PML | Plymouth Marine Laboratory

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Listen to the ocean

Biogeochemical data assimilation

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Data assimilation training session

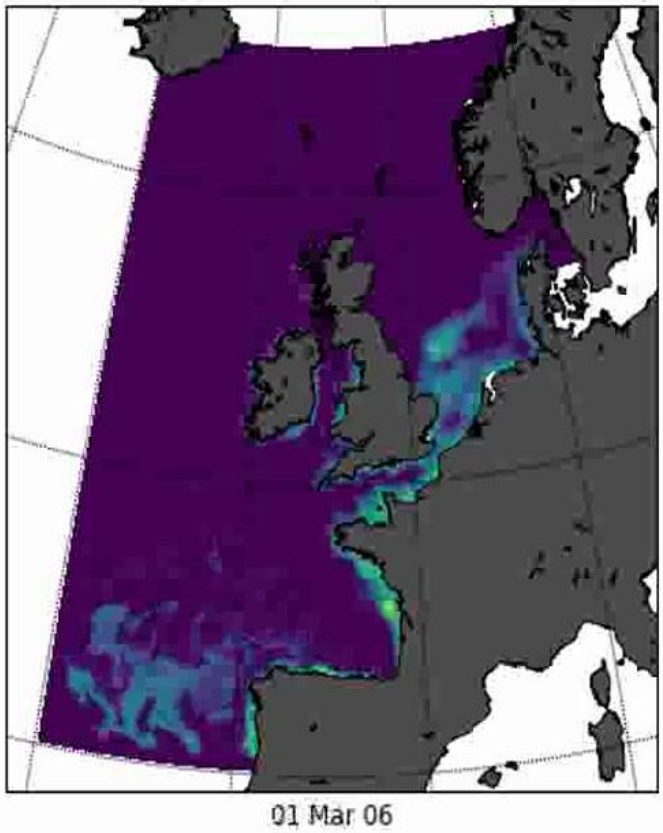
OceanPredict '19

GODAE OceanView Symposium | 6-10 May 2019 Halifax, Canada

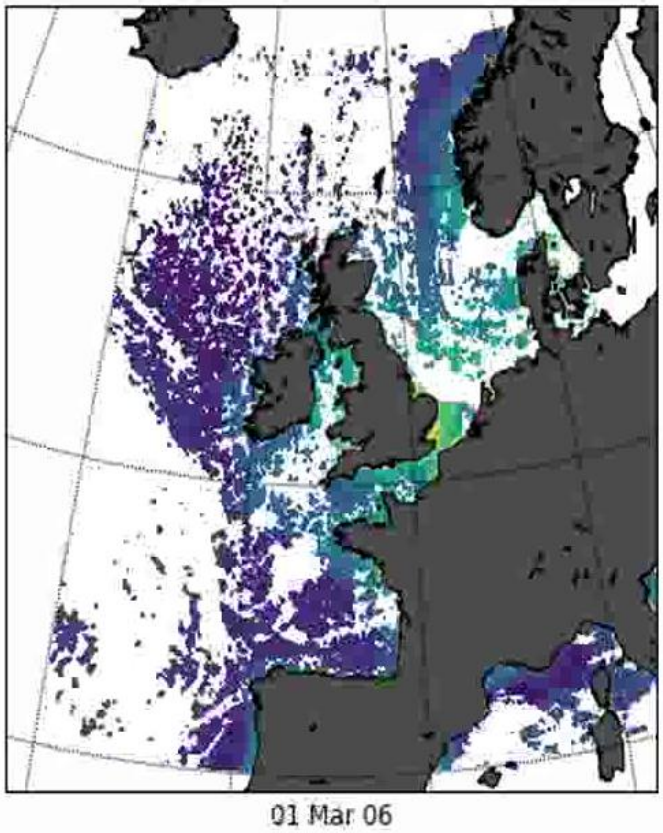
Advancing the science and application of ocean predictions

Ecosystem models and ocean colour

Model (chl)



Ocean colour (chl)



Space-time interpolation
Forecast
Data interpretation

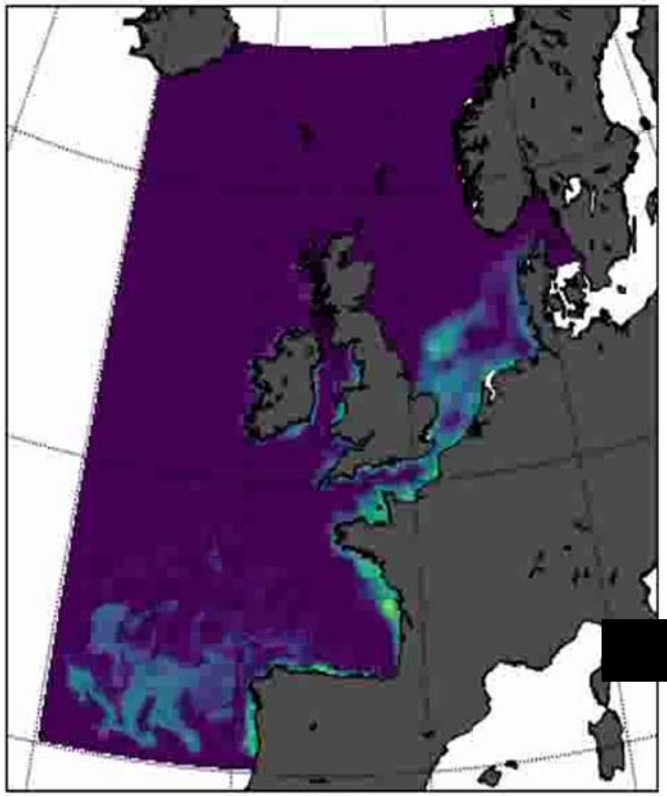
Any prossible synergy?

Calibration/validation
Model initializ/boundary
Forcing functions

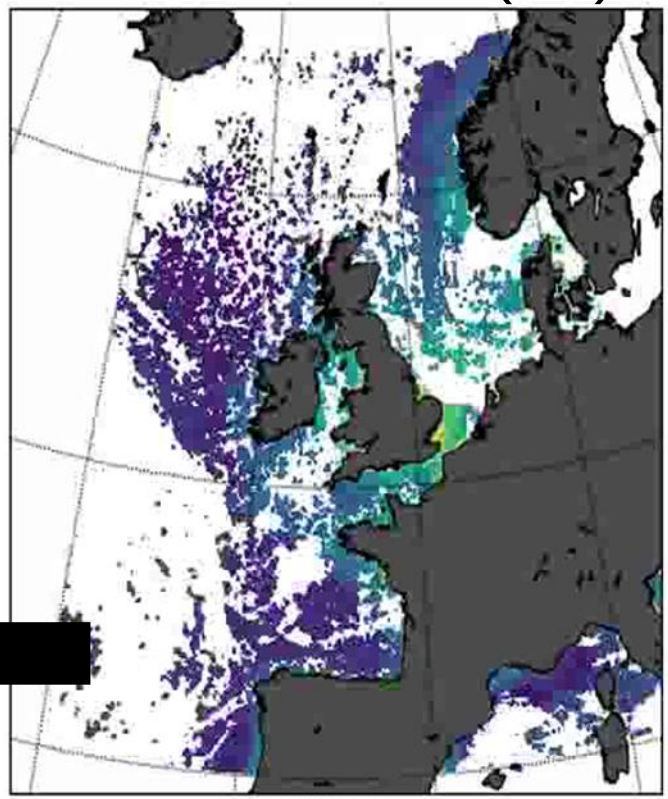
Courtesy of Momme Butenschön

Ecosystem models and ocean colour

Model (chl)



Ocean colour (chl)



Data Assimilation

Improved estimation and understanding
taking account of model and data errors

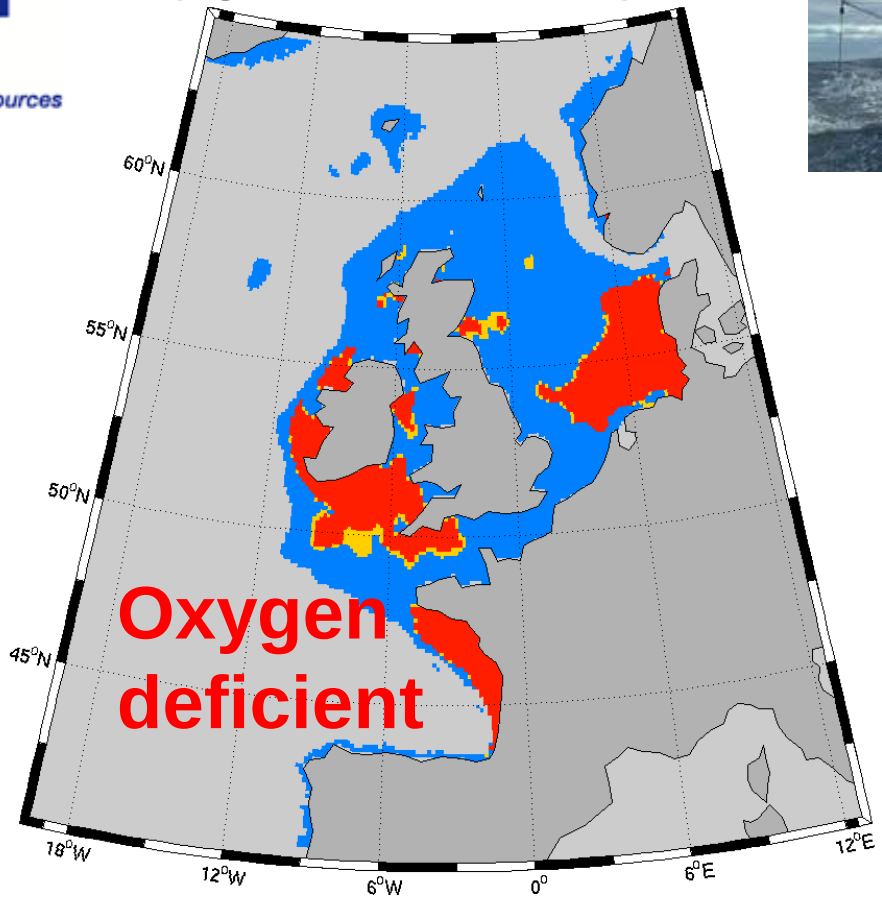
Motivation

Simulation of biogeochemical indicators and fluxes is vital for marine protection, marine policy implementation, climates studies

OSPAR COMMISSION

Protecting and conserving the North-East Atlantic and its resources

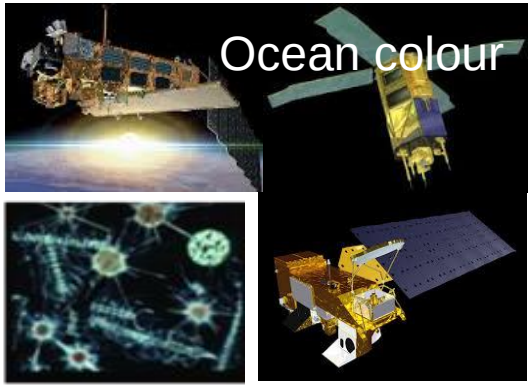
Oxygen deficiency risk

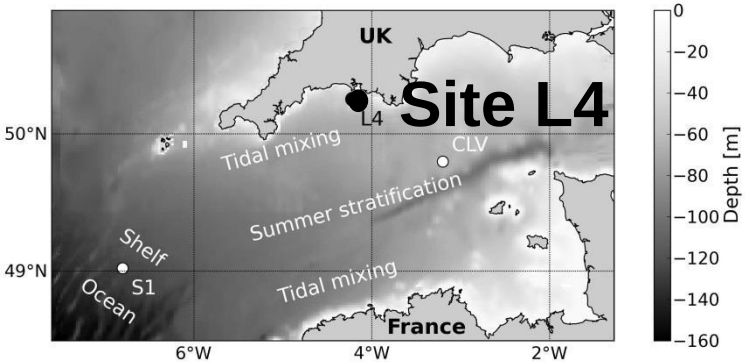


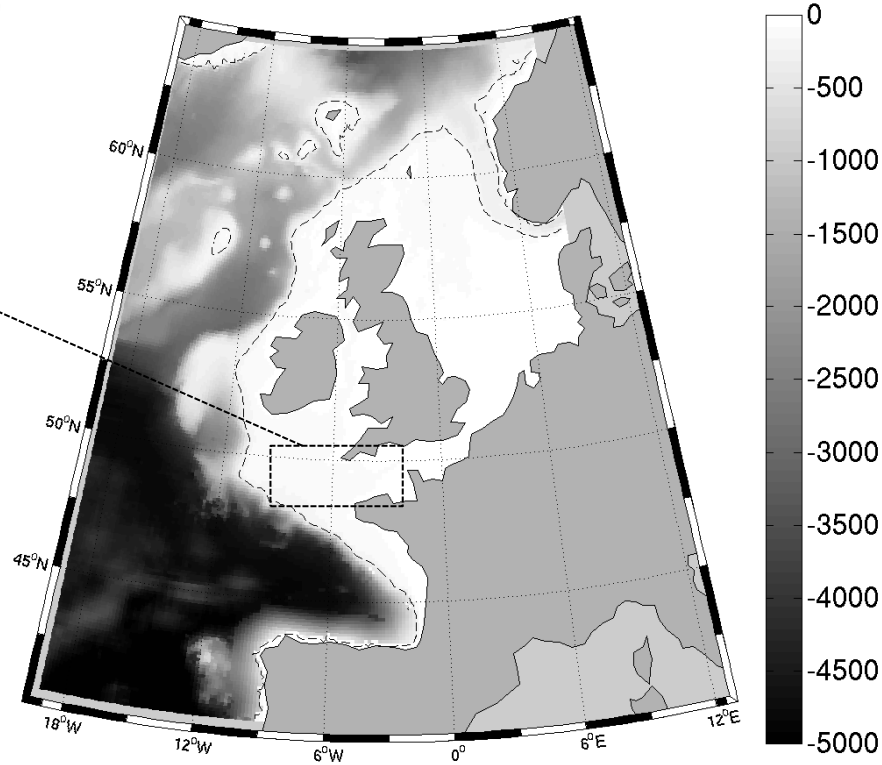
Ciavatta et al., JGR, 2016

Objectives and overview

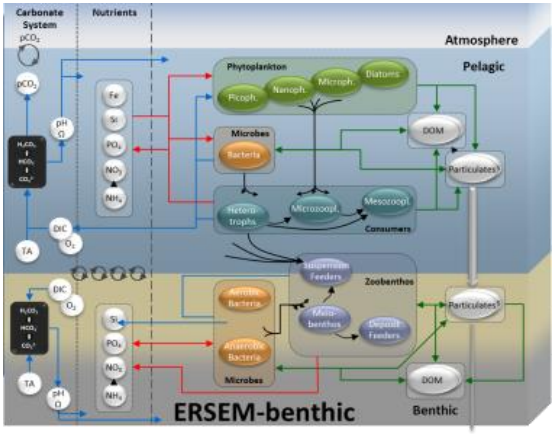
To provide some “behind-the-scenes” features of biogeochemical data assimilation







