
# Why we need more ecology in our biogeochemical models

And high resolution, too…

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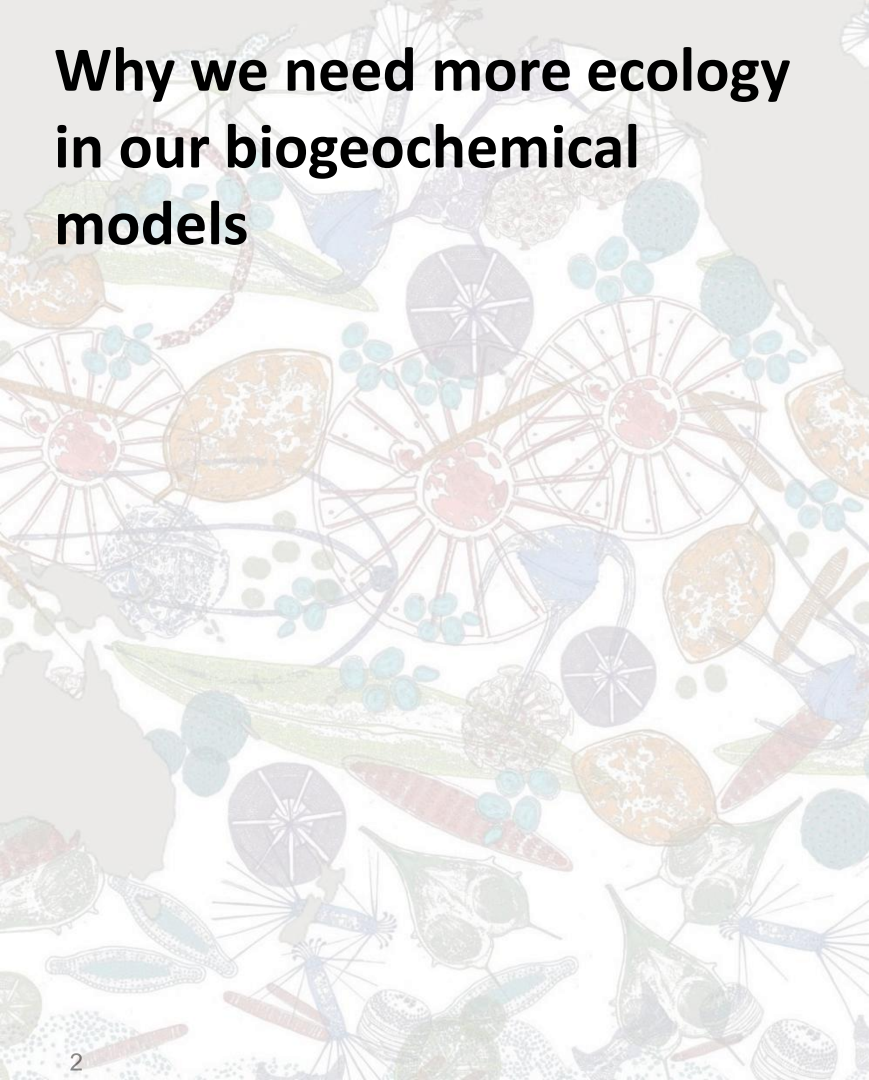
# Why we need more ecology in our biogeochemical models



## … because we need it to address a number of key challenges

To represent time-space structure of productivity and export.

