PDAF Parallel Data Assimilation Framework

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Coupled Data Assimilation for Ocean-Biogeochemical Models

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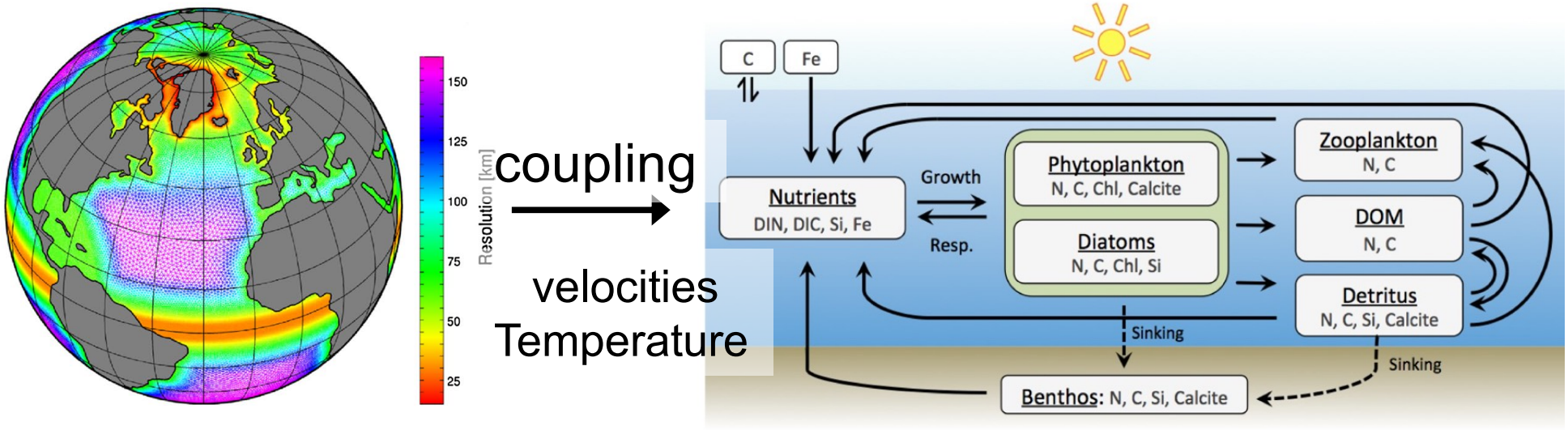
Coupled Ocean-Biogeochemical Models

Physics

Ocean Circulation Model

Ecosystem

Biogeochemical Model, …



Finite-Element Sea Ice Ocean Model

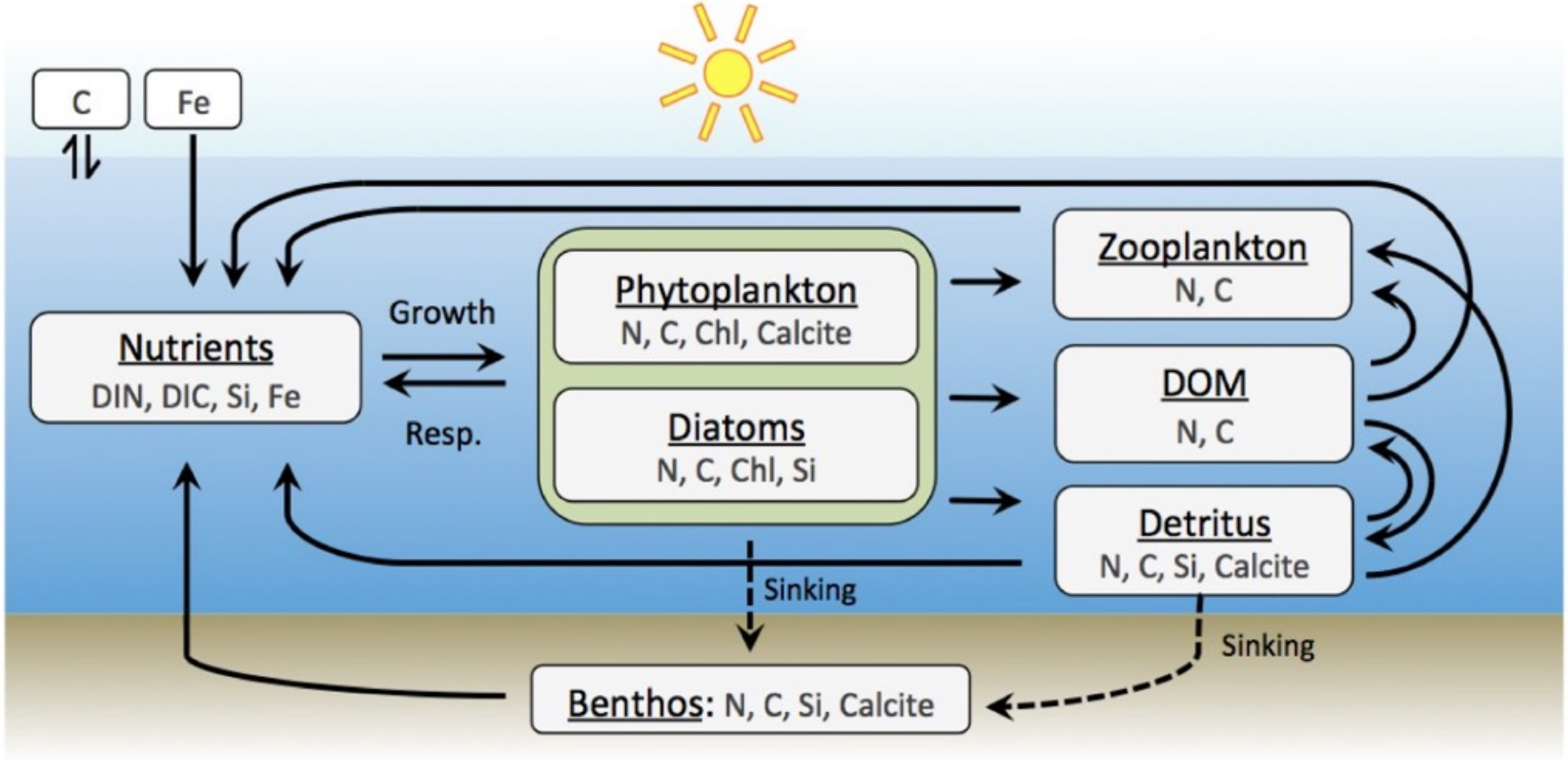
FESOM

Regulated **Eco**system **M**odel – Version **2**

REcoM2

Biogeochemical Process Models

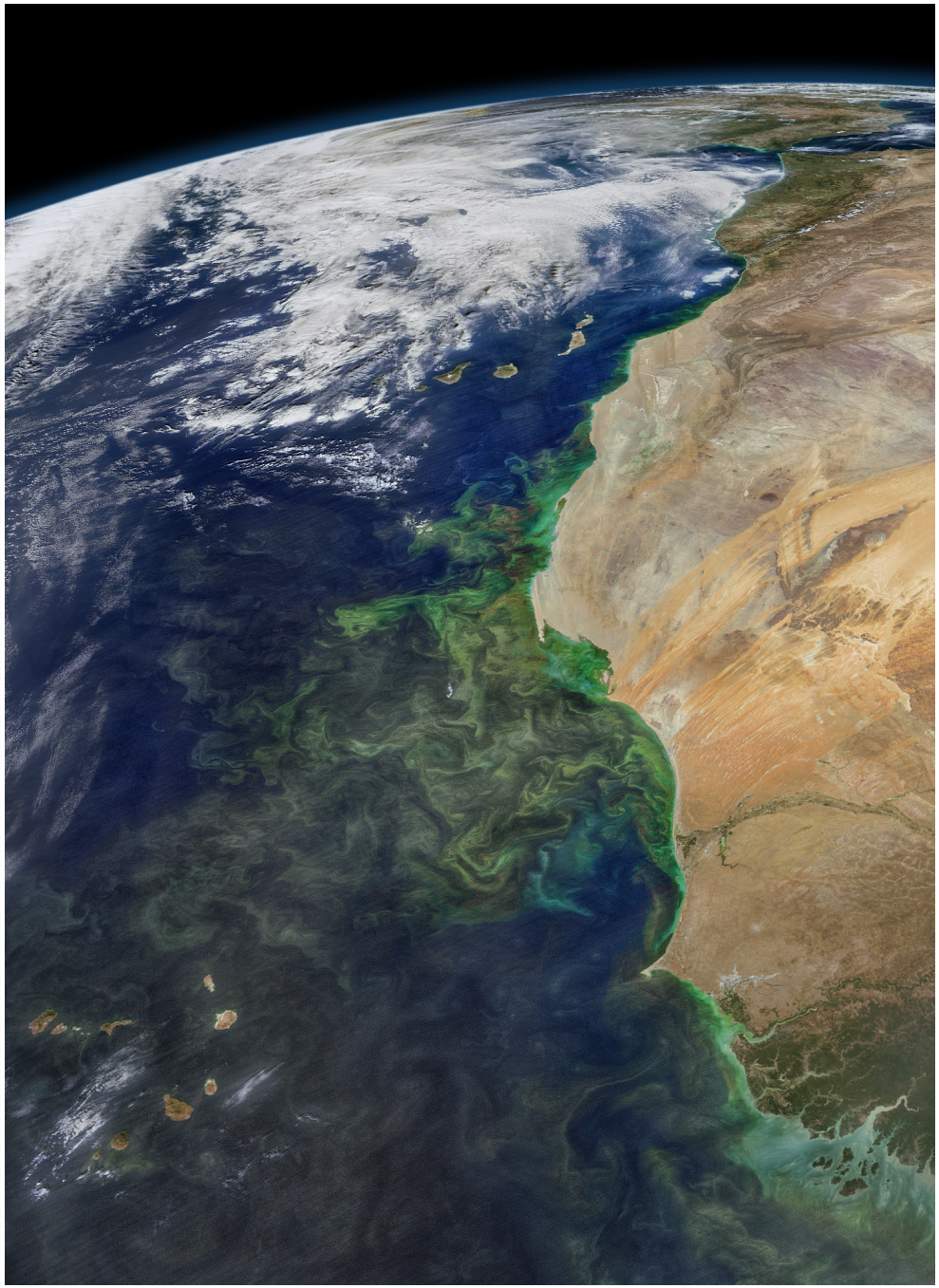
Wide variations of the model formulation



