Greenocean workshop: New observations and new methods to better constrain marine ecosystems processes in models in the context of a changing climate

Institut de la Mer de Villefranche sur Mer (IMEV), France, 12-13 February 2019.

This workshop brought together theoretical ecologists, modelers and observationalists to explore how we can better use new observations and new methods such as machine learning to improve the representation of ecosystem processes in global ocean biogeochemistry models. The workshop aimed to stimulate ideas by creating new working relationships and reinvigorating existing ones. The ultimate goal is to improve our understanding and predictive capability of the impacts of global changes on the functioning of marine ecosystems this century, and to quantify the potential feedbacks on climate change.

Summary of key points

Current projections of changes in the marine biological carbon pump have limited and largely untested reliability. The group noted that current generation global biogeochemistry models used in climate change projections have extremely limited representation of marine ecosystem dynamics. As a consequence, the projected changes in ecosystem-driven carbon fluxes in these models are relatively small and almost entirely deterministically driven directly by changes in environmental conditions (nutrients and mixed-layer depth in particular). The group felt that such projections do not do justice to the true potential for larger, less predictable, ecosystem-driven changes in carbon fluxes in the future in response to climate and other environmental changes. This point, however, has not been demonstrated in the literature, as the models currently reproduce the size of the oceanic CO_2 sink and many other observations of mean concentrations (e.g. surface Chla and nutrients). The extent to which models reproduce, or not, relevant ecosystem dynamics remain unknown due to the paucity of historical observations (with the exception of satellite images), and the heterogeneity of both plankton and the associated carbon fluxes. This becomes less the case since more modern methods have been deployed homogeneously.

New marine observation technologies provide opportunities and challenges. Recent advances in marine observation technologies means that the amount, content, quality, detail, and complexity of marine observations has exploded in the past decade. This is both an opportunity and a challenge. The new observations now provide a much broader overview of ecosystem interactions and where/how they matter for carbon fluxes. The challenge is to interpret the signals and integrate different types of observations in a meaningful and complementary way. There is further a challenge in integrating the high quantity of information originating from modern (e.g. omics) methods, encompassing several thousands of lifeforms in a qualitative way (i.e. the data are not quantitative) together with modeling outputs that integrate way fewer compartments but on a fully quantitative aspect.

New computational methods based on Artificial Intelligence can help improve the representation of marine ecosystem dynamics in models. Alongside the explosion in observational capabilities, multiple methods have been developed using AI in some form to try and capture information embedded in observations. Multiple examples were given in the workshop, including the automated detection of imaging clusters, the quantification of vital rates from genomic data, and the extrapolation of sparse variables to the whole ocean. The development of global models could make better use of such approaches, for example to better parameterise vital rates within Plankton Functional Types (PFTs) or develop alternative ways to represent ecosystem dynamics (see list below). Of particular interest to the modelling community are the new insights on particulate export dynamics that can arise from the analysis of observations from the UVP and other sources.

Global biogeochemical models need more detailed ecosystem representation. As a result of the explosion in marine observations, many potential improvements in global biogeochemical modelling have been suggested throughout the workshop (see table below). However it is difficult to say if these improvements will truly lead to a better and richer characterisation and quantification of future ecosystem-led carbon fluxes. Experience with the PlankTOM model, where multiple model versions were run with increasing level of ecosystem complexity, suggest that the richness in surface ecosystems does affect the distribution and dynamics of surface ecosystems, but it does not at present translate fully in changes in carbon export fluxes because of the simplicity of the particulate sinking dynamics. Carbon export from the surface to the deep ocean is the primary pathways by which ecosystems influence the storage of carbon in the ocean. It is the downward pathways of the biological carbon pump in the ocean.

Observed emergent ecosystem properties can help prioritise model developments. One challenge therefore is to identify metrics that could help focus model developments. The workshop participants discussed how new and existing observations could be used for this. In particular, the emergent ecosystem properties were seen as possible expressions of ecosystem-led changes in future carbon export to the deep ocean. An emergent ecosystem property is one that comes out of the system without being specified ahead of time, for example the HNLC areas. Emergent properties, we argued during the workshop, could potentially be used to guide model developments and test the suitability of models for projections of future ecosystem changes and their effects on carbon.

Next steps
The ideas that arose during the workshop will be further explored in the coming year. In particular, the PlankTOM model series will be used to test if indeed emergent ecosystem properties are improved with the representation of more complex ecosystems. Depending on the results and time, a publication might arise bringing together those ideas and providing a plan for research in this space. It is hoped that workshop participants will be able to use some of the ideas to further their own research.

