Use cases of in-situ and satellite BGC data in CMEMS Arctic Ocean Biogeochemical forecast and reanalysis products

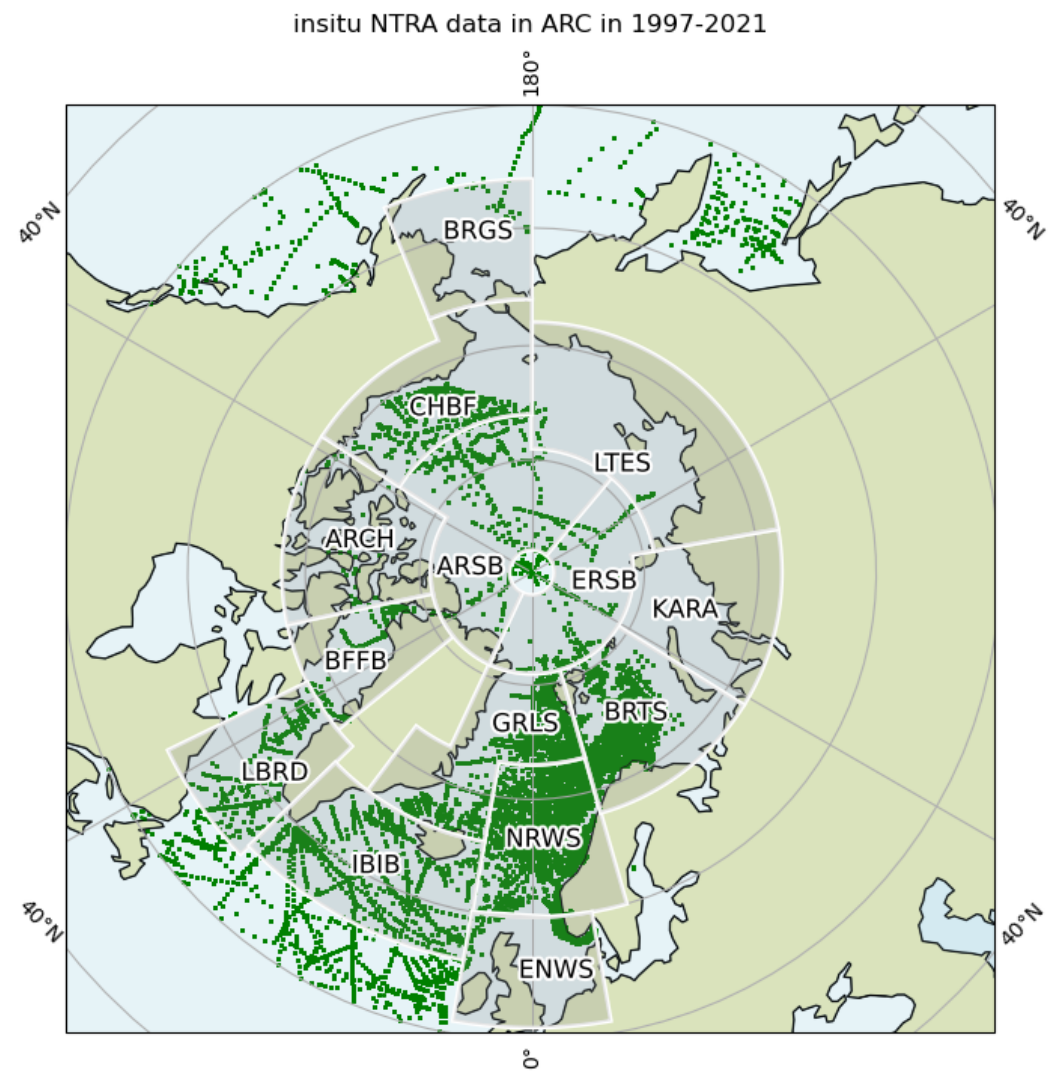
Tsuyoshi Wakamatsu, Veli Caglar Yumruktepe

The Nansen Center (NERSC) and Bjerknes Centre for Climate Research (BCCR) Bergen Norway

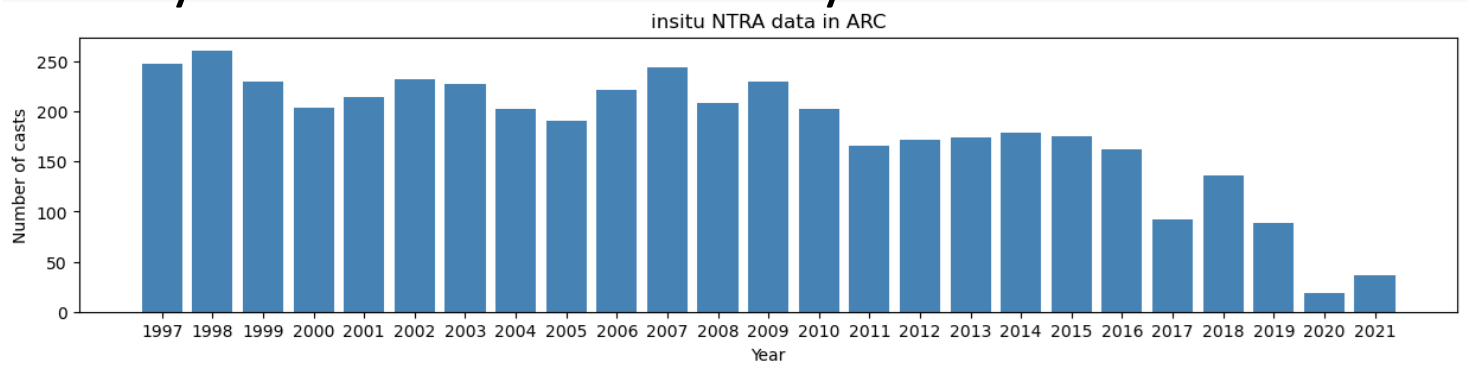
Funding: EU Copernicus Marine Service, Horizon Europe, Bjerknes Centre SKD, Norwegian Research Council and European Space Agency