Example: REcoM-2

Regulated **Eco**system **M**odel – Version **2**
(Hauck et al., 2013)

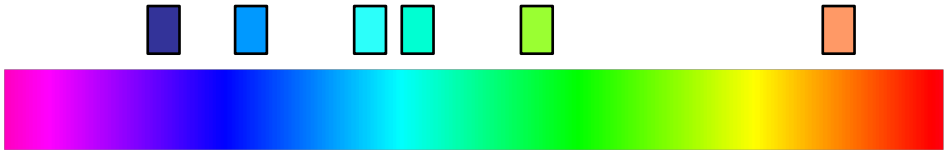
Satellite Ocean Color Observations



This is not a photograph!

Spectral data at 5-8 wavelengths in visible part of spectrum

spectral bands in ESA OC-CCI data



- Satellite data is water leaving radiance or surface reflectance

  → Data products are derived from this

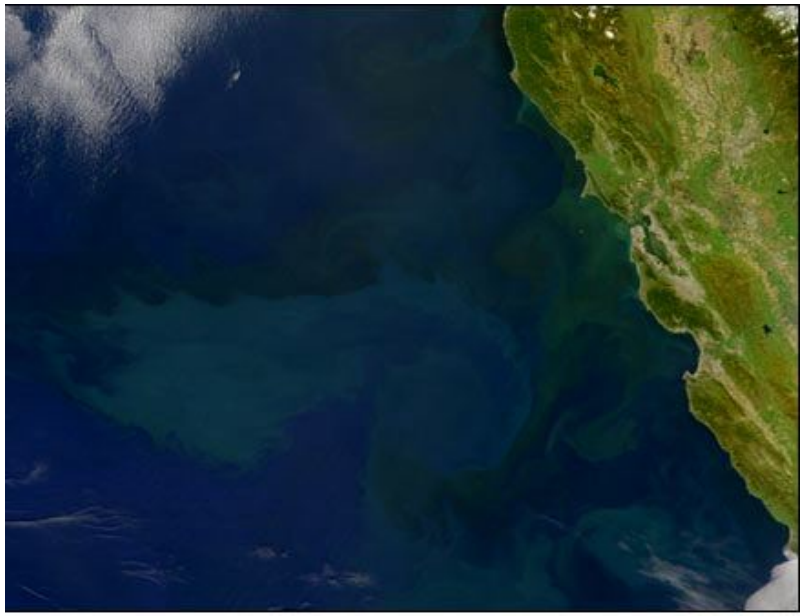
Picture source:

Suomi-NPP/VIIRS, December 10, 2018

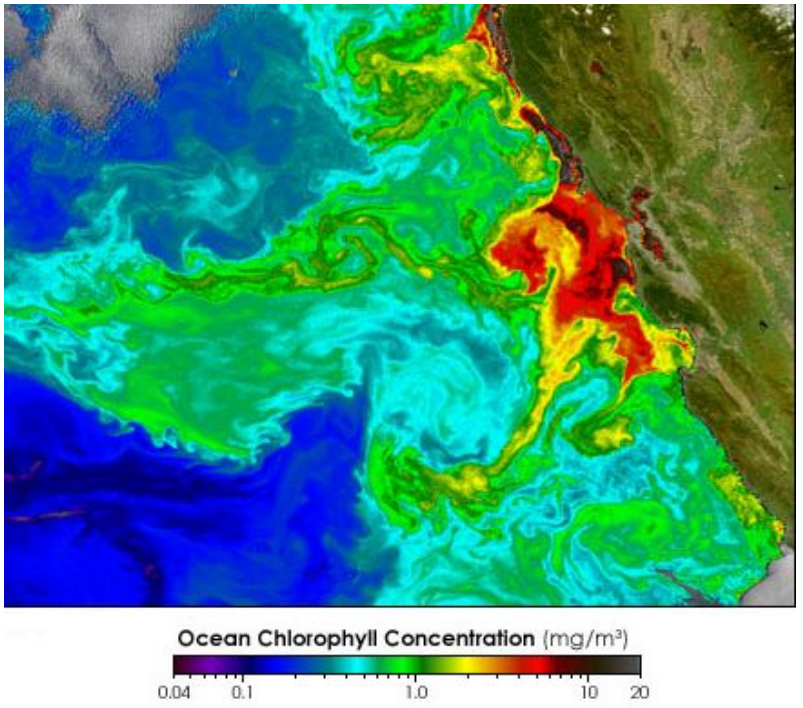
NASA (oceancolor.gsfc.nasa.gov)

Satellite Chlorophyll Data (the most common product)

Natural Color 3/16/2004



Chlorophyll Concentrations



Chlorophyll computed as

4th order polynomial of reflectance at two wavelengths:

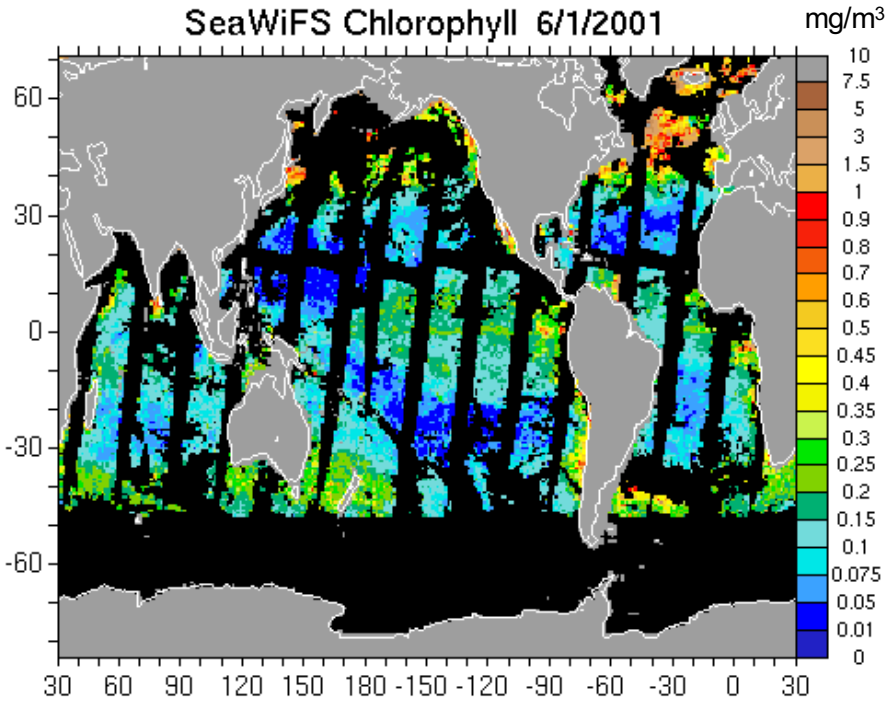
$$log_{10}(CHL_a) = a_0 + \sum_{i=1}^{4} a_i \left(log_{10} \left(\frac{R(\lambda_{blue})}{R(\lambda_{green})} \right) \right)^i$$