***The drizzle problem***

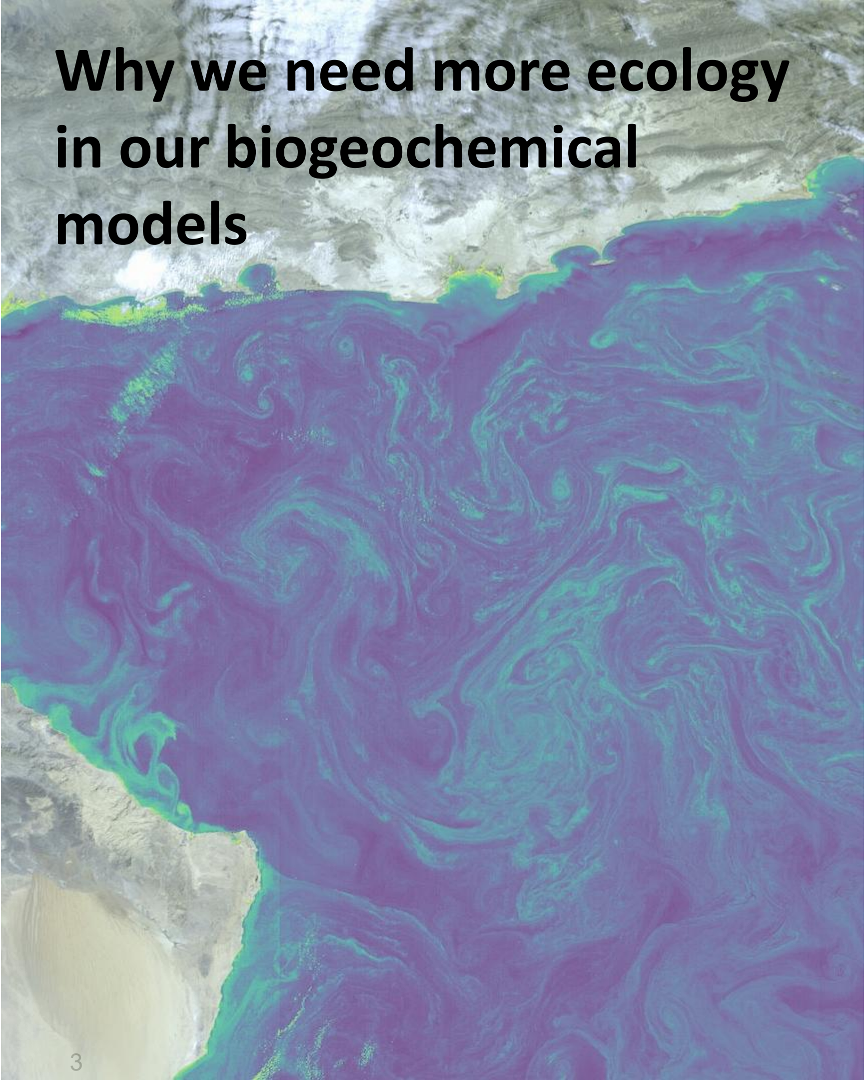
To represent the trophic structure of mass and energy flow.

***The pyramid problem***

To model response of productivity and export to climate change and extremes.

***The cascade problem***

# Why we need more ecology in our biogeochemical models



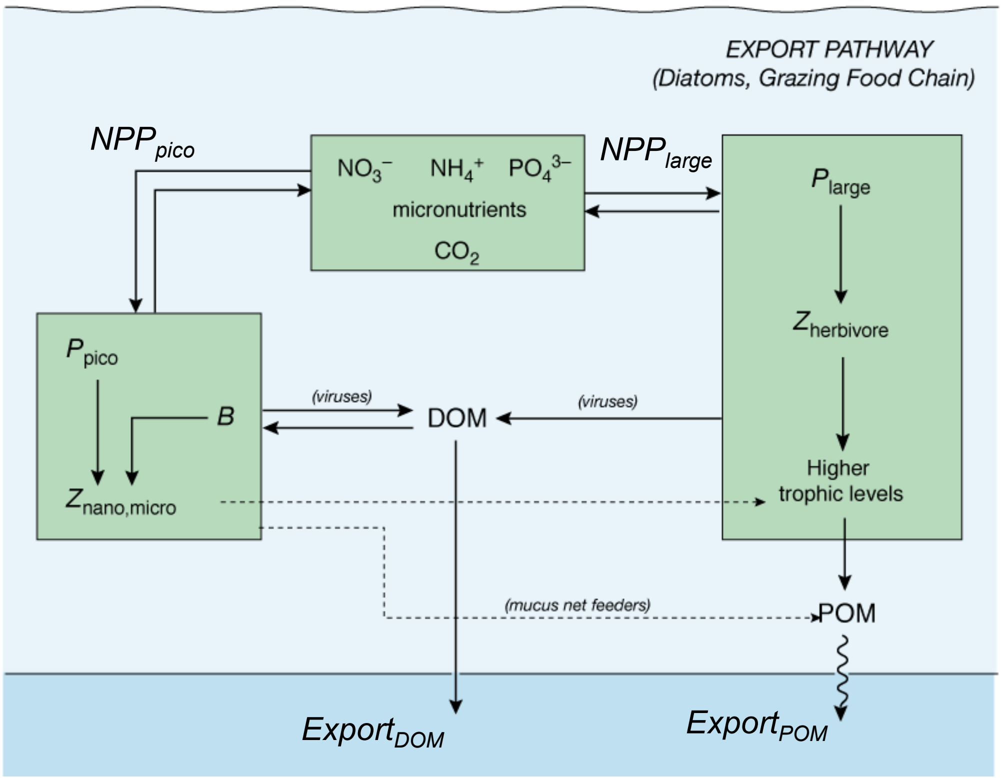
To represent time-space structure of productivity and export.

