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National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Ocean biogeochemistry reanalysis: a successful NCEO story

Stefano Ciavatta, Jozef Skakala, Ricardo Torres, Icarus Allen
David Sursham (PhD), Dale Partridge and many others

Plymouth Marine Laboratory - UK NCEO

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2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Outline

- **Why** are we assimilating biogeochemical data?
- **What data** to assimilate?
- **Some issues** (non-Gaussianity, obs errors)
- **Conclusions**

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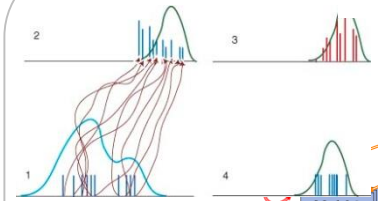
We assimilate ocean observations
to improve the understanding and simulation
of the ocean component of the earth system,
including carbon cycle and policy relevant indicators

EO

Sentinel-3

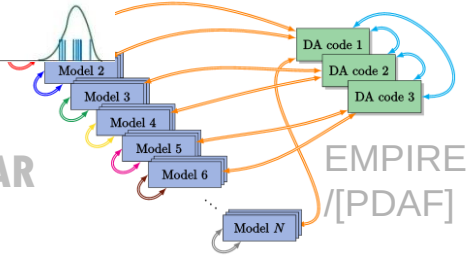
Gliders

DA methods & tools



Particle filters.

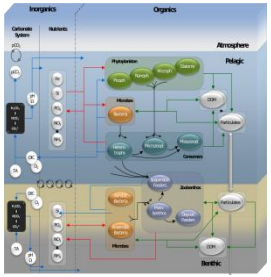
EnKF.

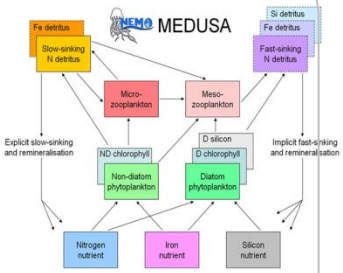


NEMOVAR

EMPIRE
/[PDAF]

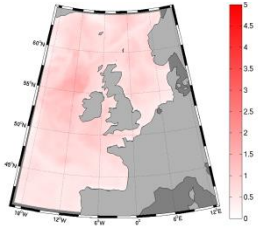
Ecosystem models

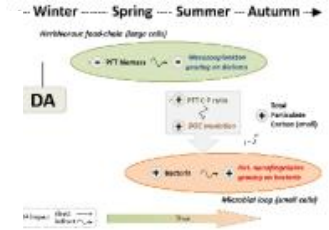




UK Shelf and ESM models

Climate & end-user applications





Atmosphere-ocean fluxes, ocean indicators

We assimilate ocean observations
to improve the understanding and simulation
of the ocean component of the earth system,
including carbon cycle and policy relevant indicators

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esa

ocean colour cci

National Oceanography Centre
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DA

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DA methods & tools

National Centre for Earth Observation
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University of Reading

Met Office

Ecosystem models

PML Plymouth Marine Laboratory

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Network and dissemination

National Partnership for OCEAN PREDICTION

MERCATOR OCEAN INTERNATIONAL

OceanPredict
Advancing the science of ocean prediction

CCG
International Ocean Colour Coordinating Group

Climate & end-user applications

UKRI Natural Environment Research Council

Department for Environment Food & Rural Affairs

Copernicus
Europe's eyes on Earth

Met Office

WWF

European Commission

Why are we assimilating biogeochemical data into ecosystem models?

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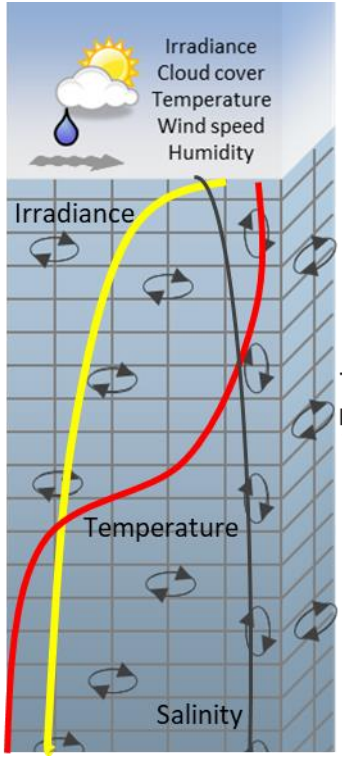
To improve the estimation of the "biogeochemical truth"

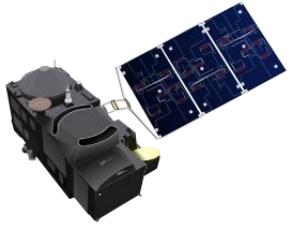


Physical (PHY) model

Transport

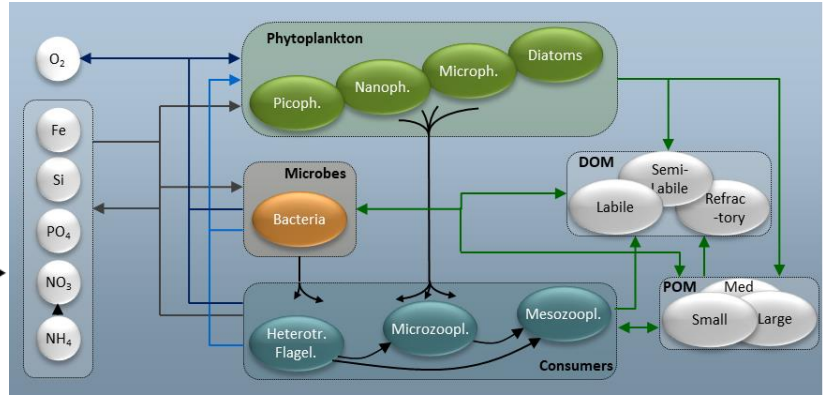
T,E,S

Ocean colour



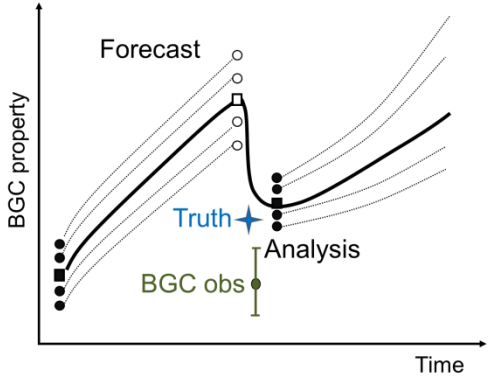
- Phytoplankton chlorophyll
- Phytoplankton functional types
- Remote sensing reflectance