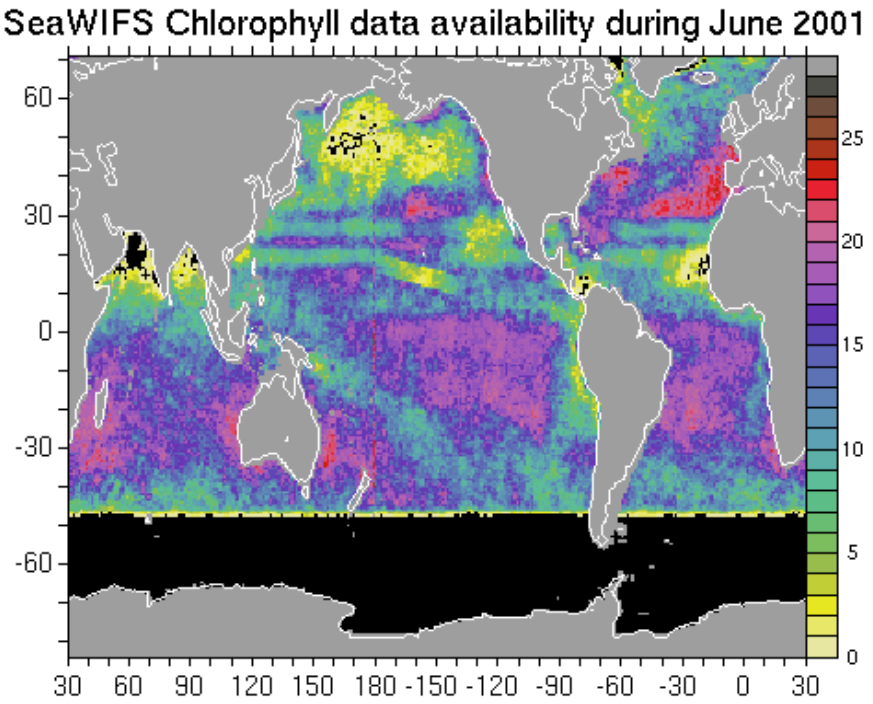
or combined with linear three-wavelength dependence

(this is empirical! – derived from statistical analysis)

Figure: NASA “Visible Earth”, Image: SeaWiFS Project, NASA/GSFC & Orbimage

Example: Chlorophyll-a (SeaWiFS)





Daily gridded SeaWiFS chlorophyll data

- gaps: satellite track, clouds, polar nights
- 30% to 50% data coverage
- irregular data availability

Nerger, L., and W.W. Gregg. J. Marine Systems **68** (2007) 237

Data Assimilation Issues

Model	
• Skill	Much higher error than in physics
• Complexity	Only fraction of fields observed
Observations	
• Data gaps	Fields are less constrained
• Data error level	15 - 30%
• Empiric algorithms	→ representation error
Assimilation	
• Approx. log-normal	Need to transform concentrations
• Diurnal variability	→ representation error
• Representation errors	Unknown, but expected to be high

Example 1

Assimilation of total chlorophyll

to constrain 2 phytoplankton groups

Example: Global Chlorophyll Assimilation

MITgcm

General ocean circulation model of MIT (*Marshall et al., 1997*).

Global configuration

80°N - 80°S, 30 layers

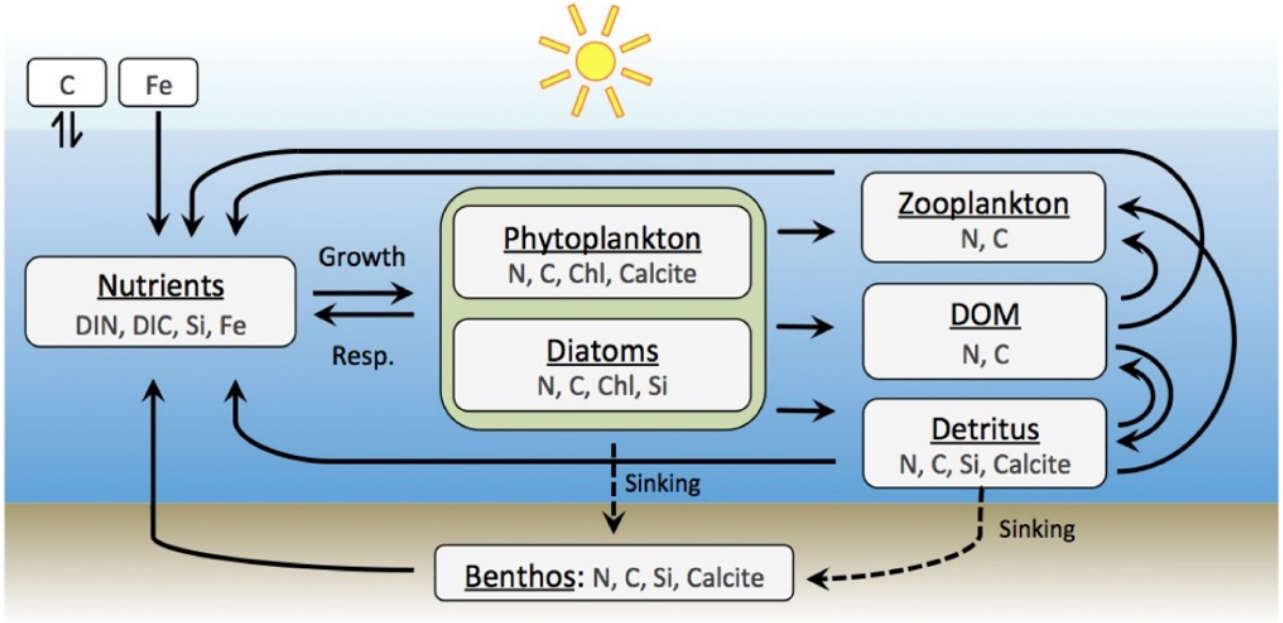
Resolution:

lon : 2 deg

lat : 2 deg in North
up to 0.38 deg in South

REcoM-2

Regulated **Eco**system **M**odel – Version **2**
(Hauck et al., 2013)

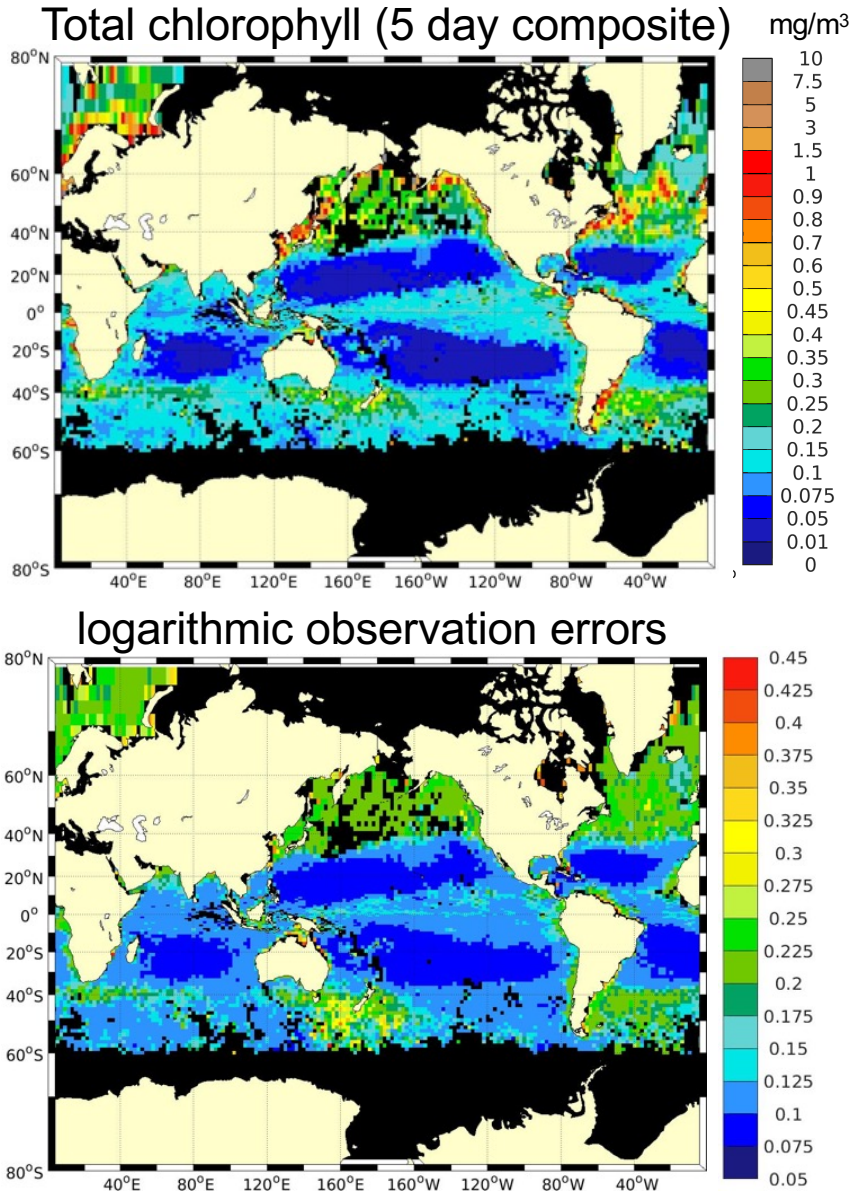


Assimilate with PDAF (http://pdaf.awi.de)

