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
Outline

• Why are we assimilating biogeochemical data?

• What data to assimilate?

• Some issues (non-Gaussianity, obs errors)

• Conclusions
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.
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.
Why are we assimilating biogeochemical data into ecosystem models?

To improve the estimation of the “biogeochemical truth”

Ocean colour

- Phytoplankton chlorophyll
- Phytoplankton functional types
- Remote sensing reflectance
  ...

Data assimilation (DA) algorithm

Physical (PHY) model

In situ observations: Chlorophyll, oxygen, nitrate, pH...
What biogeochemical data to assimilate?

Ocean colour total chlorophyll

\[ \text{CHL} = f (R_{rs}) \]

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)

ΔRMSE = -7.7%

Ciavatta et al., JGR, 2011
What biogeochemical data to assimilate?

Ocean colour total chlorophyll

Oxygen deficient bottom waters

Carbon dioxide air-sea flux

41 ± 5 TgC y⁻¹

Confidence level (%)

Air-sea CO₂ flux

Spearman correlation = 0.72 (p<0.01)

Gross primary production of phytoplankton

Ciavatta et al., JGR, 2016
Ocean colour total chlorophyll

\[ \text{CHL} = f \left( R_{rs} \right) \]

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)

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

Skákala et al., 2018
What biogeochemical data to assimilate?

Phytoplankton functional types (PFTs)

Ciavatta et al., JGR, 2019
Ciavatta et al., PiO, 2014

Optical properties ("bulk")

RMSD $K_d$ – RMSD Chl

What biogeochemical data to assimilate?
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

Physical IC

Physical Obs.

Advection & Diffusion

Biological IC

Physical-Biological Coupled model

Biological Obs.

Modified from Song et al., 2016b
Coupled physical and biogeochemical DA

Joint PHY-BGC DA with two-way coupled PHY-BGC modelling?
Addressing non-Gaussianity/non-linearity

Ideal Gaussian BGC distribution

Concentration

Probability

Non-linear BGC processes

Real non-Gaussian BGC distribution

Concentration

Particle filters

van Leeuwen, 2010

Surhsam, NCEO PhD, 2019
Addressing observational errors

\[
R_{est} = E[d_o^b (d_o^a)^T] = \mathbf{D} \tilde{\mathbf{D}}^{-1} \tilde{\mathbf{R}} = \mathbf{D}(\mathbf{I} - \mathbf{H} \mathbf{K})^T
\]
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

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

Dutkiewicz et al., 2020

van Schukman et al., 2020

Groom et al., 2019
Concluding remarks

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**

s.ciavatta@pml.ac.uk