…



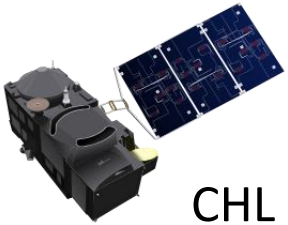
In situ observations: Chlorophyll, oxygen, nitrate , pH…

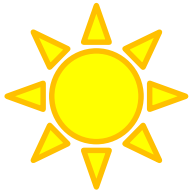
Data assimilation (DA) algorithm



What biogeochemical data to assimilate?

Ocean colour total chlorophyll

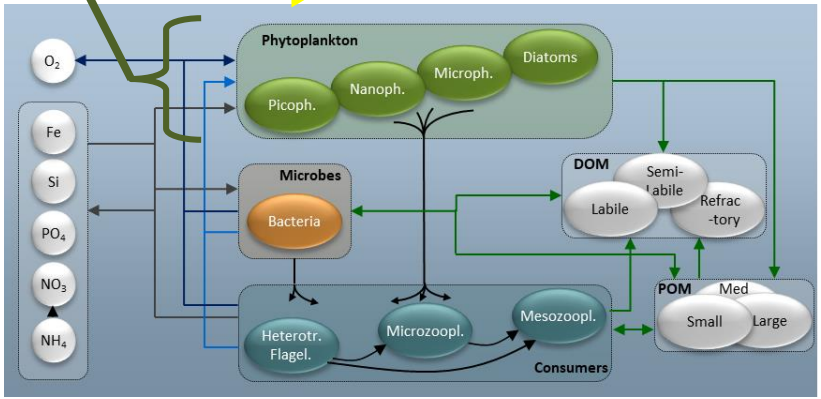




$$CHL = f\,(R_{rs})$$

NCEO@PML pioneered BGC O-C chl reanalysis in shelf-sea

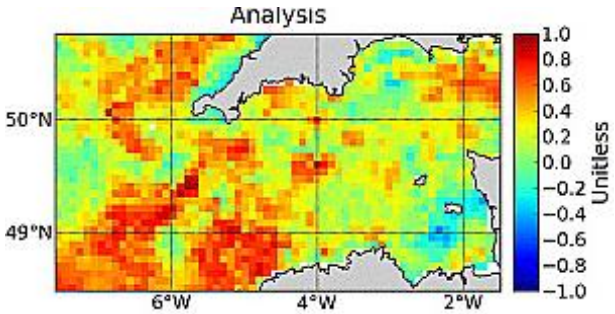
Ciavatta et al, JGR, 2011
Ciavatta et al, JGR, 2016
Torres et al., Rem Sens, 2020



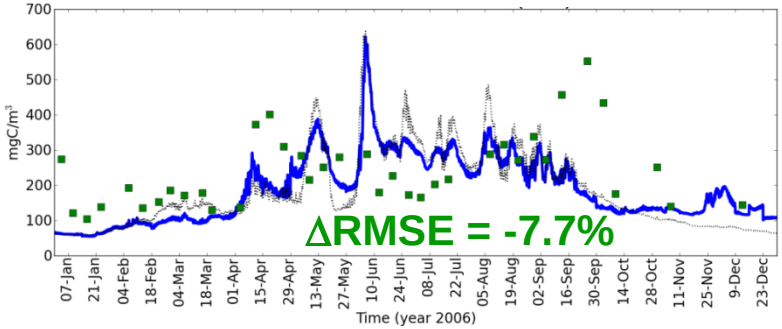
What biogeochemical data to assimilate?

Ocean colour total chlorophyll

1st 1-year long EnKF assimilative simulation



Total particulate carbon (TPC)



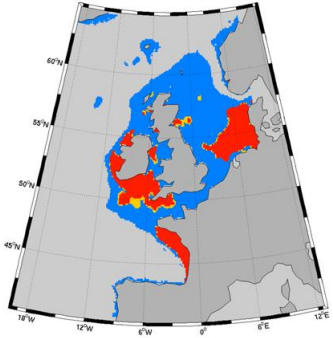
Ciavatta et al., JGR, 2011

What biogeochemical data to assimilate?