Assimilation of Total Chlorophyll

Assimilated:

Total chlorophyll from ESA OC-CCI

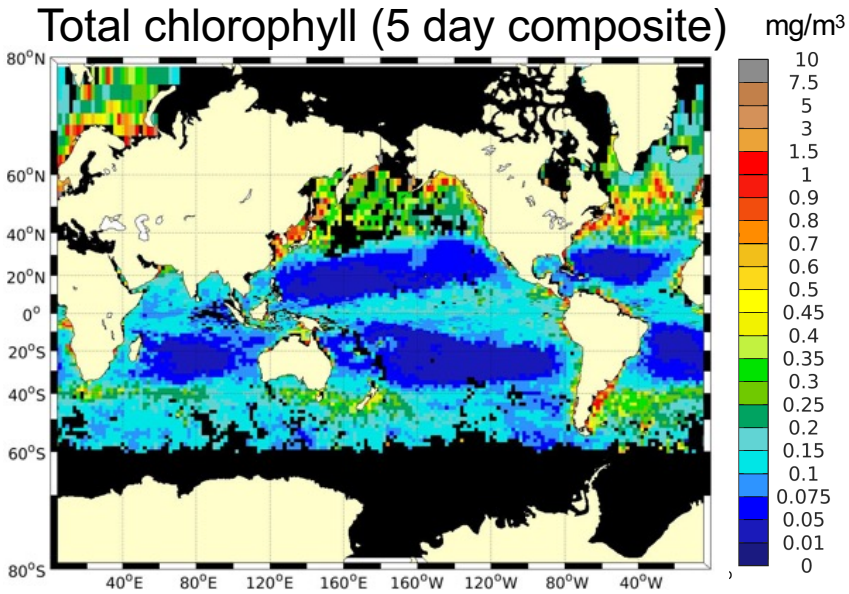


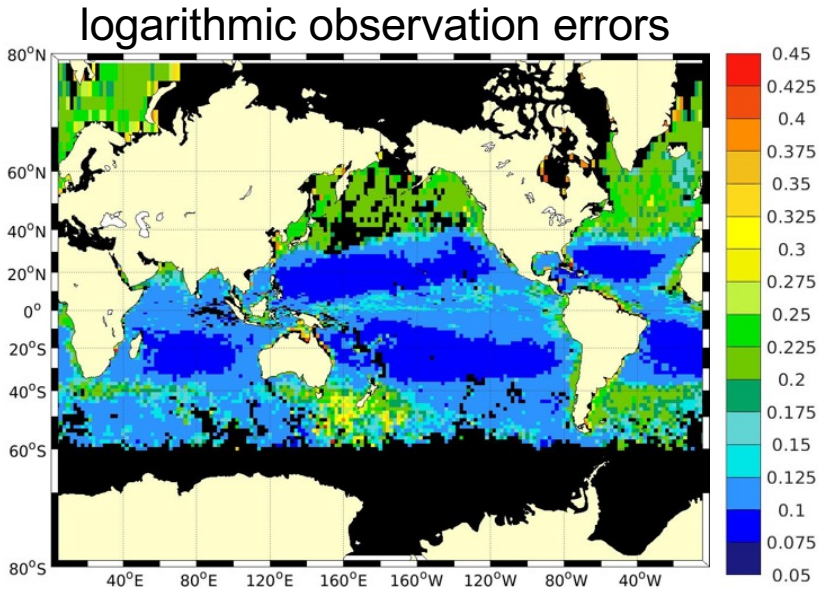
Assimilation:

- Assimilate satellite total chlorophyll (ESA Ocean color - climate change initiative):
  $Chl_{TOT} = Chl_{DIA} + Chl_{PHY}$
- Handle logarithmic concentrations
  $\log(Chl_{TOT})$, $\log(Chl_{DIA})$, $\log(Chl_{PHY})$
- Multivariate update through, e.g.
  $Cov(\log(Chl_{TOT}), \log(Chl_{DIA}))$
- How are both phytoplankton groups influenced?
- Validate with satellite and in situ data

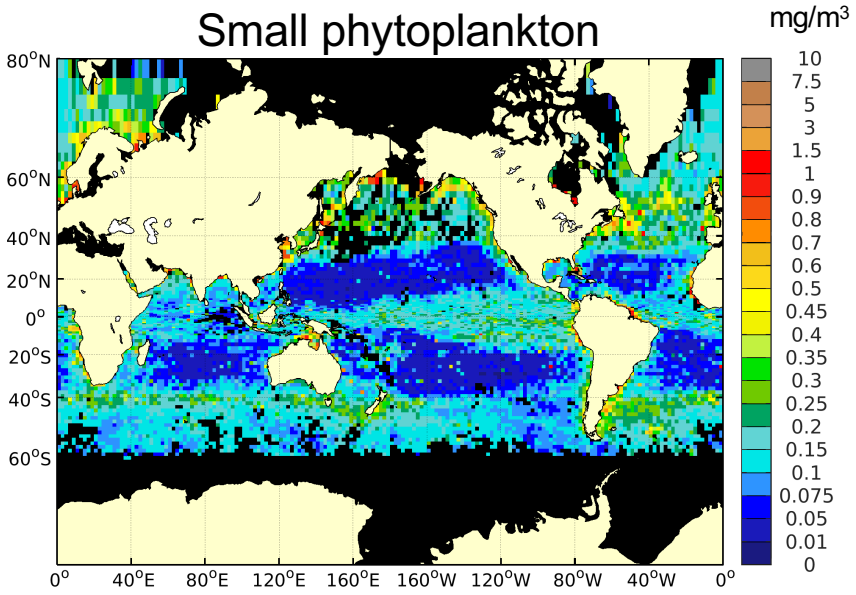
Assimilation of Total Chlorophyll

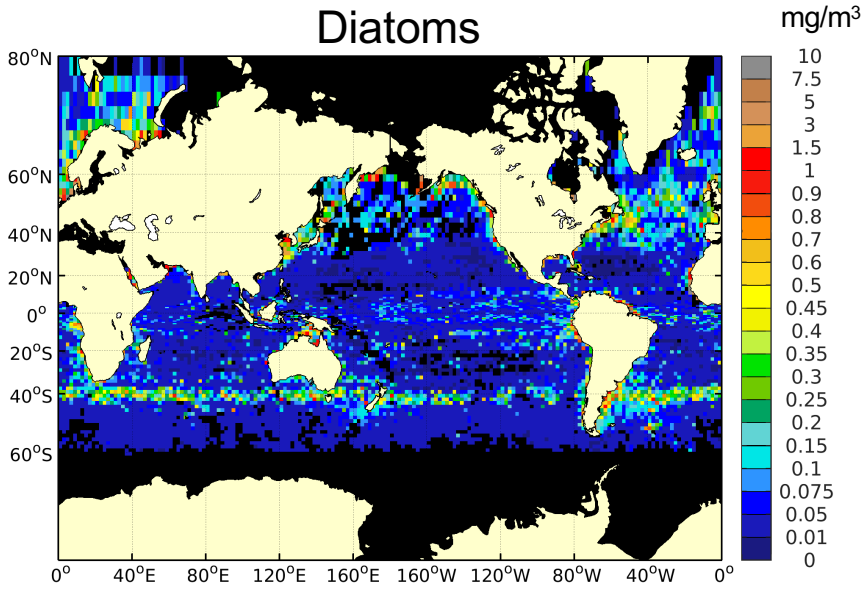
Assimilated:
Total chlorophyll from ESA OC-CCI