ERSEM

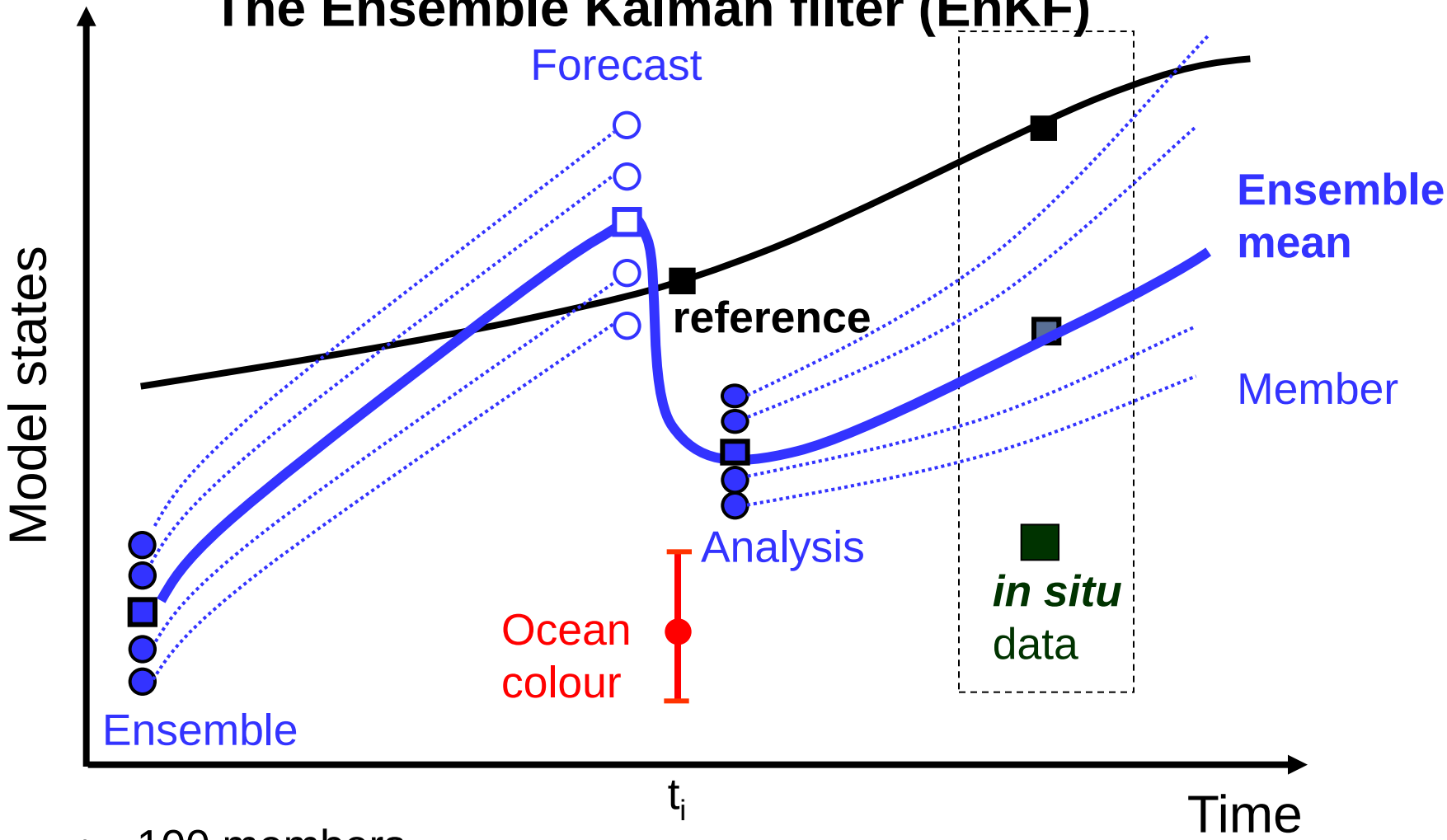


Butenschön et al., GMD, 2016

- PFTs
- Microbial loop
- Variable Chl:C:N
- Carbonate system

Assimilation of ocean colour in ERSEM

The Ensemble Kalman filter (EnKF)

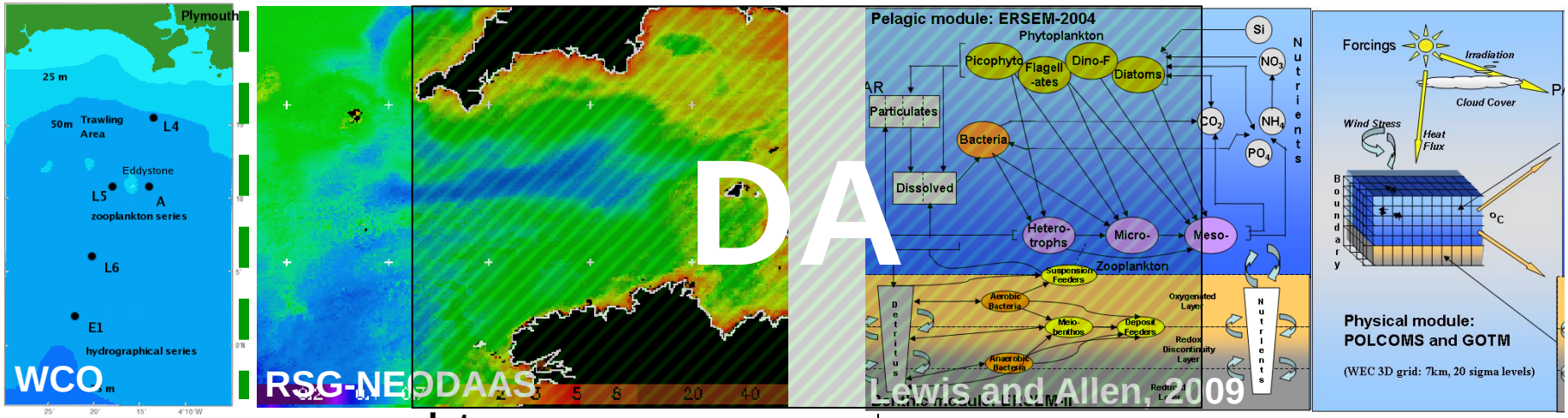


- 100 members
- Log-transformation of states and variables
- Localized analysis (spatially variable radius)
- Evolution of error covariance matrix

DA of satellite chlorophyll in ERSEM

Data **Model**

L4 biogeoch. MODIS chlorophyll ERSEM-POLCOMS



DA skills

data hind/forecast

assimilation

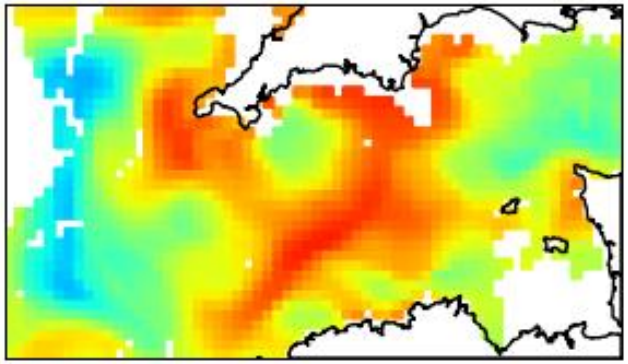
output

Can ocean colour assimilation improve biogeochemical hindcasts at L4 (in 2006)?

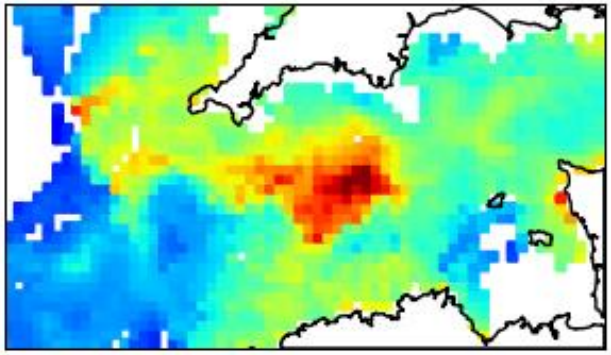
DA of satellite chlorophyll in ERSEM

Chlorophyll (day: 5 August 2006)