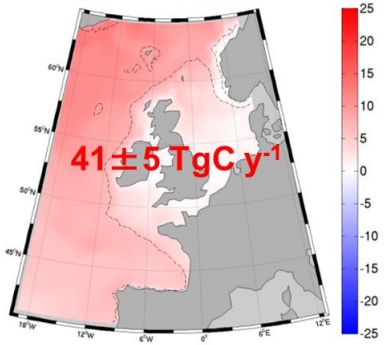
Ocean colour total chlorophyll

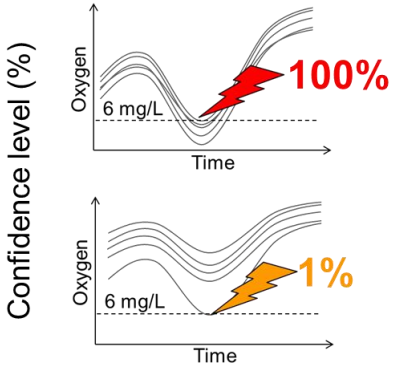
Ciavatta et al., JGR, 2016

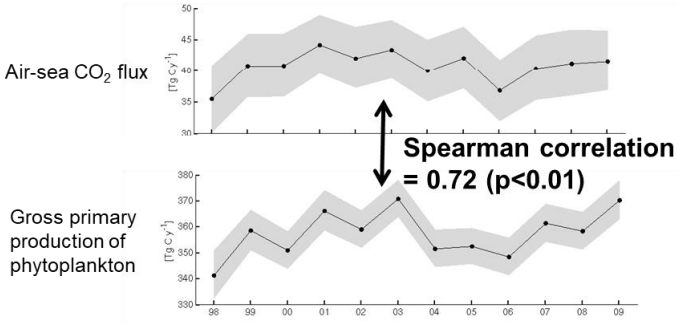
Oxygen deficient bottom waters



Carbon dioxide air-sea flux

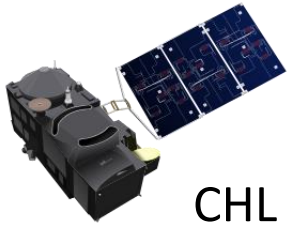






What biogeochemical data to assimilate?

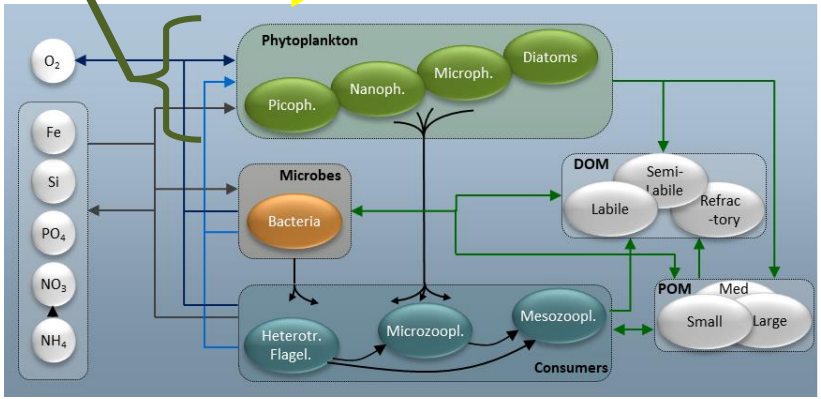
Ocean colour total chlorophyll



$$CHL = f\,(R_{rs})$$

Fine for the total phytoplankton community at surface but ….

- what about phytoplankton groups?
- what about the other BGC variables?
- what about the ocean interior?



Addressable by DA of:

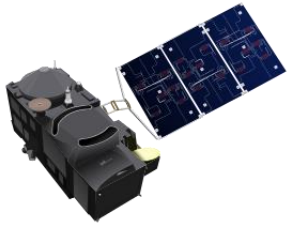
← PFTs

← Optical data

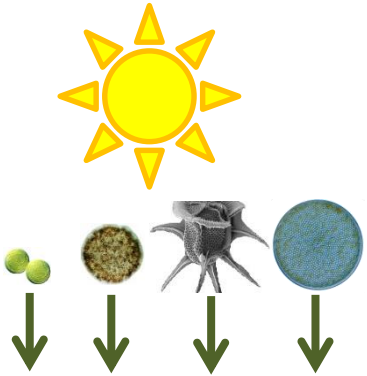
← AUVs

What biogeochemical data to assimilate?

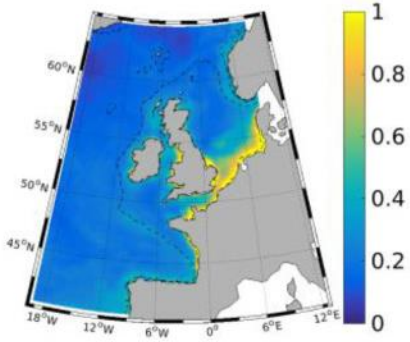
Phytoplankton functional types (PFTs)

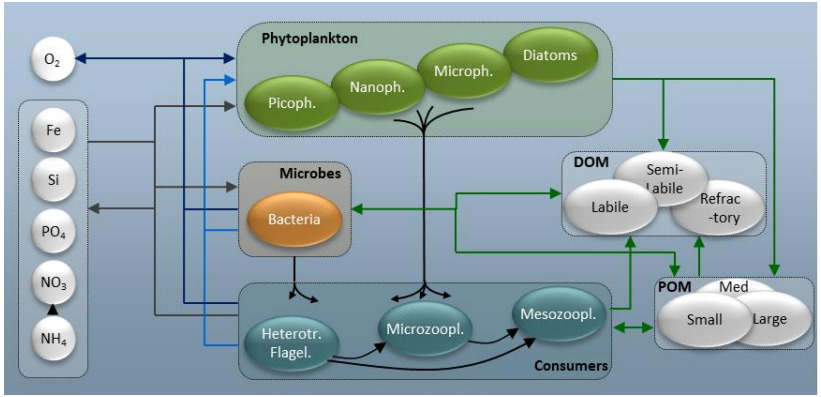


PFT Chlorophyll



Dinoflagellates





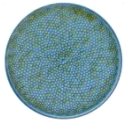
Ciavatta et al., JGR, 2018

What biogeochemical data to assimilate?