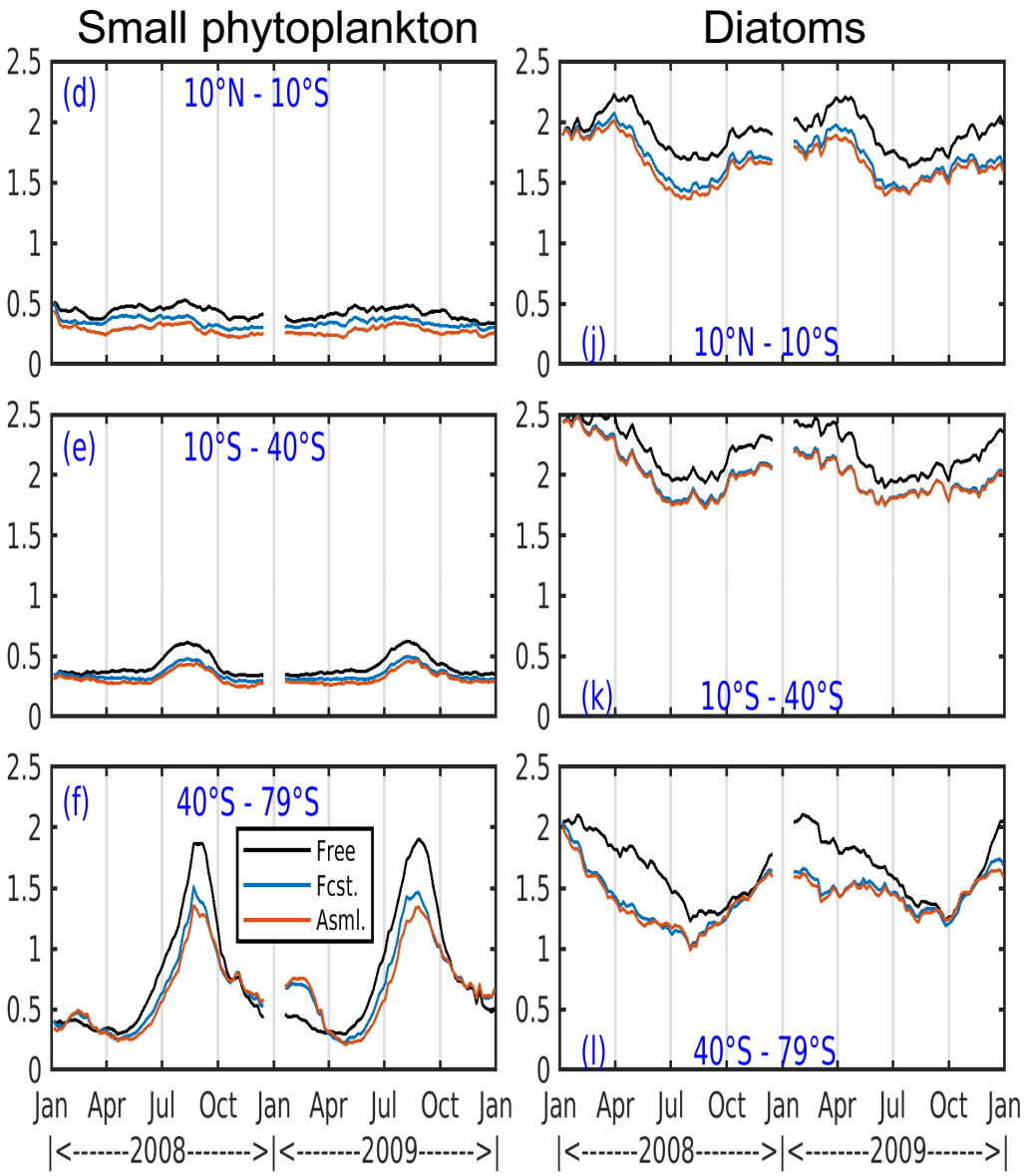
Verification: Phytoplankton group data
SynSenPFT (Losa et al. 2018)





Effect on Chlorophyll in Phytoplankton Groups

logarithmic RMS errors (southern regions)



- Assimilation improves groups individually through cross-covariances
- Stronger error-reductions for Diatoms
- In situ data comparison:

RMSe	Free	Assim.
Diatoms	1.3	0.91
Small Phyto.	0.53	0.45

(bias and correlation also improved)

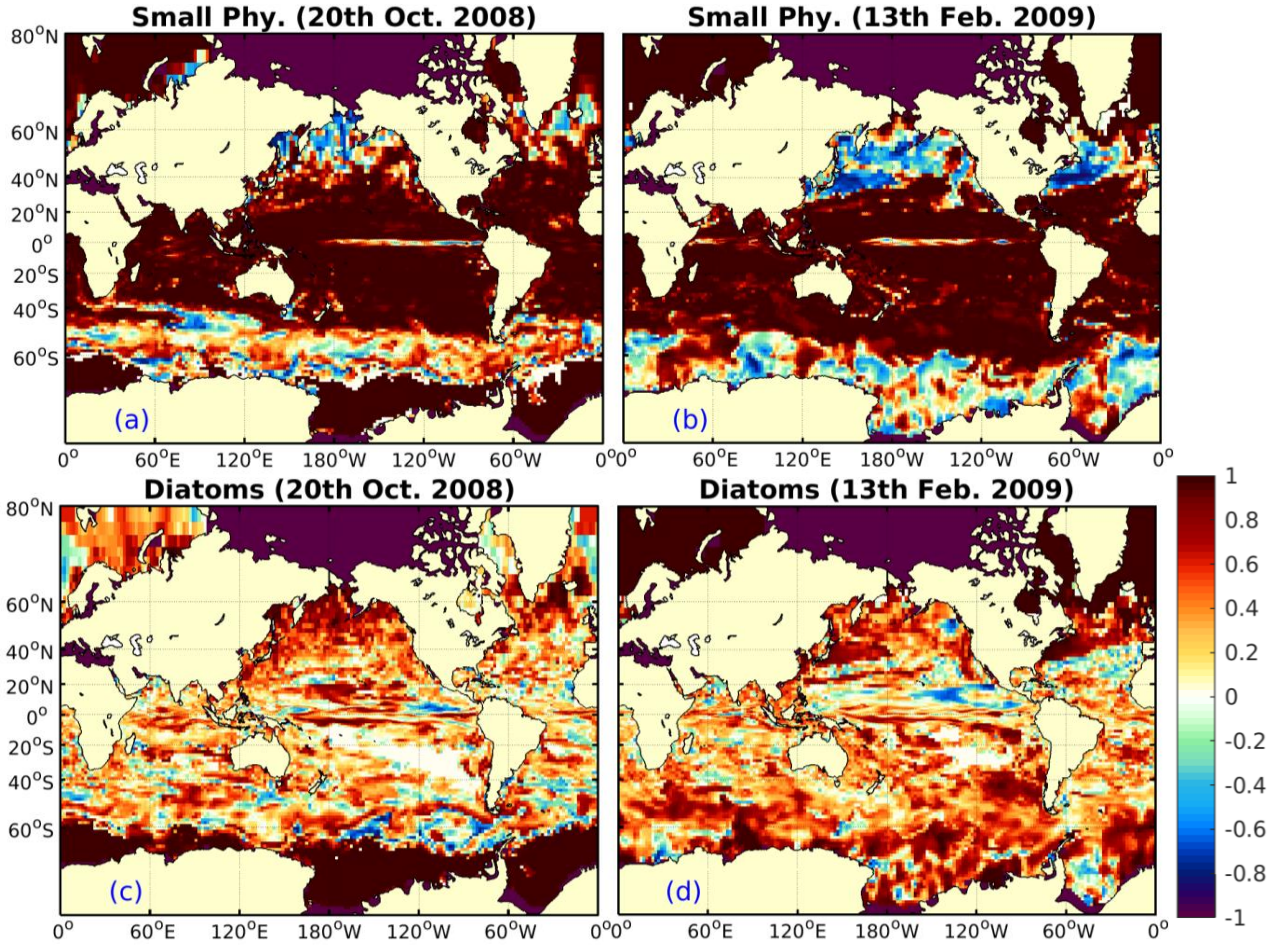
Current work

- Asses impact of assimilating chlorophyll group data (much lower errors for diatoms)

Pradhan et al., J. Geophy. Res. Oceans, *in press*, doi:10.1029/2018JC014329

Ensemble-estimated Cross-correlations

Cross correlations between total and group chlorophyll



- Significantly different correlations for small phytoplankton and diatoms
- Negative correlations exist (despite $Chl_{TOT} = Chl_{DIA} + Chl_{PHY}$)

