

Coupled assimilation of satellite temperature and chlorophyll observations for improved ecosystem predictions in the Baltic Sea

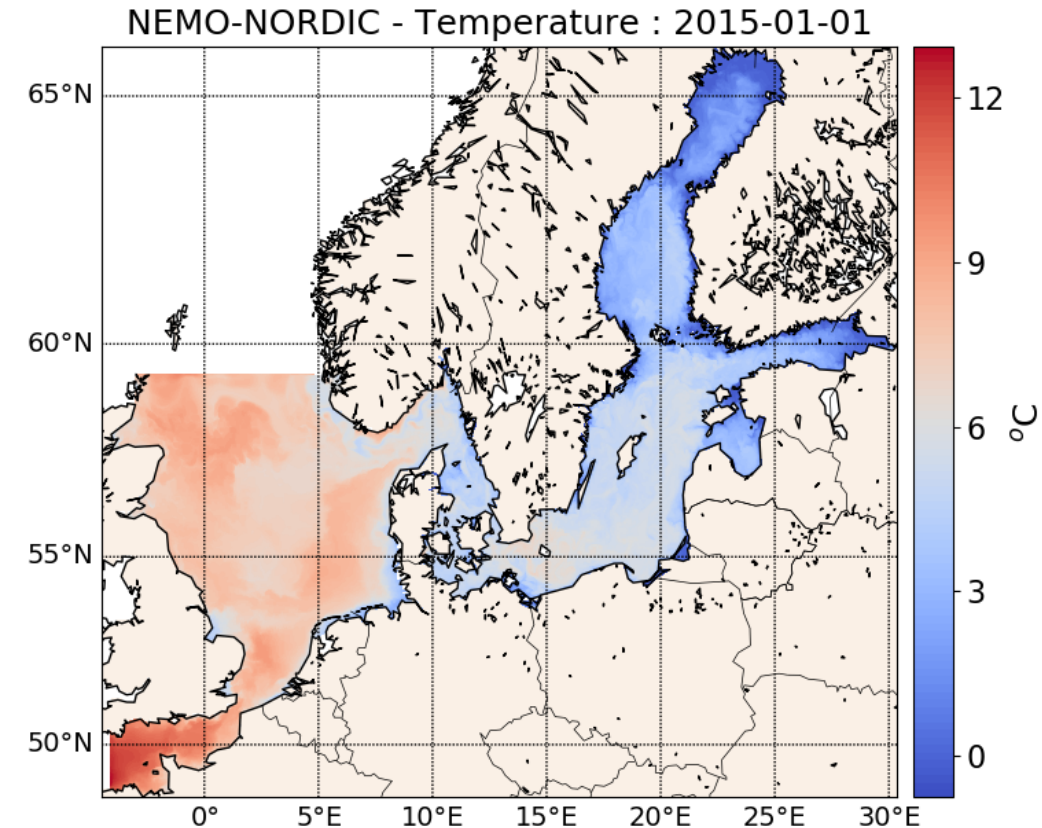
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Alfred Wegener Institute, Bremerhaven, Germany

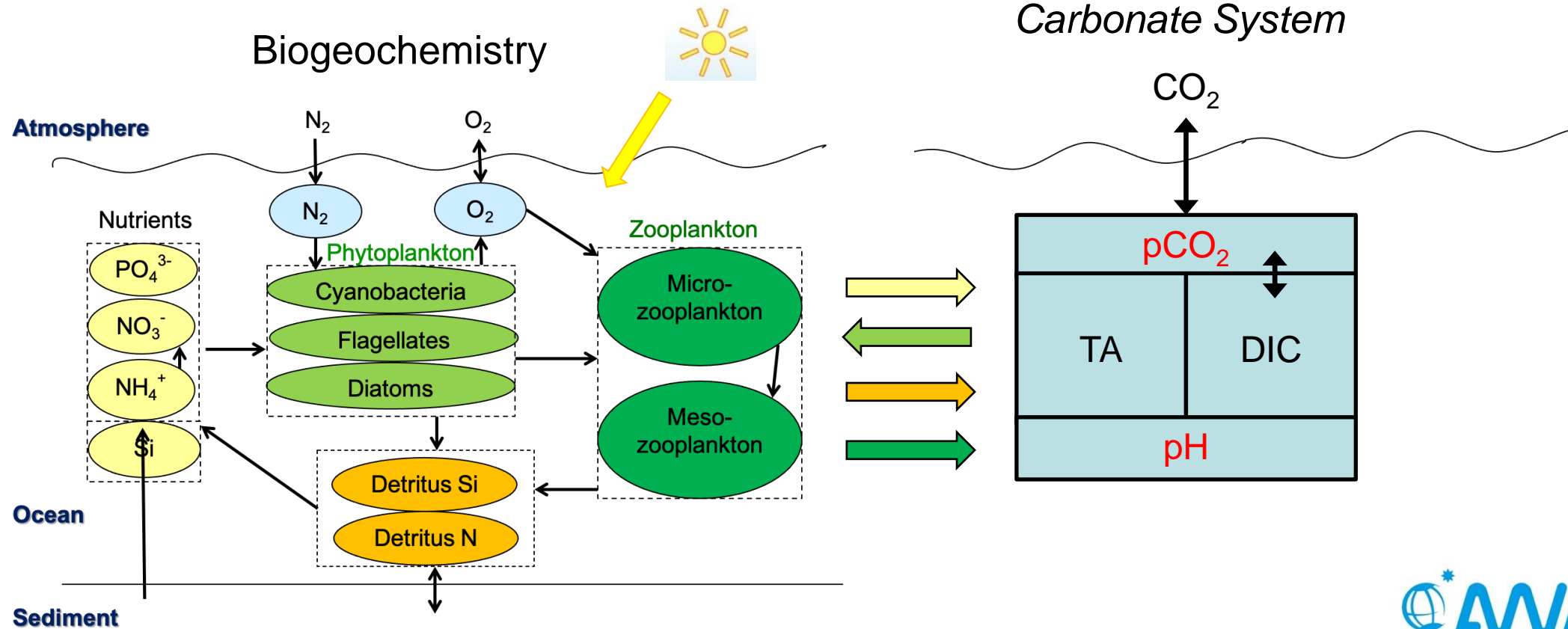


Operational configuration of CMEMS Baltic Monitoring and Forecasting Center (BAL-MFC)

- Model setup
 - NEMO-NORDIC
 - 1 nm resolution (~1.8km)
 - 56 layers
 - Time step 90 sec
 - Open boundaries in North Sea and English Channel
 - BCs from separate model for North Atlantic



- Original development for Baltic Sea (Neumann, 2000)
- based on Nitrogen
- Chlorophyll is diagnostic quantity
- Recently BSH added module for carbonate system



A unified tool for interdisciplinary data assimilation ...

- provide support for parallel ensemble forecasts
- provide assimilation methods (solvers) - fully-implemented & parallelized
- provide tools for observation handling and for diagnostics
- easily useable with (probably) any numerical model
- a program library (PDAF-core) plus additional functions
- run from notebooks to supercomputers (Fortran, MPI & OpenMP)
- ensure separation of concerns (model – DA method – observations – covariances)

Open source:

Code, documentation, and tutorial available at

<https://pdaf.awi.de>

github.com/PDAF



State

- 5 physics variables
- 16 ERGOM prognostic variables + 4 diagnostic variables
- State dimension: $704 \cdot 10^6$ (at analysis $153 \cdot 10^6$)

DA setup

- Kalman filter: LESTKF
- ensemble size: 30
- weakly coupled DA
- direct updates of model fields (no IAU)
- Physics: only 3D temperature updated
(multivariate updates result in unrealistic salinity)
- ERGOM: update 13 prognostic + 4 diagnostic variables
(no update of LDON, DIC, ALK)

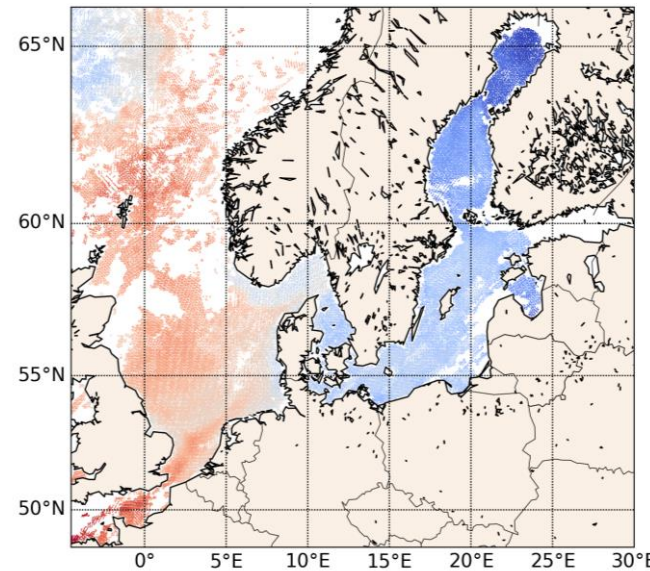
Compute requirements:

- Each NEMO-ERGOM task: 186 cores (+6 for XIOS)
- Run time: ~45 minutes to simulate 24h
(1 model month per simulation day)

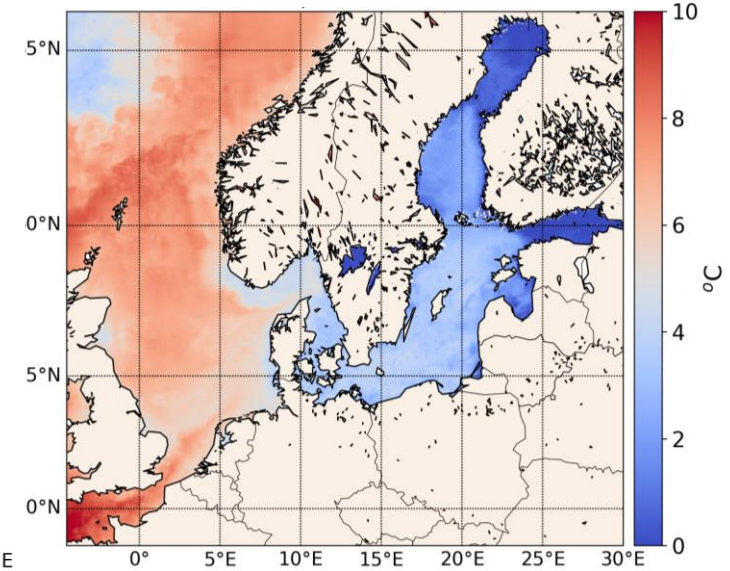
Sea Surface Temperature

- CMEMS Level 4 'reprocessed' data
- resolution 0.02°
- available daily
- observation error for DA: 0.8°C
(provided error fields not fully realistic)

Alternative L3 observations

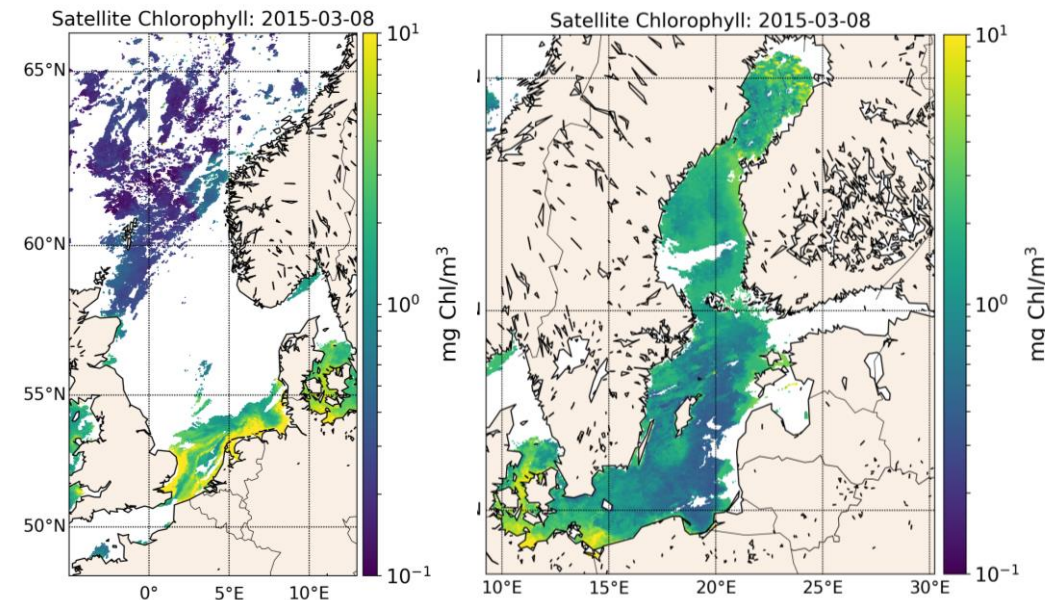


Assimilated L4 observations



Chlorophyll

- Level 3 data from CMEMS (multi-satellite multi-year)
- separate data products for North Sea and Baltic Sea
- resolution 1 km
- available daily
- observation error: relative error of 0.3



Ensemble run from Jan. 1, 2015

- ensemble perturbations in physics from EOFs (2nd-order exact sampling)
- ensemble central state from forecast
- perturb 15 process parameters of ERGOM

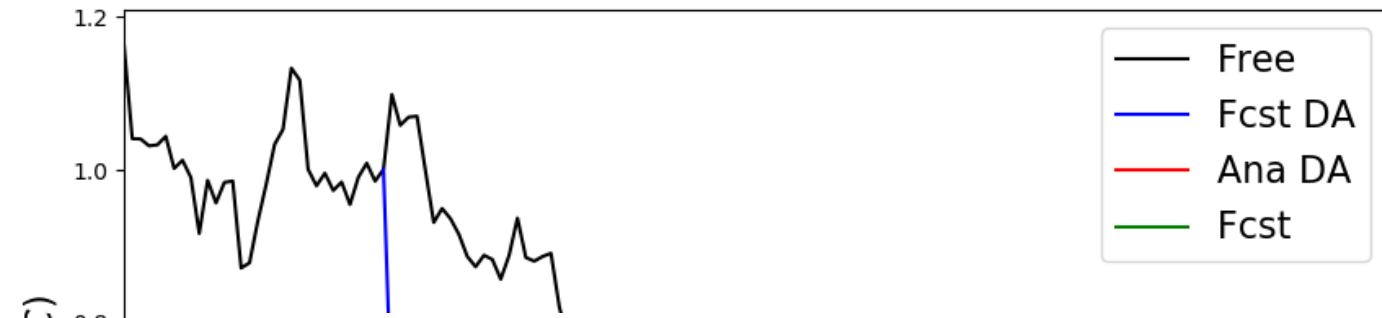
Data assimilation from Feb. 1, 2015

- Strong reduction of RMSe in SST
- RMSe increases in April
 - problem in level-4 SST data
- RMSe more consistent with L3 data

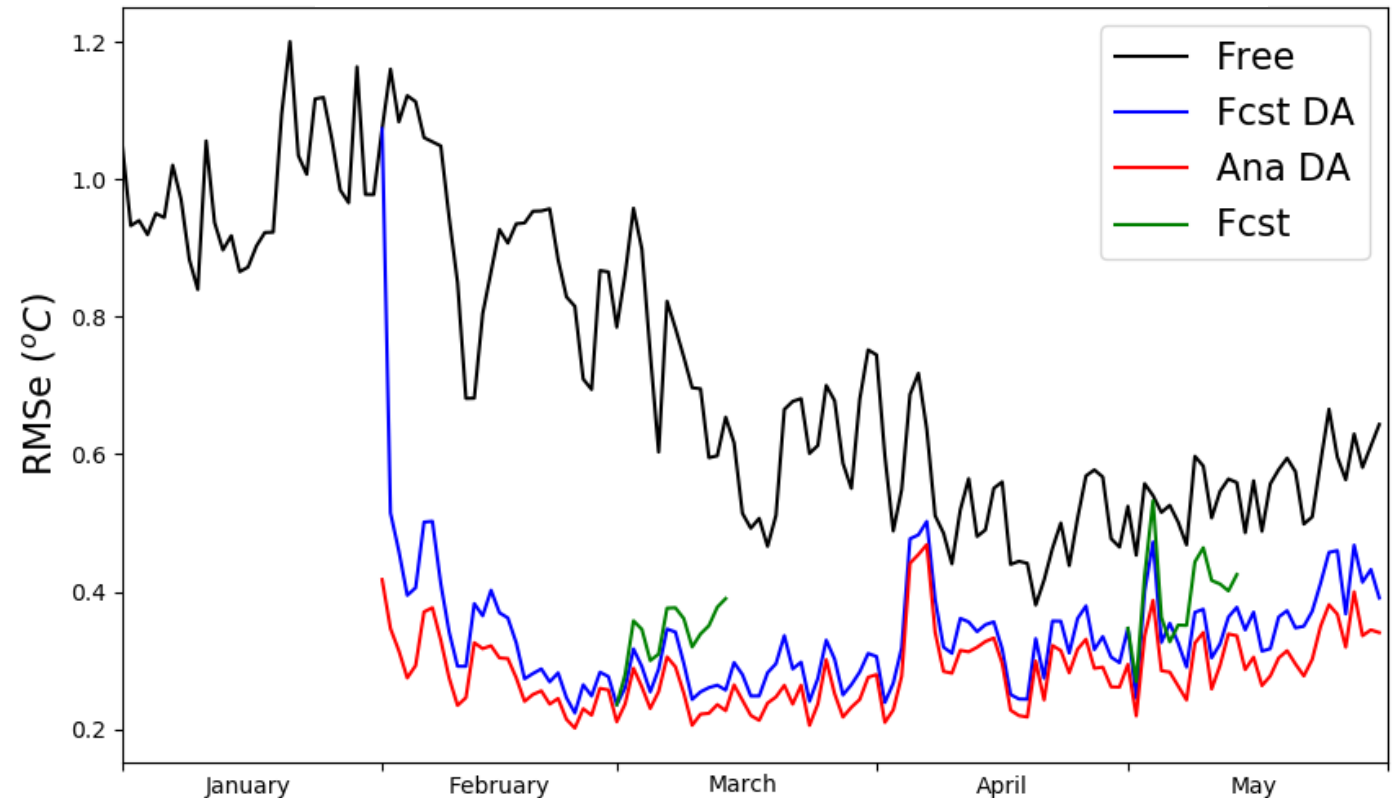
14-day forecasts (green)