***The drizzle problem***

Our ocean biogeochemistry models tend to ”drizzle” too much, and produce too little real ”rain”, that is export pulses of organic matter.

→ This has large implications for trophic transfer, export efficiency, episodicity of organic matter supply to aphotic zone, etc.

# Why are the models drizzling too much?

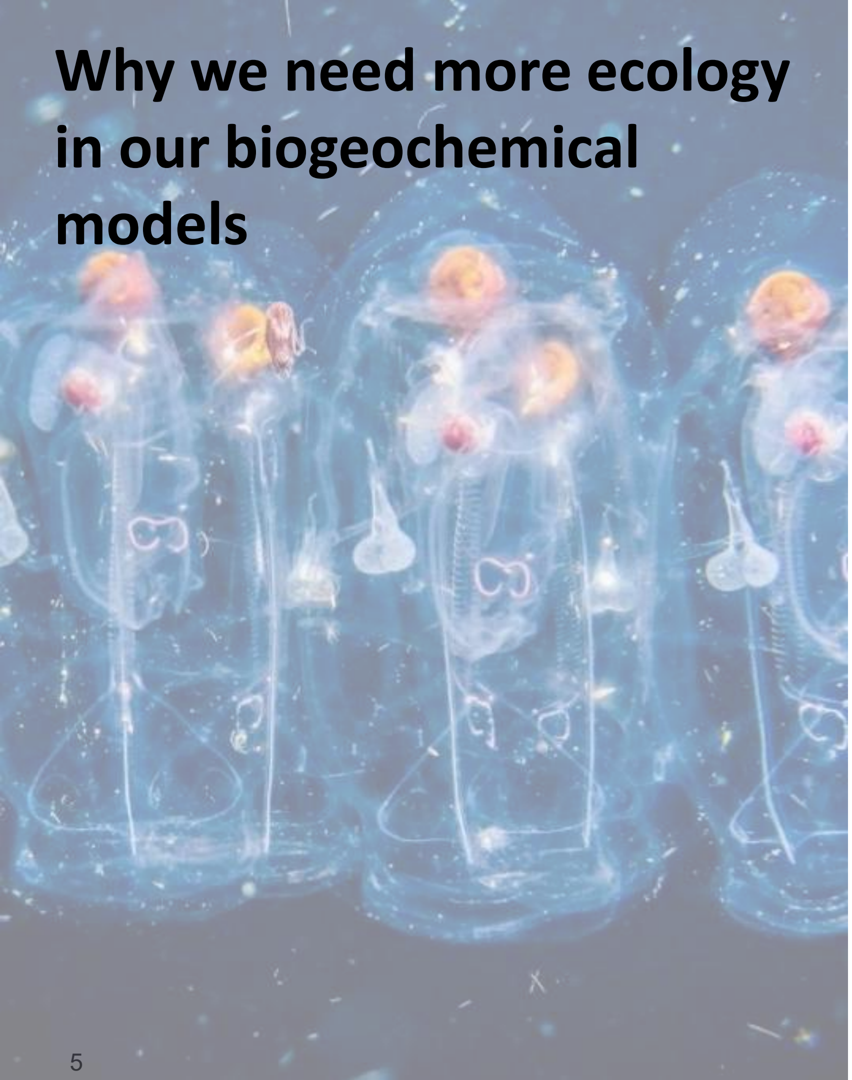



P: Phytoplankton
Z: Zooplankton
B: Bacteria
DOM: Dissolved organic matter
POM: Particulate organic matter