Pradhan et al., J. Geophy. Res. Oceans, *in press*, doi:10.1029/2018JC014329

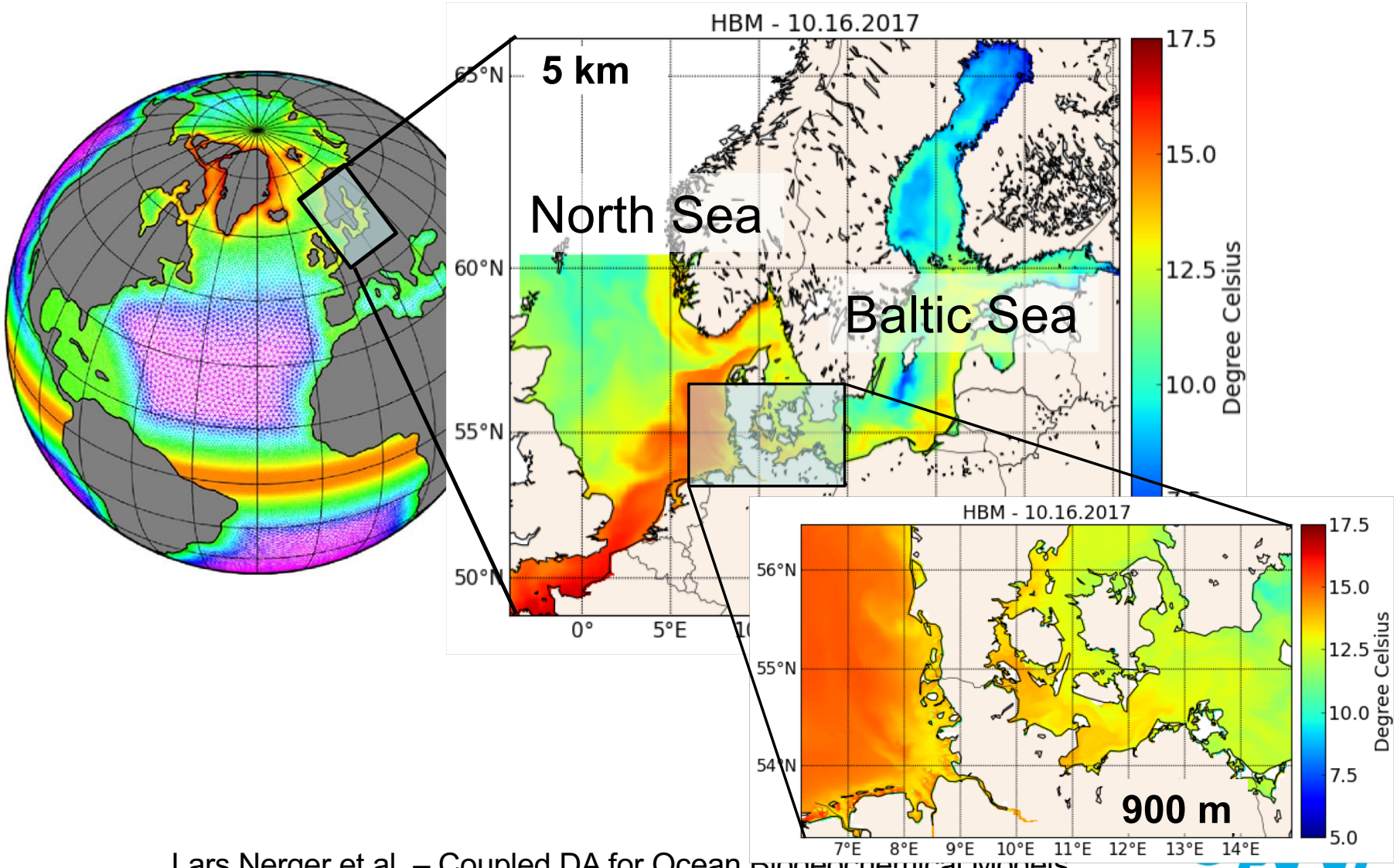
Example 2

Weakly- and Strongly Coupled Assimilation

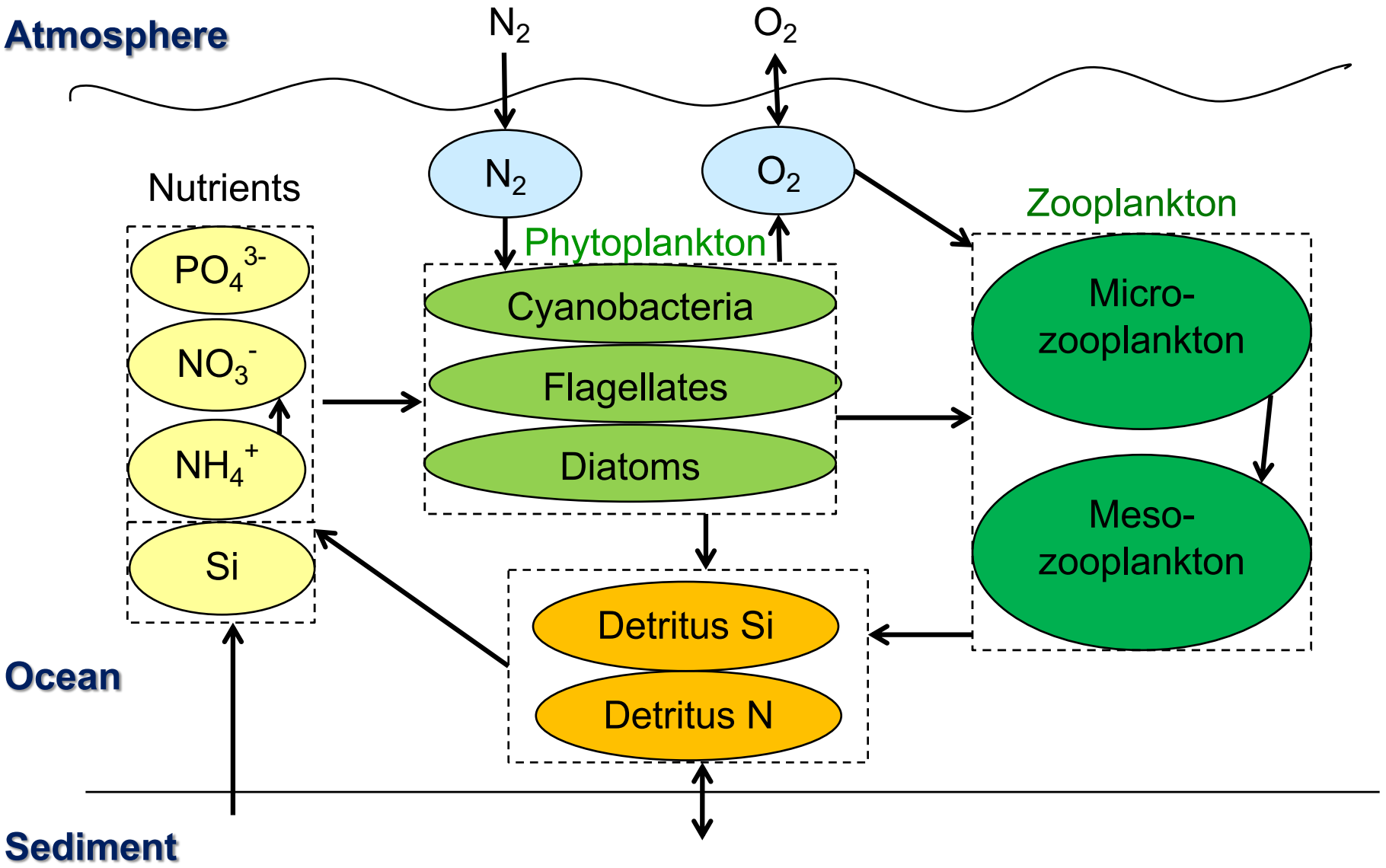
Constrain Biogeochemistry with Temperature Data

Example: weakly- and strongly coupled assimilation

HBM (Hiromb-BOOS Model) – operationally used at Germany Federal Maritime and Hydrographic Agency