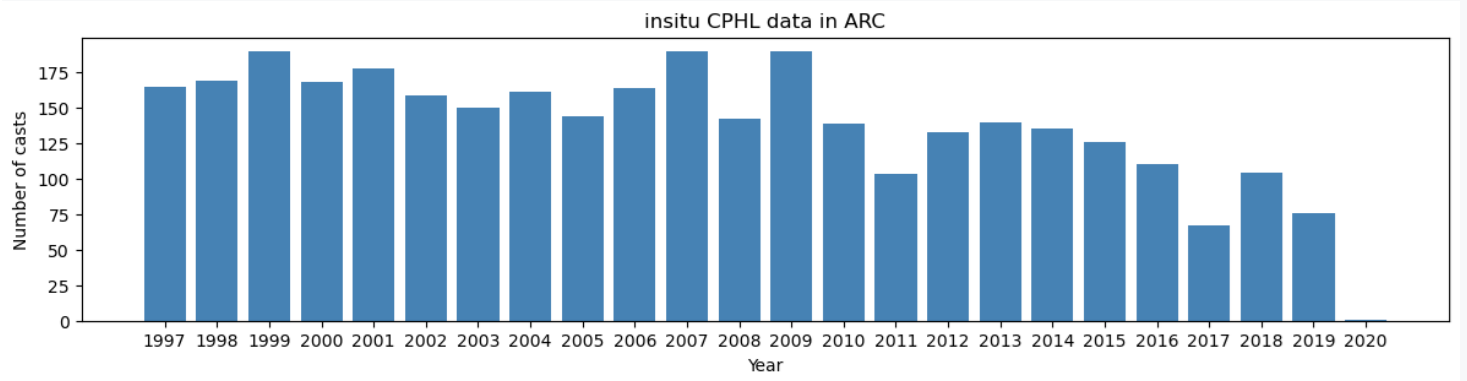
Arctic Ocean BGC observing system

Bottle sampled data (Nutrients, Chlorophyll-a) : Bathymetry > 200m



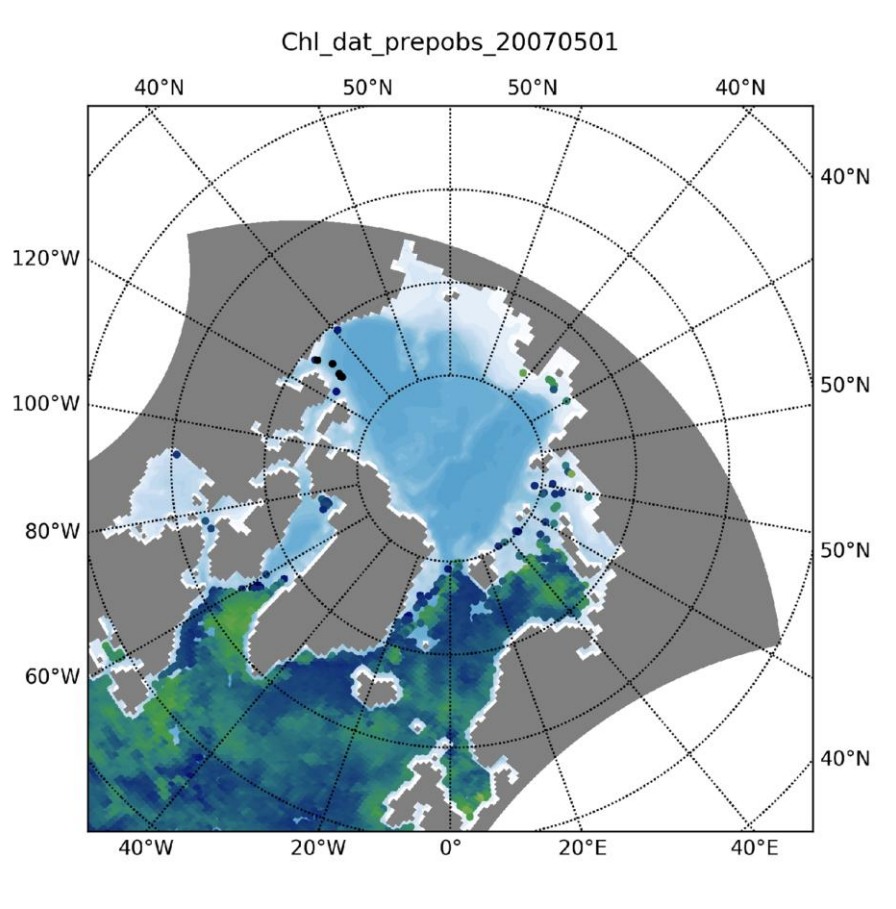
Number of bottle sample casts / year
Seasonally skewed to Spring and Autumn due to fishery stock assessment surveys



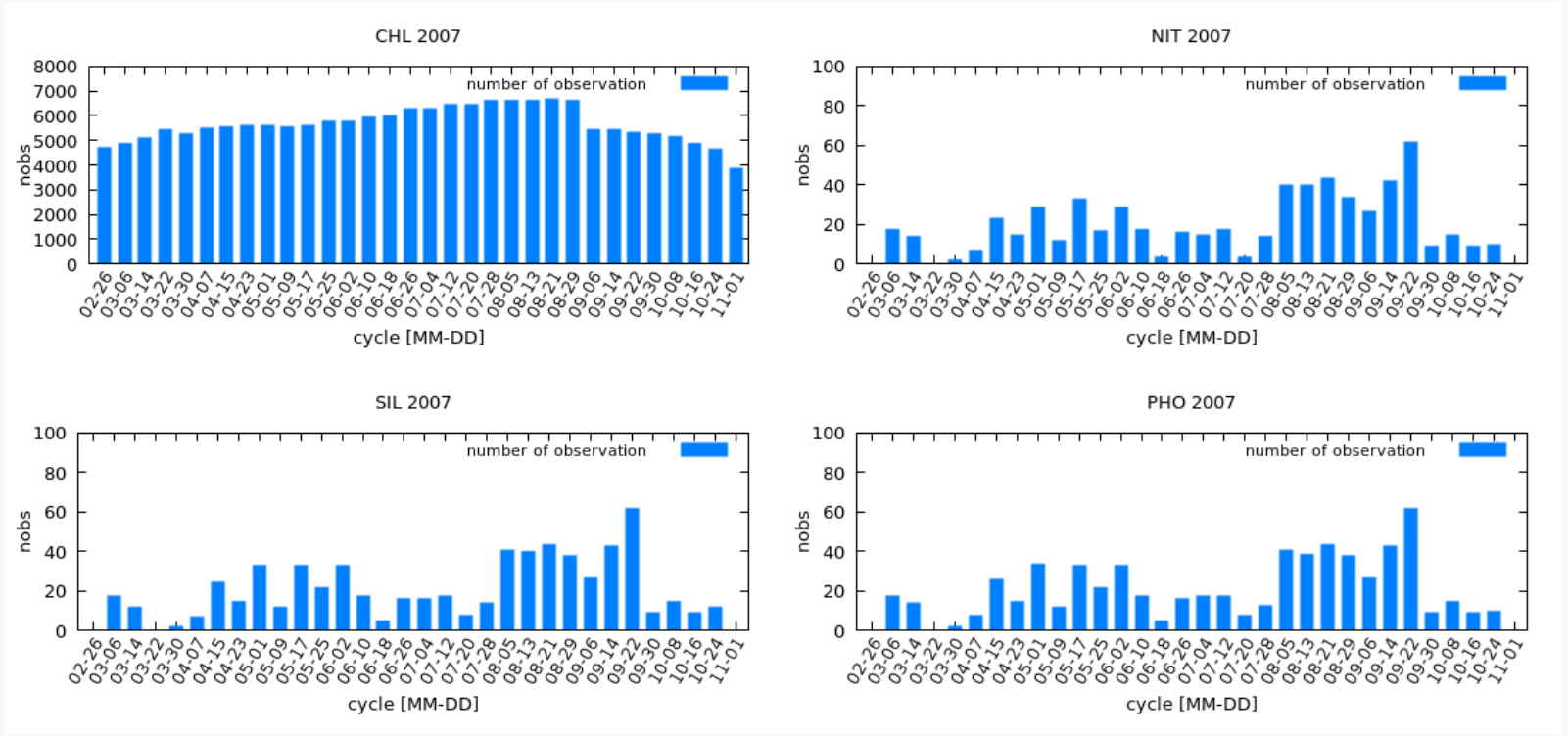


Arctic Ocean BGC observing system

Sea Surface Chlorophyll-a : ESA OC CCI v6.0 4km 8 days composite



Number of BGC data assimilated to reanalysis system
Satellite ocean color data provide the largest volume of data