Next to insufficient resolution to generate meso- and submeso-scale variations in nutrient supply and stratification, our biogeochemistry models are not well set up to alter community structure between a small plankton dominated regeneration system and a large plankton dominated export pathway.

*Sarmiento & Gruber (2006)*

# Why we need more ecology in our biogeochemical models



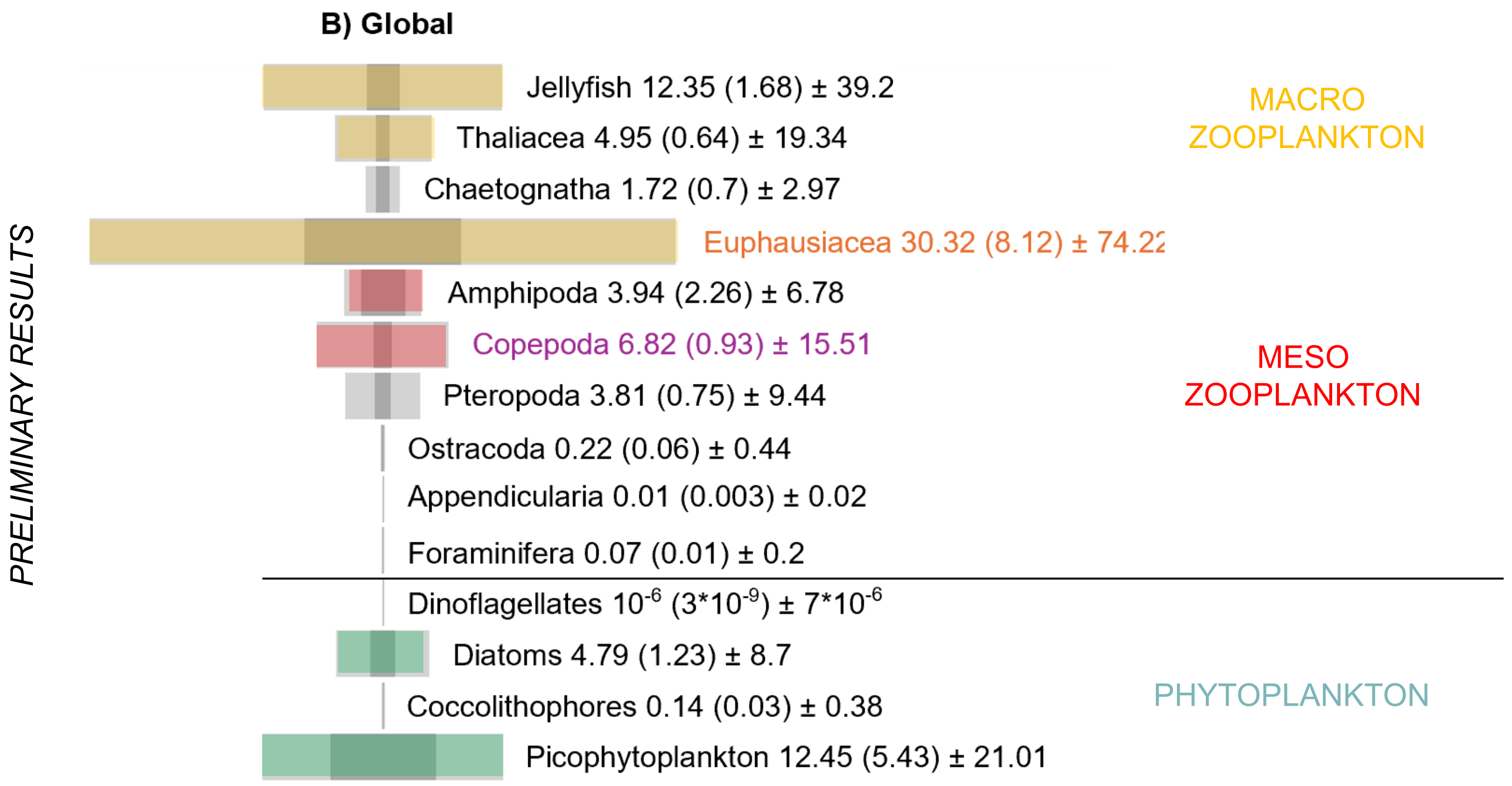
To represent the trophic structure of mass and energy flow.