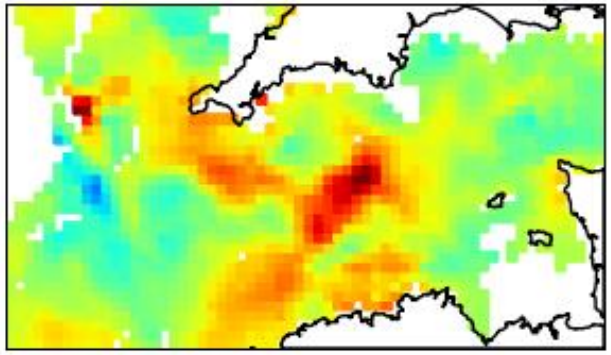
Reference run



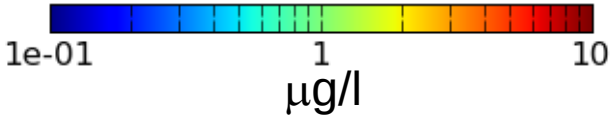
Satellite data



Assimilation



r = 0.44
RMSE = 1.57



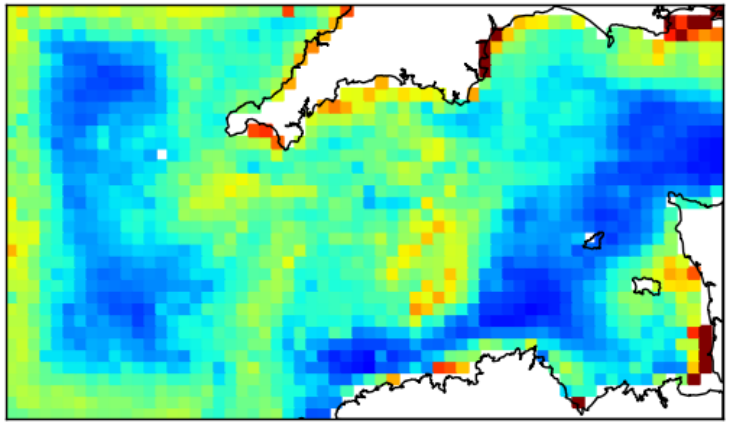
r = 0.79
RMSE = 0.99

Percentage difference RMSE=
[(0.99 – 1.57)/1.57] x100= - 37%

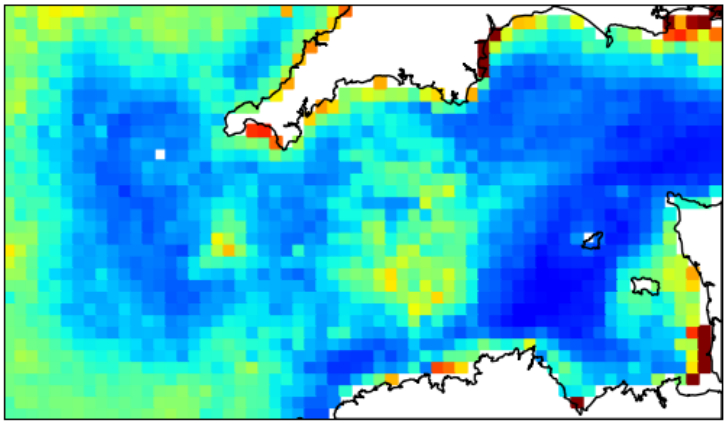
DA of satellite chlorophyll in ERSEM

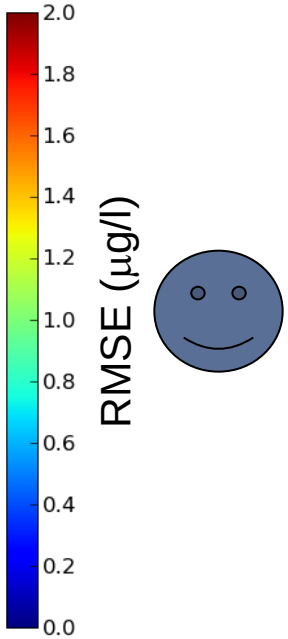
RMSE vs satellite

Reference



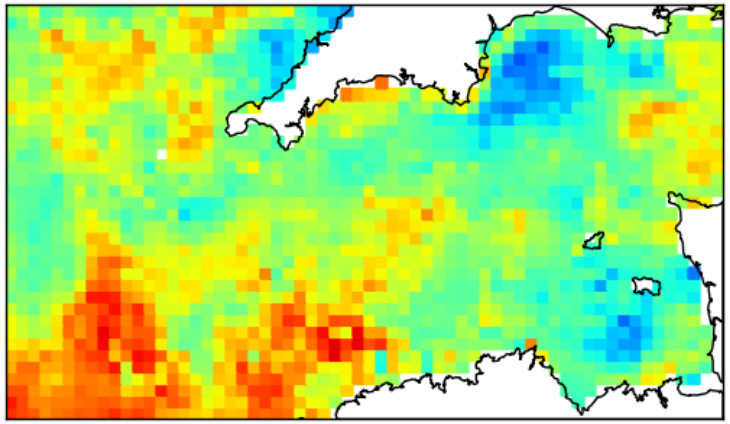
Assimilation



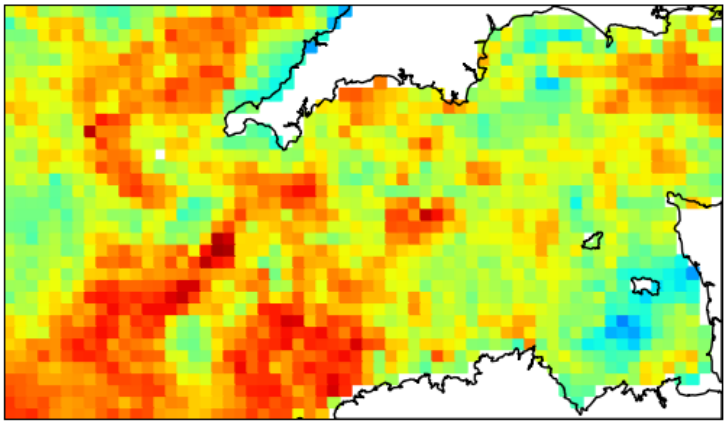


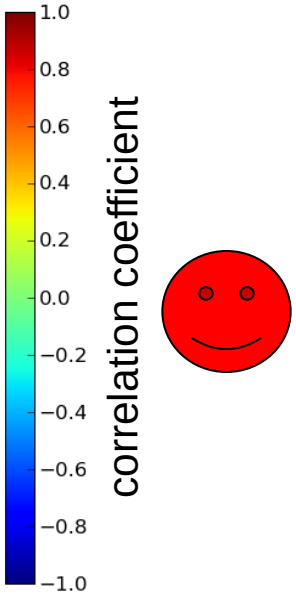
Correlation vs satellite

Reference



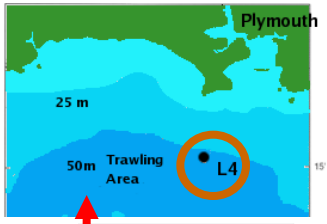
Assimilation



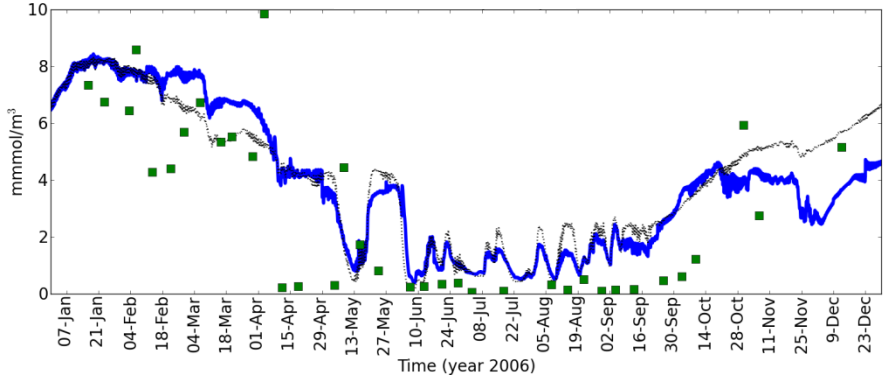


DA of satellite chlorophyll in ERSEM

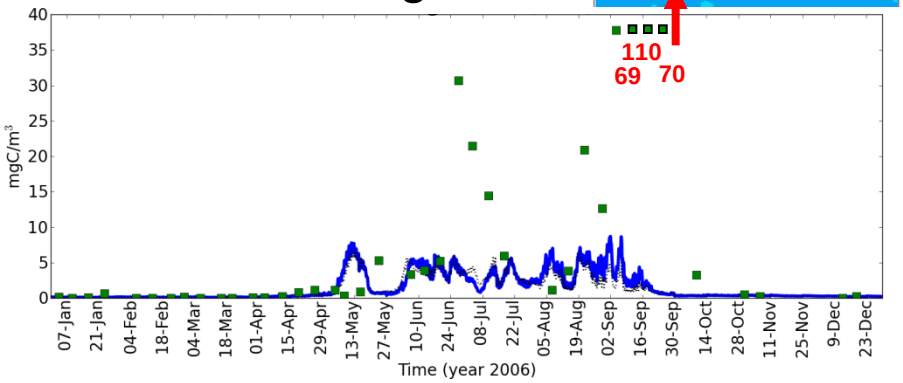
Skill in biogeochemical hindcasting at L4



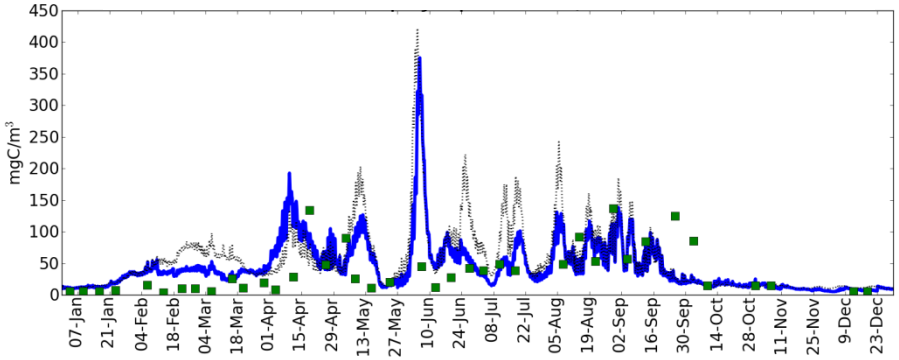
Nitrate



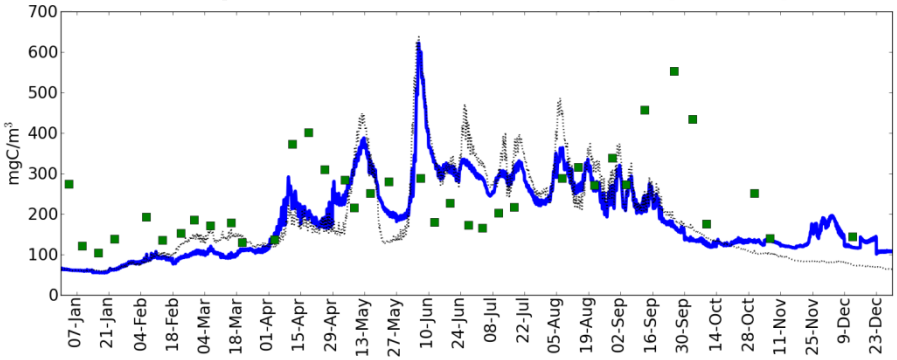
Dinoflagellates



Total phytoplankton biomass



Total particulate carbon (TPC)



Time

reference

assimilation

L4 data

RMSE=144 mgC/m3

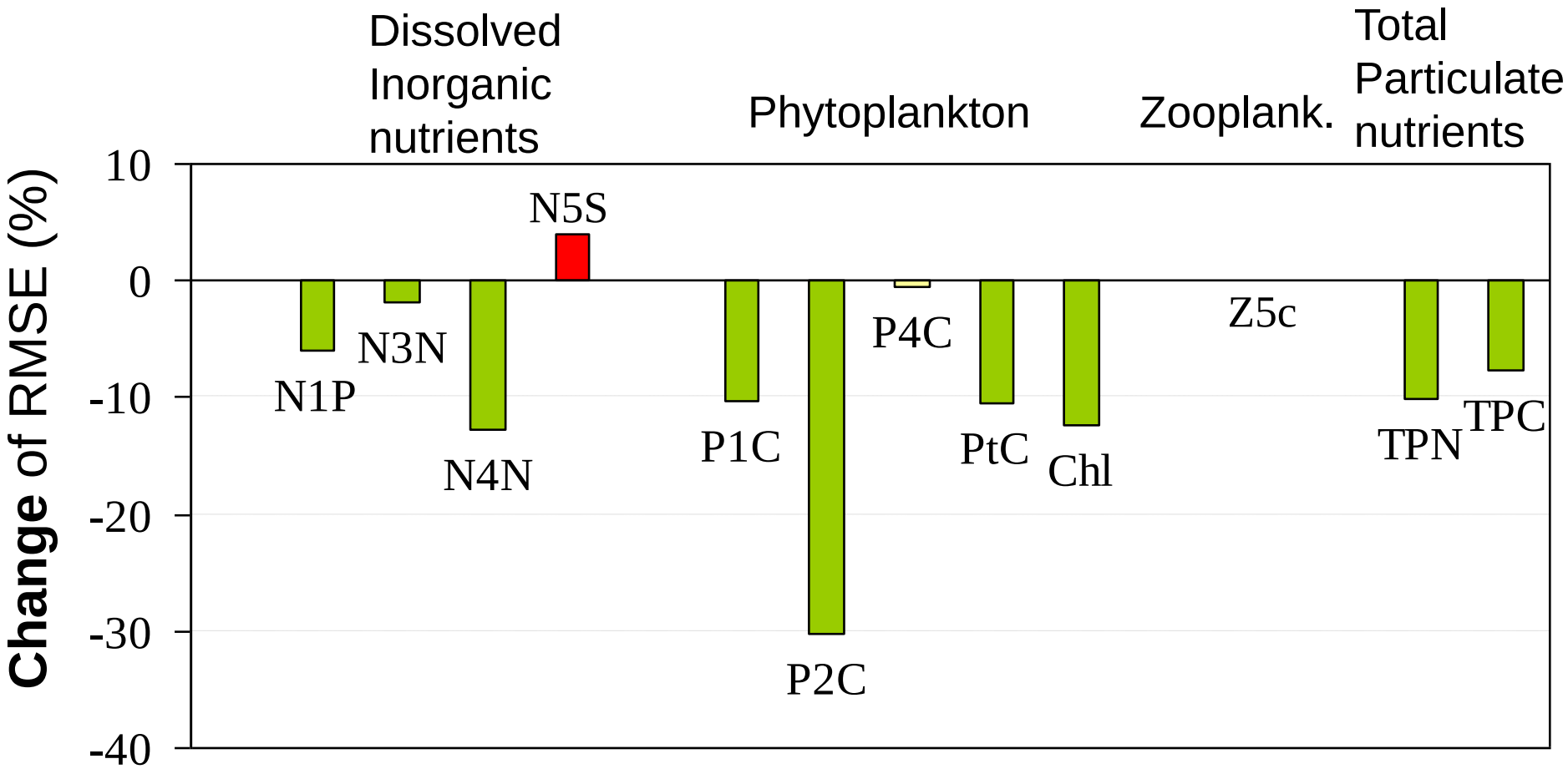
Other 8 time series...

RMSE=133 mgC/m3

ΔRMSE = -7.7%

DA of satellite chlorophyll in ERSEM

Skill in biogeochemical hindcasting at L4

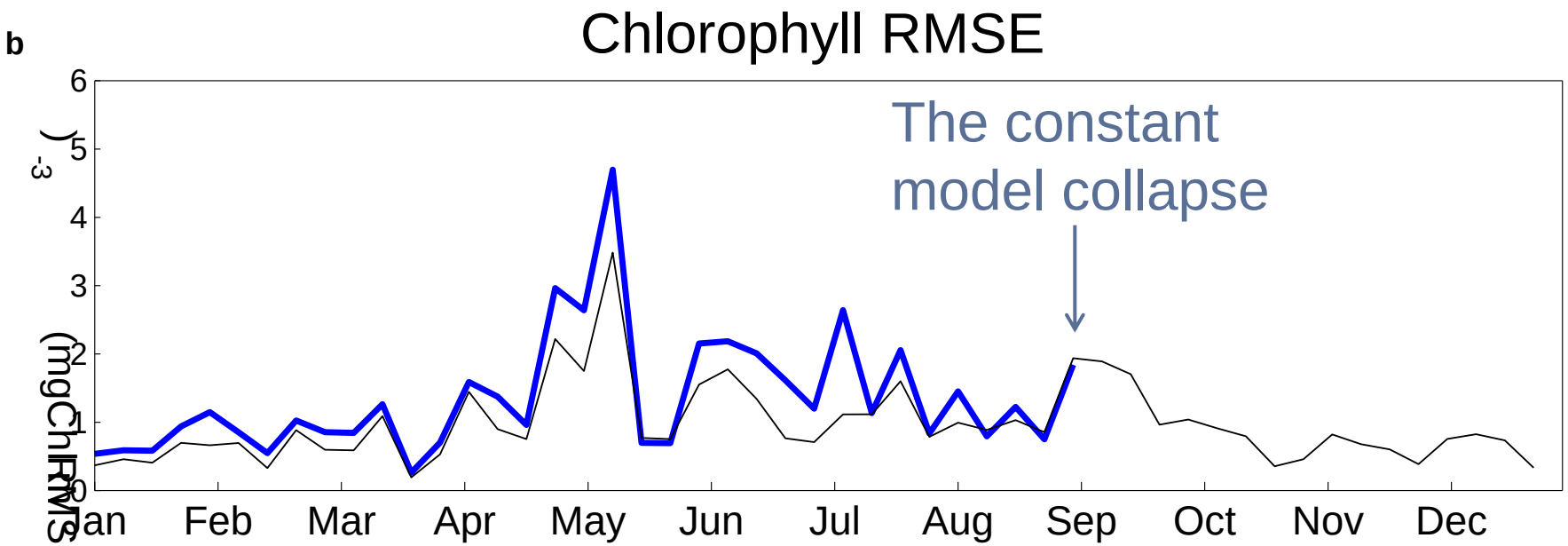


Data assimilation lead to a generalized enhancements of the model skills, according to 5 univariate skill metrics

(RMSE, correlation, model efficiency, percentage bias, cost function χ^2)