Phytoplankton functional types (PFTs)

PFT chlorophy

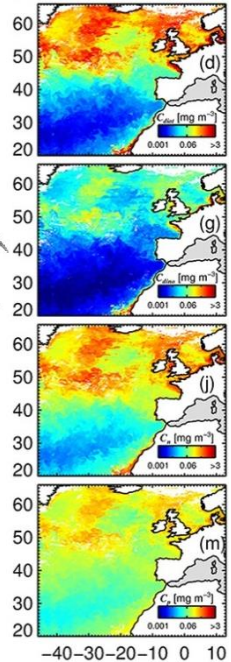
Diatoms



Dinoflagellates

Nanophytoplankton

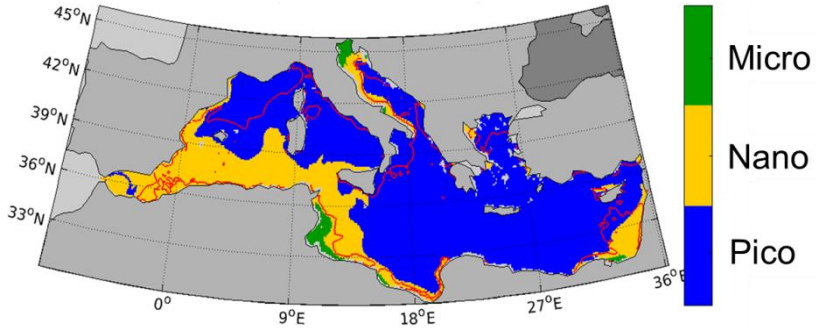
Picophytoplankton

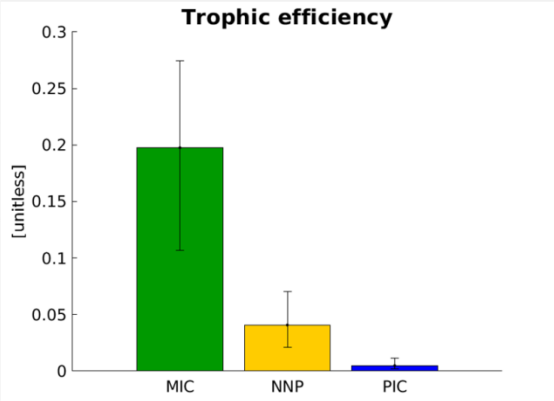


Brewin et al., 2017

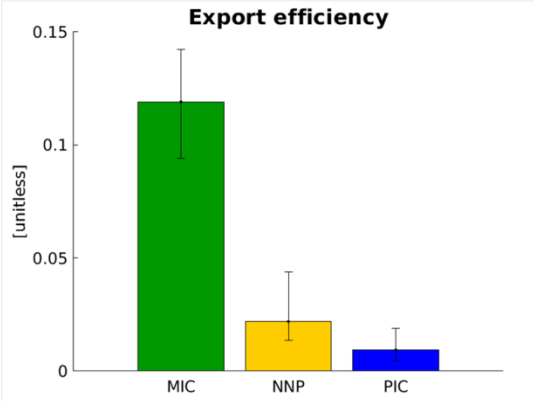
What biogeochemical data to assimilate?

Phytoplankton functional types (PFTs)





$$\frac{Mesozooplankton}{Phytoplankton}$$

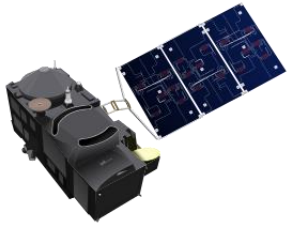


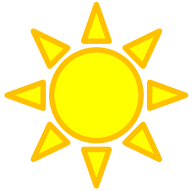
$$\frac{POC_{sink}}{GPP}$$

Ciavatta et al., JGR, 2019

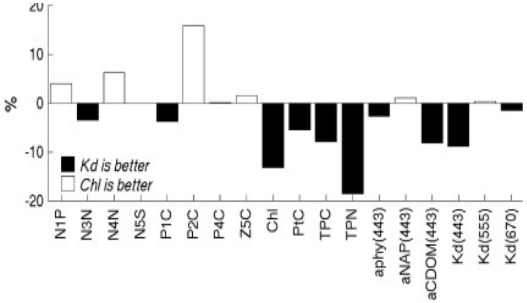
What biogeochemical data to assimilate?

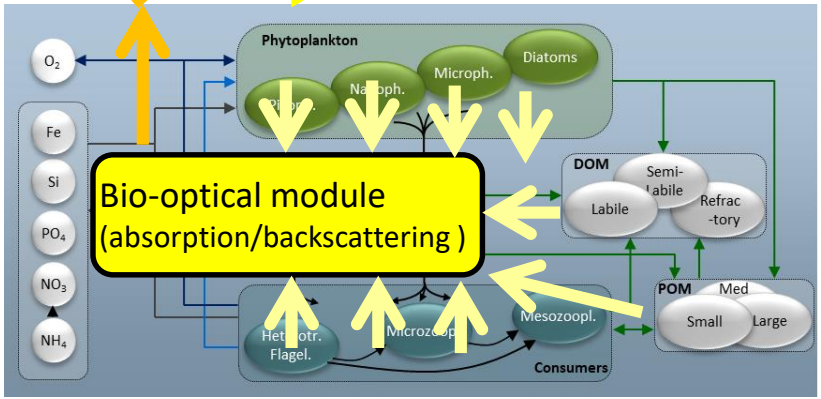
Optical properties ("bulk")