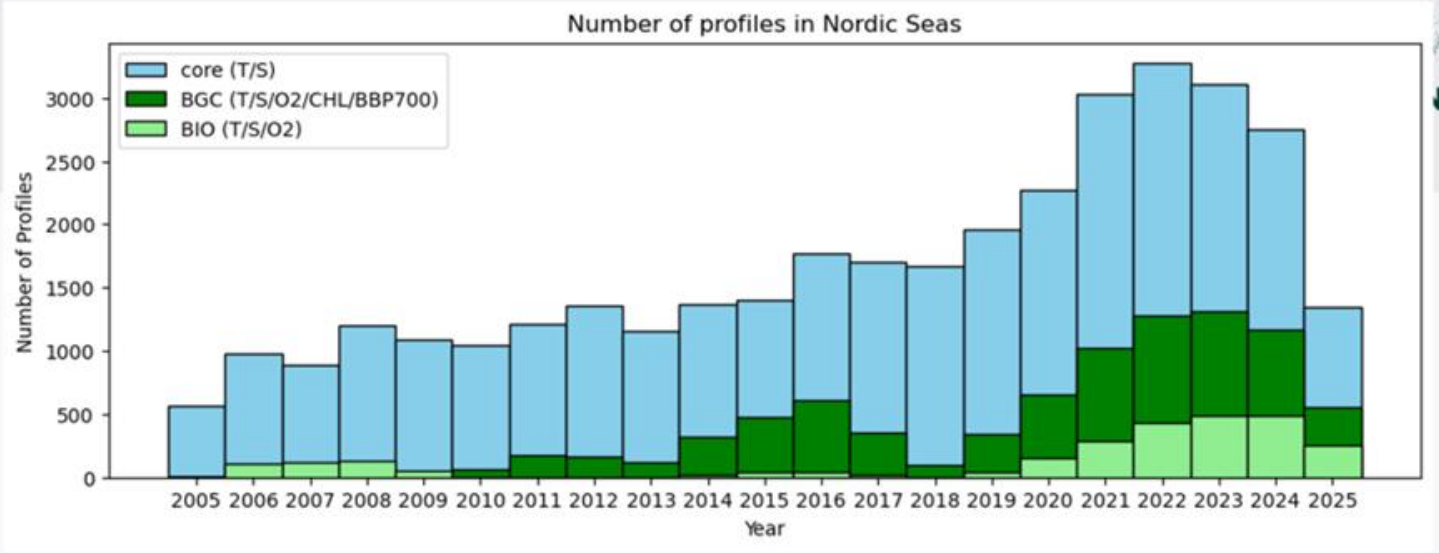


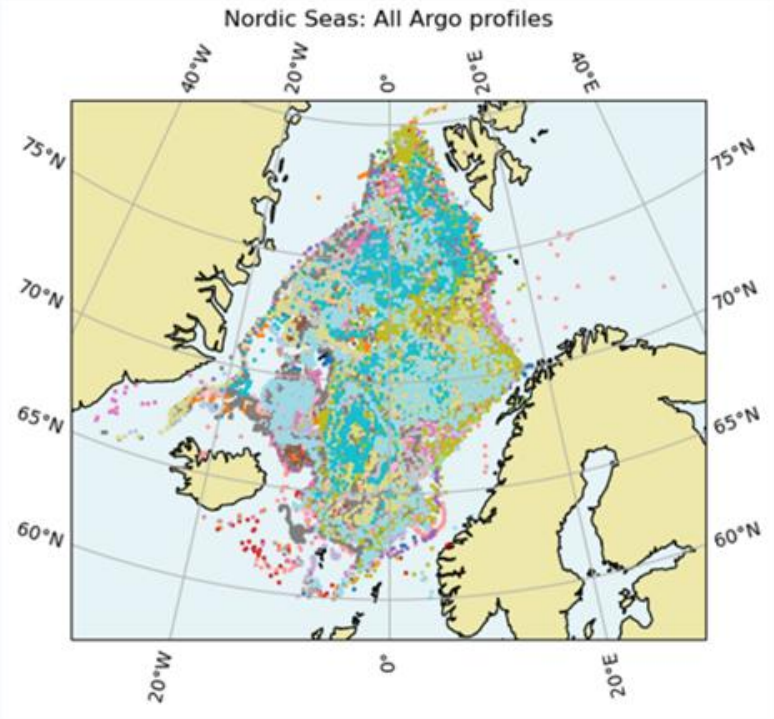
Profile coverage summary (Source: Argo GDAC (data acquired on July 28, 2025)):

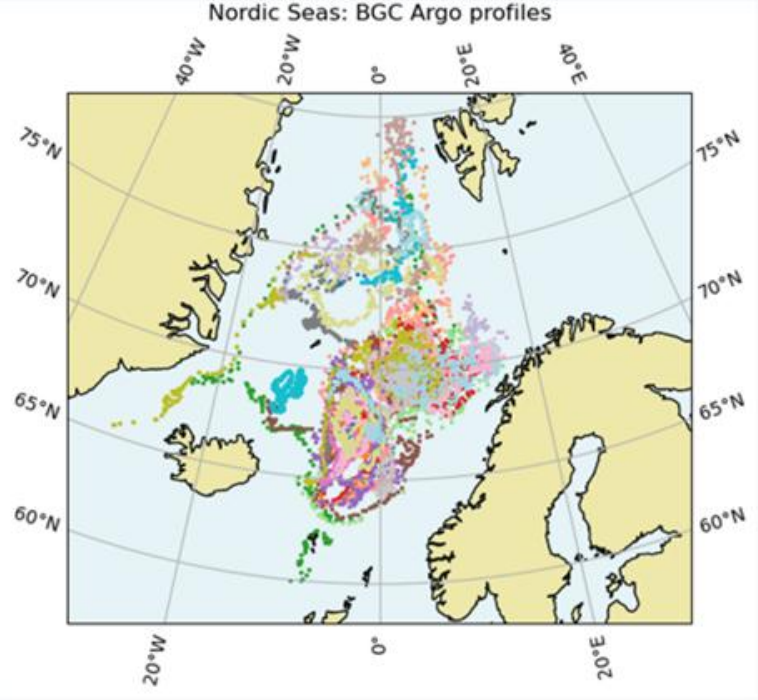
- T/S profiles cover deep Nordic Seas Basins uniformly
- Data voids exist in the BGC Argo float coverage, especially in Iceland Sea
- The total number of profiles peaked in 2022

Scientific questions

- Freshening of Norwegian/ Barents Seas and its impact to deep water formation
- Emerging oligotrophic condition during summer period in the Norwegian Sea
- Heat anomaly propagation along the Atlantic water pathway and its impact to marine heatwave







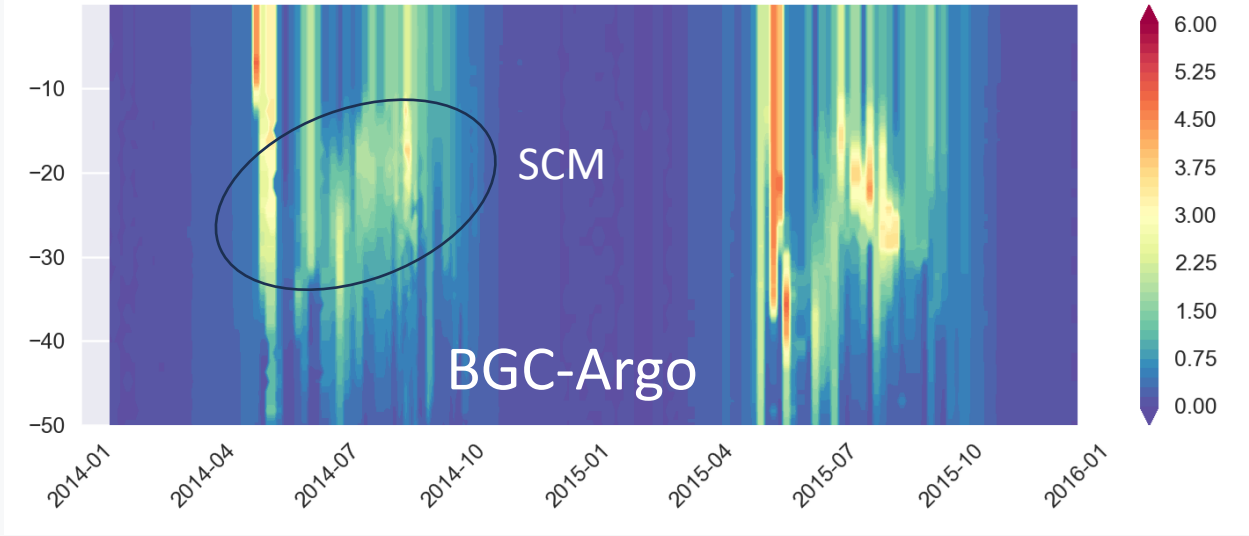
Arctic Ocean BGC observing system use case I