DA of satellite chlorophyll in ERSEM

Key: ERSEM skill & plasticity



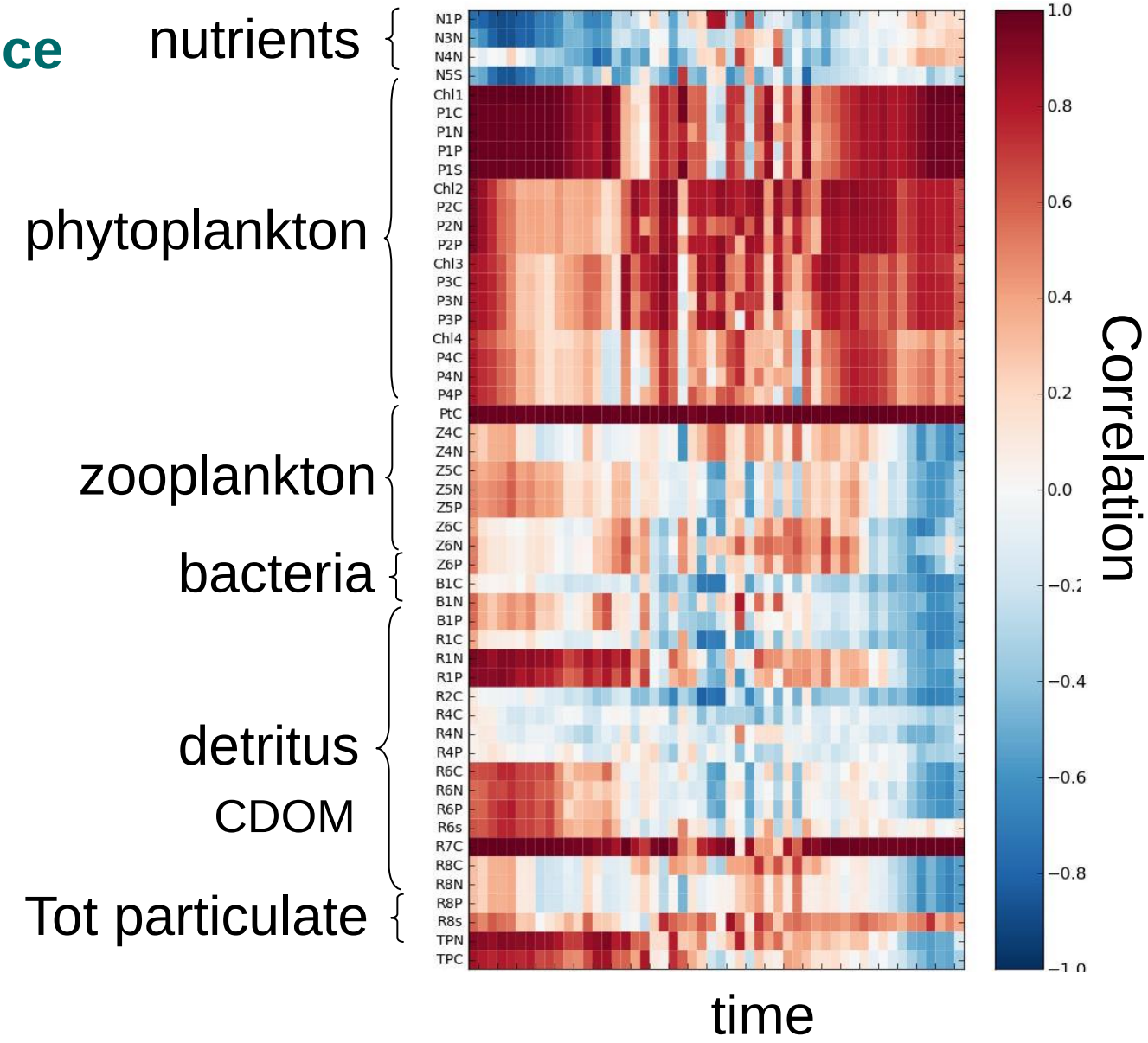
Model with constant C:Chl & C:Si:N:P

ERSEM

Ciavatta et al., 2001

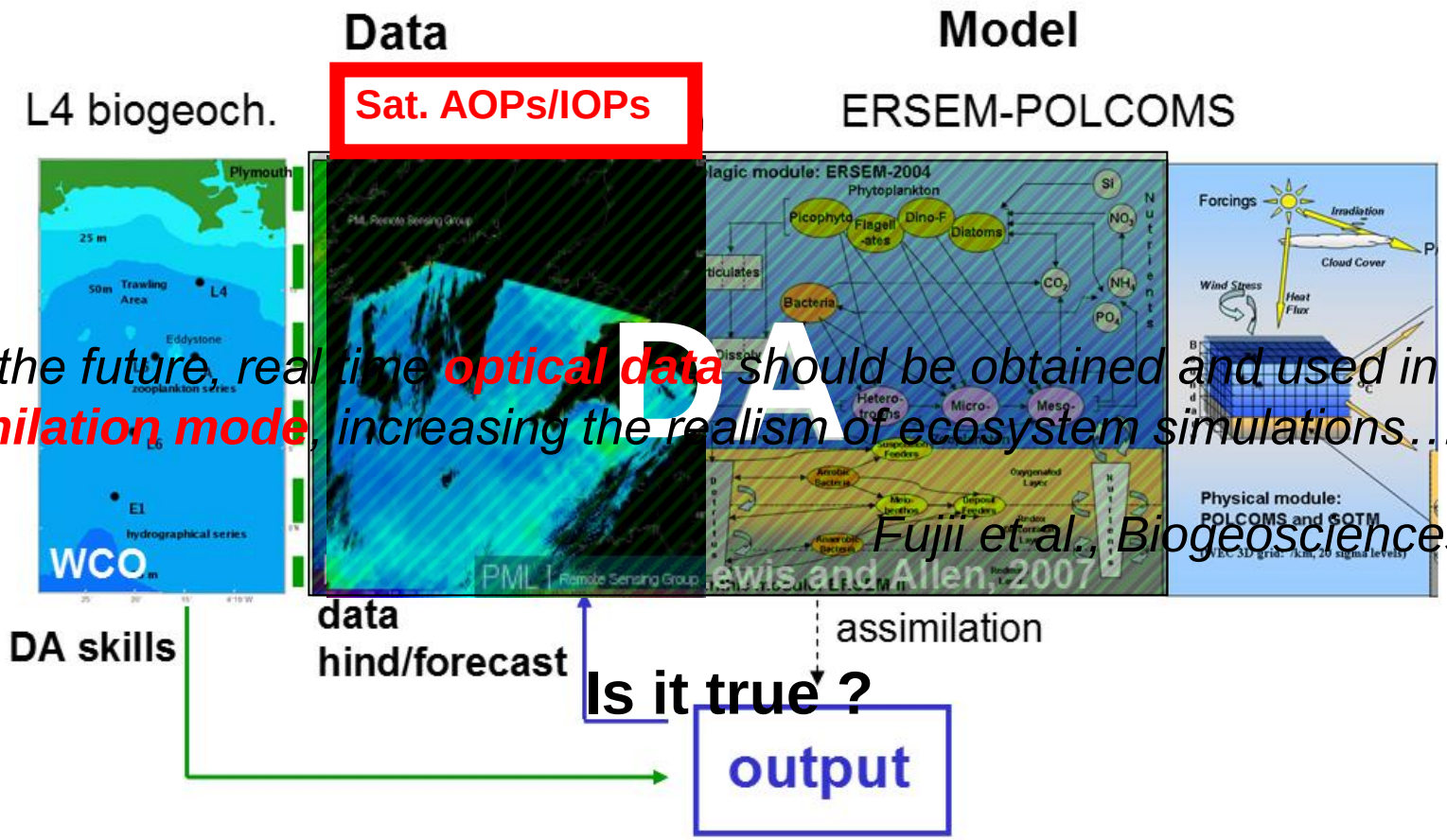
DA of satellite chlorophyll in ERSEM

Key: EnKF & evolving covariance



Ciavatta et al., 2001

DA of satellite optical properties in ERSEM



➢ *"In the future, real time **optical data** should be obtained and used in an **assimilation mode**, increasing the realism of ecosystem simulations…"*

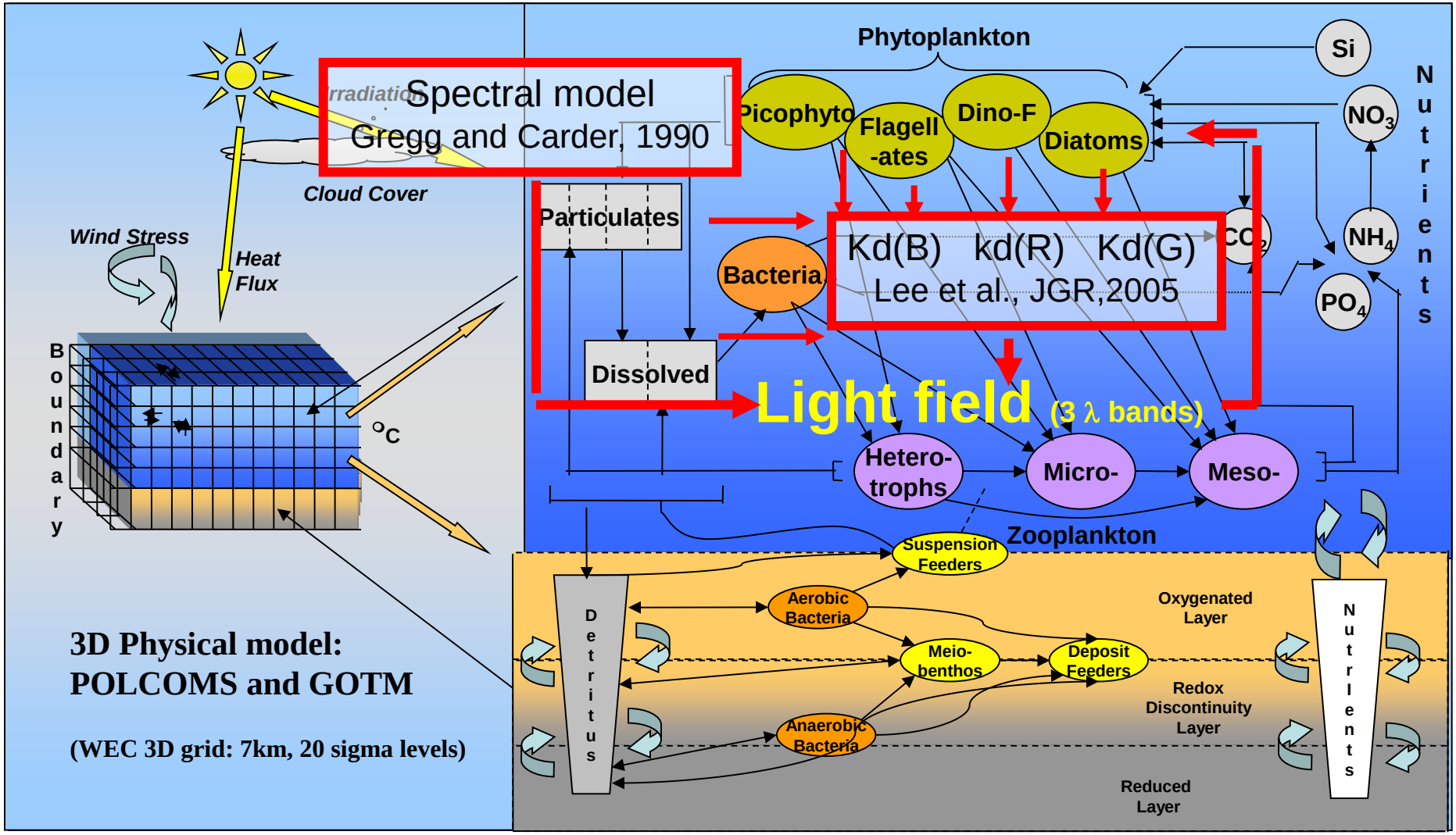
Fujii et al., Biogeosciences, 2007

Objective: To explore the advantages of assimilating optical properties (from satellite) in shelf sea models

Ciavatta et al., 2014

skip

The coupled optical-ecosystem model

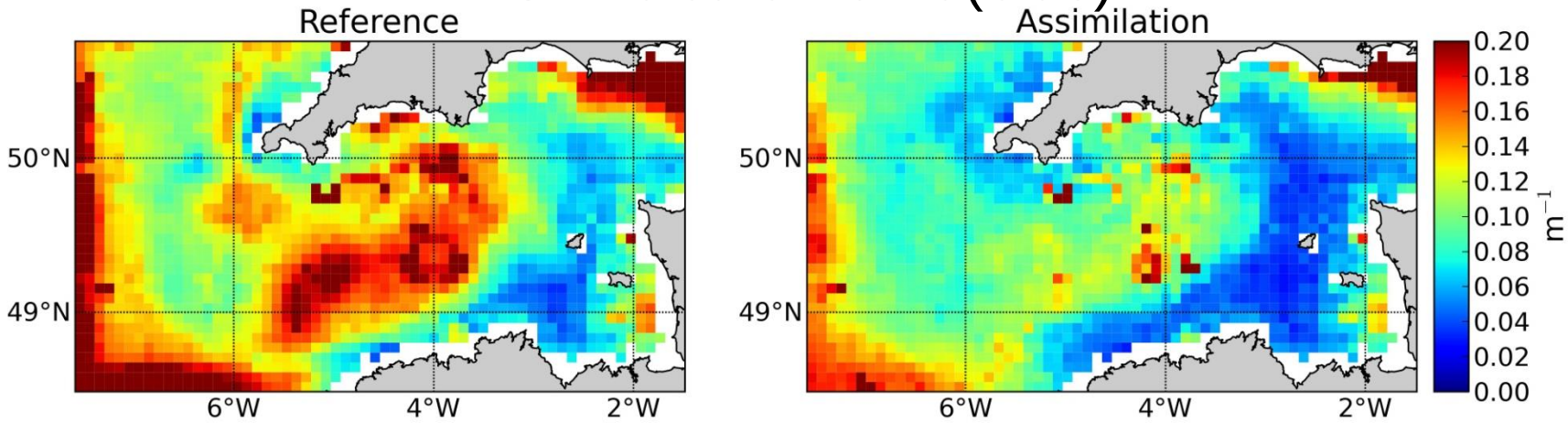


Kd(λ): spectral light attenuation coefficient

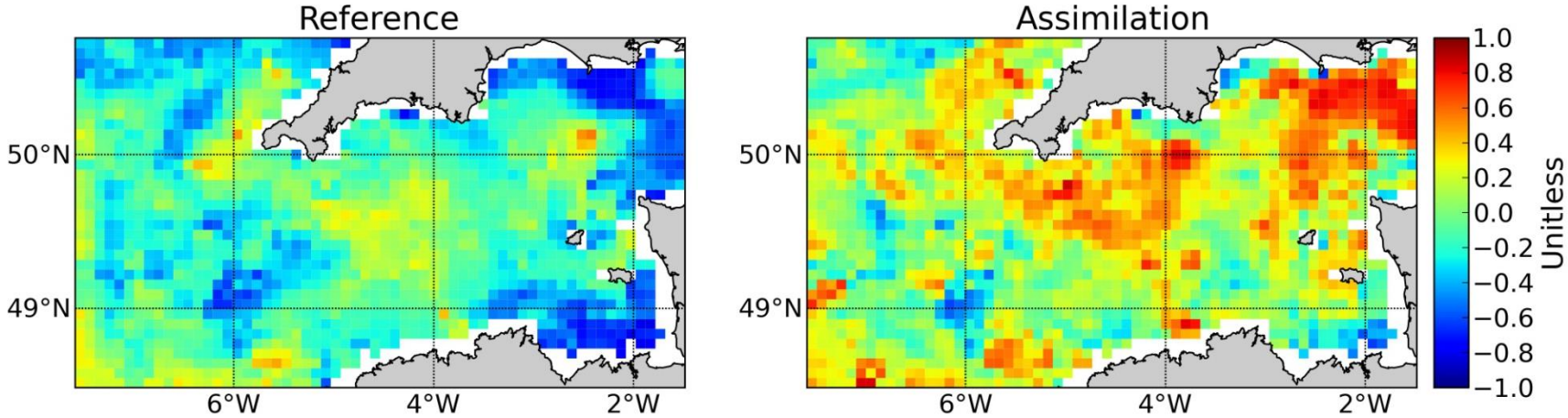
skip

Assimilation of Kd(blue) & hindcast of Kd(blue)

