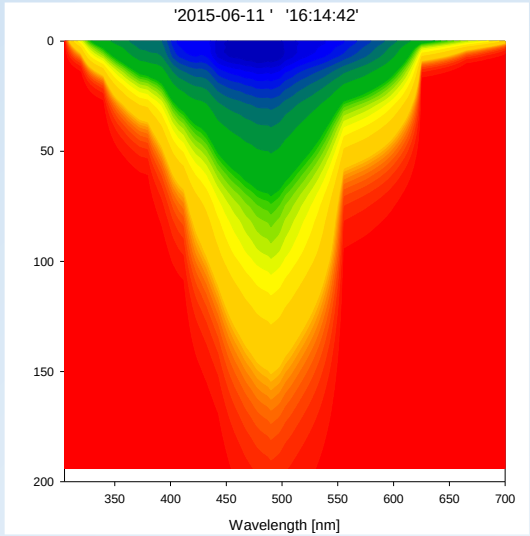


Absorption line height at 676 nm – $a_{LH}(676)$

Apparent optical properties - AOPs are those properties that depend both on the medium, the IOPs and on the directional structure of the ambient light field

Diffuse attenuation coefficient – $K_d(\lambda)$ – describes rate at which solar irradiance is attenuated with depth and how energy is distributed in water column

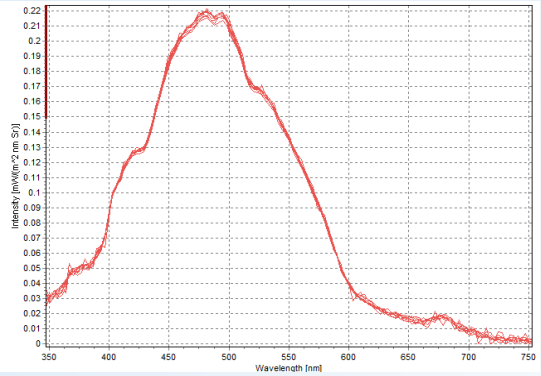
$$K_d(\lambda) = \frac{d \ln E_d(\lambda,z)}{dz} = \frac{1}{E_d(\lambda,z)} \frac{dE_d(\lambda,z)}{dz}$$



Remote sensing reflectance – $R_{rs}(\lambda)$ – a quantity easily measured by optical sensors mounted on floating, airborne or spaceborne platforms and quantify a visually sensed color

$$R_{rs}(\lambda) = \frac{L_{wl}(\lambda)}{E_d(\lambda)} = 0.33 \frac{b_b(\lambda)}{a(\lambda)}$$

(Morel and Prieur, 1977)



Benefits of optical measurements in application in marine biogeochemistry

- *Optical measurements conducted with standardized commercially available instruments are easy to conduct in situ and in the laboratory*.
- *Simplified and miniaturized instrument can be mounted on floats, UAV (i.e. gliders) or commercial vessels (i.e. Ferry box systems) extending spatial and temporal coverage*.
- *Through selection of measured parameters and spectra region offers observation of numerous biogeochemical parameters:*

- absorption in UVA and visible spectra bands – CDOM, DOC
- absorption in visible spectra band (blue, red) – chlorophyll-a
- absorption in UVB – nitrates
- backscattering and attenuation in green and red spectra bands – particles concentration and POC
- spectral attenuation – particles size distribution
- spectral absorption, backscattering and scattering – phytoplankton functional types
- spectral fluorescence - chlorophyll-a, phytoplankton communities, DOM composition, DOC

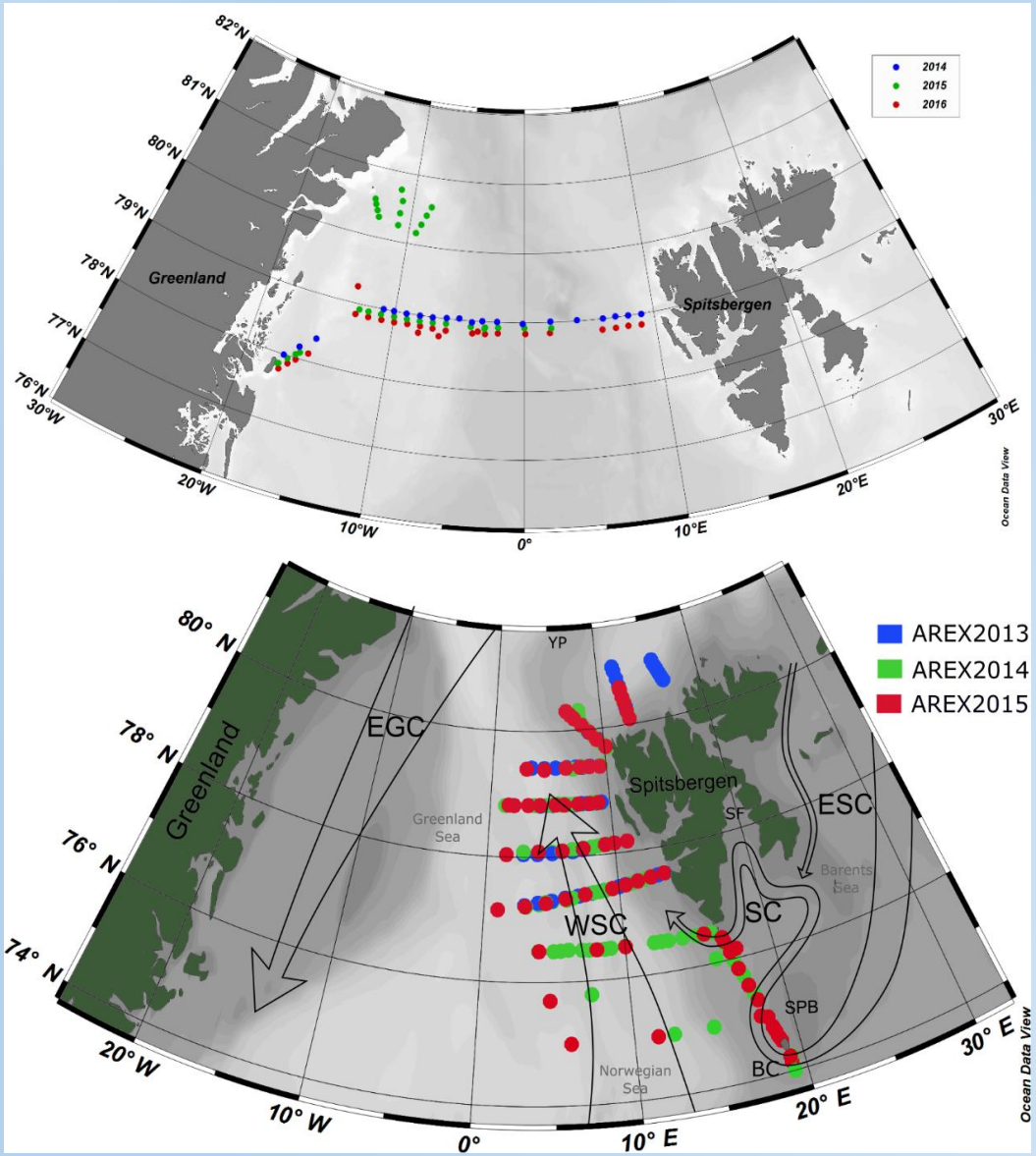
- *Concentrations of specific constituents could be estimated only through empirically derived relationships between chosen parameters and specific inherent optical properties – SIOPs*
- *IOPs (and thus concentrations of constituents) could be estimated through the inversion algorithms and satellite or airborne remote sensing*