***The pyramid problem***

Our ocean biogeochemistry models tend to produce a bottom-heavy trophic pyramid, while observations strongly suggest an inverted pyramid.

→ This implies a wrong transfer of energy and material properties through the food web, and a corresponding mismatch of export.

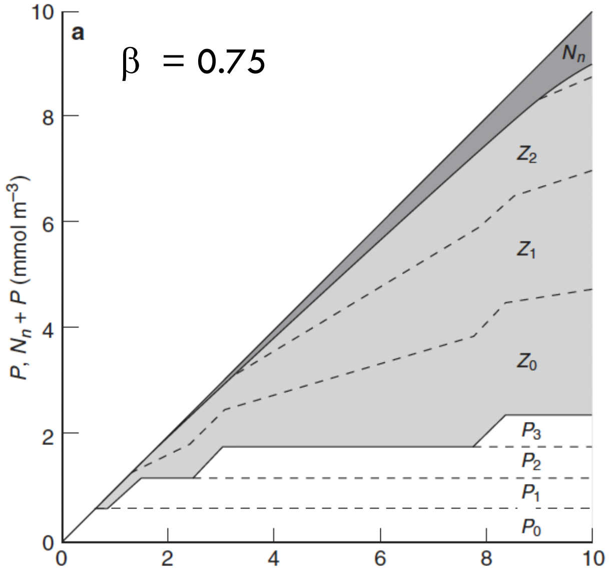
# Trophic biomass pyramid

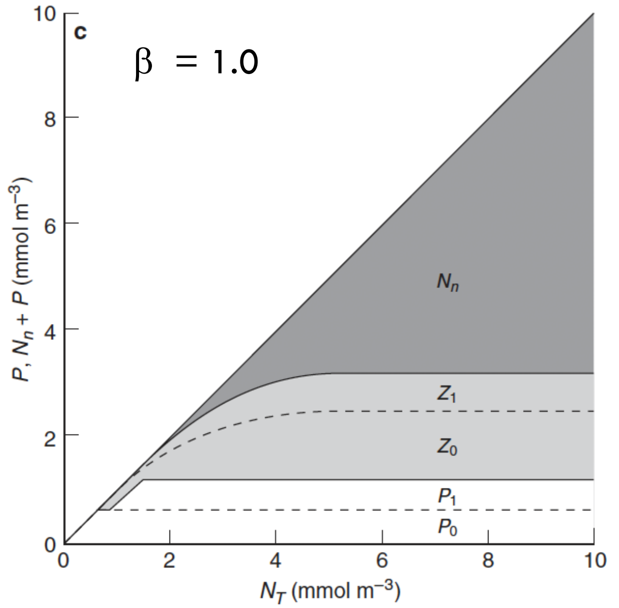