RMSE vs satellite Kd(blue)



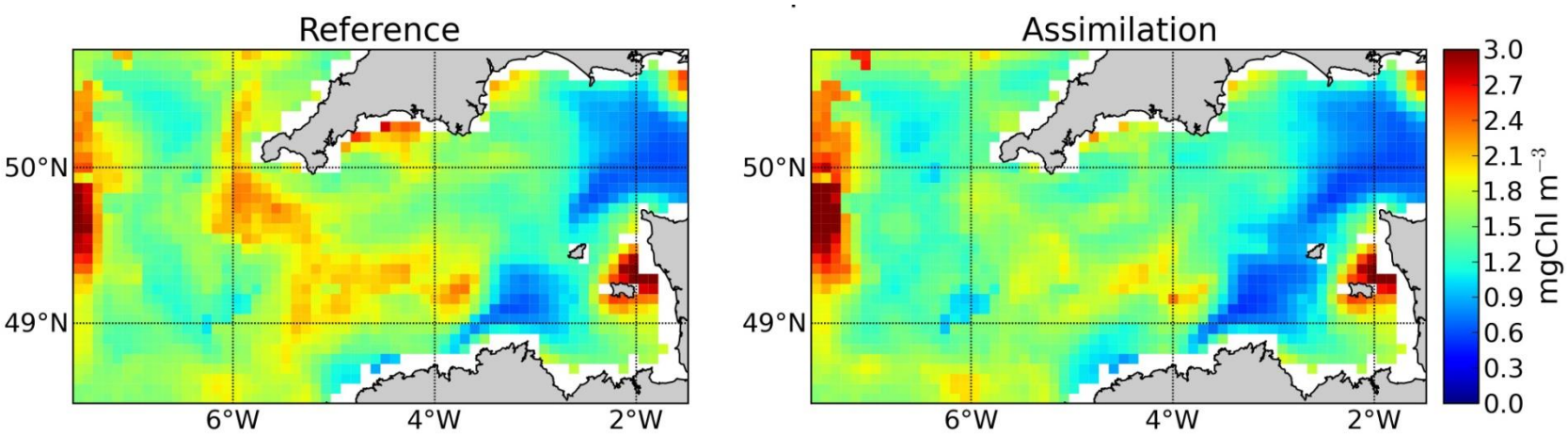
Correlation vs satellite



skip

Assimilation of Kd(blue) & hindcast of chlorophyll !!!

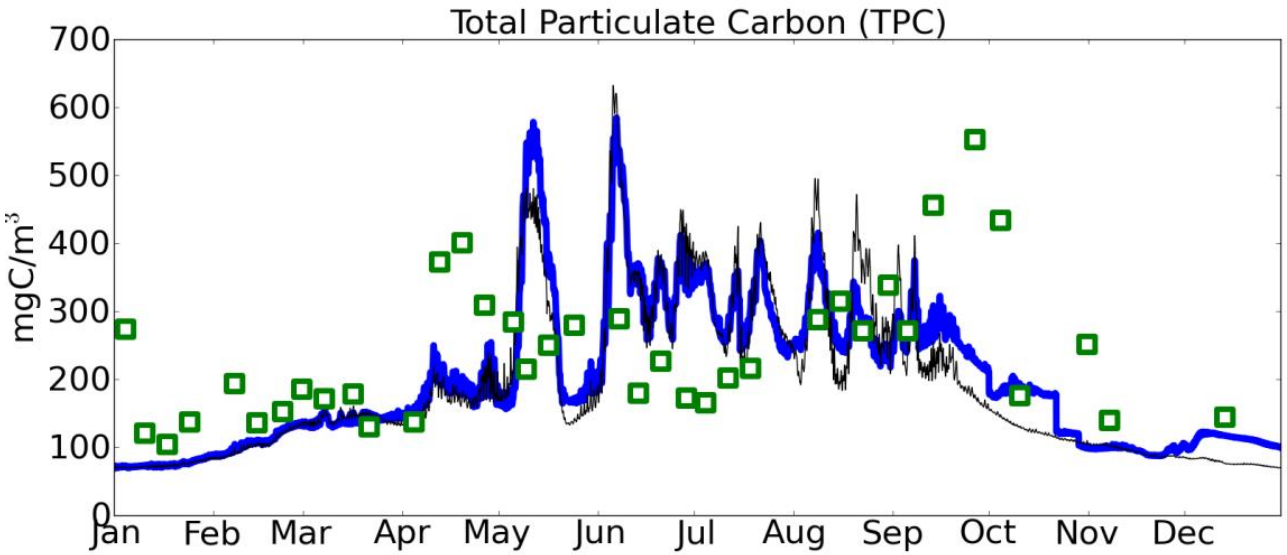
RMSE vs satellite chlorophyll



RMSE of chlorophyll improved !
(correlations not that much)

skip

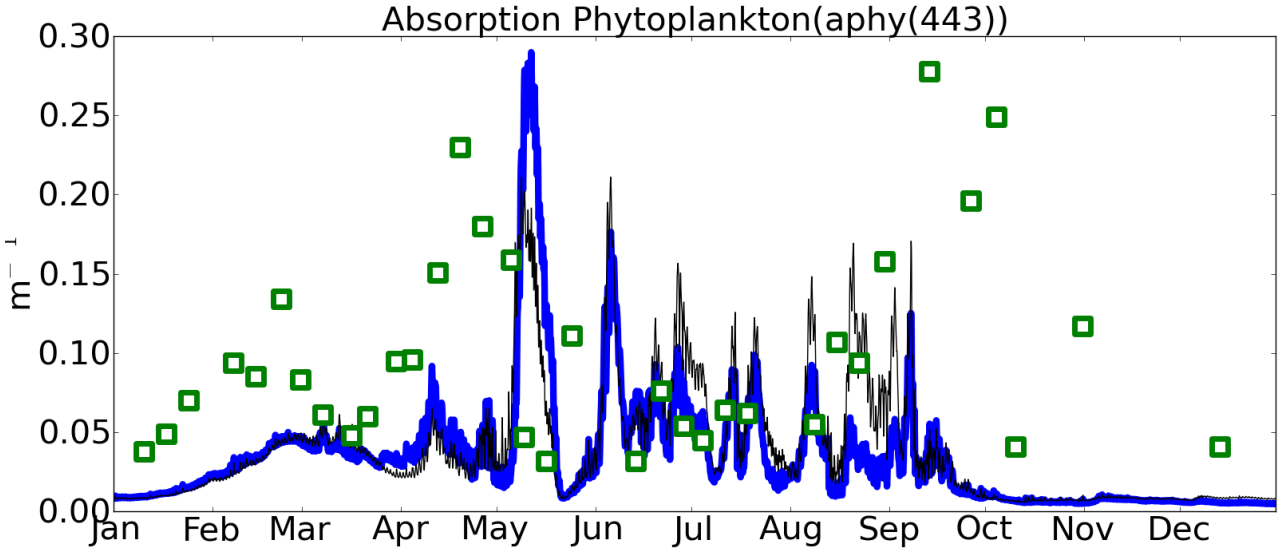
DA of satellite optical properties in ERSEM



Reference bias= 149%

Assimilation bias=139%

Difference bias~ - 10%



Reference bias= 51%

Assimilation bias=55%

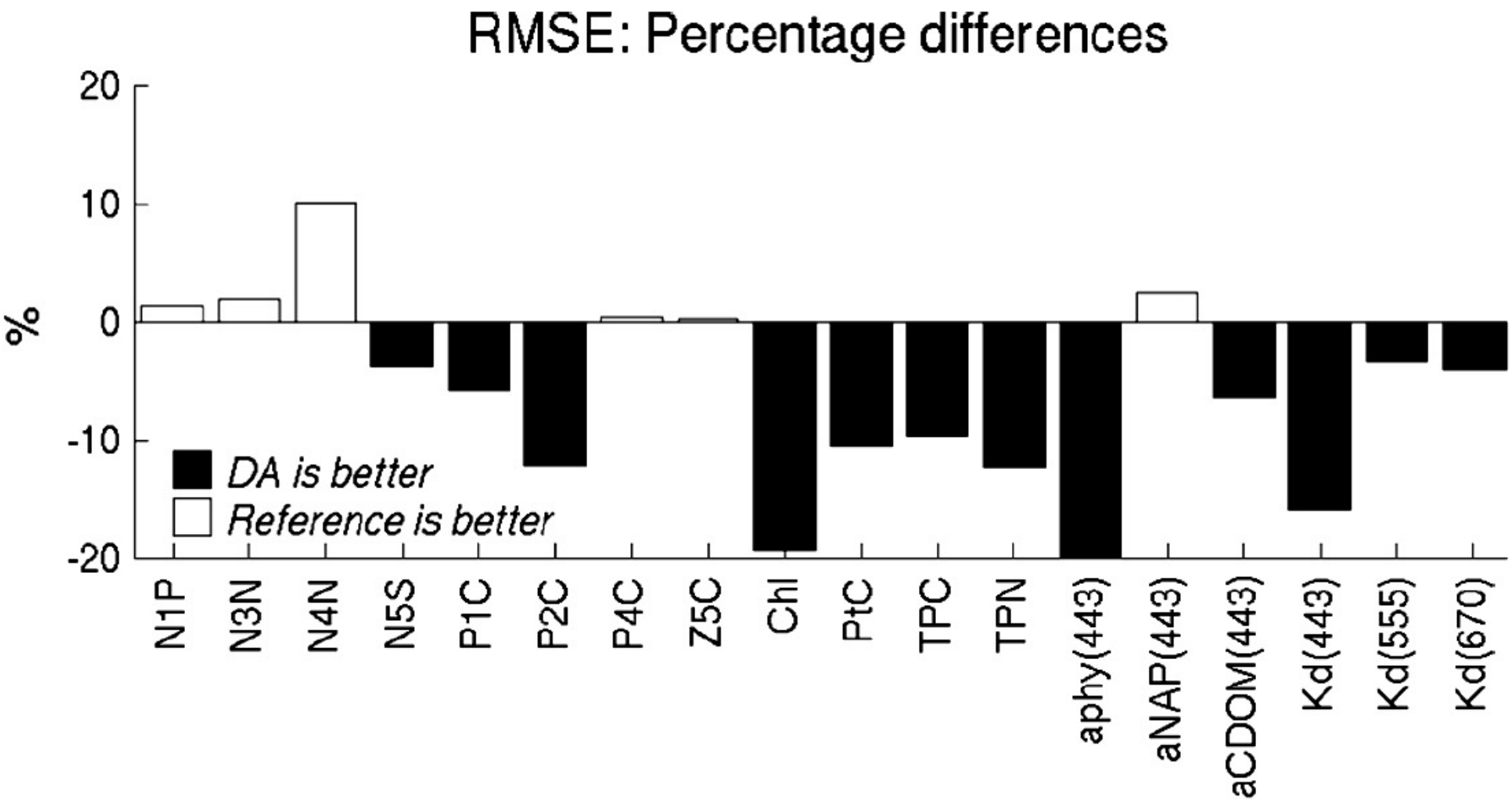
Difference bias~ + 4%

Other 16 variables…

skip

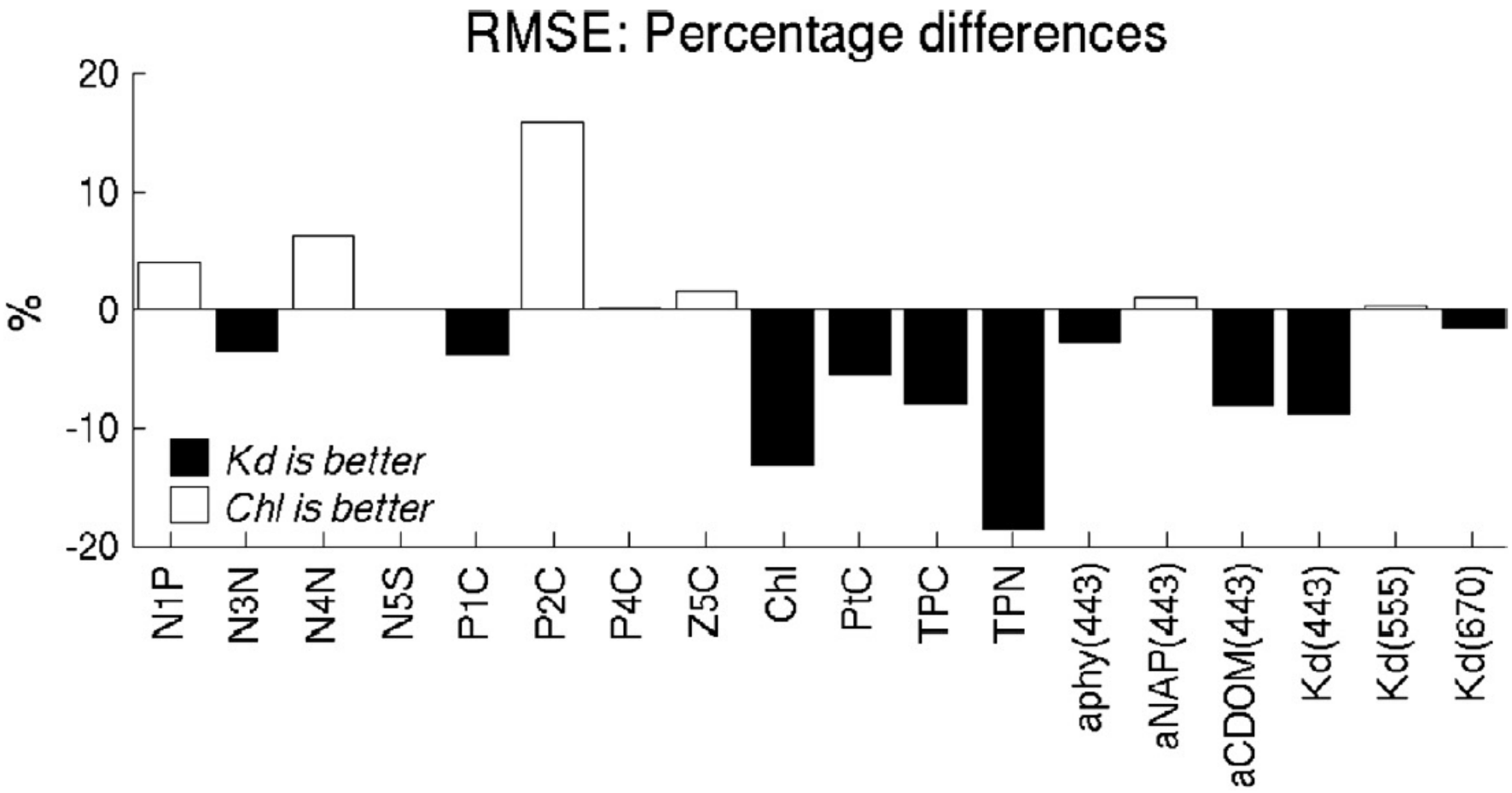
DA of satellite optical properties in ERSEM