RMSD K_d – RMSD Chl

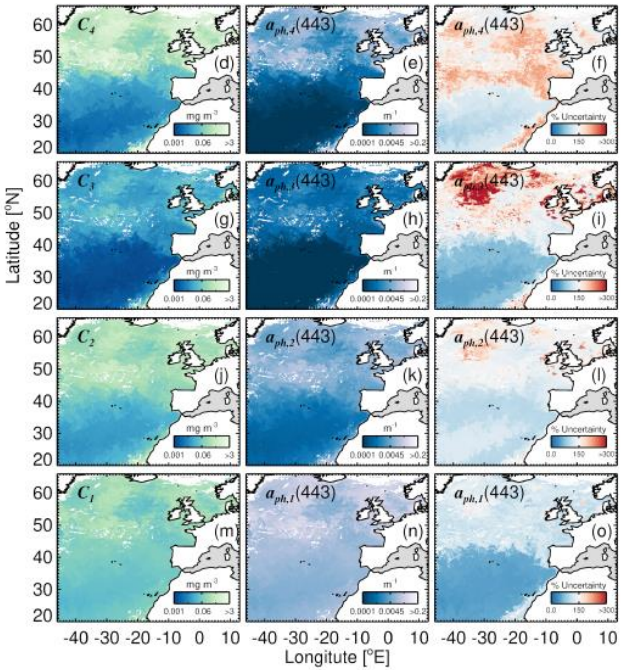


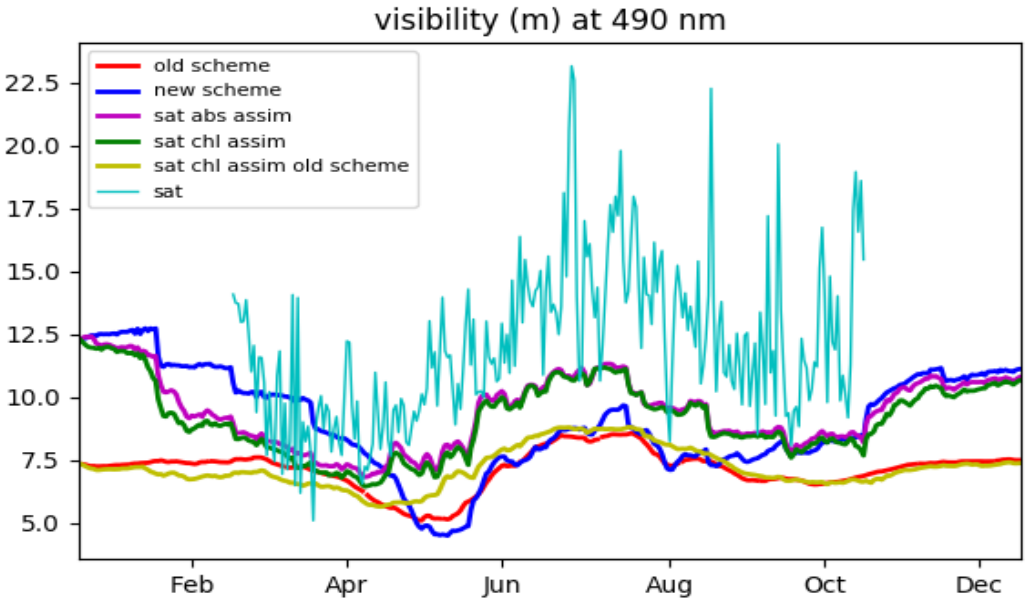


Ciavatta et al., PiO, 2014

What biogeochemical data to assimilate?

Optical properties (PFT absorption)





Brewin et al., JGR, 2019

Skakala et al., JGR, 2020

What biogeochemical data to assimilate?

Autonomous underwater vehicles

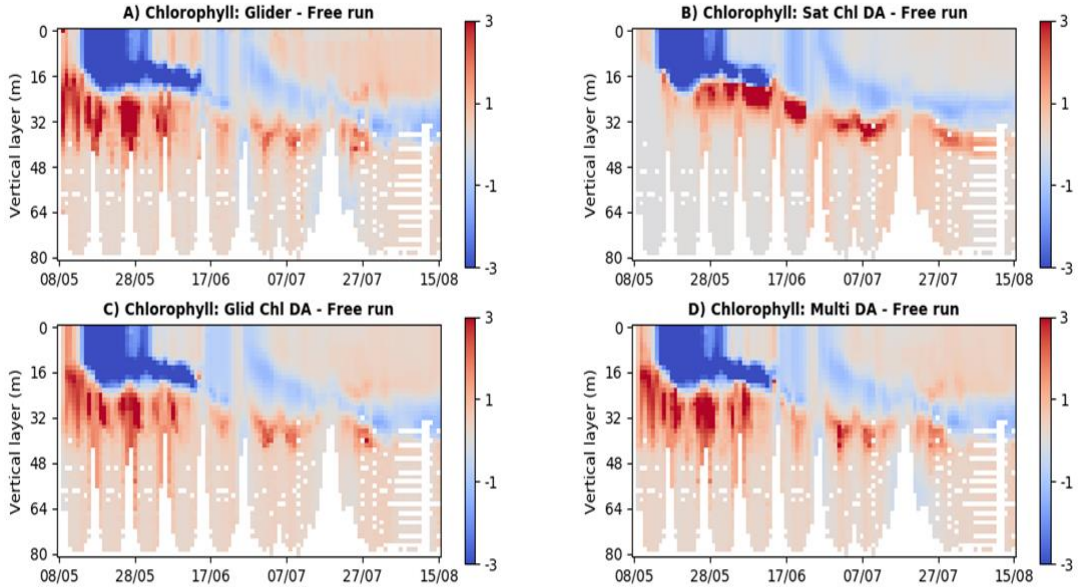
- **To develop an integrated approach** combining observing networks and marine models
- **To deliver better understanding** of fine-scale processes and system variability
- **To identify a cost-effective, optimized monitoring networks**
- **To deliver improved evidence for ecosystem-based management**

Gliders

BGC-Argos

What biogeochemical data to assimilate?