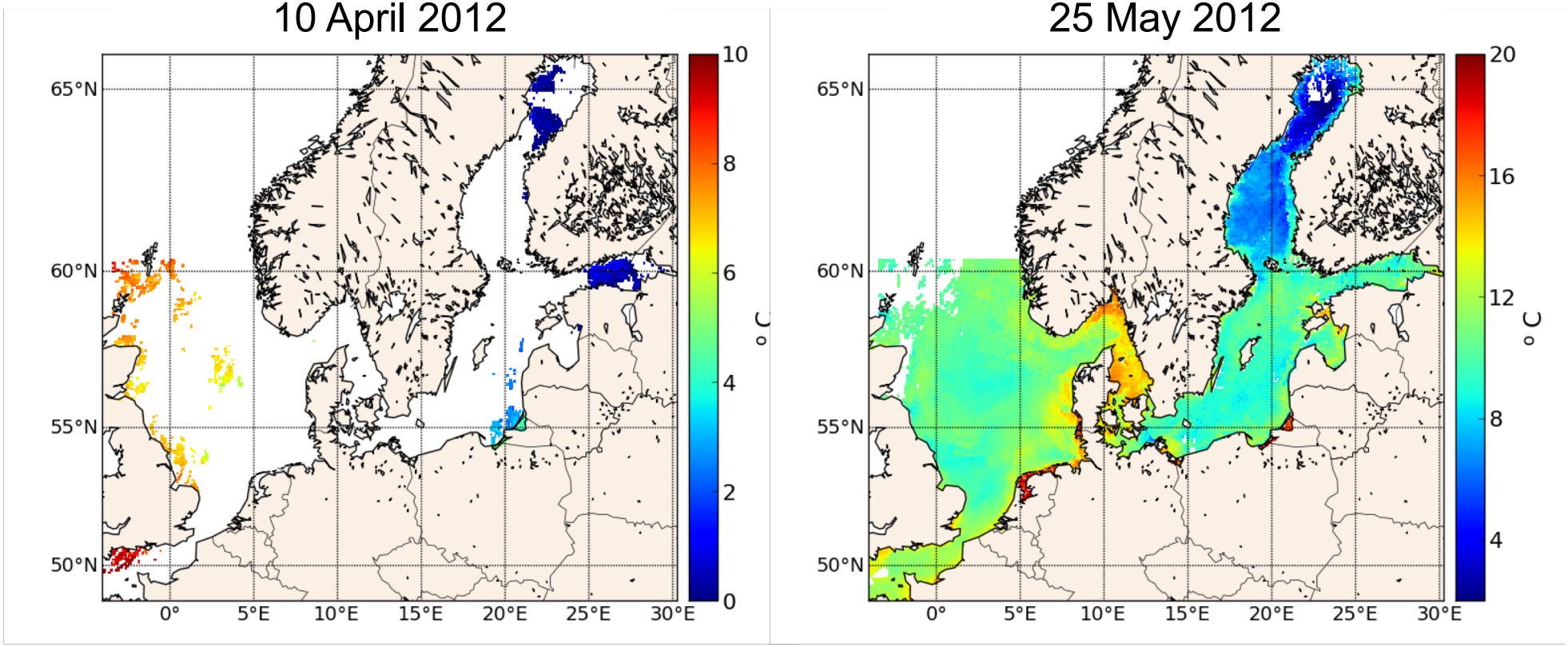


Biogeochemical model: ERGOM



Observations – Sea Surface Temperature (SST)

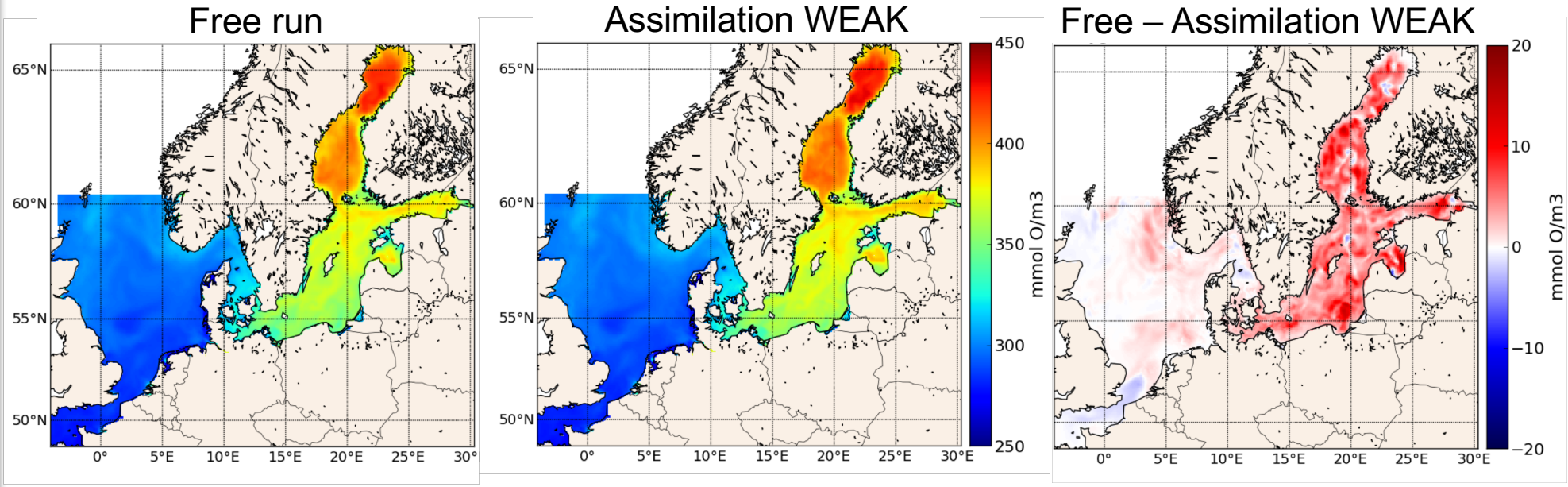
NOAA/AVHRR Satellite data



- 12-hour composites
- Vastly varying data coverage (due to clouds)
- Effect on biogeochemistry?
- Assimilation using assimilation framework PDAF

Weakly & strongly coupled effect on biogeochemistry

Oxygen mean for May 2012 (as mmol O / m^3)

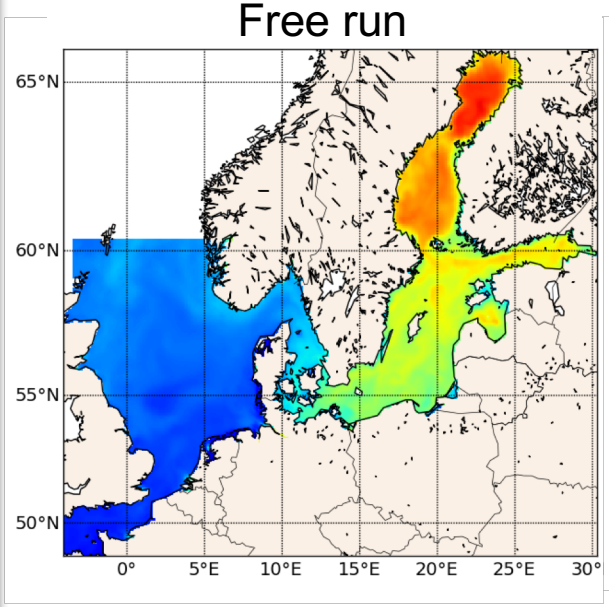


- Changes up to 8% (slight error reductions)
- Larger in Baltic than North Sea

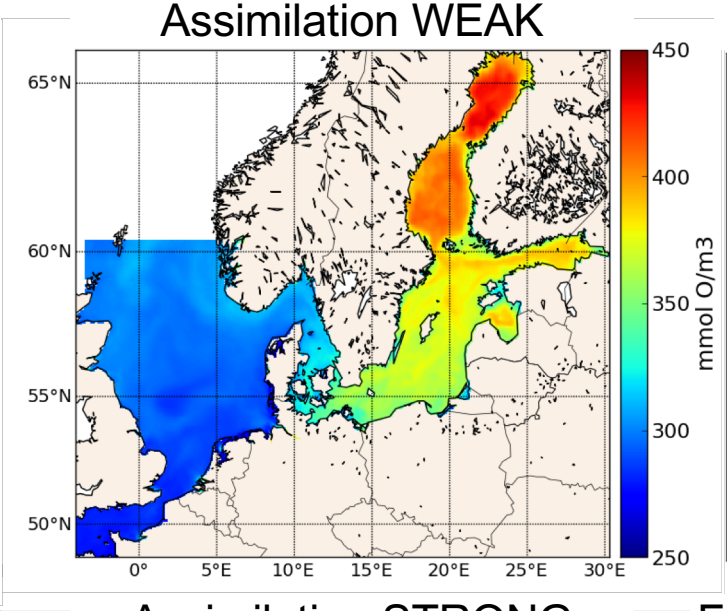
Weakly & strongly coupled effect on biogeochemistry

Oxygen mean for May 2012 (as mmol O / m^3)