Further details

Emergent ecosystem properties

A number of emergent ecosystem properties have been identified and discussed during the workshop. Here are listed those properties that truly emerge from the composition and/or functioning of the ecosystems, and are not a simple direct result of properties of the environment. Some properties are well known, but others stem directly from ecosystem research of the past decade.

1. **Bloom dynamics.** The presence of biomass bloom in Spring is an emergent ecosystem property as it reflects the timing difference between growth of phytoplankton and grazing by zooplankton. The presence of a secondary bloom in late Summer is a variation of the Spring bloom and can be used as a further constraint.
2. **North/South Chla ratio.** The North to South ratio of Chla biomass is a measure of the different nutrient conditions in the two hemispheres and how they drive different ecosystem dynamics. It is a measure of the HLNC contrast. It was shown to be not only dependent on iron availability, but also on the trophic pressure.
3. **North/South ef-ratio.** Likewise, the North to South differences in ef-ratio could be seen as an emergent property. The ef-ratio is the ratio of new or export production to total primary production.
4. **Pyramid of the trophic structure.** Unlike on land, the biomass of marine ecosystems is approximately distributed among planktonic trophic levels, rather than diminishing with the trophic level as is the case on land. This property emerges possibly from the very rapid turnover rate of the phytoplankton biomass, and the mismatch between the seasonal dynamics of phytoplankton and the zooplankton that graze on them. The pyramid shape varies between regions but has large-scale typical patterns.
5. **Patchiness versus size.** Plankton biomass observations show that patchiness (a measure of the standard deviation of biomass in similar locations) increases with size, both for phytoplankton and for zooplankton. This could be a result of their mobility or vertical migration.
6. **Redfield ratio.** The emergent constance of the ratio between C:N:P is a measure of the feedback loops that control ecosystem interactions. This metric is more difficult to use to guide model developments because it requires long equilibrium simulations. It is included here for completeness.
7. Other properties suggested during the workshop that could be explored:
    a. Functional clusters or emerging dominance of groups; diatom-copepod ecosystems, vs jellyfish dominated vs Tricho dominated vs rhizaria dominated; Interactions (or co-occurrence) within the community.
    b. Diatoms exploiting loopholes
    c. Diatoms as antisocial compared to other phytoplankton
    d. Phil Boyd’s different C export systems (also time-dependence)
    e. Properties associated with the deep chla maximum

Model improvements

Improvements of global biogeochemical models have been suggested during the workshop. These were not explored in detail or prioritised. They mostly involve the inclusion of additional processes or components, such as:

- Additional components
    - Viruses
    - Two or more diatoms (C:Si)
    - Salps
- Improved components
    - Diversity
    - More knowledge needed about death rates

    - Trait-based Plankton Functional Type (PFT) representation
    - Represent size-spectrum within PFT
    - Include uncertainties (formal)
    - Stoichiometry
    - Use omics-based measurements to better assess the effects of climate change on plankton ecosystems
- Additional processes
    - Life cycles
    - Adaptive dynamics and evolution
    - Mixotrophy
    - Zooplankton vertical migration
    - Behavior
    - Coastal habitats

In addition, other ways forward than PFT representation were discussed, which mainly aimed to answer the broader questions:

- How to represent biodiversity?
- How to get more representative cell division rates for plankton in their natural environment?
- Hybrids prok (metabo) euk (classical)
- Hybrids with ML/AI
- Represent size-spectrum instead of PFTs

Finally, it was suggested that more systematic methods could be used to improve the way models are developed, such as:

- Use omics-based measurements to refine the definition of actual PFTs
- Incorporation of plankton “interactions" into the definition of PFTs (towards ecoPFTs;), to eventually establish better connections between PFTs
- Do a PCA of the obs to isolate separate PFTs
- Automated validation
- More homogenous and inter-calibrated methods and observations

Programme

Wednesday 12 February

9.15 Arrival, refreshments

9.30 Welcome and introduction to the Laboratoire d'Océanographie de Villefranche
Roundtable introductions
Goals of the workshop

9.45 - 11.15 New marine observations and ecosystem composition
(Co-chairs Corinne Le Quéré and Lionel Guidi)