Model calibration: Argo float track-following 1D model system

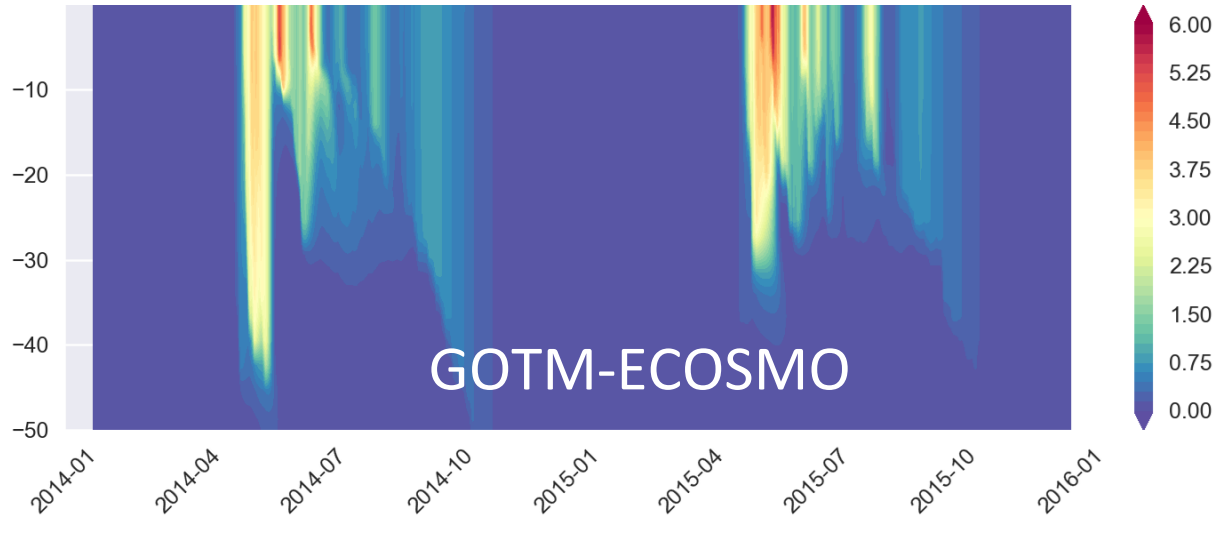


1D Physics (GOTM) ⇄ **Coupler (FABM)** ⇄ Biogeochemistry (ECOSMO)

Argo float detect subsurface Chl-a maximum (SCM)

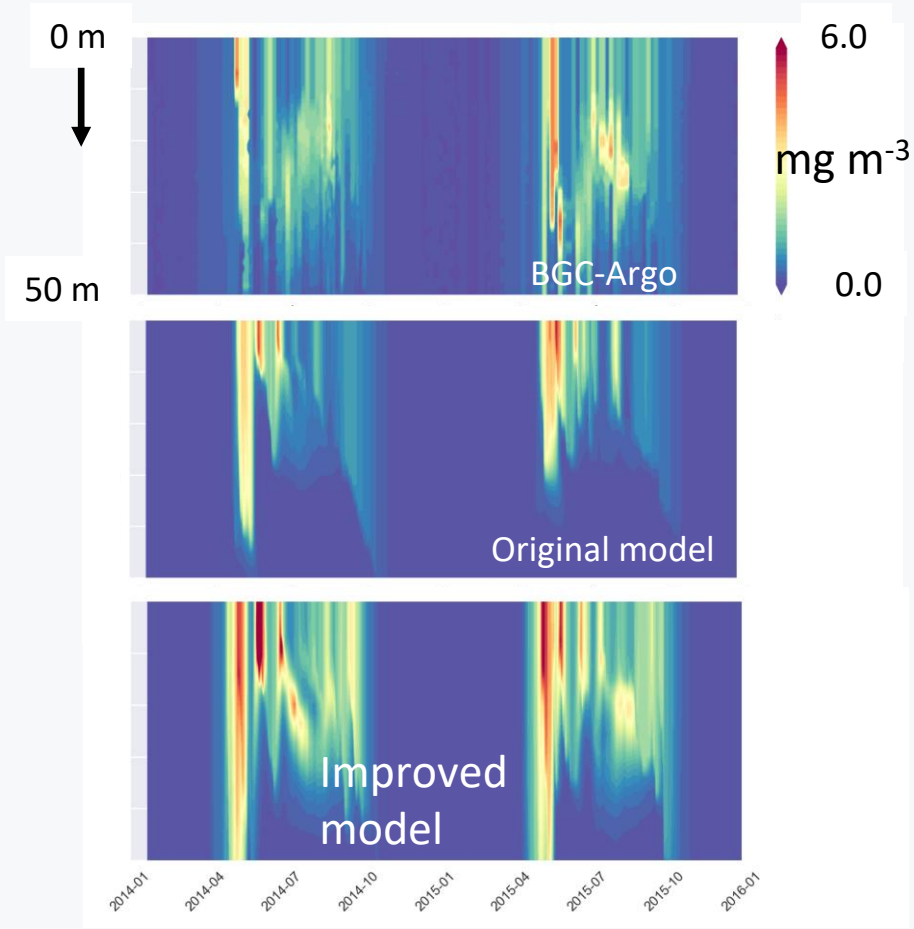


Default model does not produce SCM

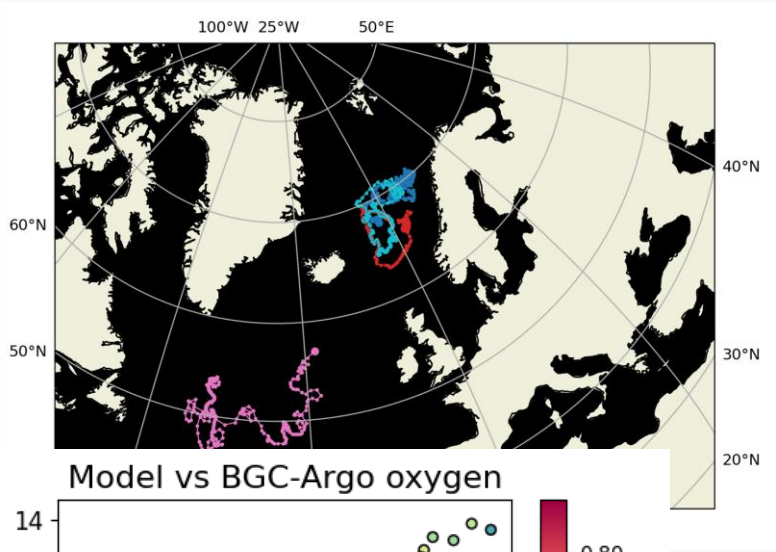


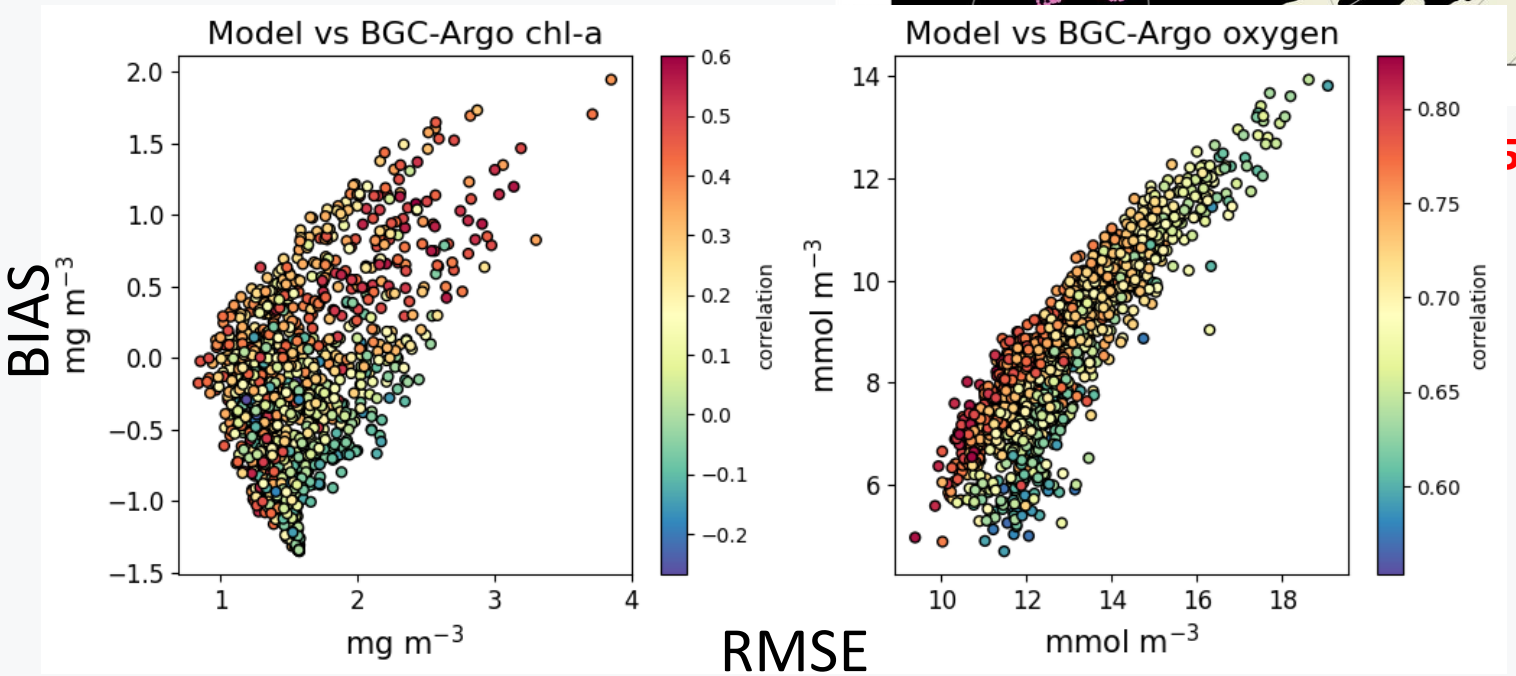
Arctic Ocean BGC observing system use case I