Biomass (mg $m^{-3}$) of plankton groups estimated from AtlantEco database

*Johanna Berger (Master thesis, ETHZ)*

# Why do models get the trophic biomass pyramids wrong?



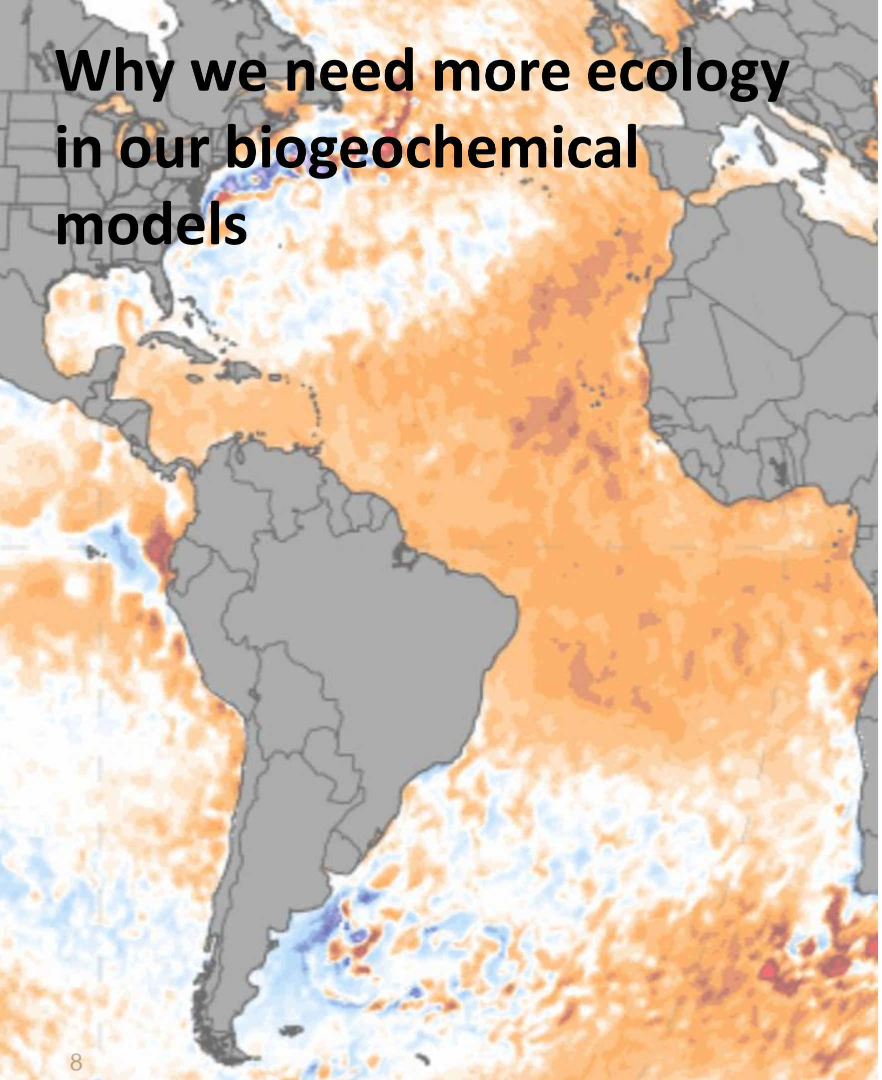

$$(V_{max})_i = (V_{max})_0 \cdot (L_i/L_0)^{-\beta}$$

Armstrong (1994)

One possible reason is the lack of consideration of proper size classes in the models and wrong choices in the allometric parameters describing the scaling with size.