Difference bias: assimilation of Kd(blue)



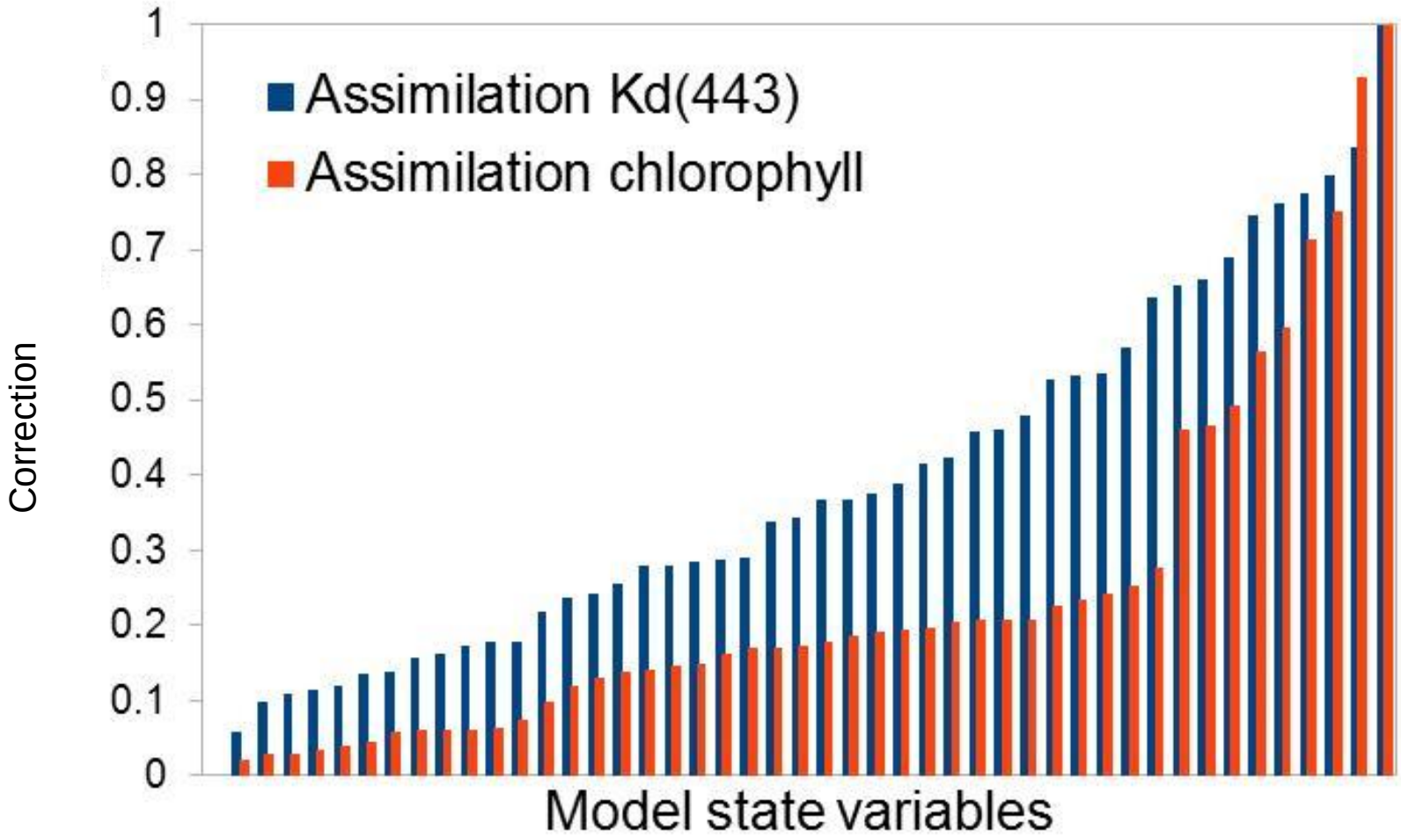
skip

DA of satellite optical properties in ERSEM



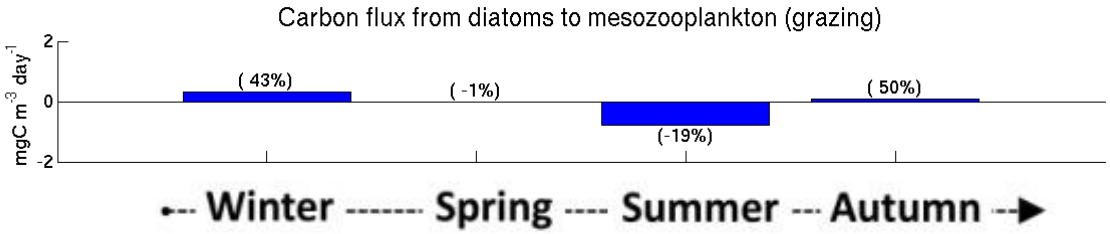
DA of satellite optical properties in ERSEM

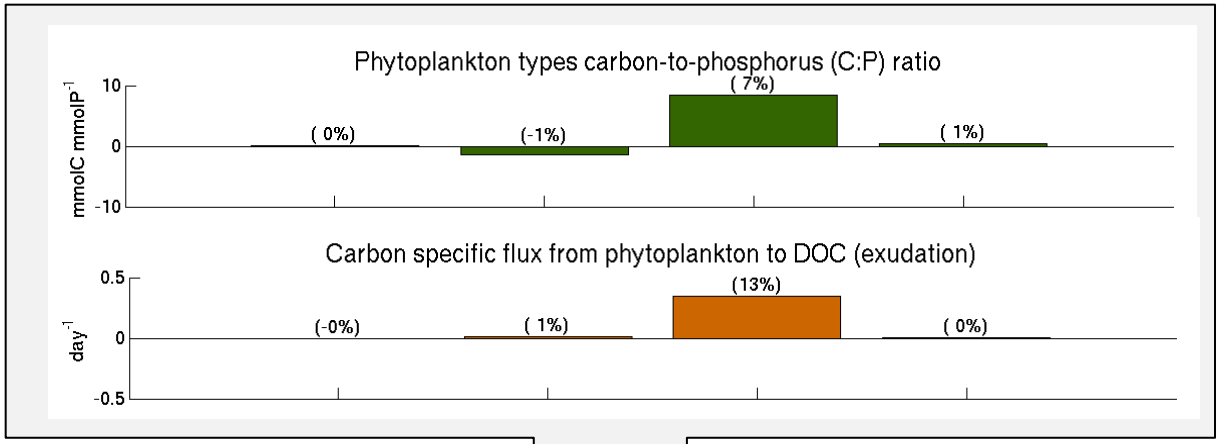
"Spread" of DA corrections



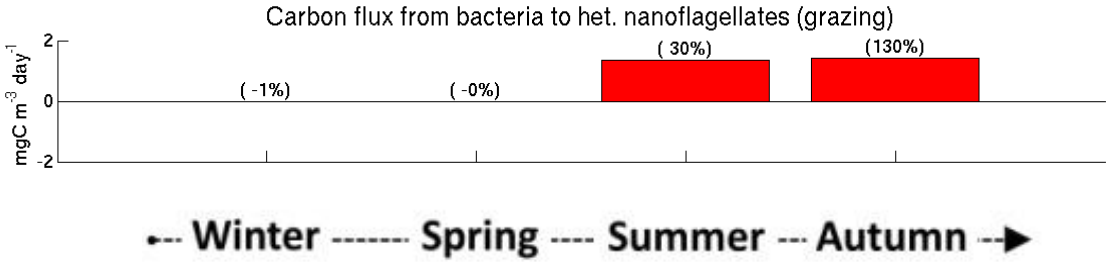
DA of satellite optical properties in ERSEM

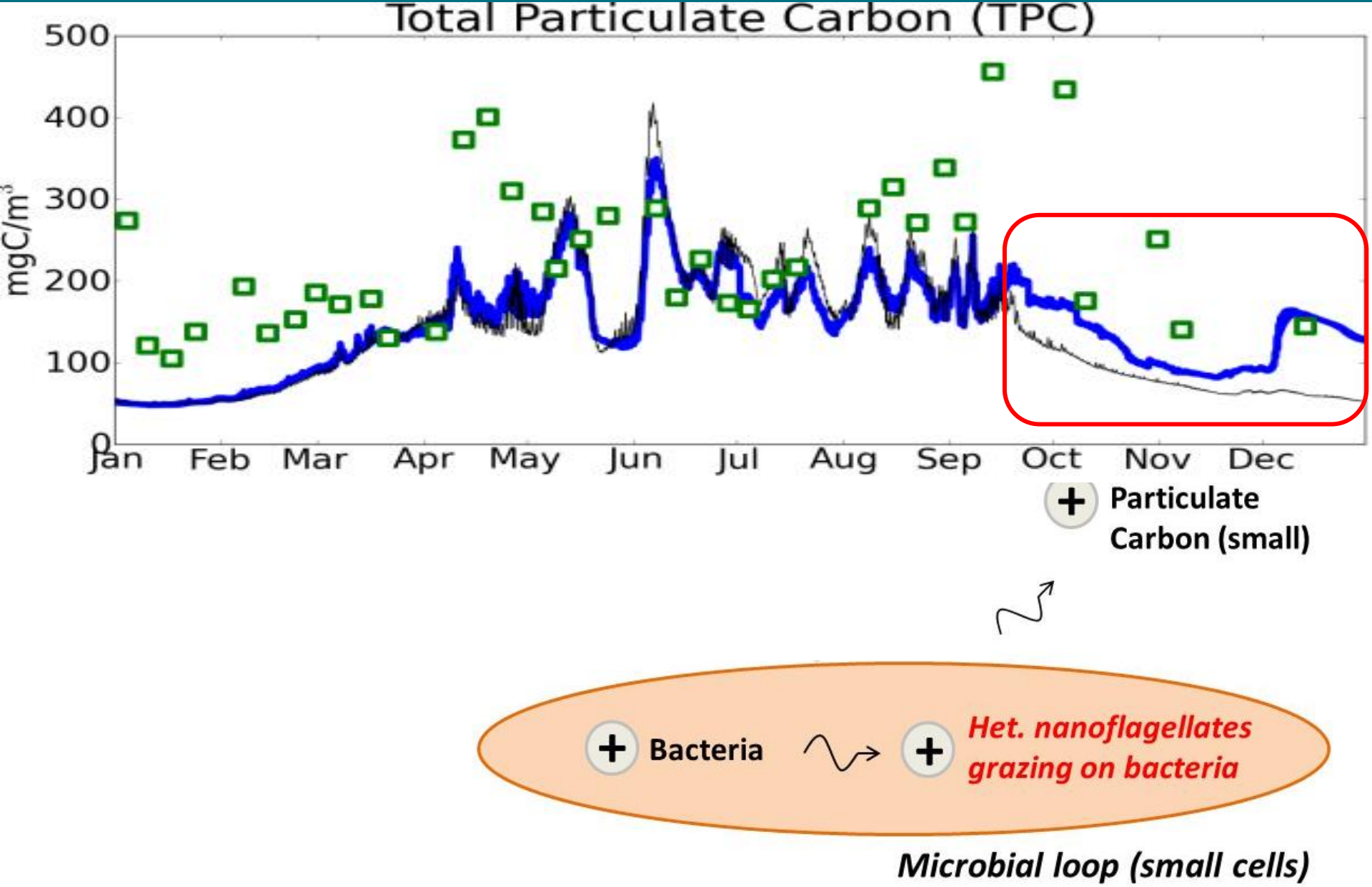
Herbivorous food-chain (large cells)





Microbial loop (small cells)