- Slow error increase in March; faster in May

RMSe relative to L4 data



RMSe relative to L3 data



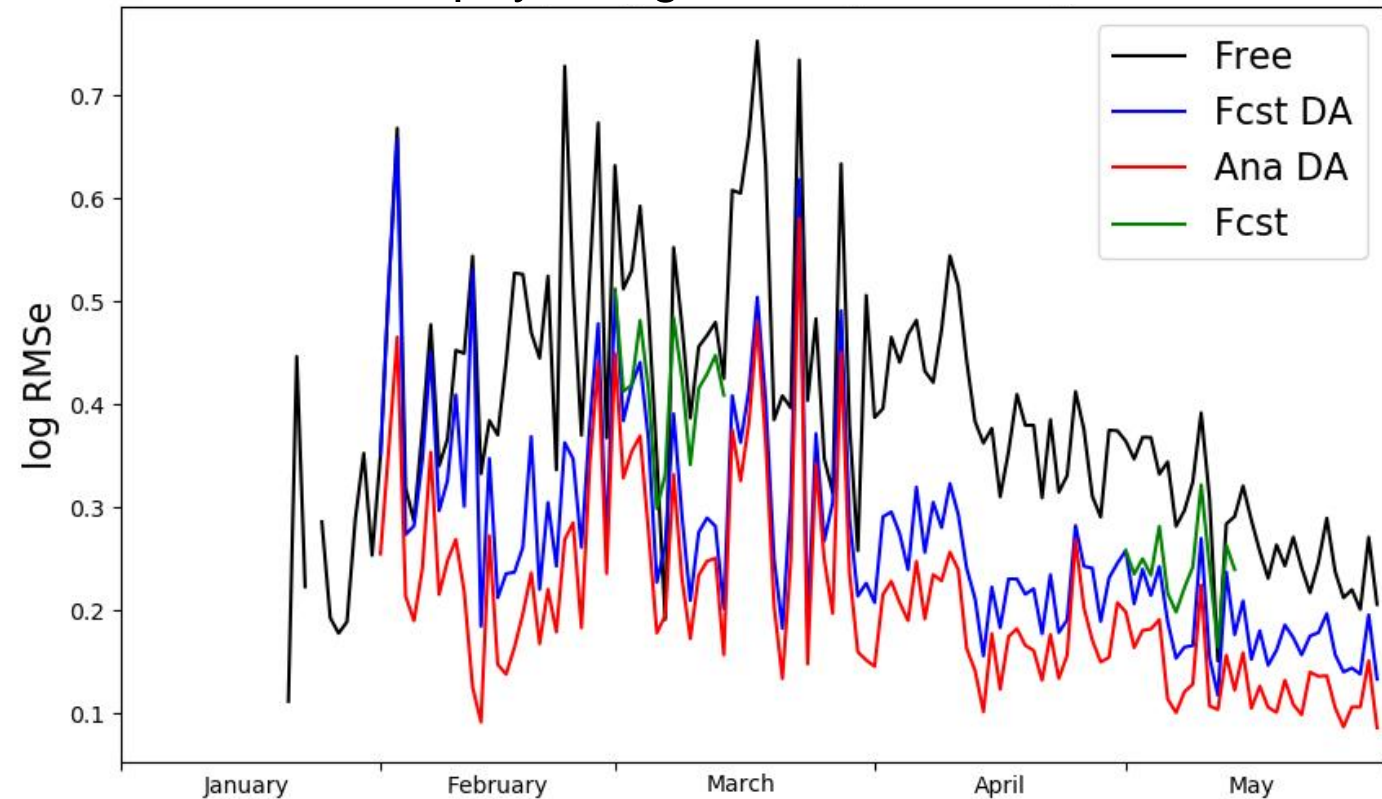
Daily assimilation from Feb. 1, 2015

- RMSe reduced
- Strong fluctuations in February and March (varying data coverage)

14-day forecasts (green)

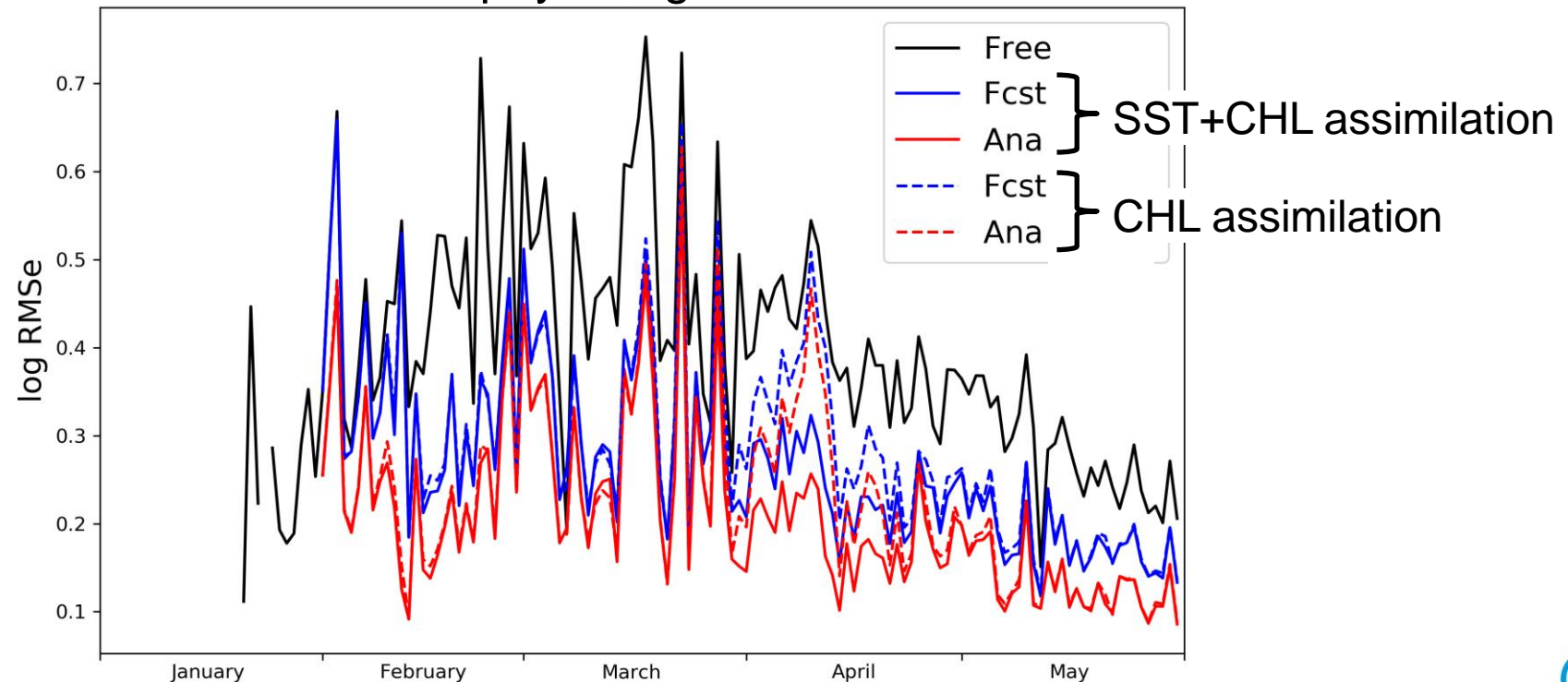
- Larger error increase than for SST (less forecast skill)