Sarmiento & Gruber (2006)

# Why we need more ecology in our biogeochemical models



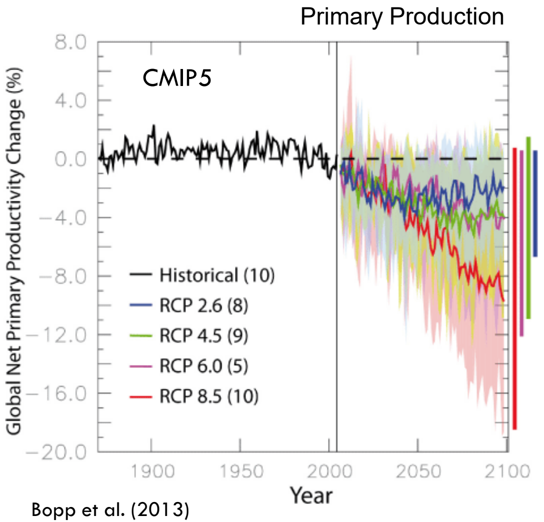
To model response of productivity and export to climate change and extremes.

***The cascade problem***

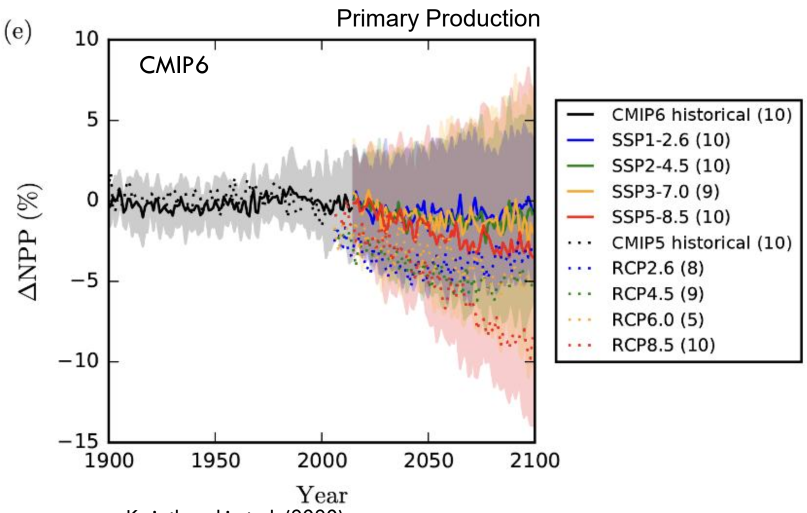
Our ocean biogeochemistry models tend to give highly divergent results with regard to how they respond to climate change and other perturbations, such as extremes.

→ This has large implications for our ability to assess the risks associated with key ocean ecosystem services.