- Chris Bowler - *Overview*
- Emile Faure - *From omics data to biogeochemical functions, who is doing what and where ?*
- Fabien Lombard - *Plankton imaging at different scales*
- Marie Racault - *Observations of ocean primary producers from space*
- Fabio Benedetti - *Observations-based objective classification of PFTs to be used in ecosystem models*

11.15 - 11.45 Break

11.45 - 12.30 New marine observations and carbon export processes
(Co-chairs Chris Bowler and Becci Wright)

- B.B. Cael - *New export observations (from a modeling perspective)*
- Lionel Guidi - *Particulate and export, touching on genomics*

12.30 - 14.00 Lunch

14.00 - 14.45 New marine observations and carbon export processes (Continued)

- Lars Stemmann - *Interactions between export and zooplankton*
- Christine Klaas - *The Southern Ocean biological carbon pump from observations*

14.45 - 16.15 Advances in theoretical ecosystem modelling
(Co-chairs Marie Racault and Louis Legendre)

- Sergio Vallina - *Ecological evolution (eco-evo) modelling and genomics data: * mind the gap **
- Samuel Chaffron - *Community networks reveal the structuring of plankton in the global ocean*
- Guillaume Le Gland - *On the use of mutations to account for diversity in a multi-trait model of phytoplankton community*
- Benoit Delahaye - *Statistical Model Checking for parametrisation of uncertain (biogeochemical) models*

16.15 - 16.30 Break

16.30 - 17.00 Discussion (Co-chairs Corinne Le Quéré and Lionel Guidi)

19.00 Conference dinner, restaurant Le Mayssa, 9 Place WILSON, Villefranche sur mer

Thursday 13 February

9.00 - 10.30 New machine learning methods applied to marine biogeochemistry
(Co-chairs Rhaphaëlle Sauzede and Christine Klaas)

- Anna Sommer - *Machine Learning and Observations to improve parametrisation in biogeochemical models*
- Jean Olivier Irisson - *Using unsupervised learning to describe the diversity of plankton and particles from quantitative images*
- Damien Eveillard - *Constraint-based modeling to infer biogeochemical cycles and dependencies from omics knowledge*
- Hervé Claustre - *Filling the gaps in Ocean Observation with robots…and machine learning*

10.30 - 11.00 Break

11.00 - 12.30 Advances in global ecosystem modelling
(Co-chairs Nicolas Mayot and Corinne Le Quéré)

- Baye Cheikh Mbaye - *Towards emerging structures of zooplankton communities from a marine ecosystem size spectrum model*
- Corentin Clerc - *Mesozooplankton modelling*
- Rebecca Wright - *Investigating the role of jellyfish for carbon export using a global OBGM*
- Erik Buitenhuis - *Large Contribution of Pteropods to Shallow $CaCO_3$ Export*

12.30 - 13.30 Lunch

13.30 - 15.30 Discussion & next steps (Co-chairs Corinne Le Quéré and Lionel Guidi)

Participants confirmed:

Global modelling of ocean ecosystems and biogeochemistry

1. Corinne Le Quéré (UEA)
2. Joanna Guest (UEA)
3. Anna Sommer (UEA)
4. Rebecca Wright (UEA)
5. Nicolas Mayot (UEA)
6. Erik Buitenhuis (UEA, remote participation)
7. Fabio Benedetti (ETH, remote participation)
8. Sakina-Dorothée Ayata (ENS, remote participation)
9. Corentin Clerc (ENS)
10. Alessandro Tagliabue (Liverpool, remote participation)

New observations or PFT diversity and export processes

11. Lionel Guidi (LOV)
12. Chris Bowler (ENS)
13. Emile Faure (CNRS)
14. Marie Racault (PML)
15. Fabien Lombard (LOV)
16. B.B. Cael (NOC)
17. Christine Klaas (AWI)
18. Pierre Ramond (IFREMER)
19. Hervé Claustre (LOV)
20. Rainer Kiko (LOV)

Theoretical and computational ecology

21. Louis Legendre (LOV)
22. Damien Eveillard (Nantes)
23. Samuel Chaffron (Nantes)
24. Sergio Vallina, theoretical ecology (Gijon Oceanography Centre)
25. Jean Olivier Irisson (LOV)
26. Guillaume Le Gland (Gijon)
27. Dieter Wolf-Gladrow (AWI)
28. Rhaphaëlle Sauzede (LOV)
29. Benoit Delahaye (Nantes)
30. Baye Cheikh Mbaye (LOV)