Winter ------ Spring ---- Summer --- Autumn --▶

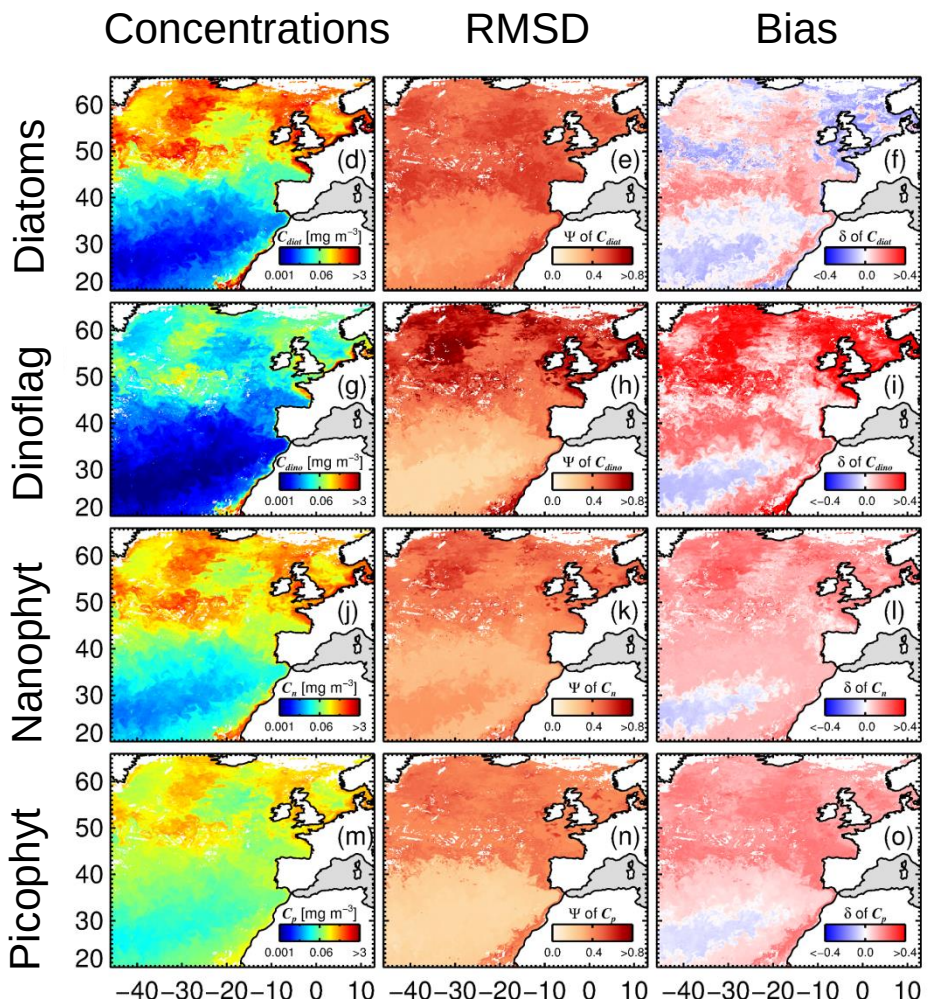
Assimilation of ocean colour PFTs

New time series of:

- 4 size-classes phyto chlorophyll
- daily concentrations
- Spanning 1998-2015
- At a resolution of 4 km

Novelties:

- 4 vs 3 components
- Per-pixel errors
- Temperature dependency



TOSCA

Brewin et al., Frontiers in Marine Science, in revision

PFT into a pre-operational model: reanalysis

The “1-month forecasts” vs satellite PFT chlorophyll

Forecast RMSD %Diff RMSD

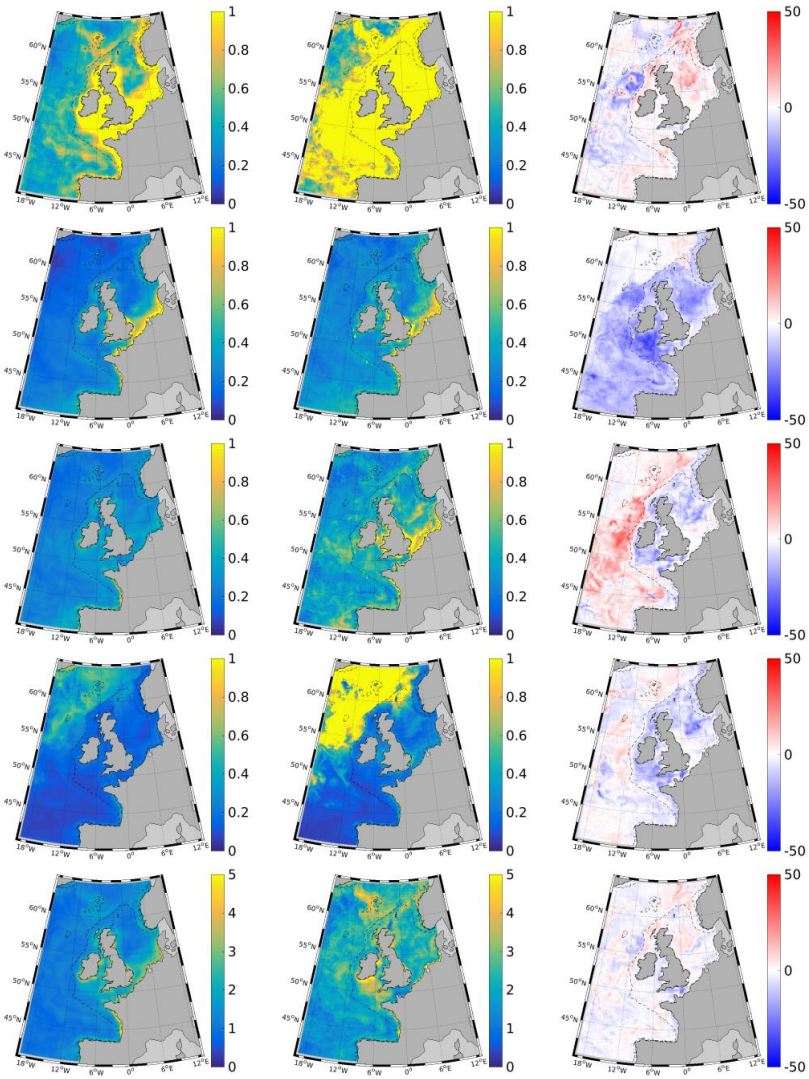
Diatoms

Dinoflagel

Nano-phytopl.

Pico-phytopl.

Tot chl

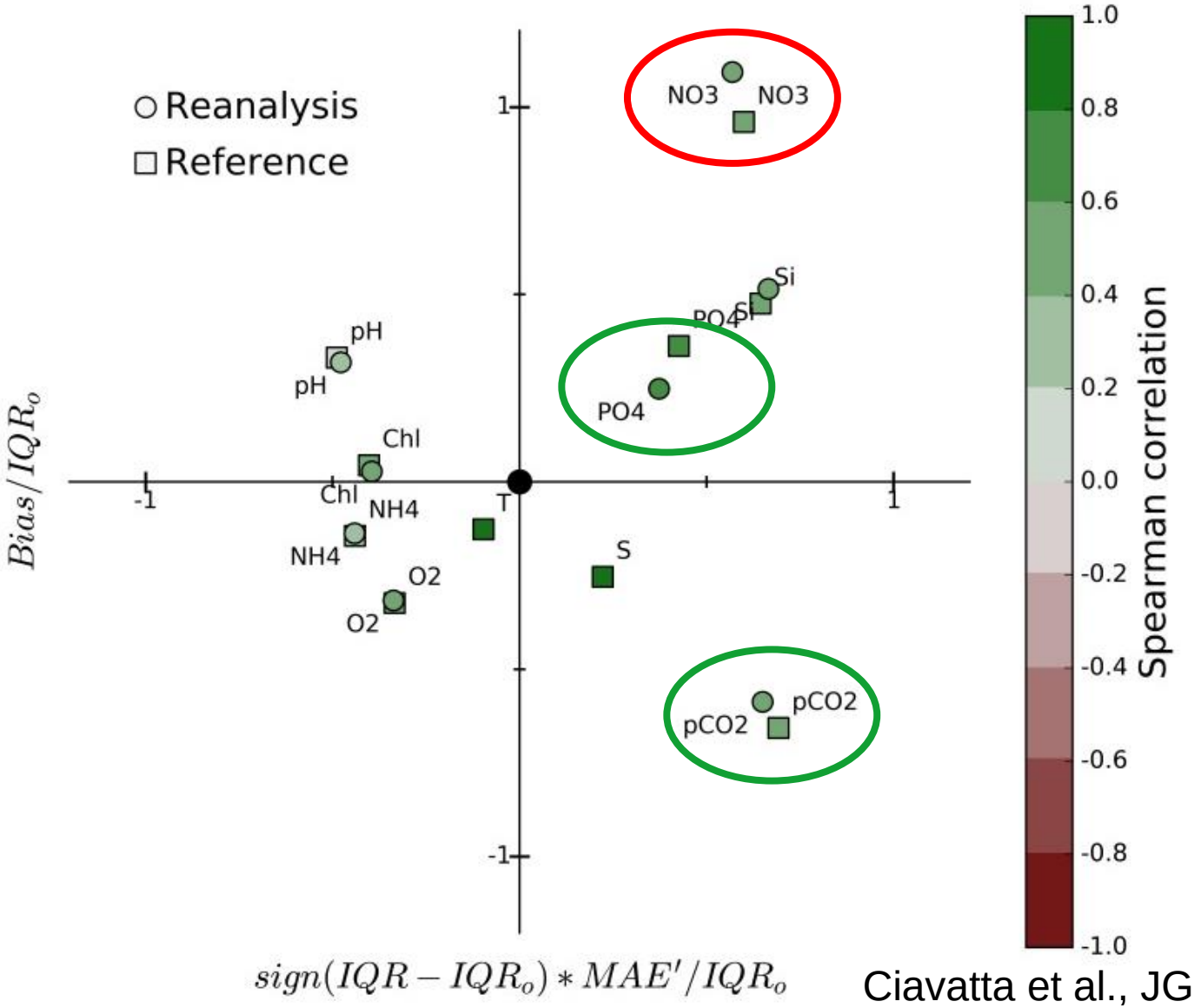


Ciavatta et al., JGR, 2018

Ciavatta et al., JGR, 2018

PFT into a pre-operational model: reanalysis

Skill versus in situ data of biogeochem indicators

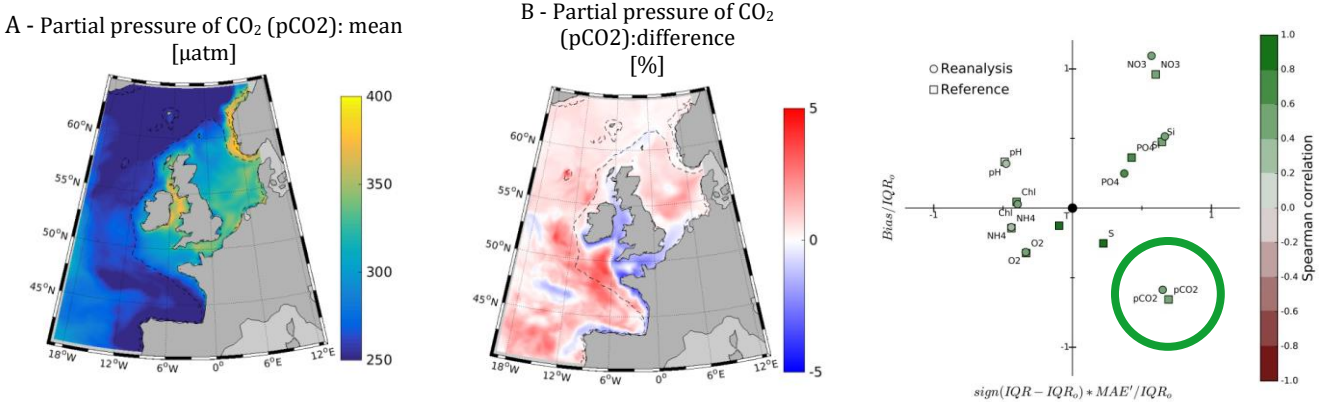


Ciavatta et al., JGR, 2018

PFT into a pre-operational model: reanalysis

Impact on simulation of pCO2 and C fluxes

pCO_2

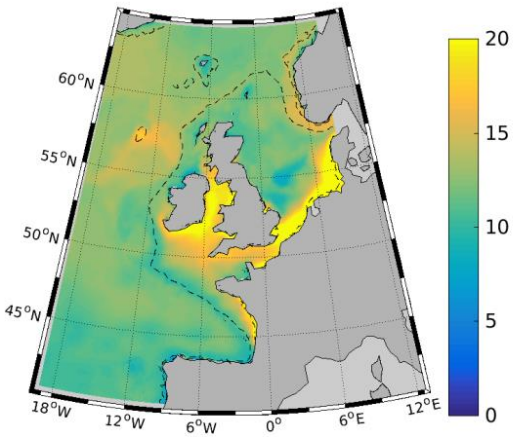


Ciavatta et al., JGR, 2018

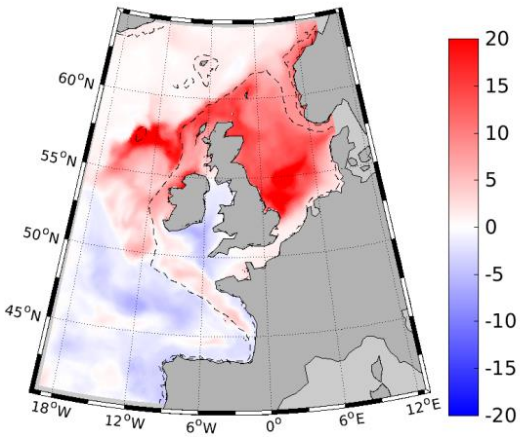
PFT into a pre-operational model: reanalysis

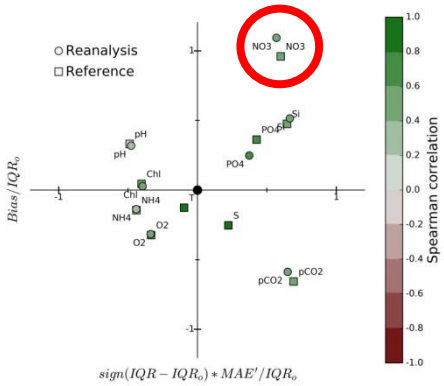
Impact on simulation of Nitrate and N fluxes

A - Nitrate: mean
[mmol N m^{-3}]



B - Nitrate: difference
[%]