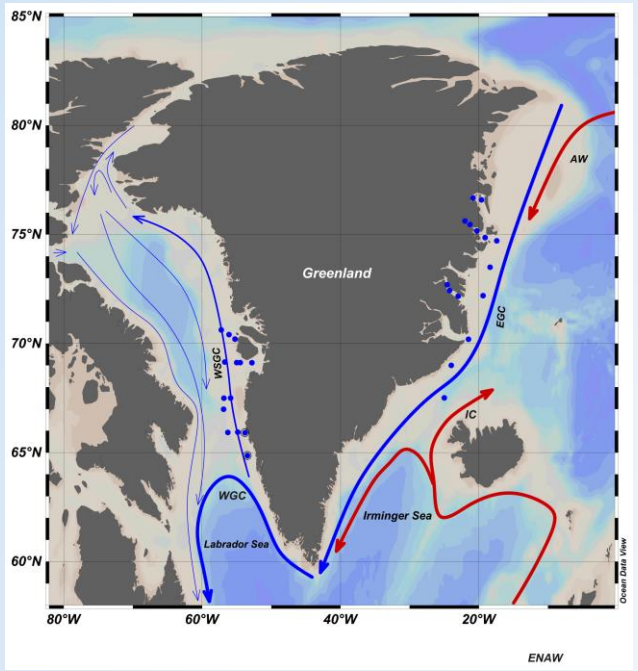
Optical monitoring in the European Arctic - examples

West Spitsbergen Shelf (AREX Cruises – r/v Oceania – 2014 – present)

Fram Strait – r/v Lance – 2014-2016 Kronprins Haakon – 2021, 2024

East Greenland Shelf – ECOPTIP project cruises, r/v Dana -2021, r/v Maria S. Merian - 2022





Methods

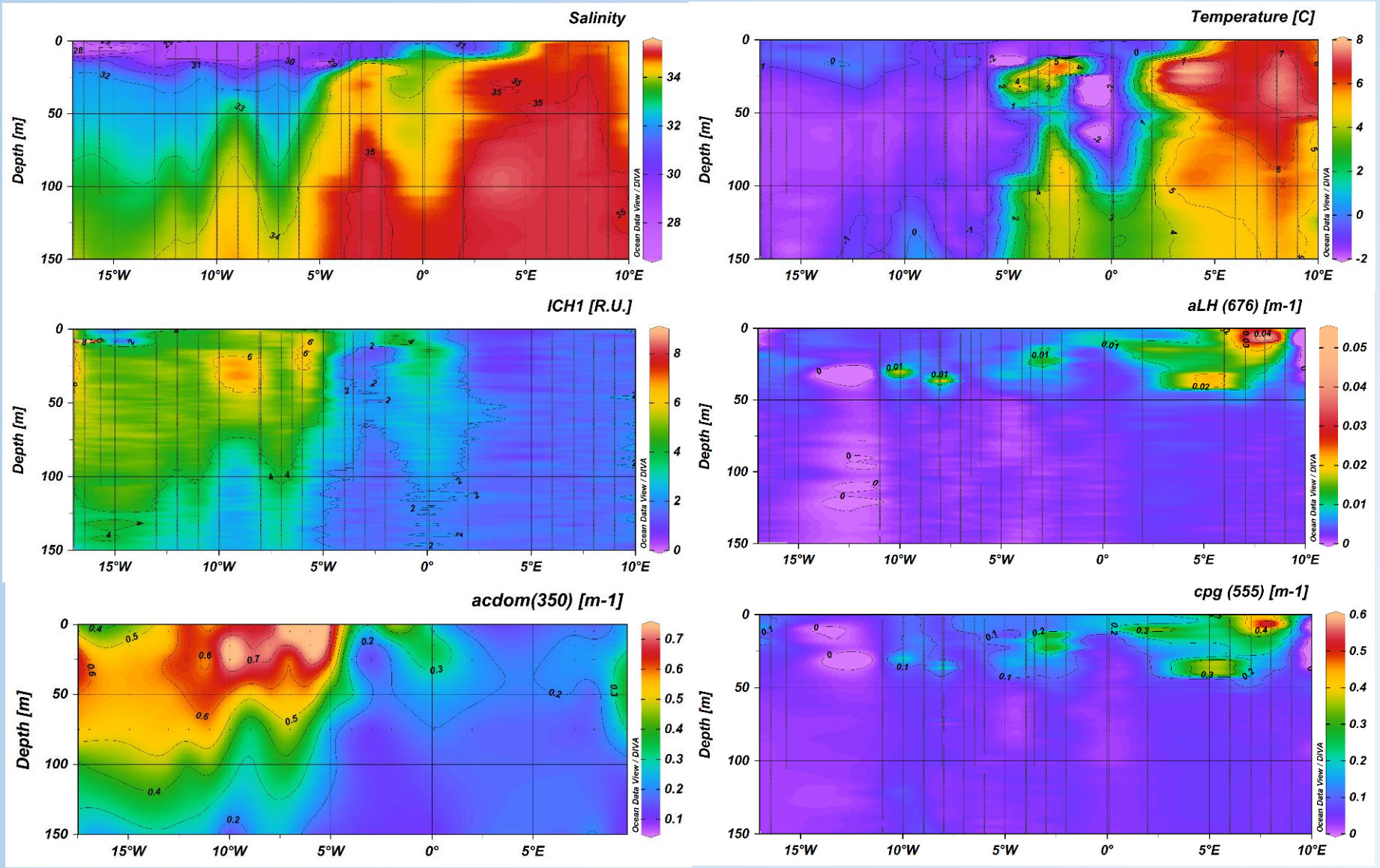
Instrumental in situ measurements:

Integrated Optical Probe – ac-9/**acs**, FDOM fluorometer at 3 ex./em. wavelengths, Chl-a flurometer, CTD probe

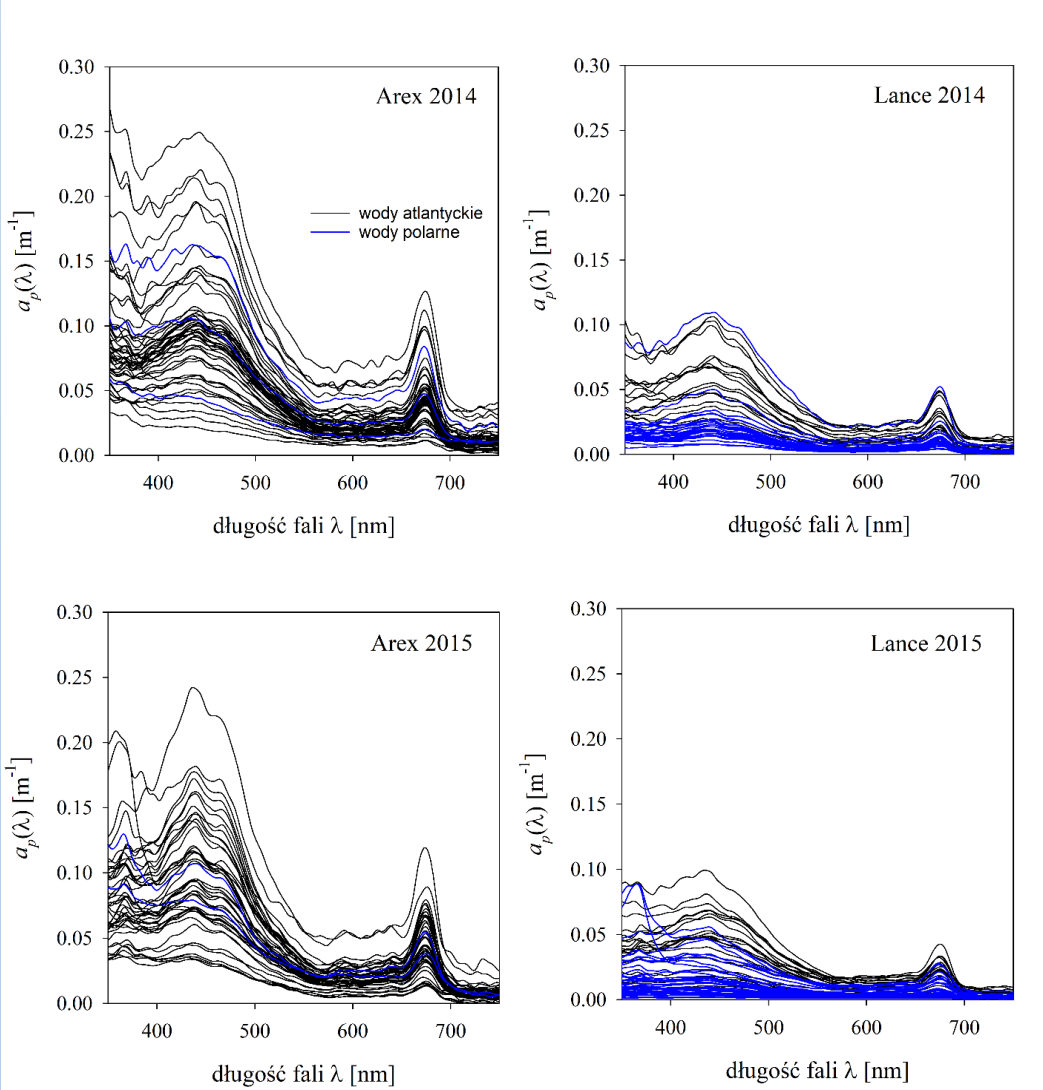
Water samples at discrete depths:

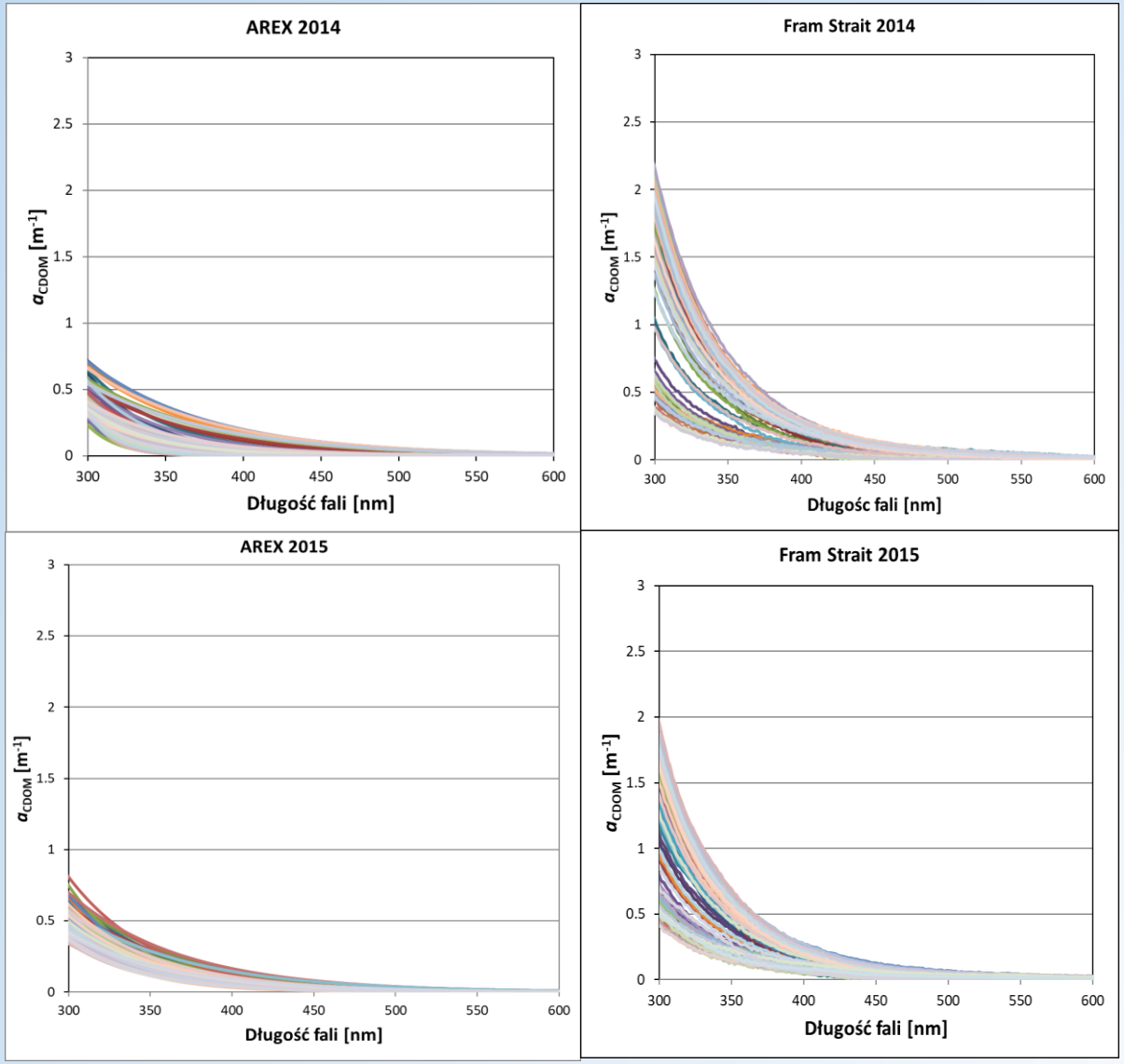
- on board filtration and preservation
- land based laboratory measurements for particulate absorption, CDOM absorption, FDOM EEMs, chlorophyll-a/**pigment concentration – HPLC, POC,** DOC

Typical distribution of physical and optical properties of sea water across Fram Strait in the late summer – example from August 2016