Chlorophyll: Log10-RMSe in Baltic Sea



- Compare 2 cases:
 - Weakly coupled DA of SST + CHL satellite data
 - Assimilation of only CHL data
- Significant differences only during April: lower errors if temperature is corrected by SST-DA

Chlorophyll: Log10-RMSe



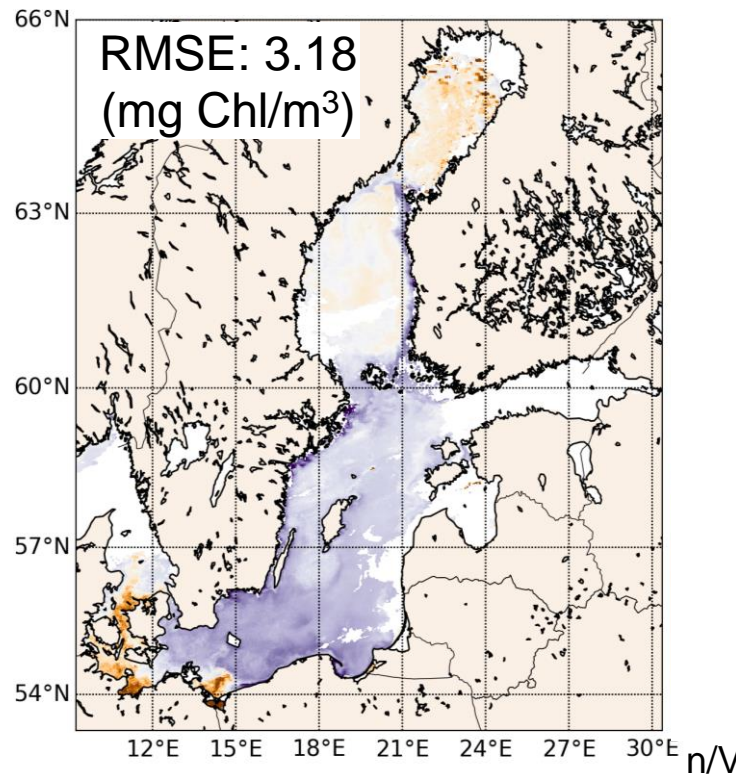
Effect of DA on longer forecasts: Chlorophyll

Performed 14-day ensemble forecasts initialized from DA analysis

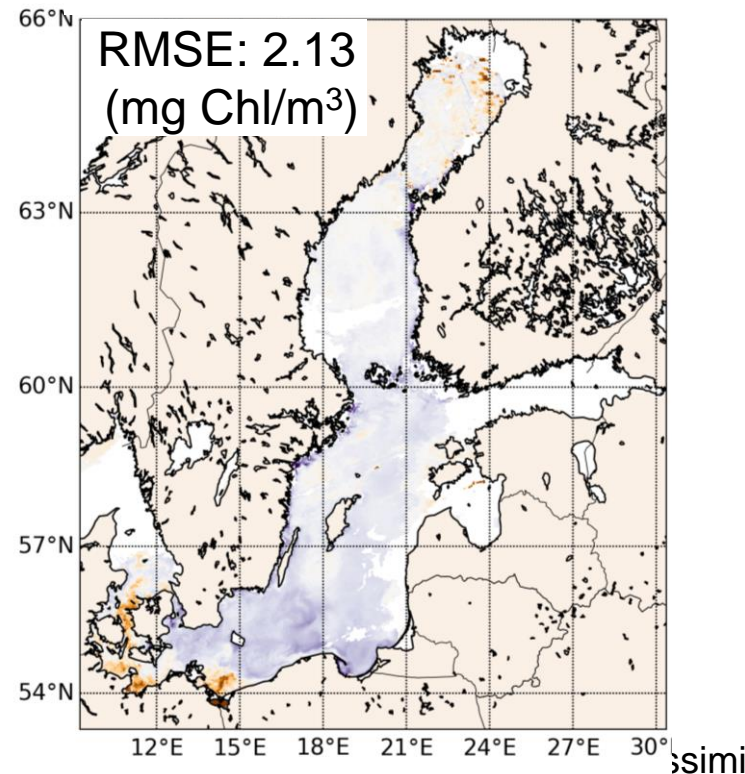
- Error reduction in 24-h forecast: 33 %
8-day forecast: 20 %
14-day forecast: 5 %

Surface chlorophyll: model - observations

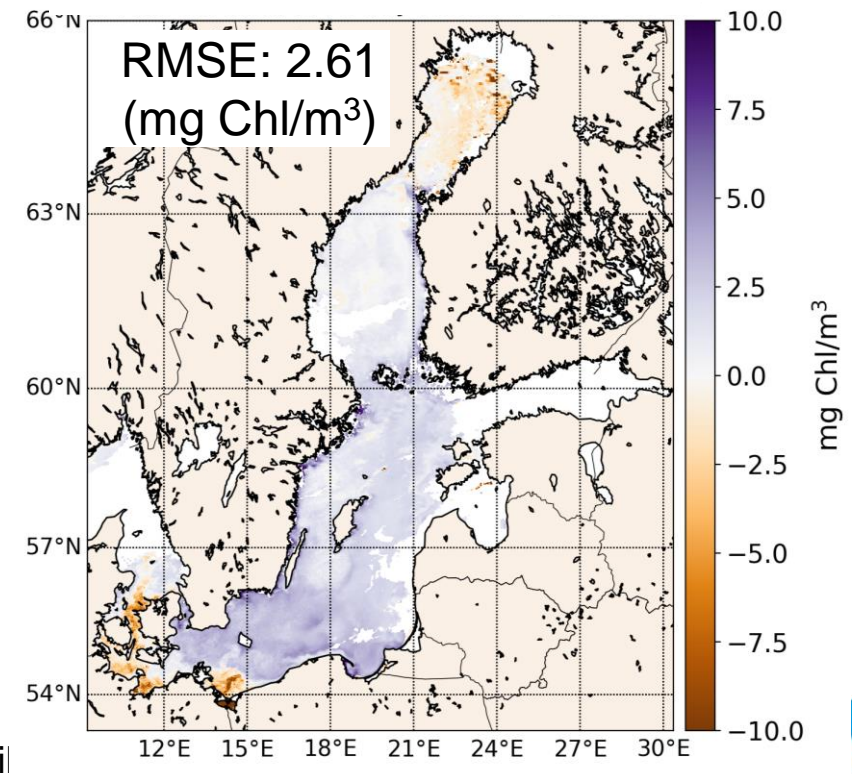
Free run on March 8



24h forecast (init March 7)



8-day forecast (init March 1)