Model calibration: Improvement in ECOSMO formulation and ensemble parameter tuning with 1D model system



ECOSMO BGC model parameters optimization (cost function) against BGC Argo Chl-a and O2 data





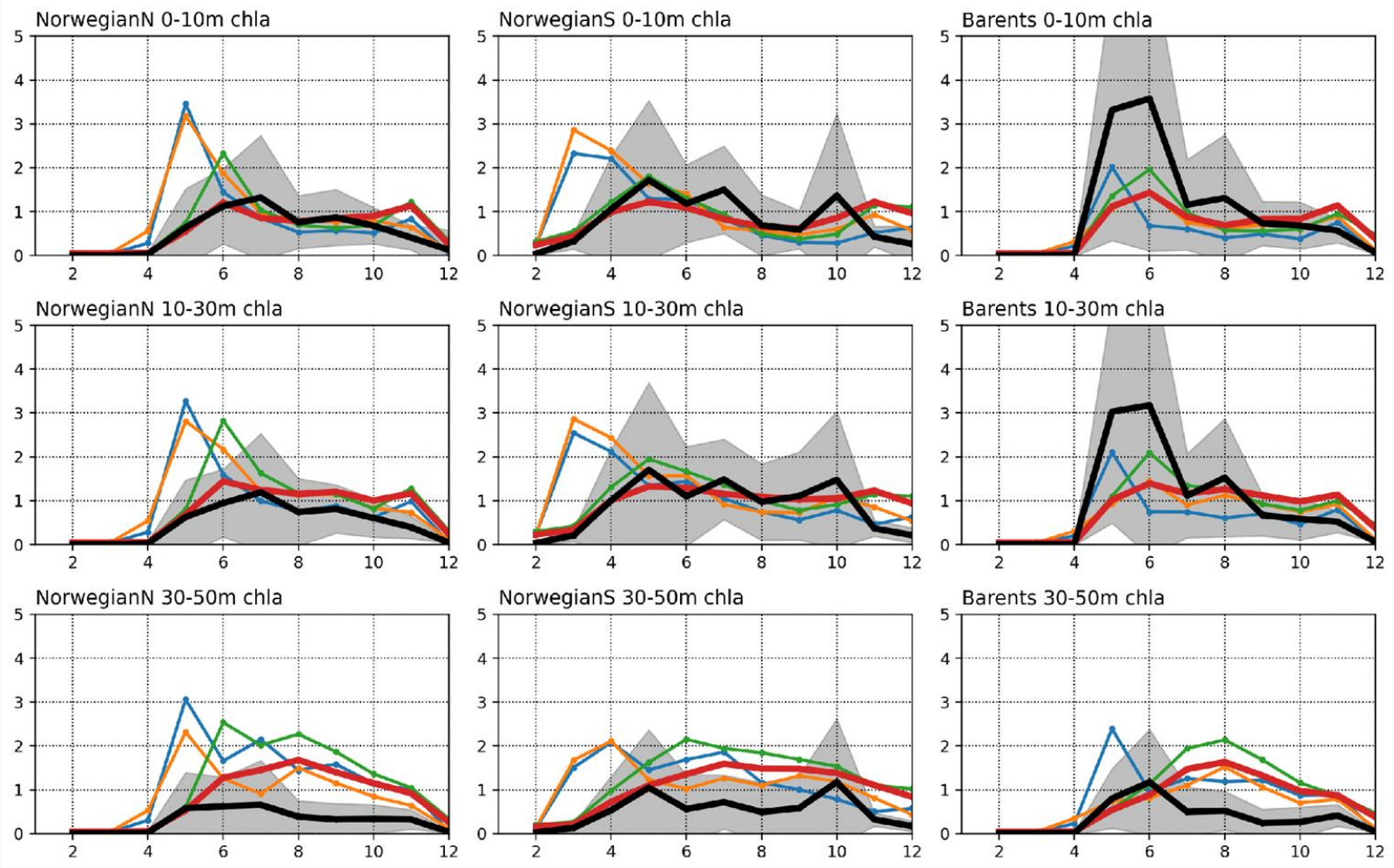
Impact of Arctic Ocean BGC data to operational system

Impact of BGC model optimization in 1D system on 3D system

Validation against in-situ Chl-a climatology

Obs vs Opitmized model vs Default models

- **Reduction** of excess chl-a concentration compared to the reference experiments in the Norwegian Sea
- Improved spring bloom across different depth intervals
- More experimentation is required for the Barents Sea
- Large error in subsurface may be attributed to not corrected physics



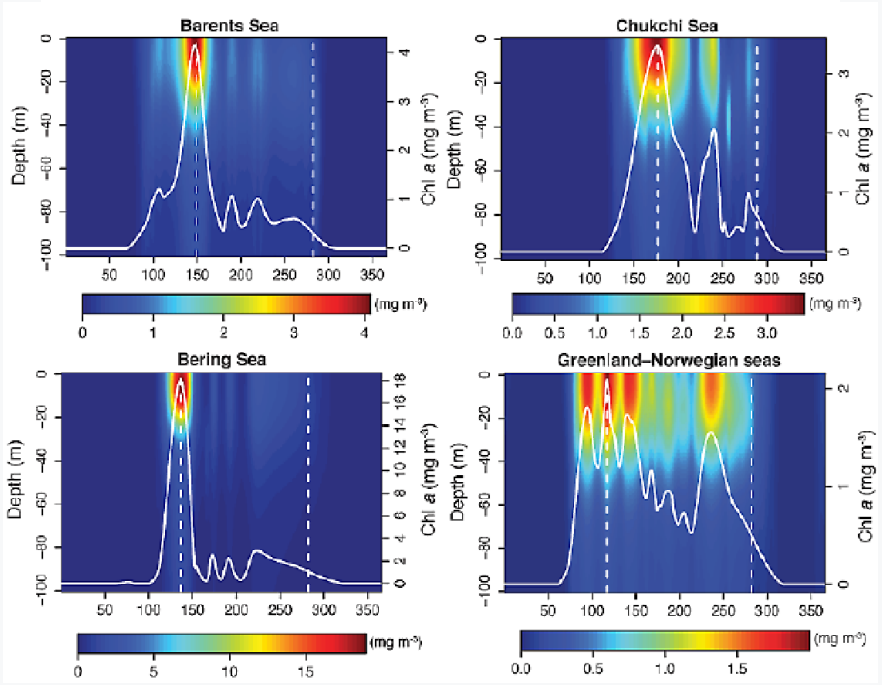
Arctic Ocean BGC observing system use case II

Projection of surface Chl-a to subsurface Chl-a profile: Empirical (analytical) function and Machine learning algorithm