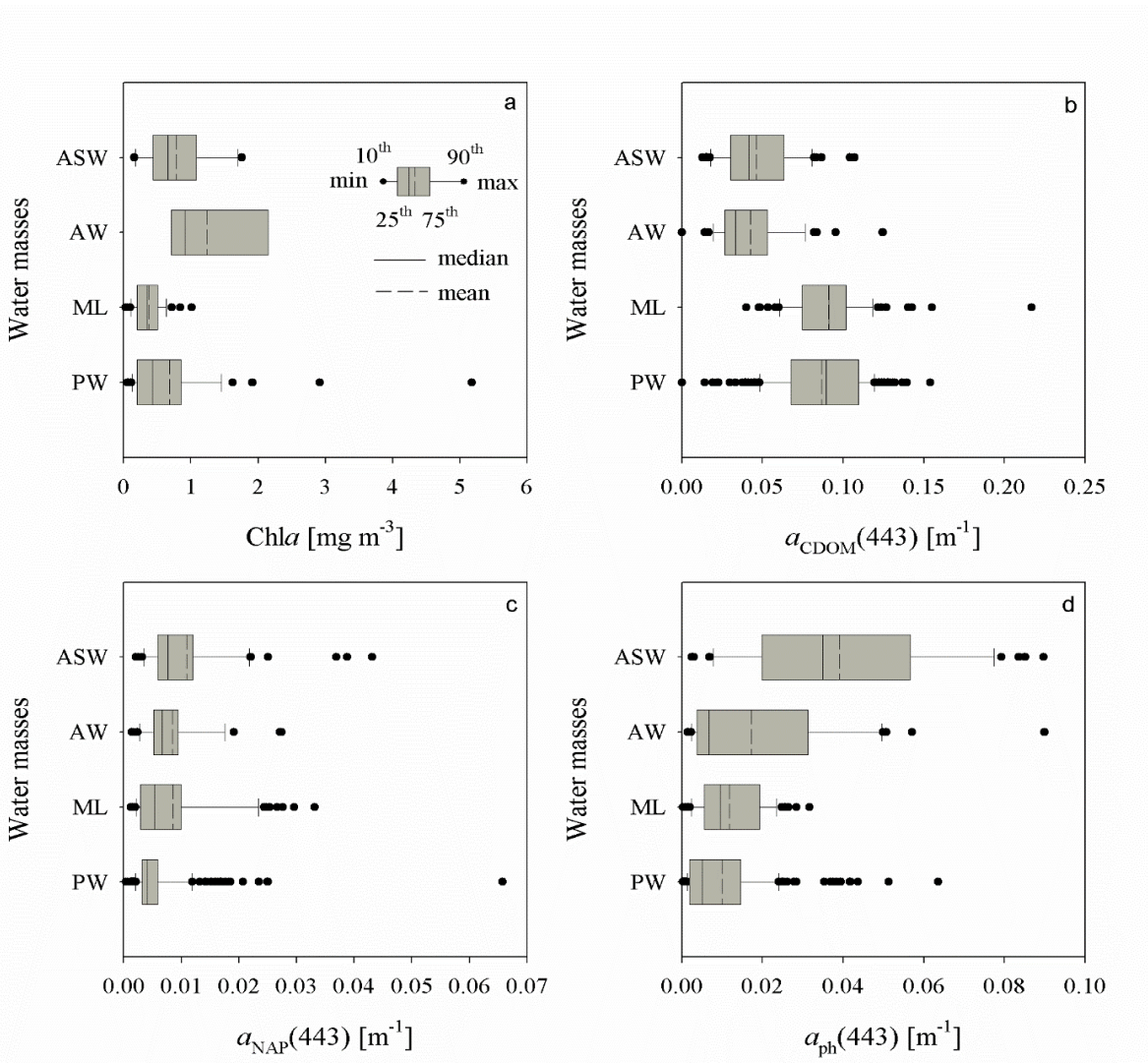


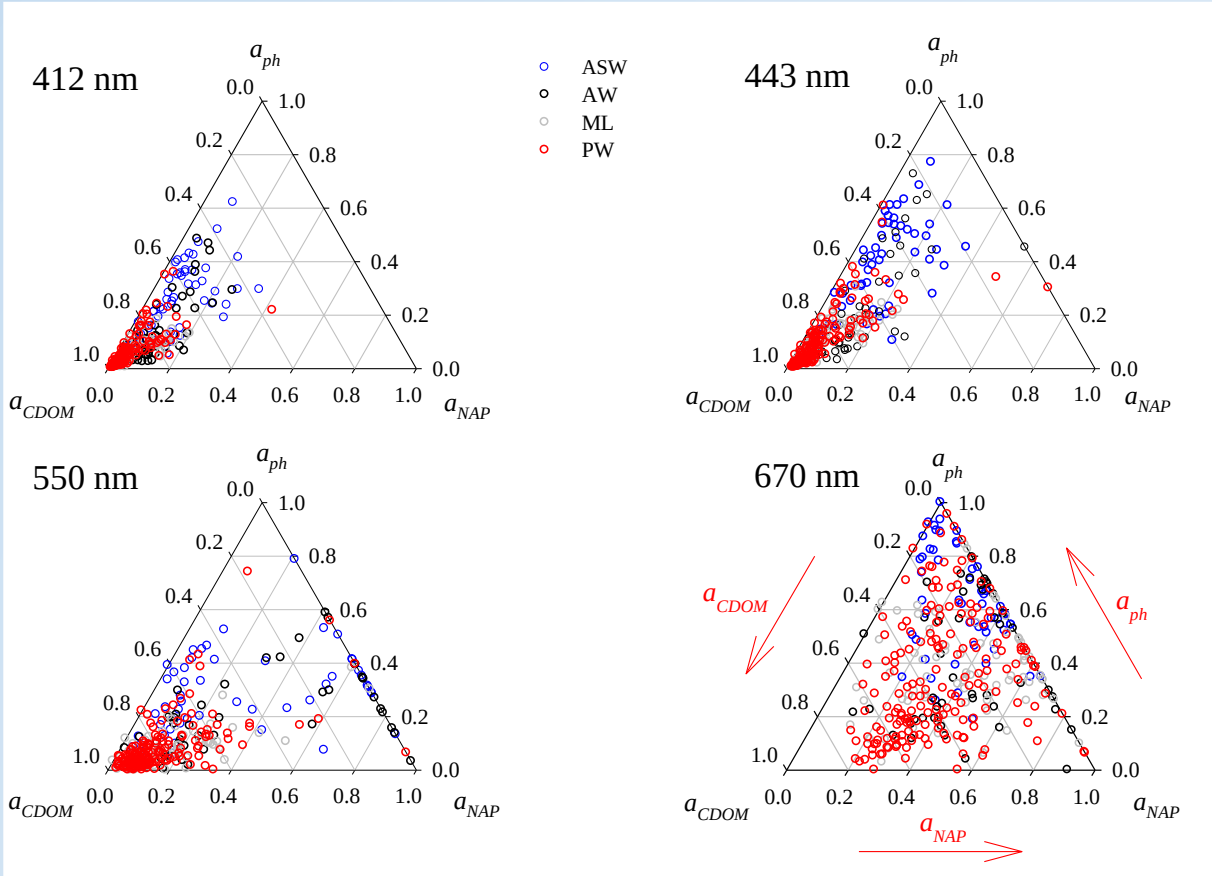
Spectral properties and seasonal variability of particulate and CDOM absorption across Fram Strait