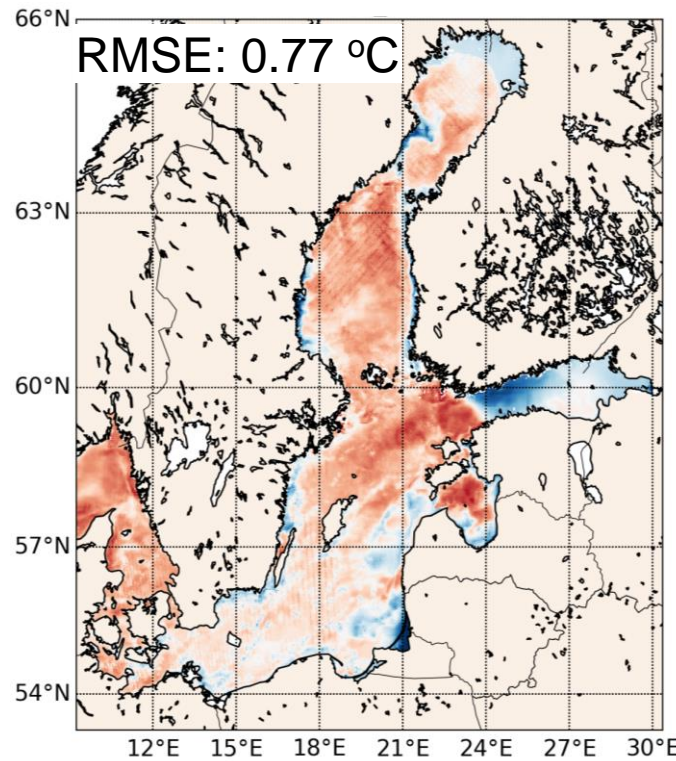


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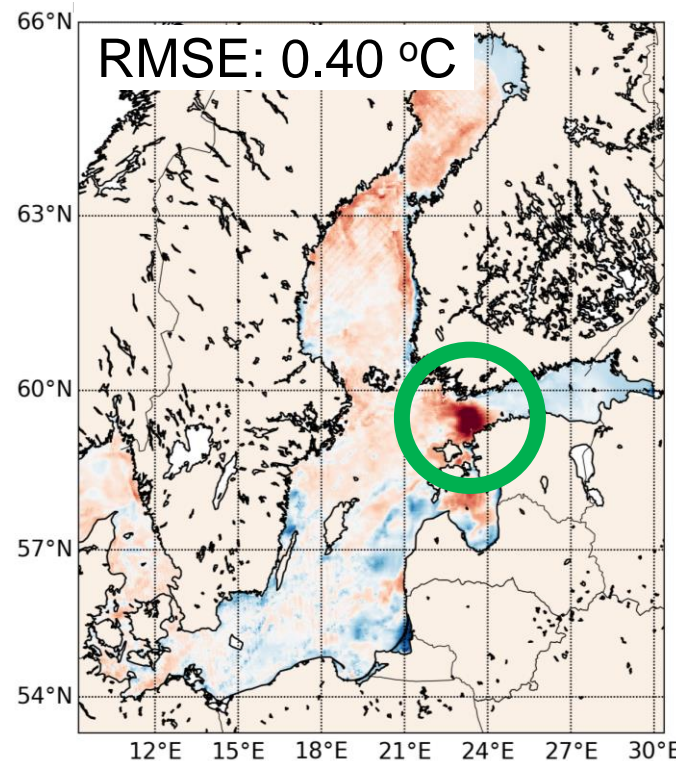
- Error reduction in 24-h forecast: 48 %
8-day forecast: 43 %
14-day forecast: 35 %

Surface temperature: model - observations

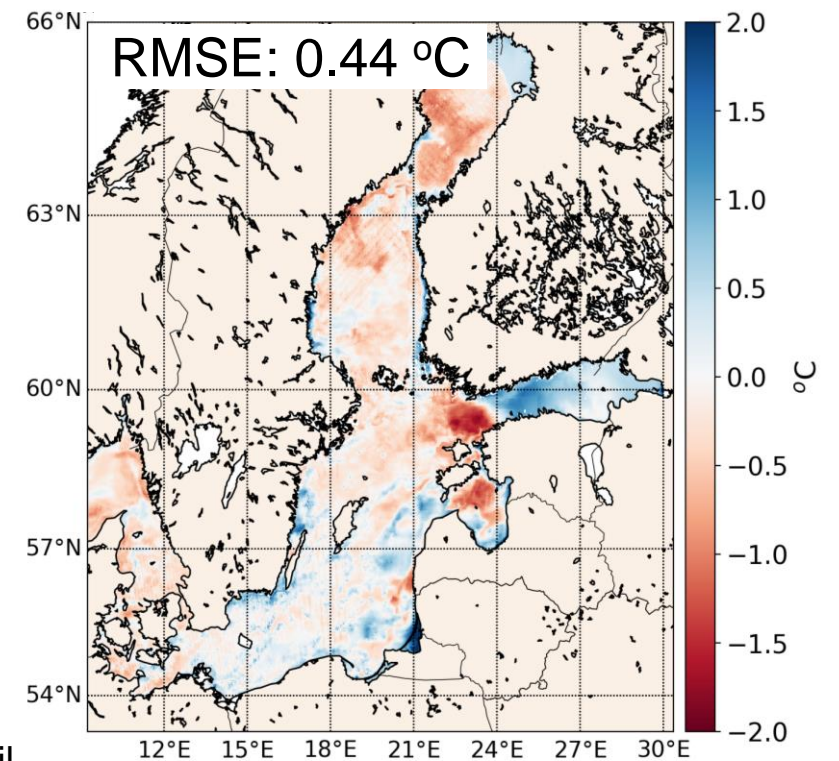
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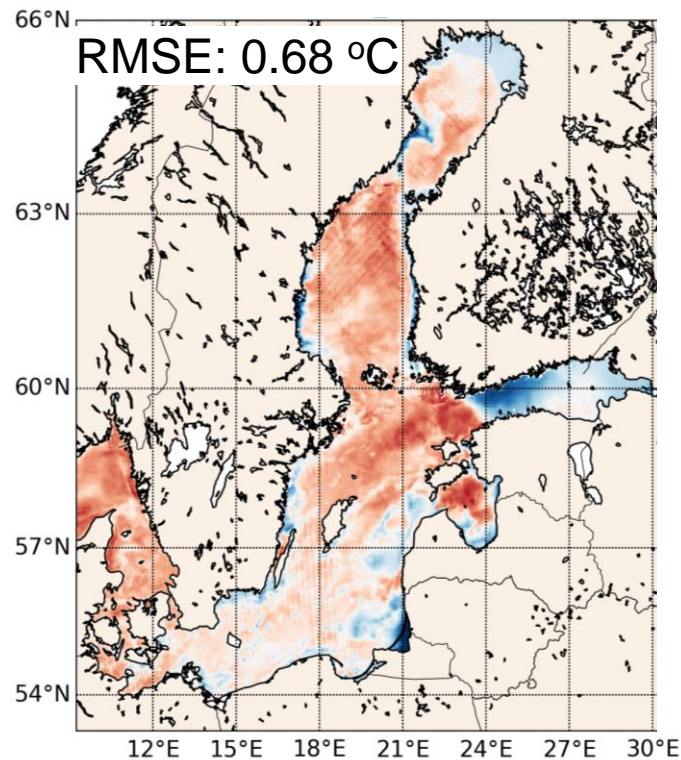


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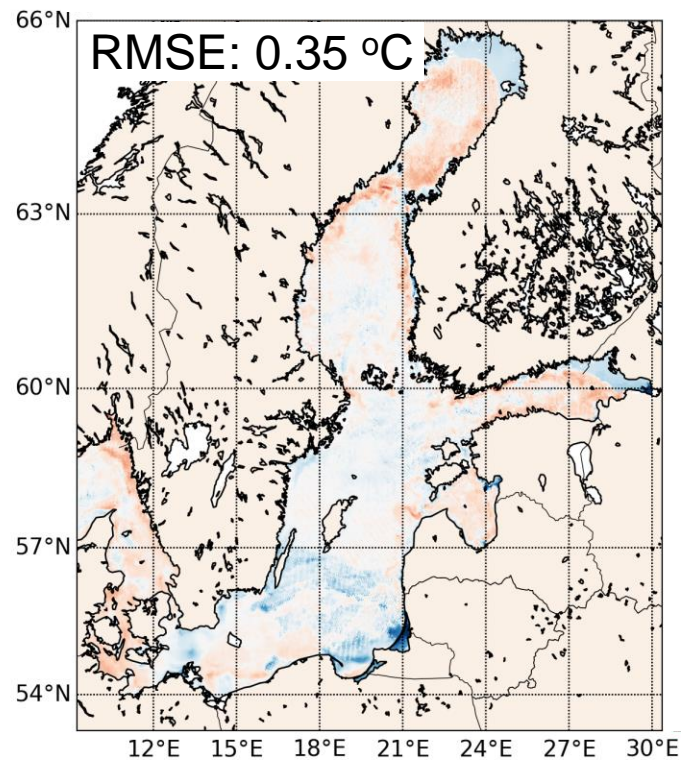
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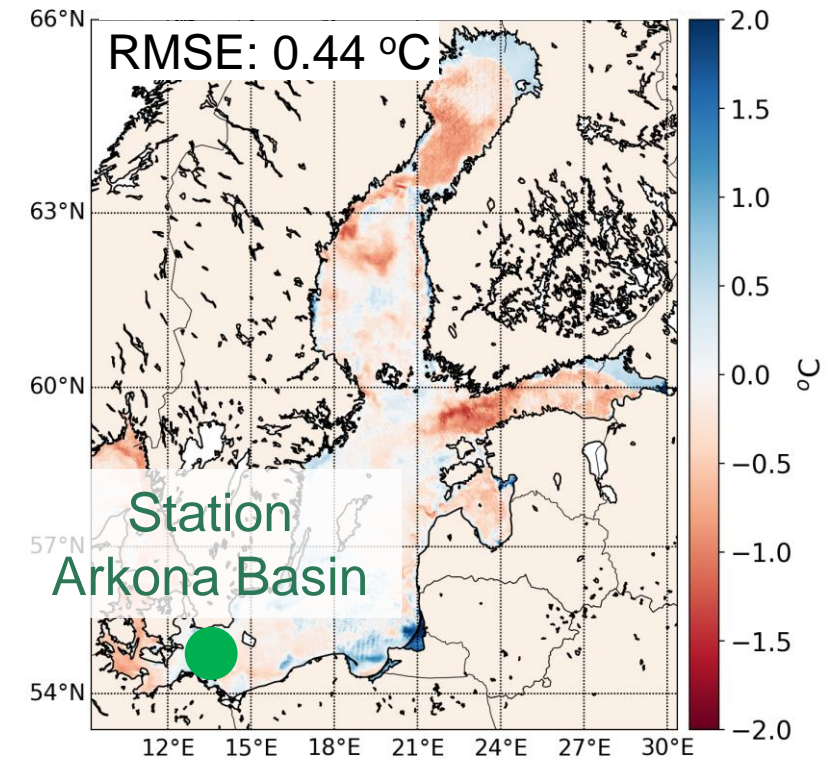
Free run on March 14