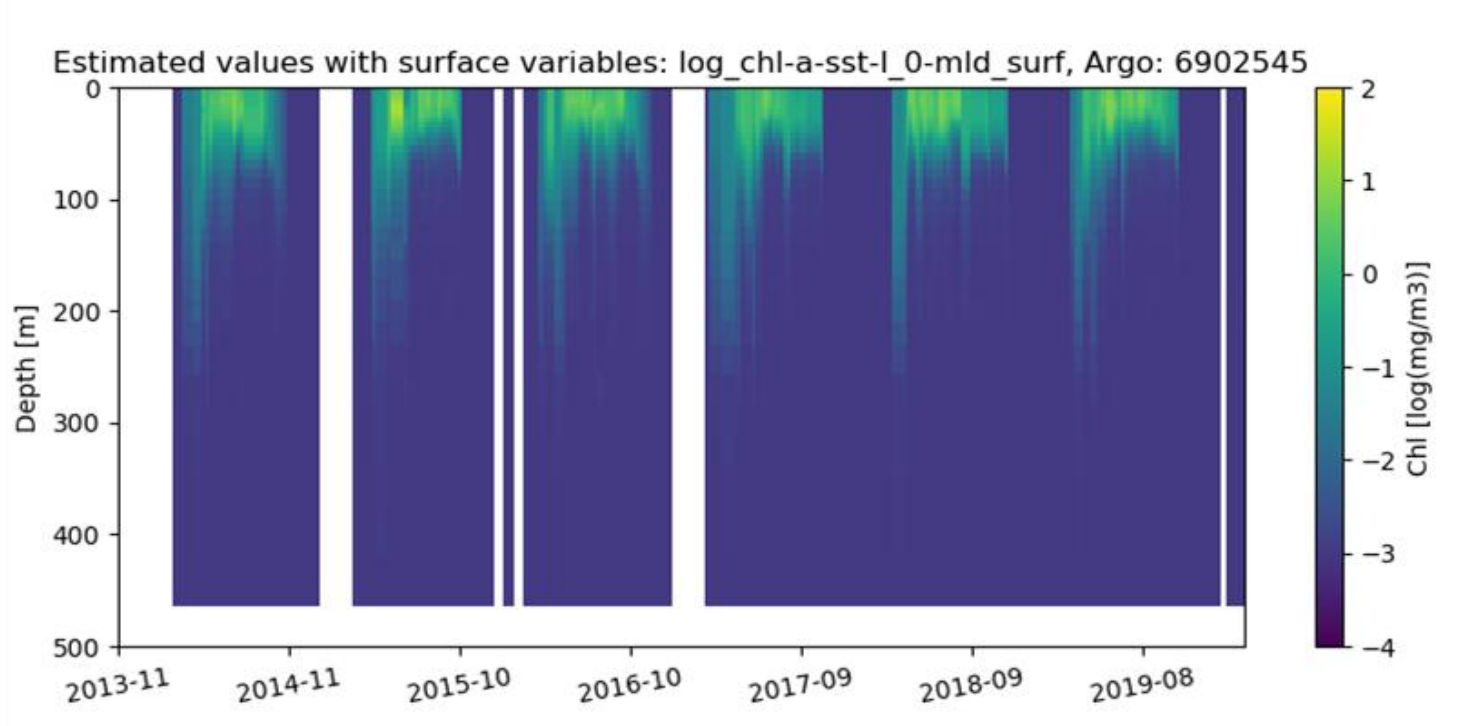
Presence of SCM indicates sub-surface Chl-a profiles are important information, but number of BGC Argo floats are limited > Projection of surface Chl-a (satellite) to subsurface by

1. Analytical function (Ardyna et al. 2013)

$$c(z) = C_b - sz + C_{max} e^{-\left[\left(\frac{z - Z_{max}}{\Delta z}\right)^2\right]}$$



2. Machine learning (in progress)

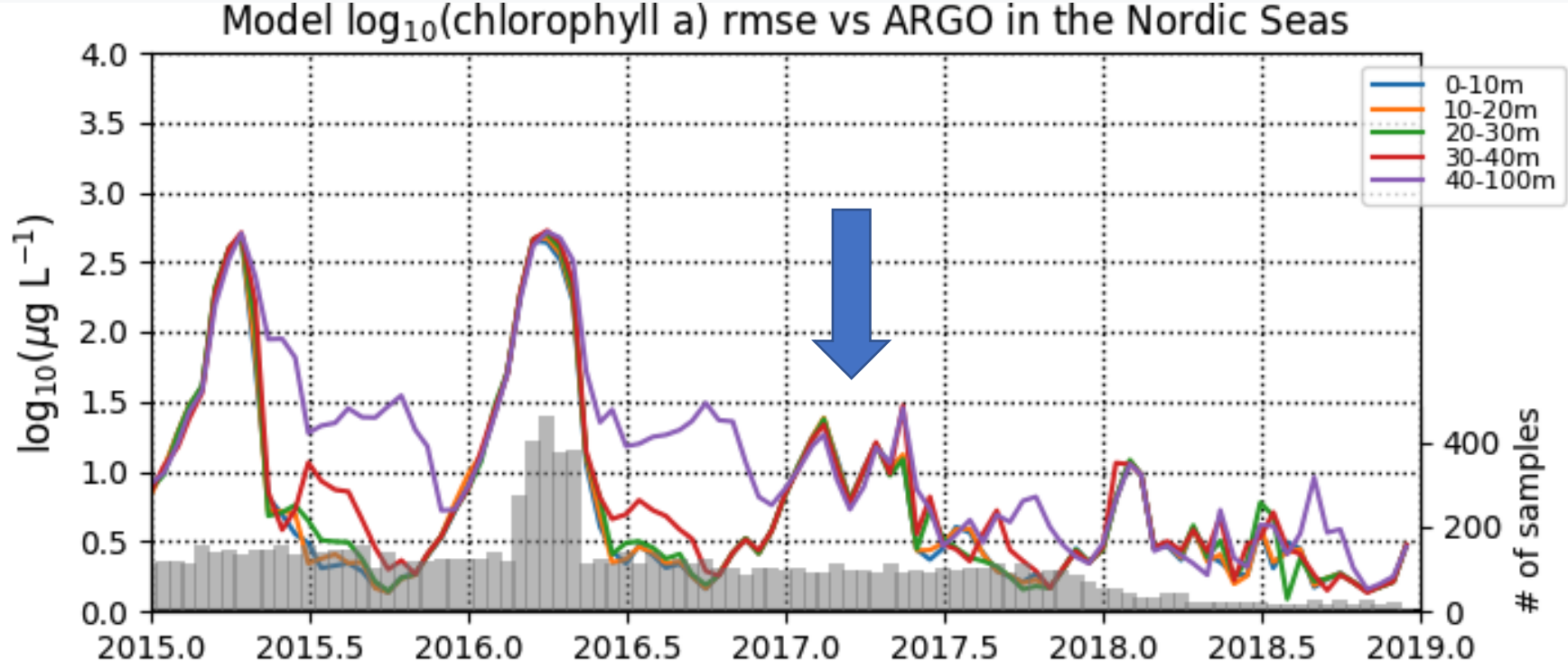


Impact of Arctic Ocean BGC data to operational system

Impact of BGC data assimilation to NRT product (before BGC model tuning)

Validation against BGC Argo floats Chl-a profiles:

- RMSE against Chl-a profiles is reduced significantly after introduction of Chl-a nudging with Ardyna et al. (2013) algorithm.



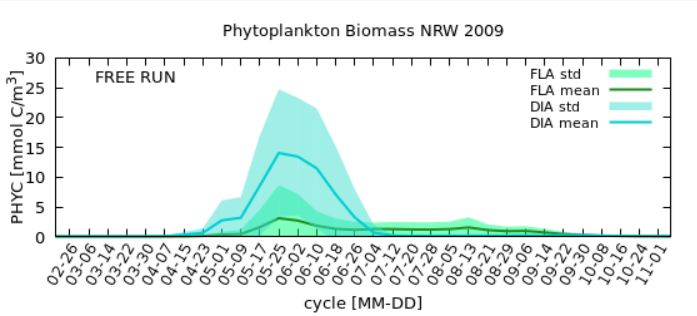


Impact of Arctic Ocean BGC data to operational system

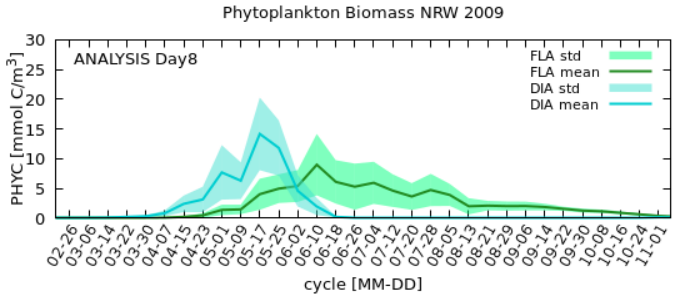
Impact of BGC data assimilation to MY product (before BGC model tuning)

Assessment of impact of multiplatform BGC data assimilation to ecosystem indicators, Chl-a, NPP, PFT, POC, by the coefficient of variation (CV) ratio in July 2019. Large CV ratio in PFT (large to all) is attributed to PFT shift after DA.