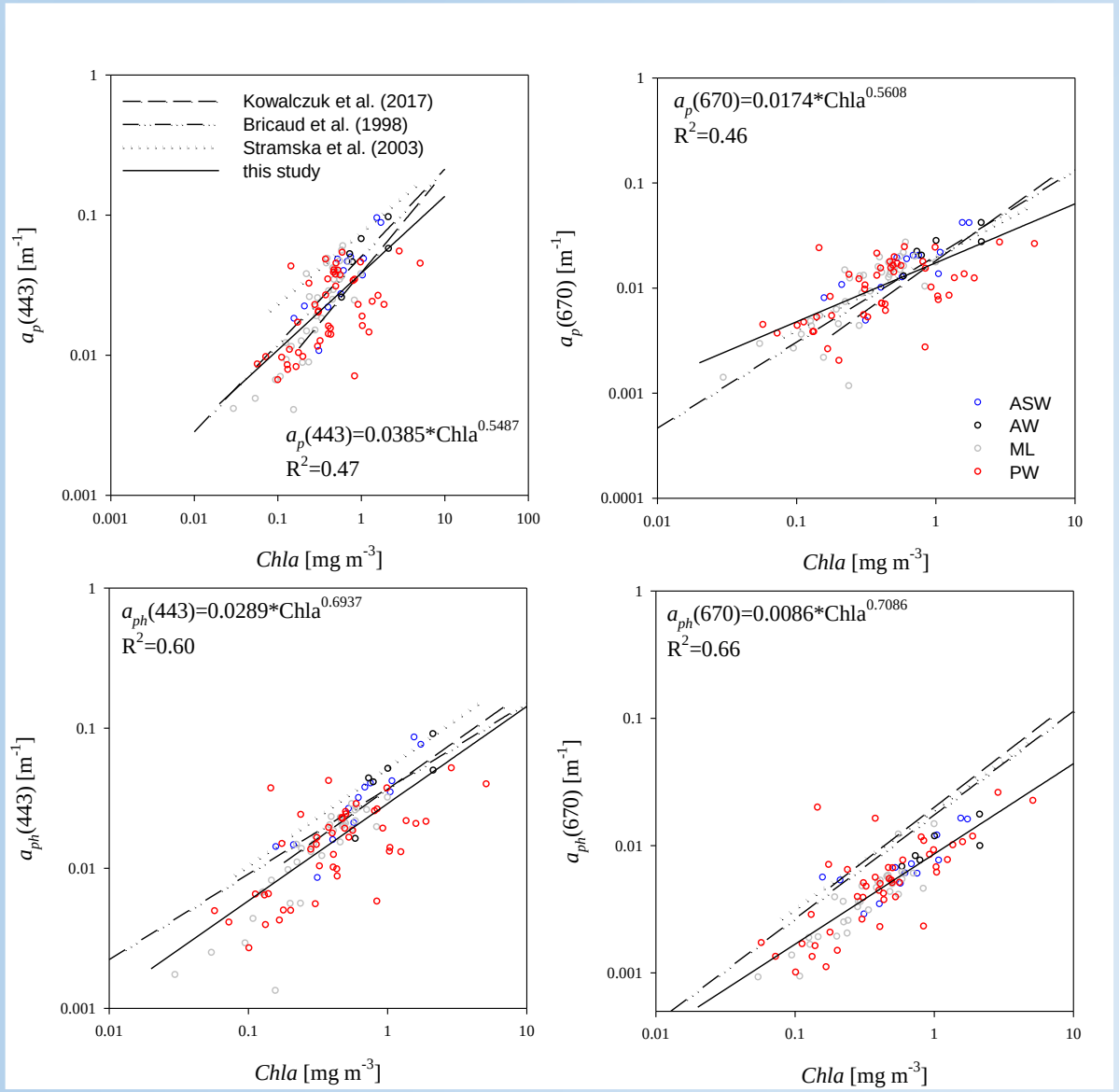


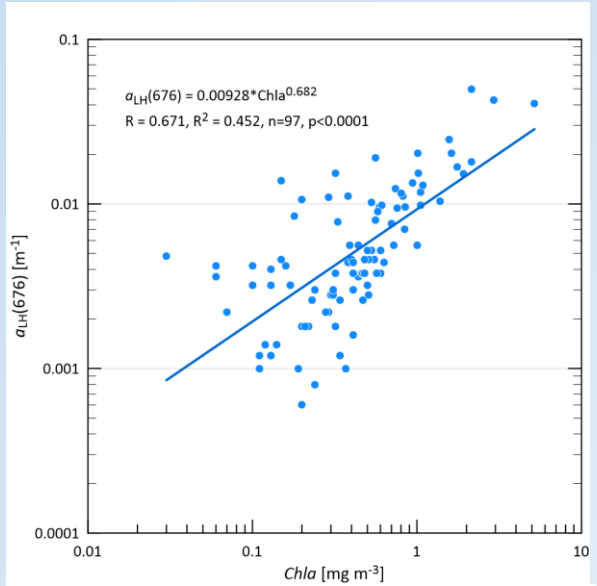
Optical characterization of water masses and absorption budget