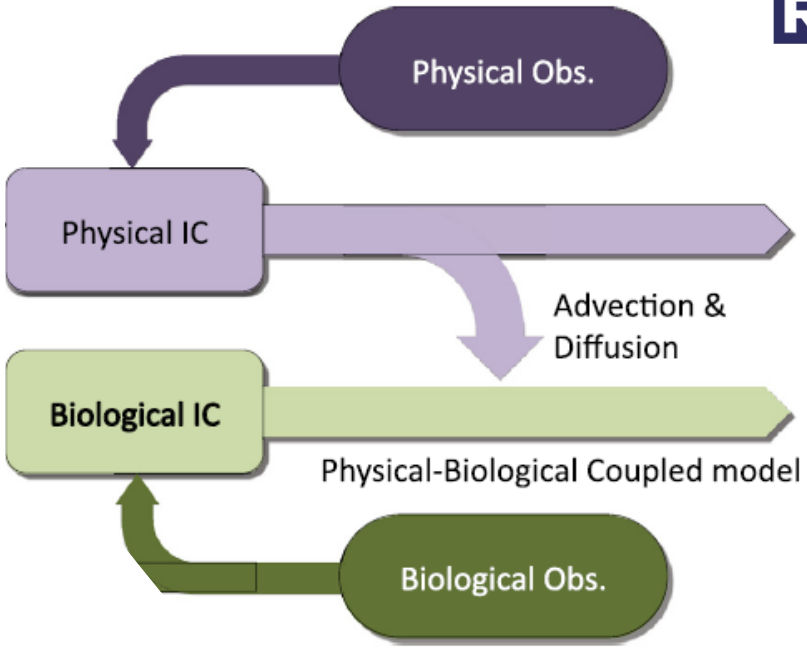
Chlorophyll



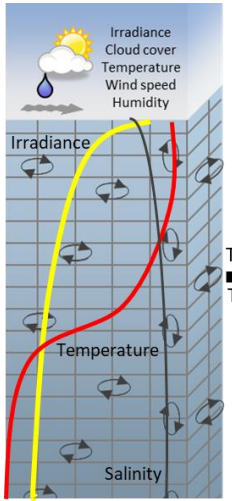
See Jozef's talk Session 1 @ H 12.30!

Skakala et al., JGR, submitted

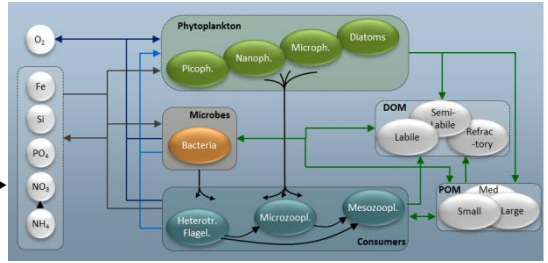
Coupled physical and biogeochemical DA



Modified from Song et al., 2016b

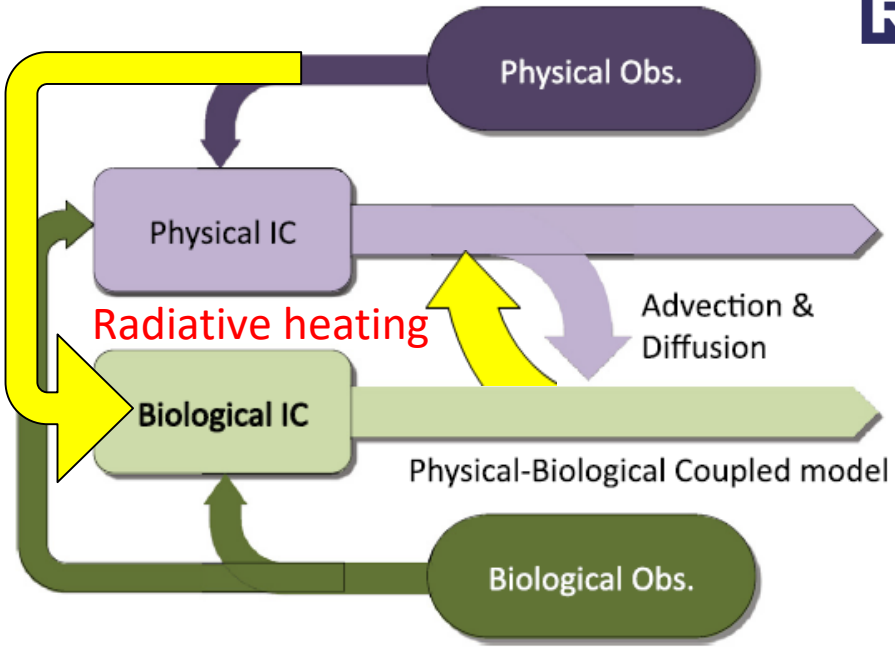


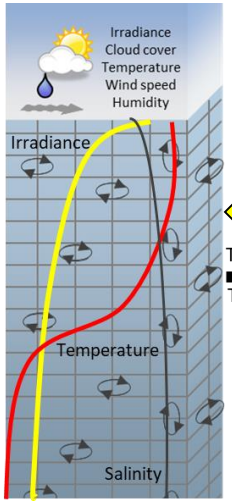
Transport
T,E,S



Coupled physical and biogeochemical DA

Joint PHY-BGC DA with two-way coupled PHY-BGC modelling?

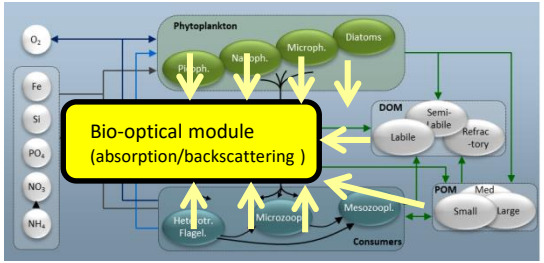




E

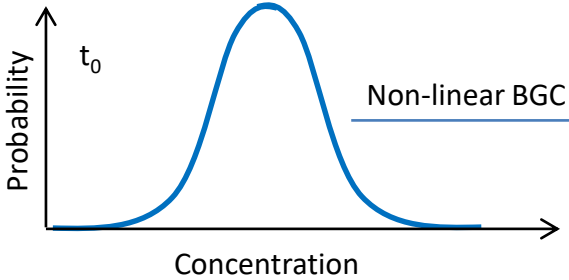
Transport

T,E,S



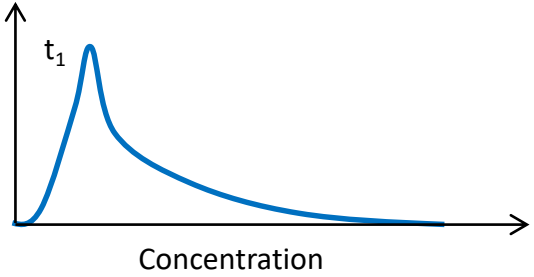
Addressing non-Gaussianity/non-linearity