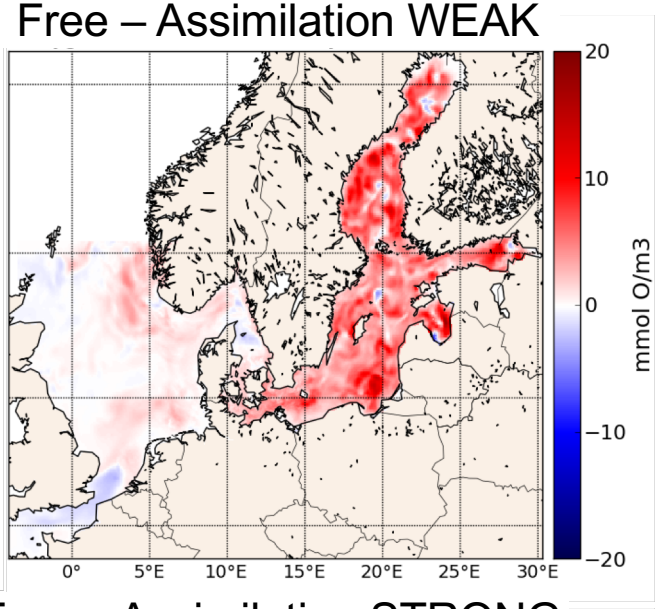
Free run



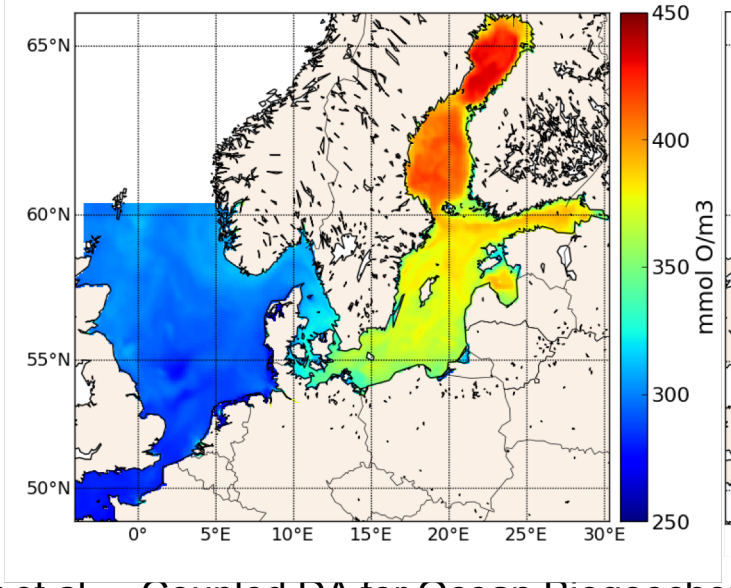
Assimilation WEAK



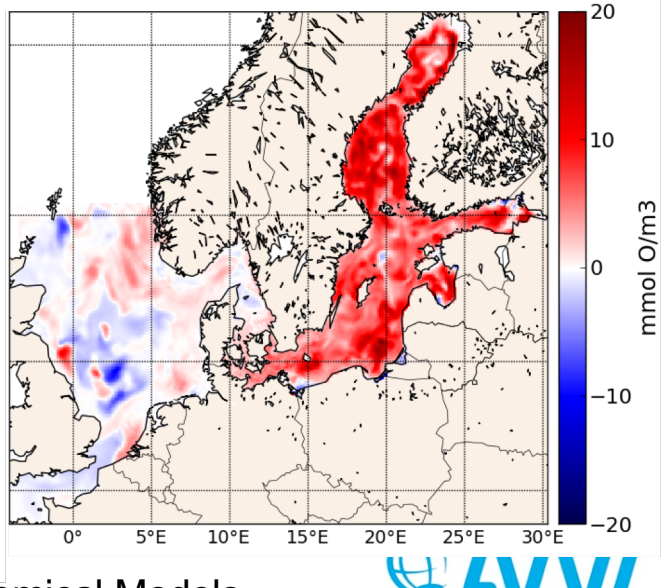
Free – Assimilation WEAK



Assimilation STRONG



Free – Assimilation STRONG



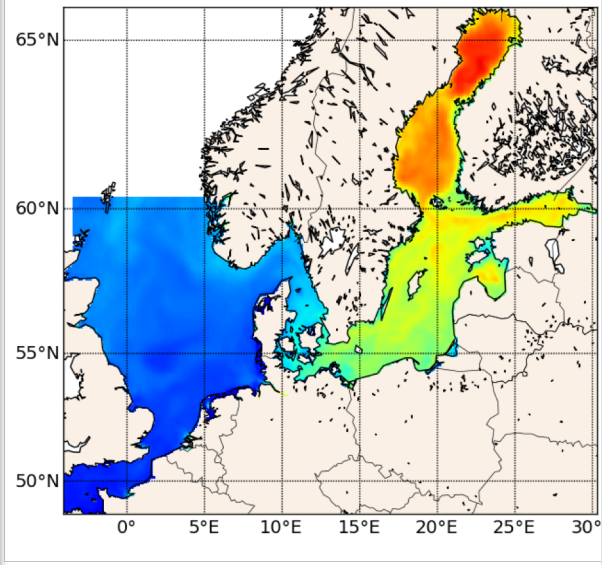
Strongly coupled

- slightly larger changes
- Strongly coupled DA further improves oxygen
- Used actual (linear) concentrations

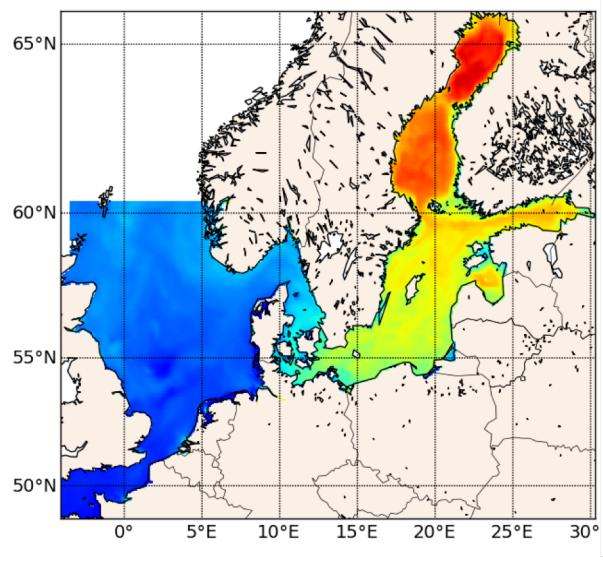
Using Logarithmic Concentrations

Oxygen mean for May 2012 (as mmol O / m^3)

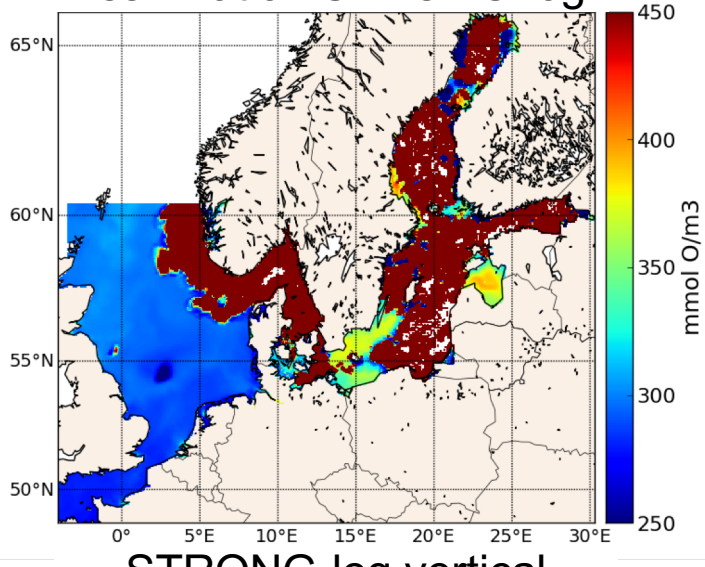
Free run



Assimilation STRONG-lin



Assimilation STRONG-log



Use logarithmic concentrations in analysis step

→ Unrealistic concentrations

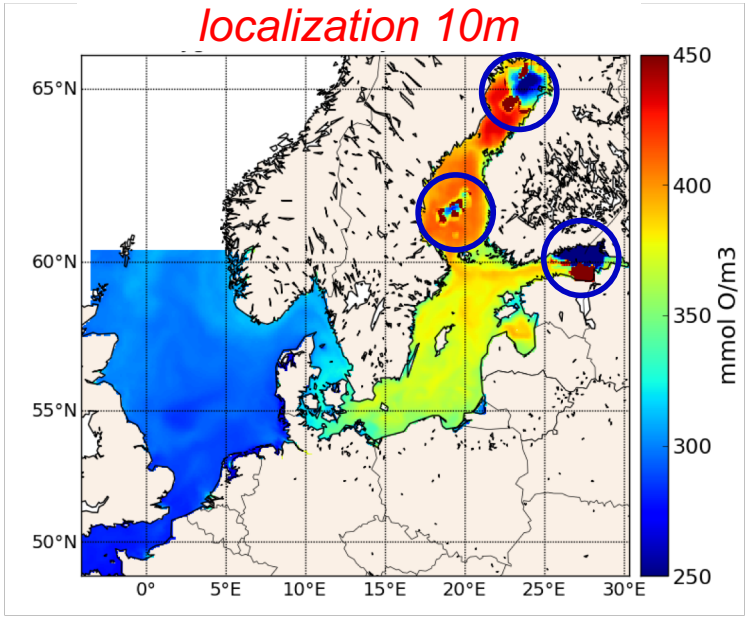
- Much too high in deeper ocean regions
- Caused by unrealistic cross-covariances between SST & sub-surface oxygen

Vertical localization

→ Helps in most regions (but not all)

→ Is log-normal assumption correct?

STRONG-log vertical *localization 10m*



Summary

- Biogeochemical model skill worse than physical
- Ocean-color observations
    - Most direct data: surface reflectance
    - Data products from empirical algorithms (chlorophyll, carbon, absorption, diffuse attenuation, ...)
- Strongly coupled DA of SST successful for linear concentrations
- Log-normal assumption might not be fully valid
    - Leads to stability issues
    - Vertical assimilation impact particularly problematic

Thank you!

Lars.Nerger@awi.de

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AWI