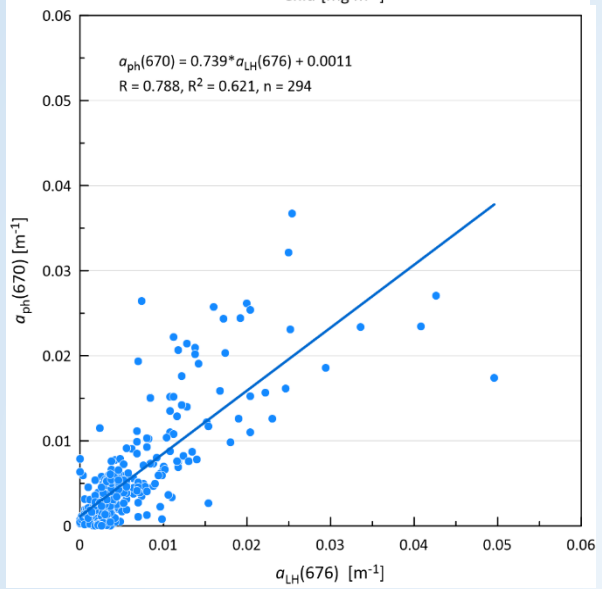




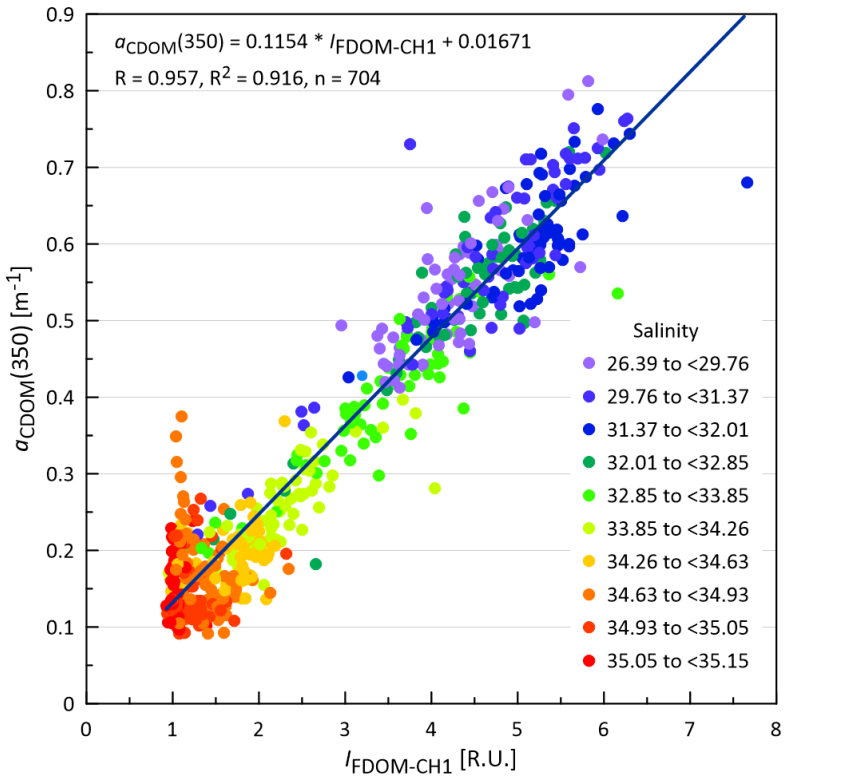
Biooptical models – relationship between IOP's and chlorophyll-a concentration