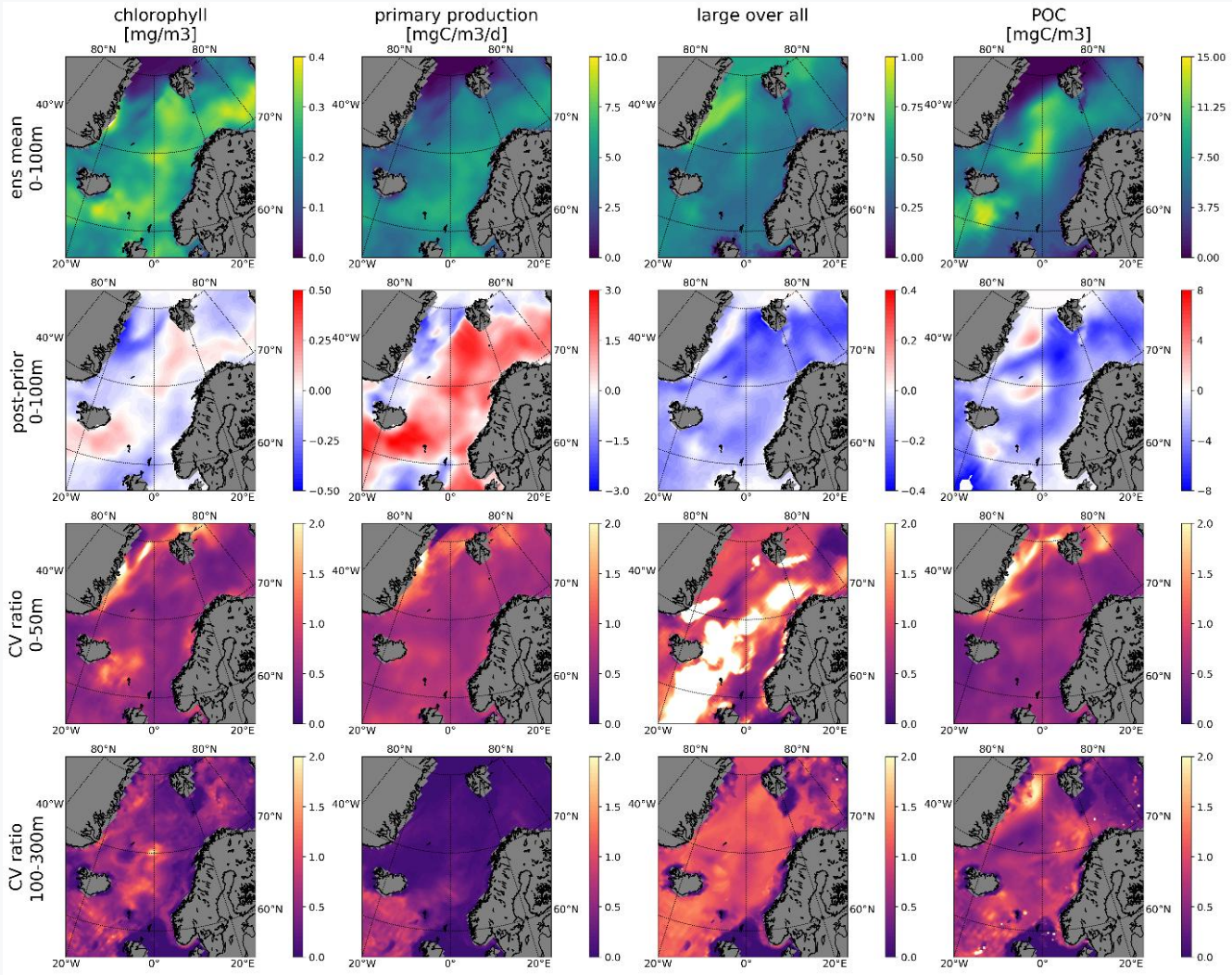
$$CVRATIO = \frac{CV^{post}}{CV^{prior}} = \frac{\sqrt{1/Nr \cdot \sum_{l=1}^{Nr}\left(y_{i,l}^{post} - \overline{y_i^{post}}\right)^2}}{\overline{y_i^{post}}} \Big/ \frac{\sqrt{1/Nr \cdot \sum_{l=1}^{Nr}\left(y_{i,l}^{prior} - \overline{y_i^{prior}}\right)^2}}{\overline{y_i^{prior}}}$$