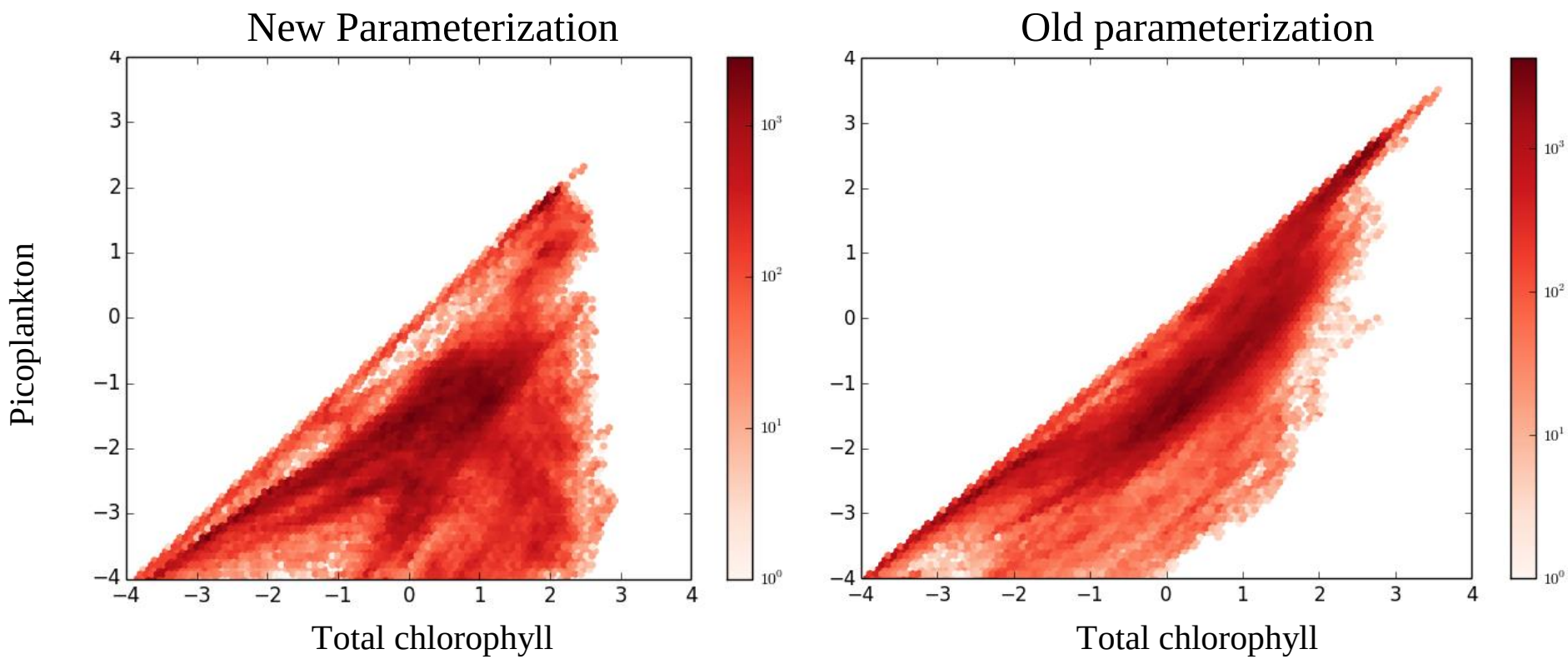




Ciavatta et al., 2018

Discussion: why PFT outperformed chl DA?

PFT chlorophyll vs total chlorophyll (log10)



The state-of-the-art parameterization introduced (realistic) **non-linearity** that weakened EnKF hypothesis.

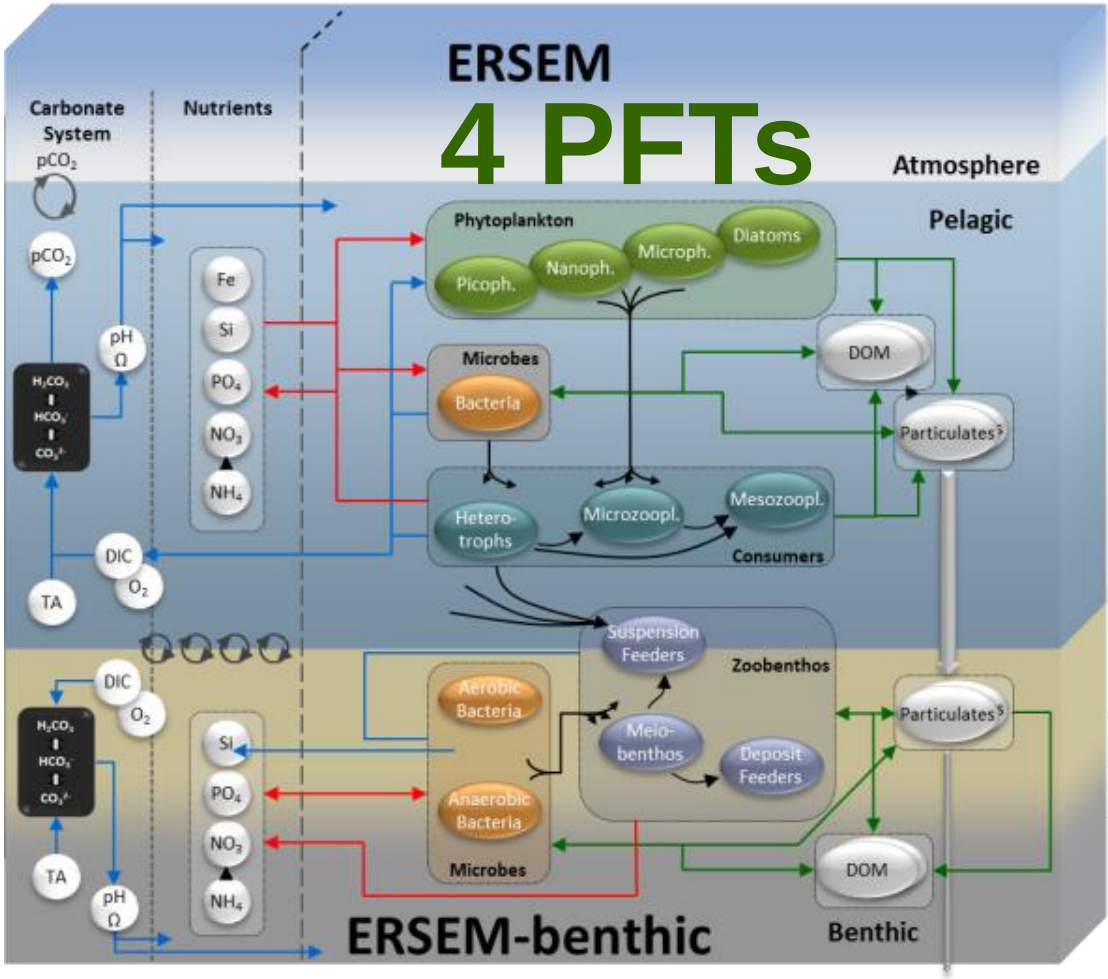
DA into an operational model: prediction

The ecosystem model: NEMO-FABM-ERSEM

NEMO V3.6

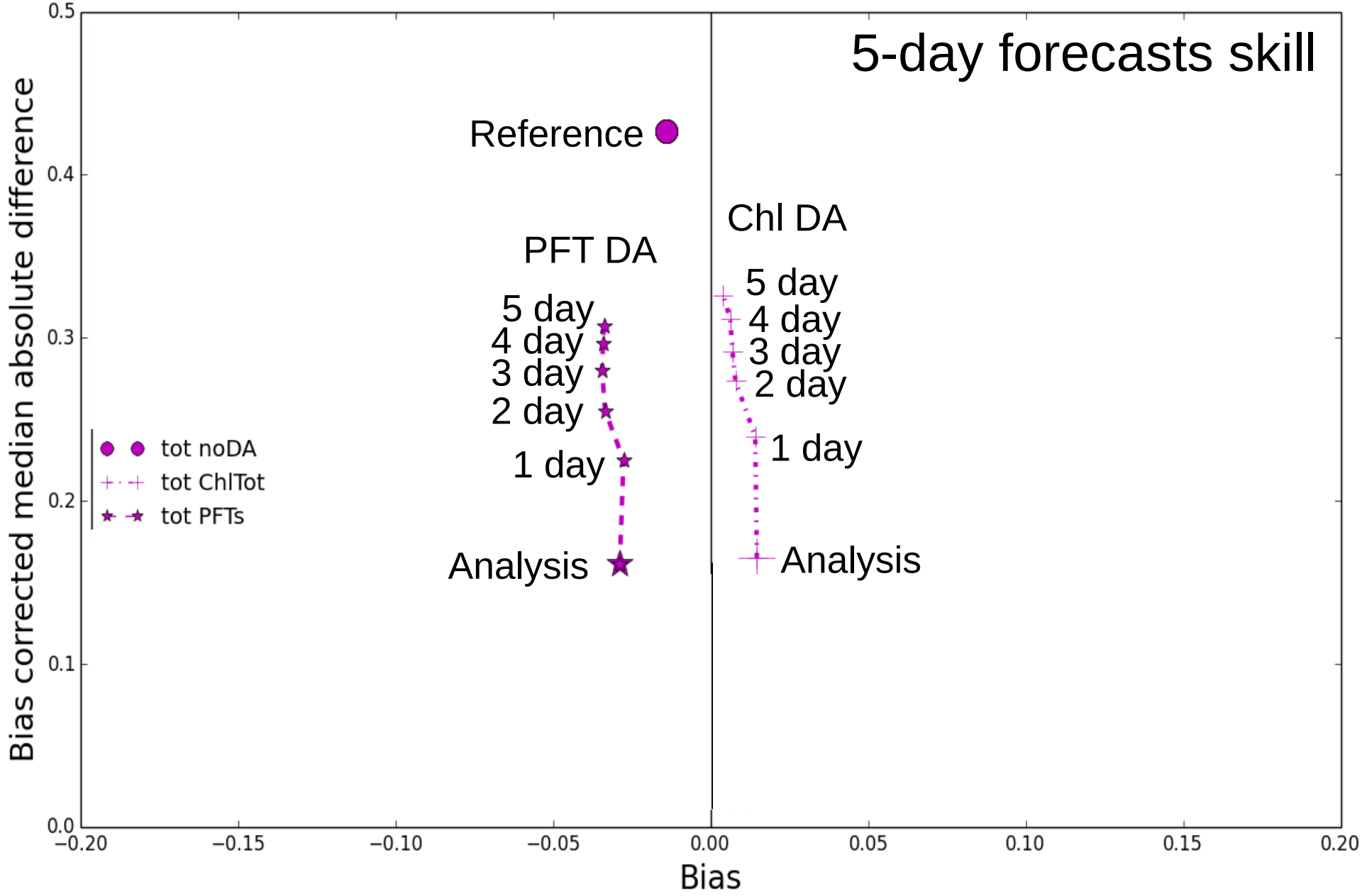
NEMOVar

3D-VAR
First-Guess—At-Appropriate-Time
Log-transformation
Incremental Analysis Update
Conservation of PFT Chl:N ratios

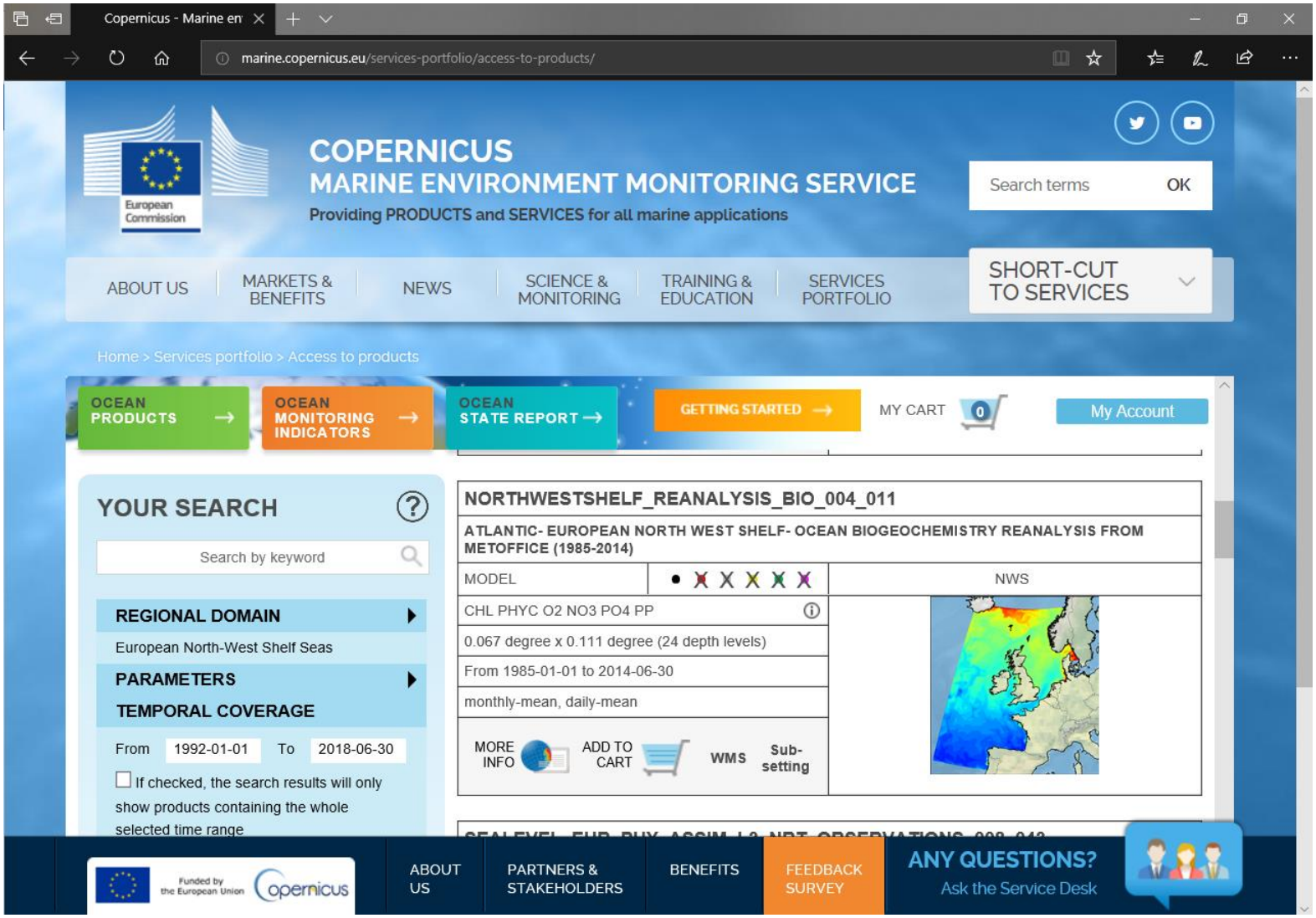


Skakala et al, JGR, 2018

DA into an operational model: prediction



DA into an operational model: prediction



NCEO PFT DA expected to be REA operational in 2019-20

NCEO PFT DA expected to be NRT operational in late 2020

Concluding remarks

- Assimilation of ocean colour can improve the simulation of biogeochemical variables that are not observable from space
- Errors of model and ocean-colour observations are critical
- "New" ocean-colour products can outperform the assimilation of chlorophyll (e.g. K_d, PFTs, r_{rs}), but have some drawbacks
- Combined assimilation of ocean-colour products and in situ biogeochemical data (e.g. biogeochemical-Argos)