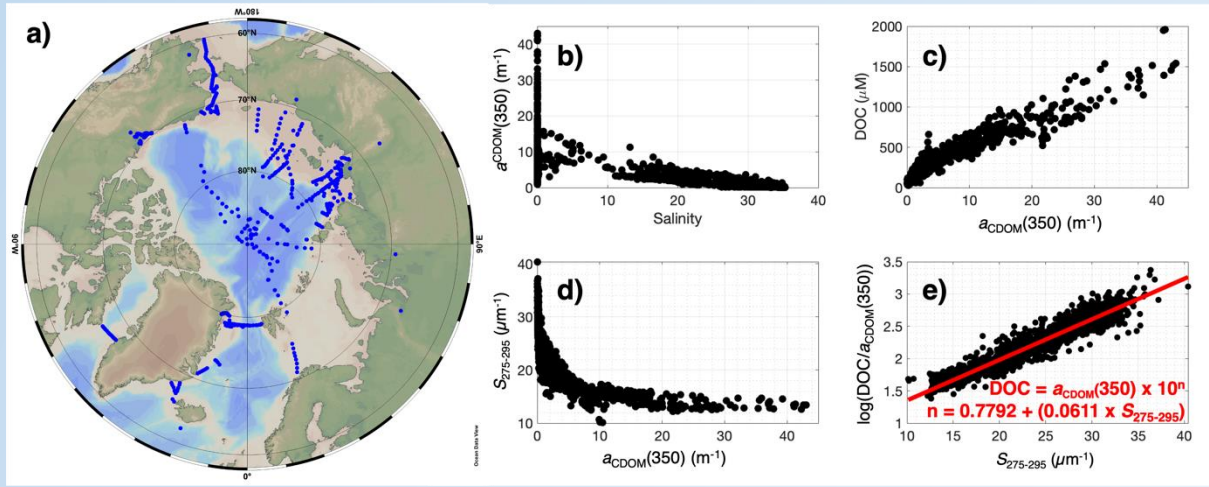






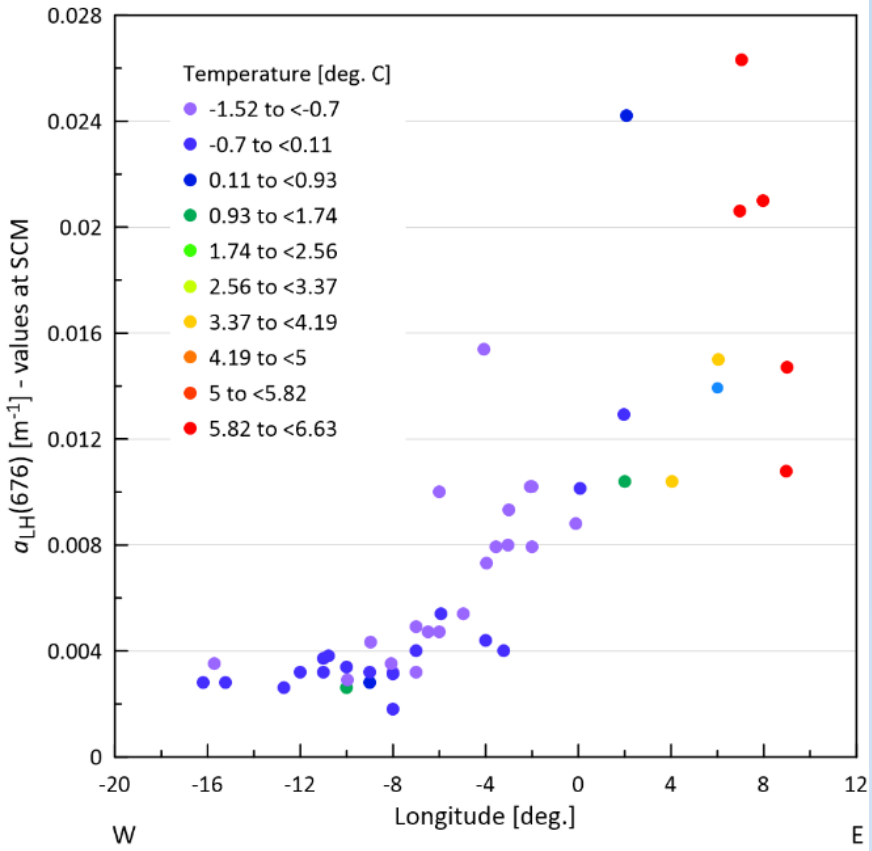
CDOM fluorescence and absorption and their relationship with DOC

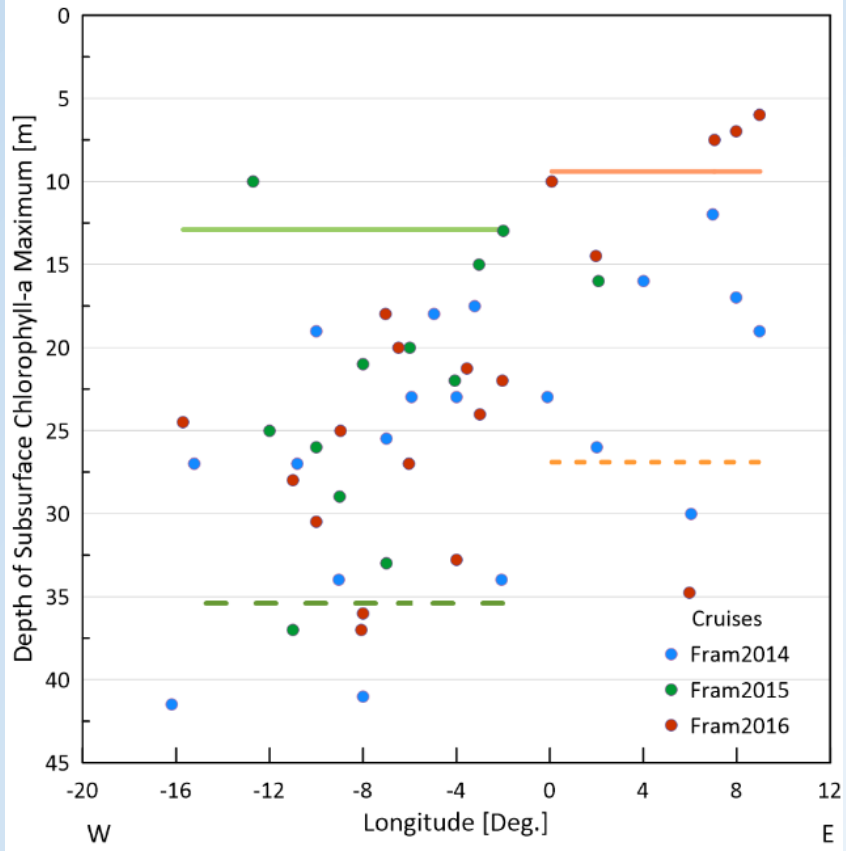




Gonçalves-Araujo et al., (2022)

The challenge for remote sensing estimation of phytoplankton biomass in East Greenland shelf





Low biomass, concentrated deep and below remote sensing detection limit, and masked with overlying highly absorbing, CDOM dominated Polar Water

Future directions

Foster collaborative international research activities in European Arctic to:

- *extend existing knowledge about IOPs and AOPs variability in the Arctic Ocean, characterize a vertical distribution of optically significant sea water constituents, associated with water masses structure, and assess how this effect in the uncertainty of chlorophyll-a detection in the Arctic Ocean with the use of ocean color remote sensing,*
- *provide a quantitative characterization already observed changes in the phytoplankton community structure at the East Greenland Shelf and Arctic Ocean and assess how the resulting change affect bio-optical relationships between IOPs and phytoplankton pigments and POC concentrations,*
- *extend absorption spectral range observations and establish, test and validate an optical proxy for nitrate concentration in the Arctic Ocean*
- *derive regionally optimized radiative model for more accurate estimation of underwater light field structure and the distribution of solar energy in the water column, as well as the further development of regionally optimized ocean color satellite remote sensing algorithms for retrievals of selected biogeochemical variables*