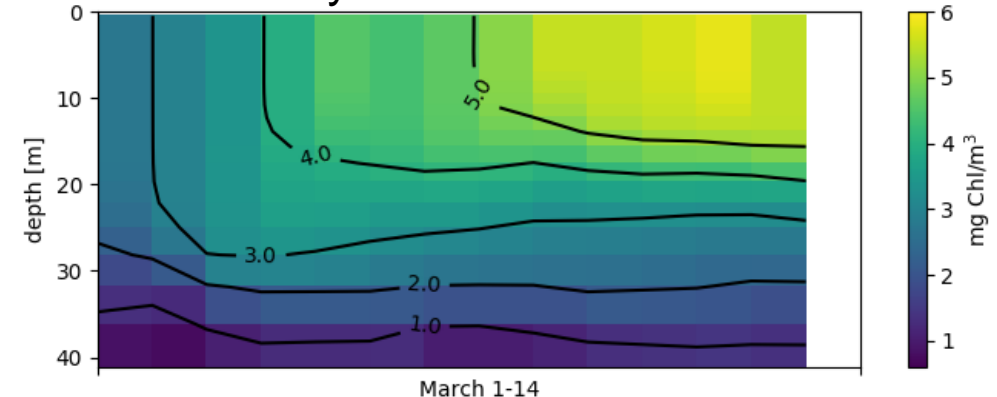
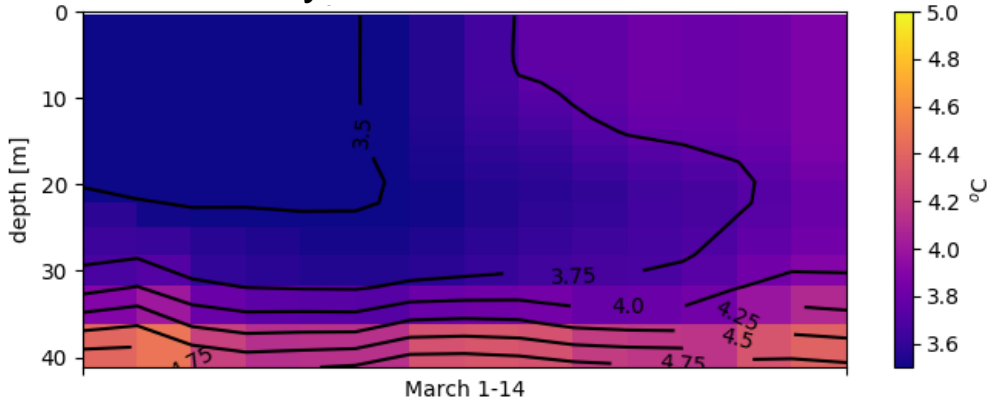
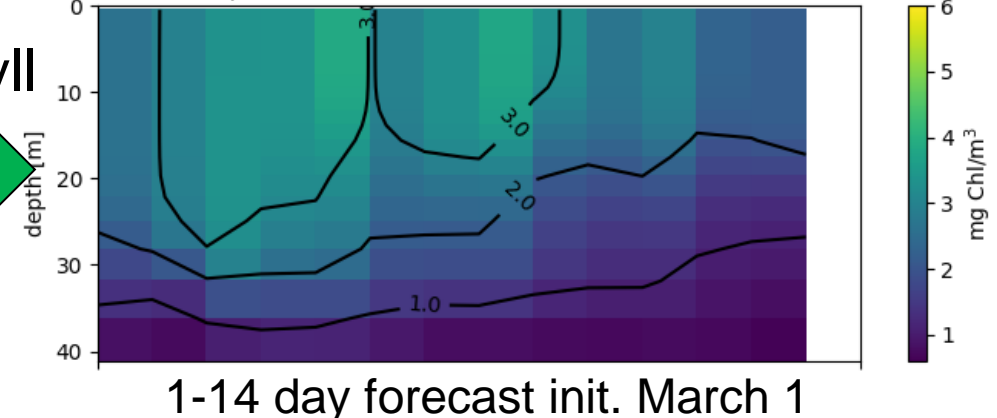
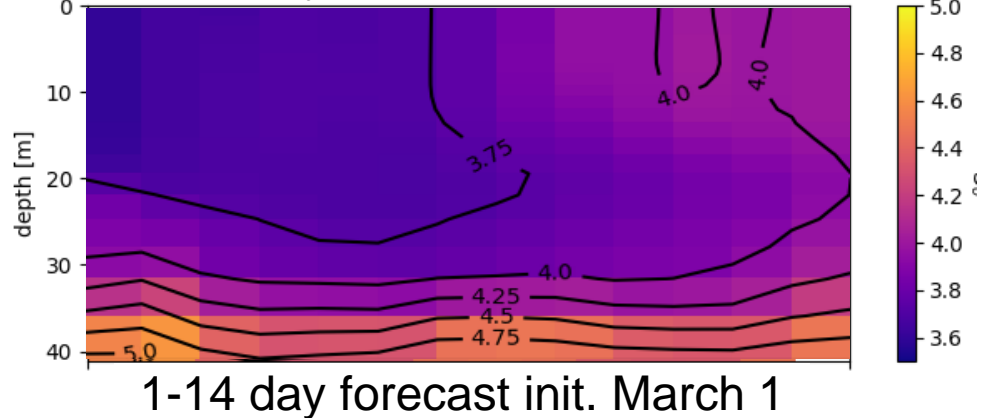
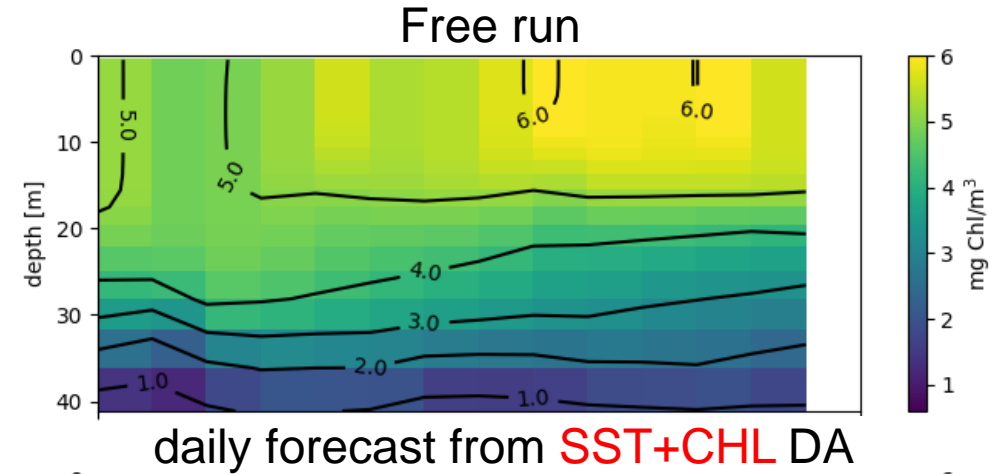
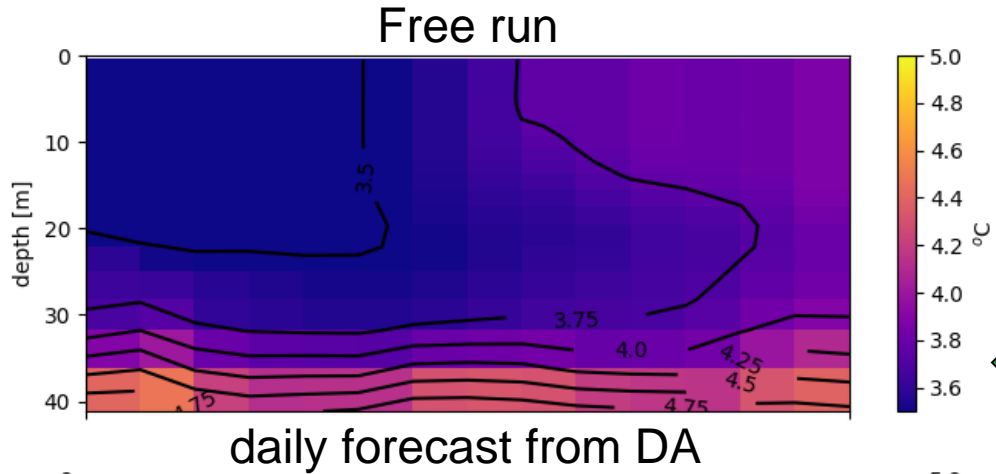
24h forecast (init March 13)