w/o DA



with DA



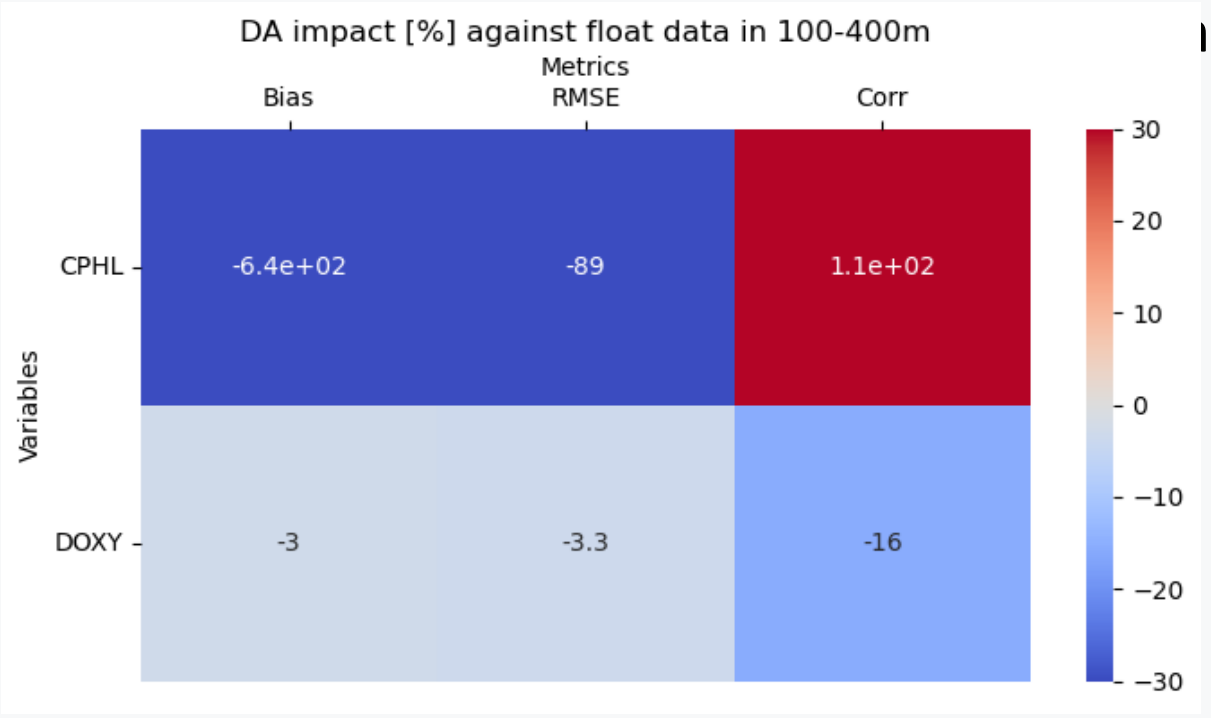
Cossarini et al., 2026, Ocean Modeling

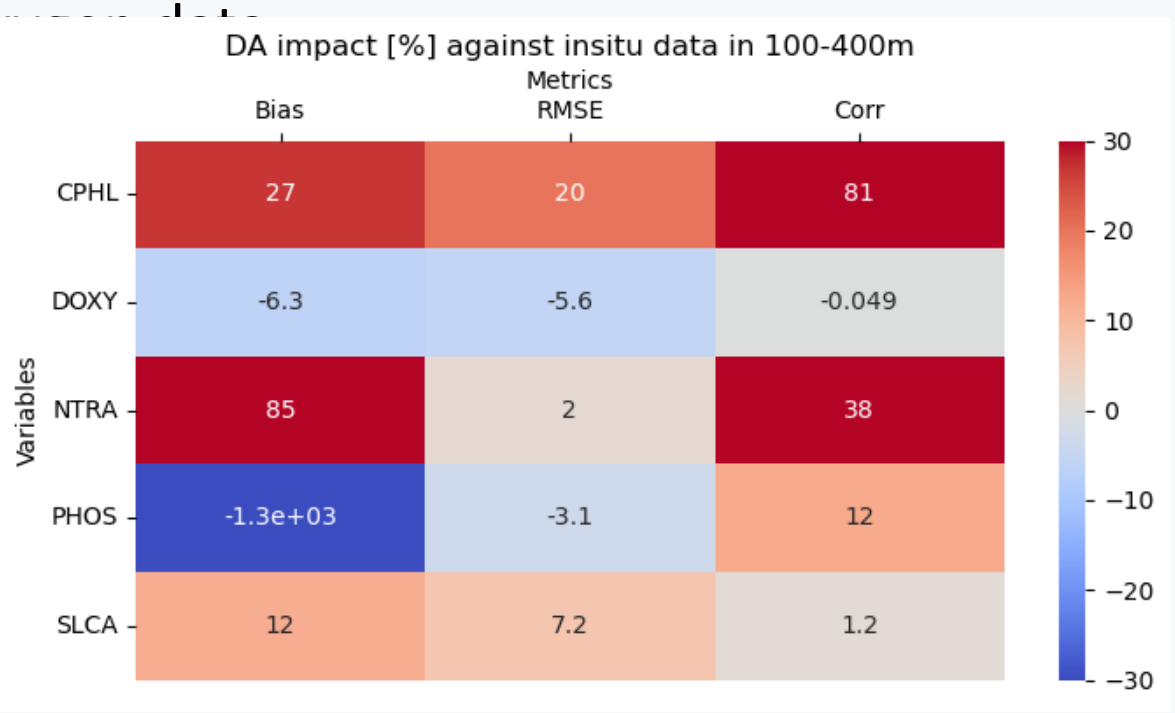
Impact of Arctic Ocean BGC data to operational system

Impact of BGC data assimilation to MY product (before BGC model tuning)

Validation against in-situ nutrients/Chl-a and BGC Argo floats Chl-a profiles in 2019 summer:

- Bias/RMSE/Corr against Argo Chl-a data are reduced significantly after satellite Chl-a DA.
- Validation against in situ observation shows mixed messages.
- DA has more positive impact in sub surface against insitu data, but not against BGC float data



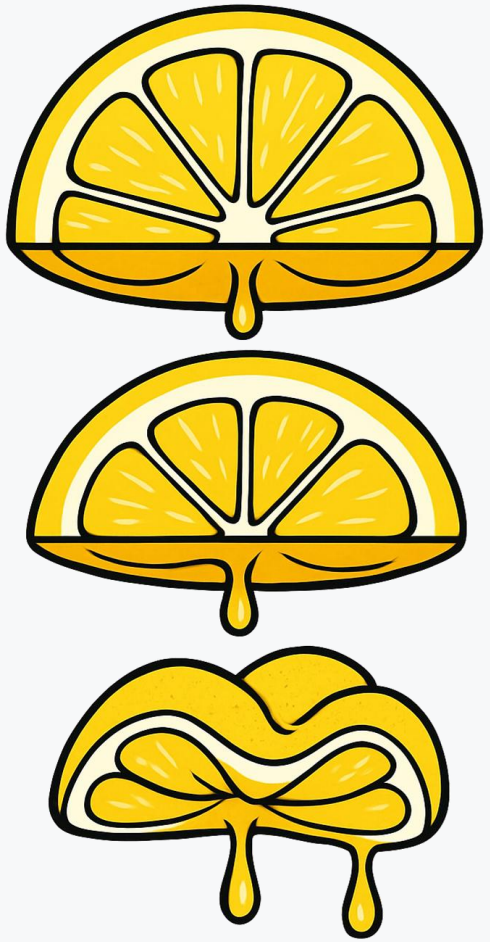


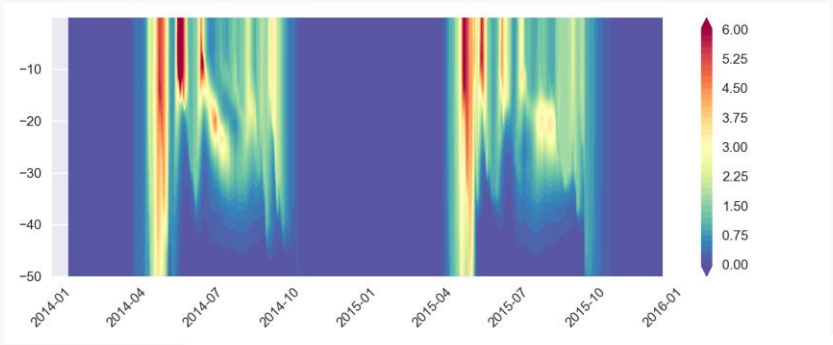
Summary

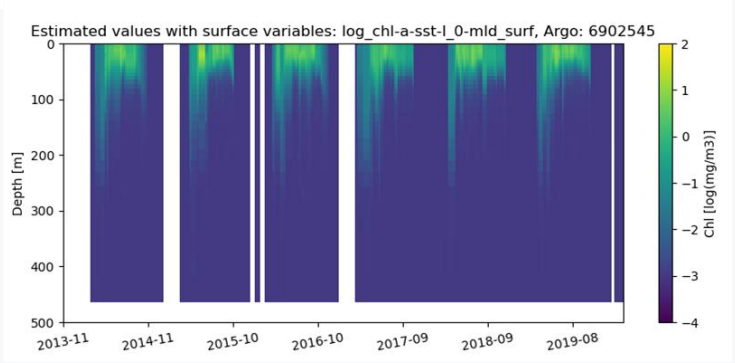
Strategy of BGC data usage in the Arctic Ocean BGC operational products:

We squeeze information contents out from observed data.

Hierarchical approache towards launch of ARC MFC III (2025-2027) new operational products in 2027





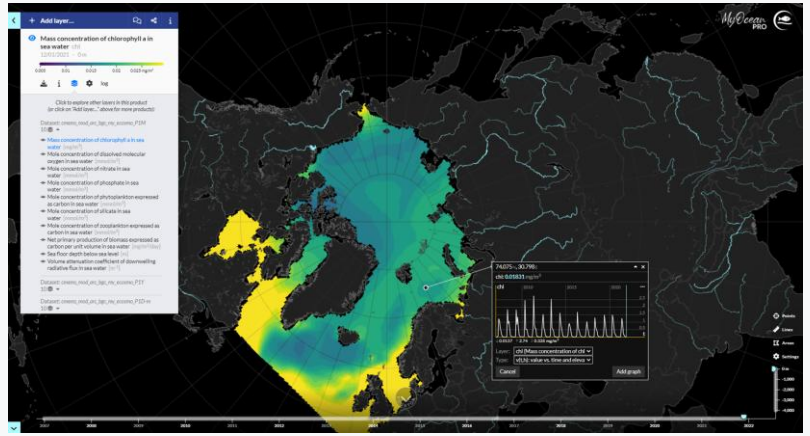


1.BGC model reformulation and optimization

- impact to NRT and MY **LARGE**

2. Vertical projection of surface Chl-a with empirical function and ML

- impact to NRT **LARGE**
- Impact fo MY under investigation



3. BGC data assimilation

- impact of satellite OC to NRT/MY **LARGE**
- Impact of BGC Argo to MY under investigation

Consistency among BGC observing systems

High consistency among BGC Argo – Satellite (ESA OC CCI) –Insitu Chl-a in Nordic Seas: Algorithms calibration against HPLC (High-performance liquid chromatography) data