Ideal Gaussian BGC distribution

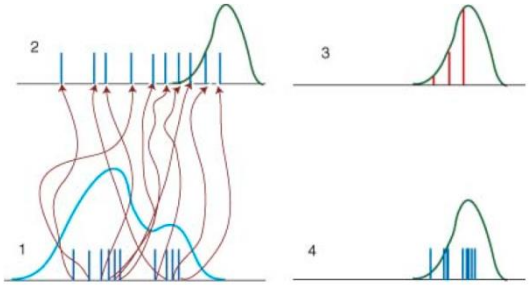


Non-linear BGC processes

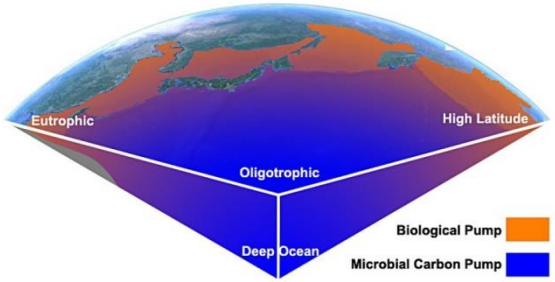
Real non-Gaussian BGC distribution

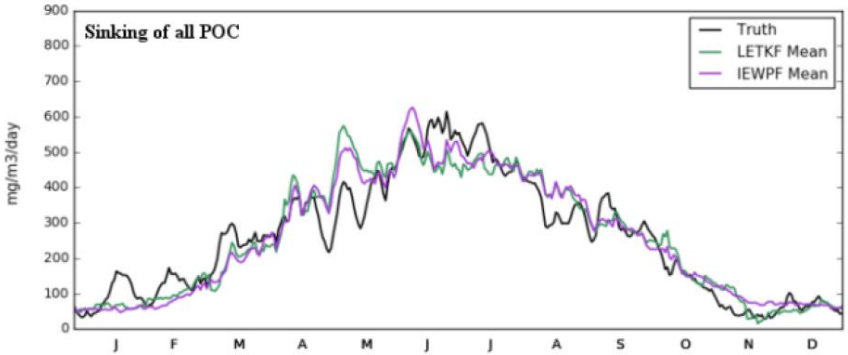


Particle filters



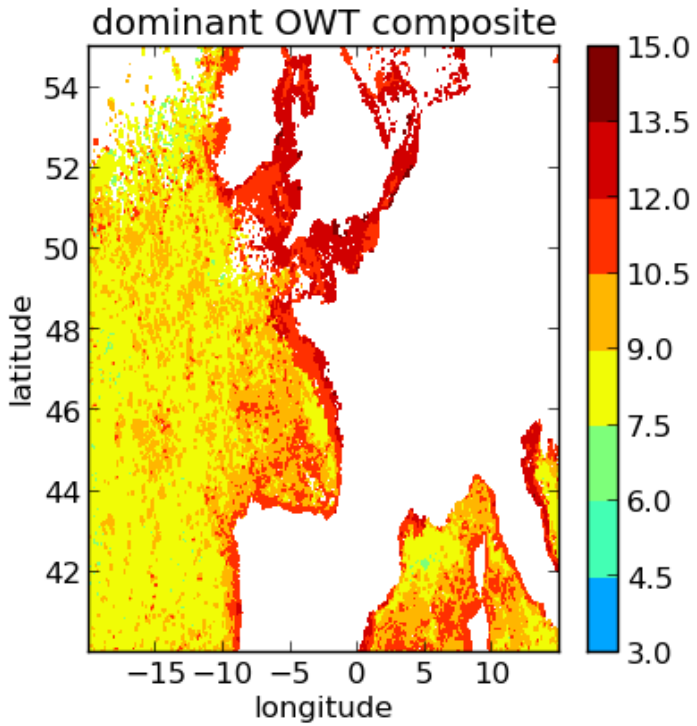
van Leeuwen, 2010



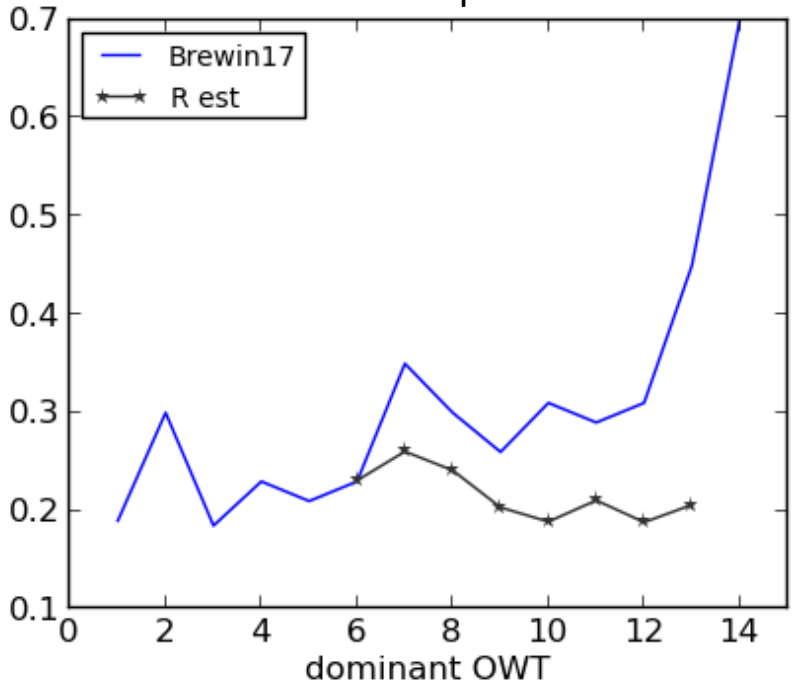


Surhsam, NCEO PhD, 2019

Addressing observational errors



Standard deviations of sample estimates of R^{est}



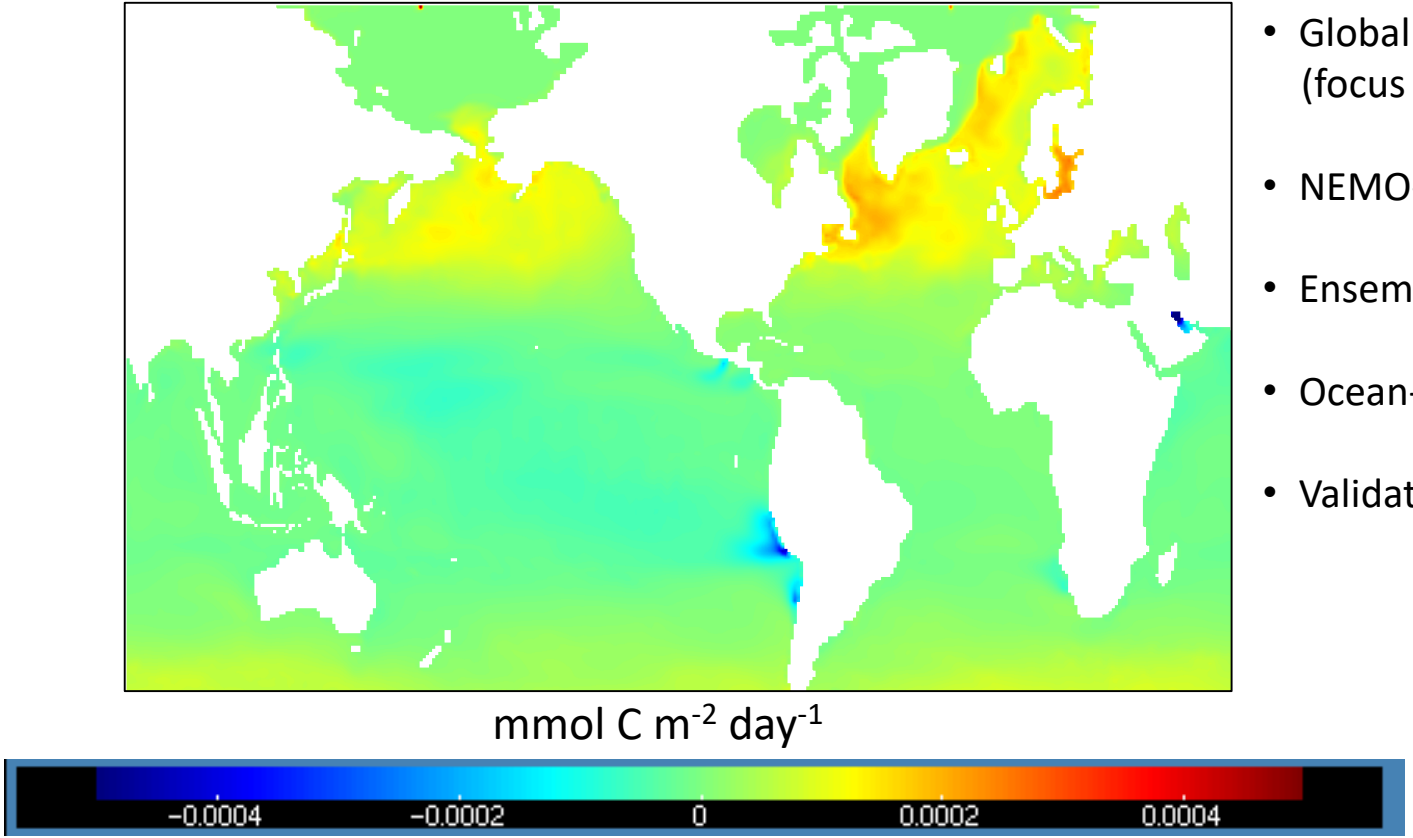
$$\mathbf{R}^{est} = E[\mathbf{d}_o^b(\mathbf{d}_o^a)^{\mathrm{T}}] = \mathbf{D}\widetilde{\mathbf{D}}^{-1}\widetilde{\mathbf{R}} = \mathbf{D}(\mathbf{I} - \mathbf{HK})^{\mathrm{T}}$$

Fowler et al, in preparation

Global reanalysis of carbon fluxes

Air-sea CO2 flux

(Hindcast Jan 1979 -> Dec 2017)



- Global reanalysis C fluxes (focus on biological pumps)
- NEMO-FABM-MEDUSA
- Ensemble DA
- Ocean-colour C stocks
- Validation/DA BGC-Argo

See Giorgio's talk Session 3 @ H 12.30!

Network & dissemination

OceanPredict
Advancing the science of ocean prediction

Fennel et al., 2019
Moore et al., 2019
Mey-Fremeaux, 2019

iCCG
International Ocean Colour Coordinating Group

Dutkiewicz et al., 2020

MERCATOR OCEAN INTERNATIONAL
Copernicus
Europe's eyes on Earth

van Schukman et al., 2020

esa
ocean colour cci

Groom et al., 2019

PML Plymouth Marine Laboratory

Concluding remarks

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

1. NCEO is underpinning **UK world-class research** in ocean biogeochemistry DA
2. BGC DA can **improve prediction of BGC indicators**
3. **"New" data** (PFTs, optics, BGC-Argos): pros & cons
4. **Non-Gaussianity**/non-linearity issue: more work needed
5. **Two-way coupling** of PHY-BGC modelling & DA
6. Reanalysis of global **ocean (bio) C fluxes**

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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