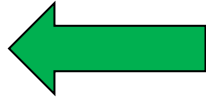
14-day forecast (init March 1)



Profiles at station Arkona Basin – March 1 - 14



Temperature



Chlorophyll



Free run on April 1

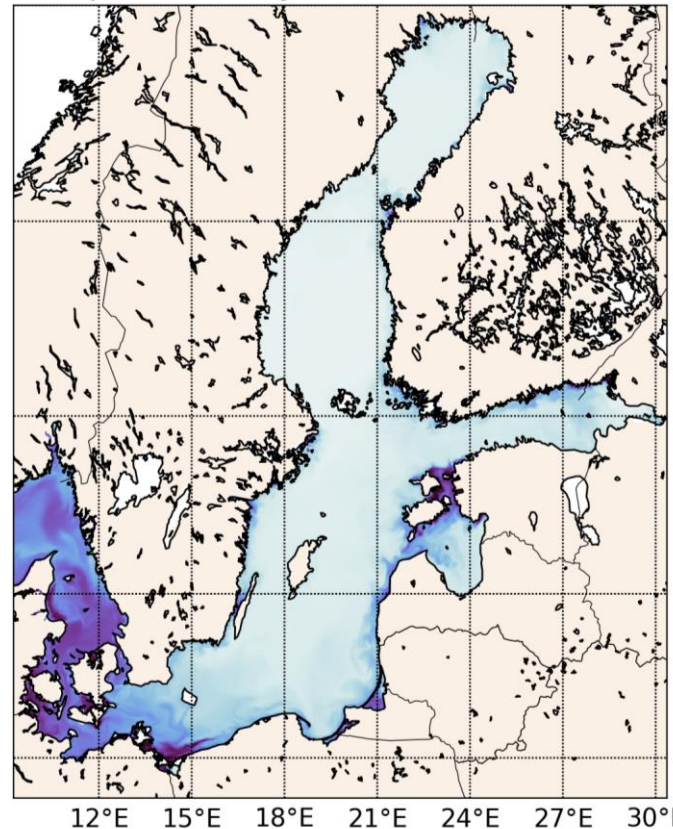
24h forecast on April 1

**Trophic efficiency:
zooplankton /
phytoplankton**

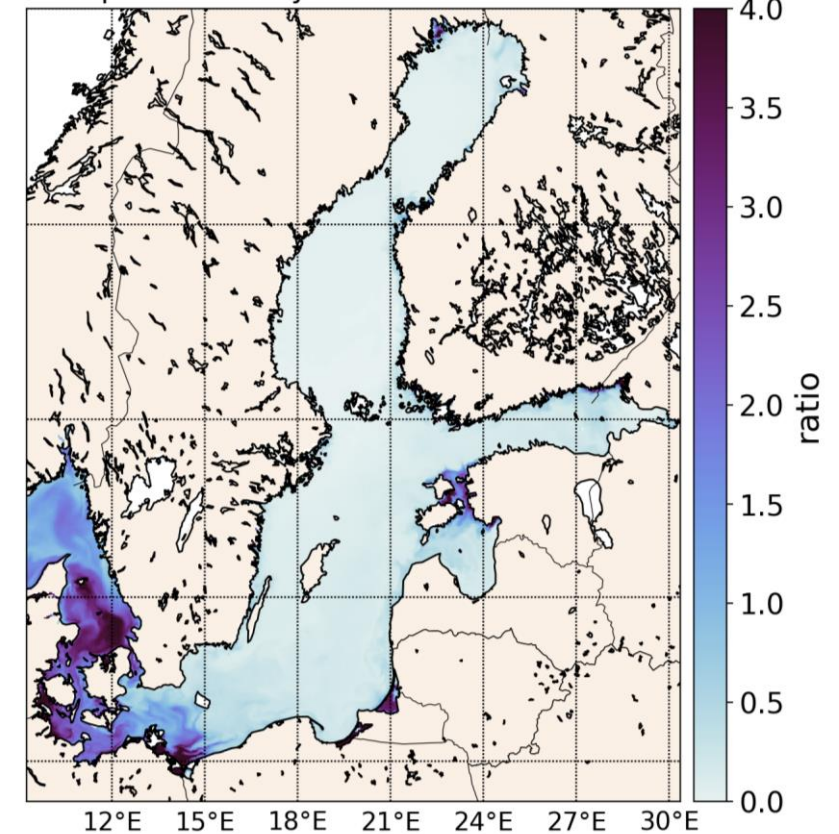
On April 1 only significant
zooplankton in the transition
zone to North Sea

DA increases the ratio

Trophic Efficiency free run on 2015-04-01



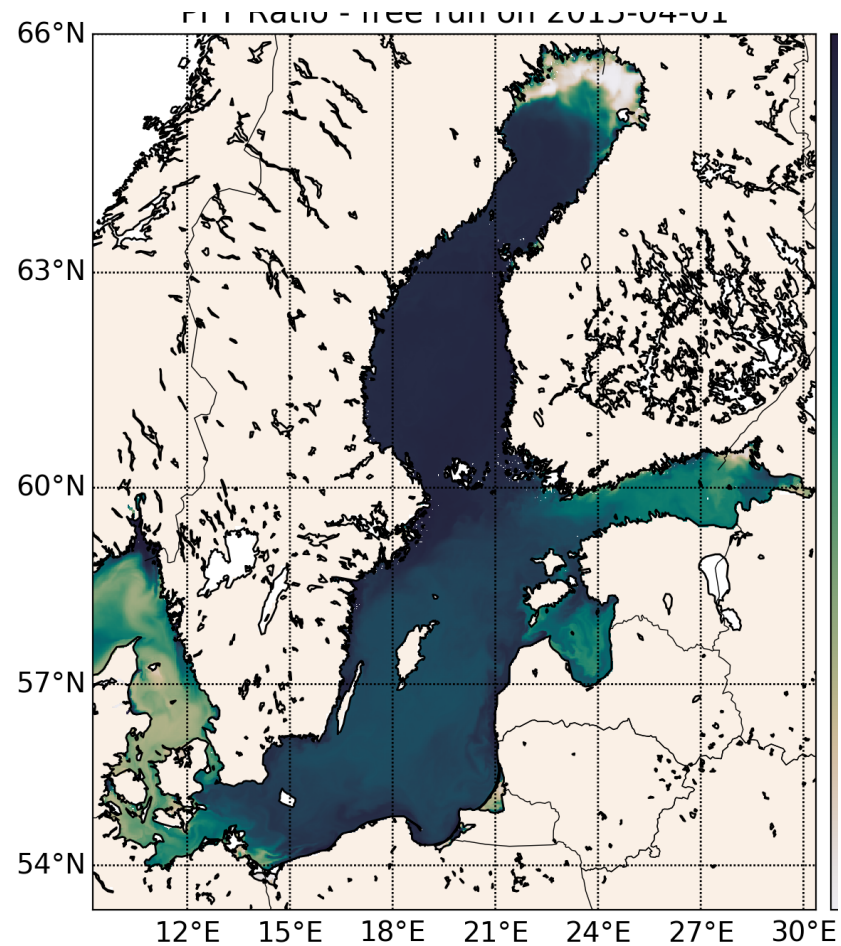
Trophic Efficiency forecast on 2015-04-01



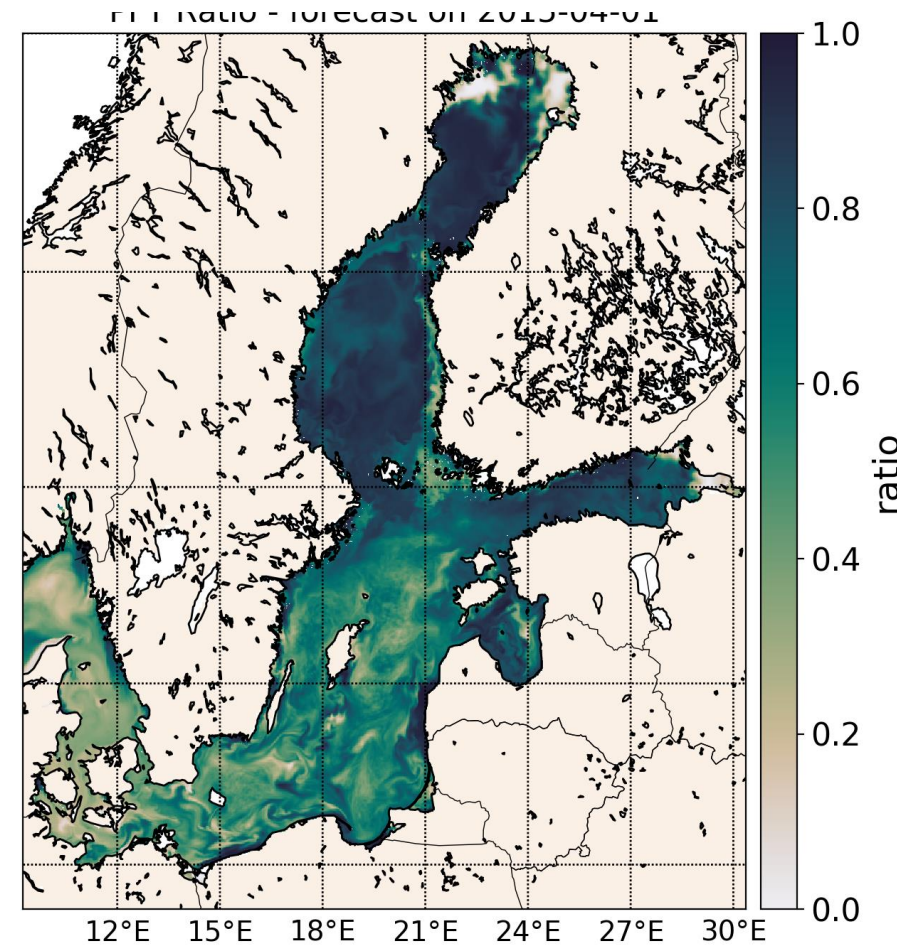
Ratio of diatoms to total phytoplankton

DA reduces relative abundance of diatoms in several regions

Free run on April 1



24h forecast on April 1

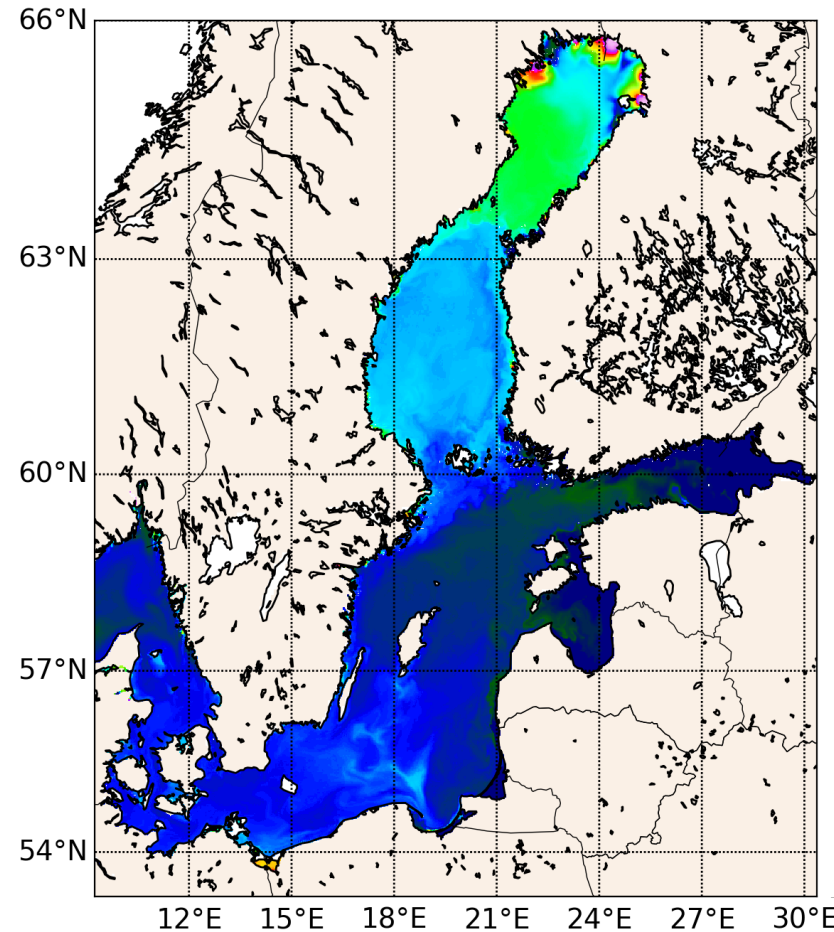


pH

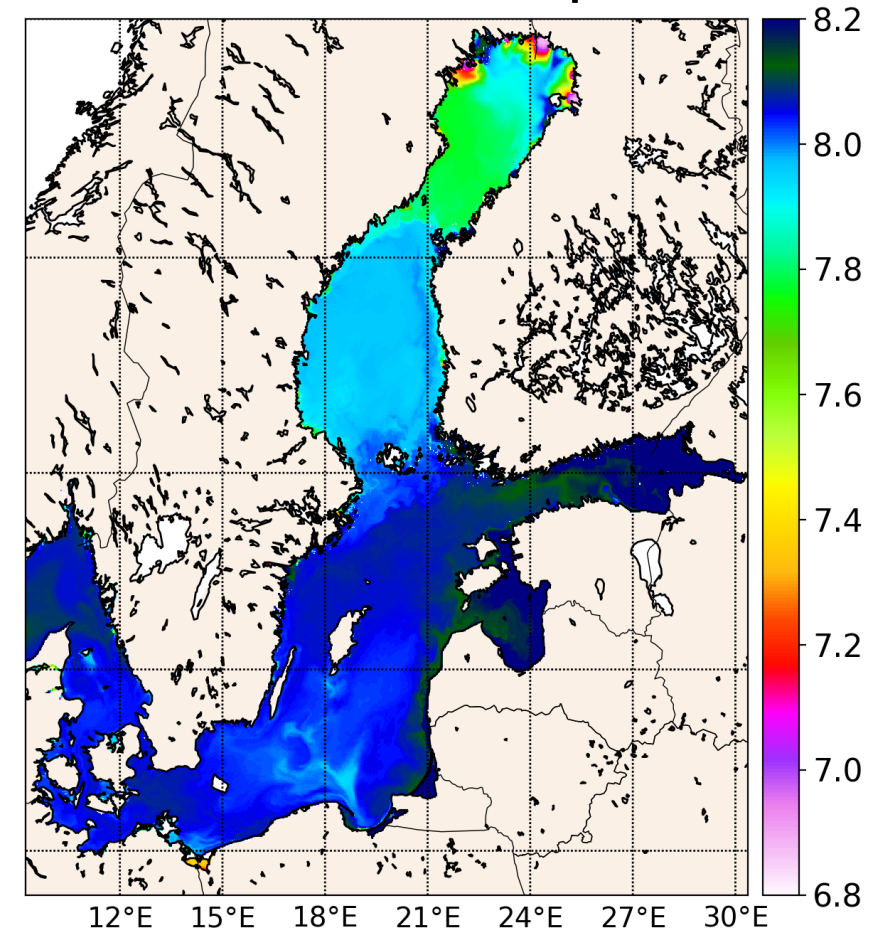
Significant variations in the Baltic Sea.

The DA lowers pH slightly in the Baltic proper and Bothnian Sea

Free run on April 1



24h forecast on April 1



- Coupled assimilation of satellite SST and chlorophyll
- Improvements in temperature and chlorophyll in analysis and 14-day forecasts
- Combined SST+CHL assimilation improves result over CHL-only assimilation
- Next steps
 - Validation with in situ data
 - re-running with L3 SST data
 - Strongly coupled assimilation



- Visible rectangles visible beginning of April
 - Jumps in temperature when data becomes available in previously data-void regions
 - Not reflected in error maps of data product
- Rerun with level 3 data

L4 SST on April 6, 2015