# Why do models diverge so much in response to climate change?



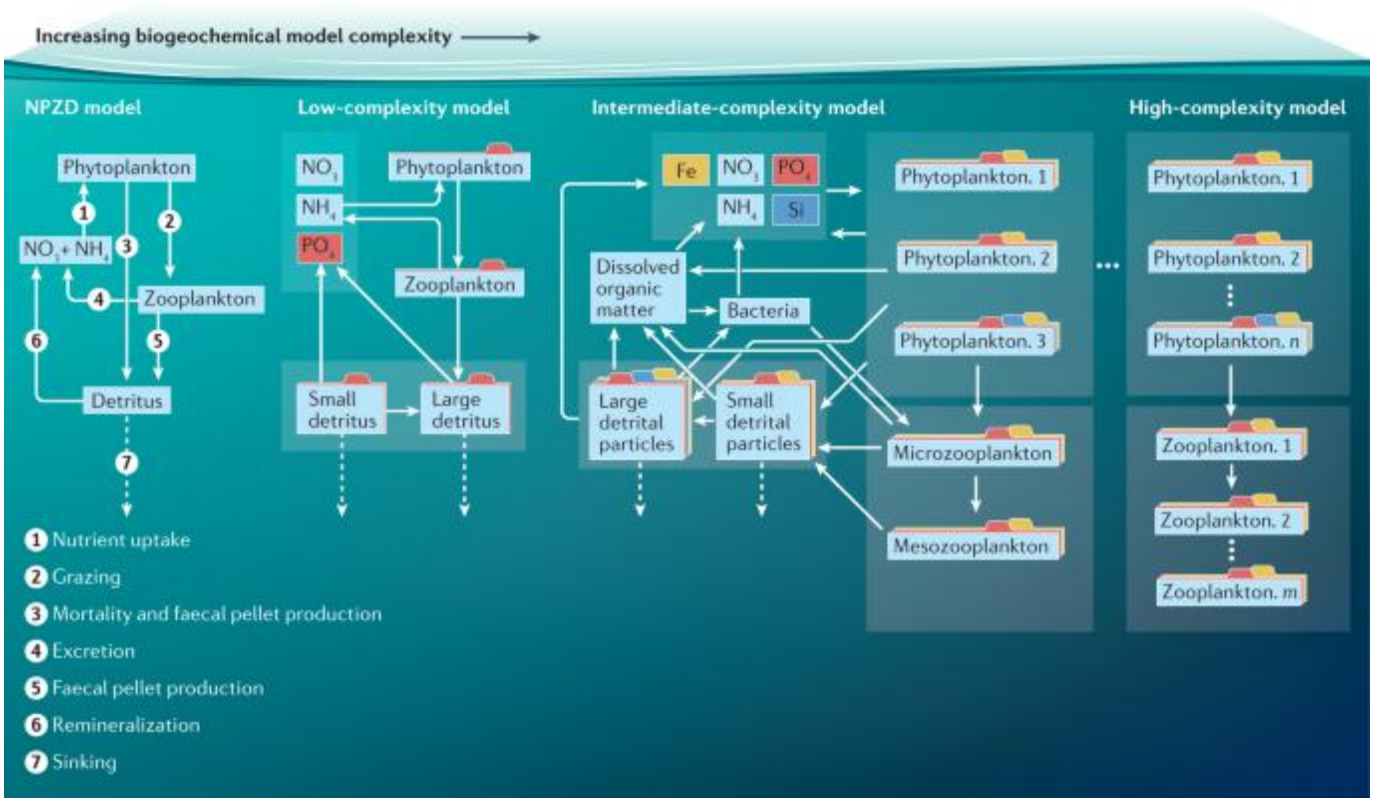

Bopp et al. (2013)




Kwiatkowski et al. (2020)

I don’t know. But problems in representing the seasonal cycle and the mean gradients between low and high productivity regions suggest that it is much more than simply differences in bottom up controls (nutrients, light, etc), but rather the lack of consideration of biotic interactions (top-down control).

# We need to bite the bullet and increase the ecological complexity….




How far and how much we have to increase the ecological complexity is to be determined.



Fennel et al. (2022)

# What we can bring to the table…

XCLAIM

See next slides

CEPHALOPOD

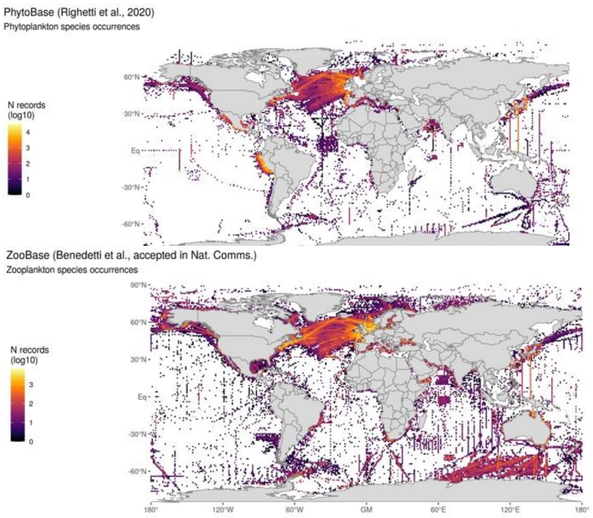
**Comprehensive Ensemble Pipeline for Habitat modelling Across Large-scale Ocean Pelagic Observation Datasets**

## PhytoBase

*Righetti et al., 2019, 2020;*

## ZOOBase

*Benedetti et al., 2021;*
*Vogt et al. 2023*




And many more things…

# EXCLAIM

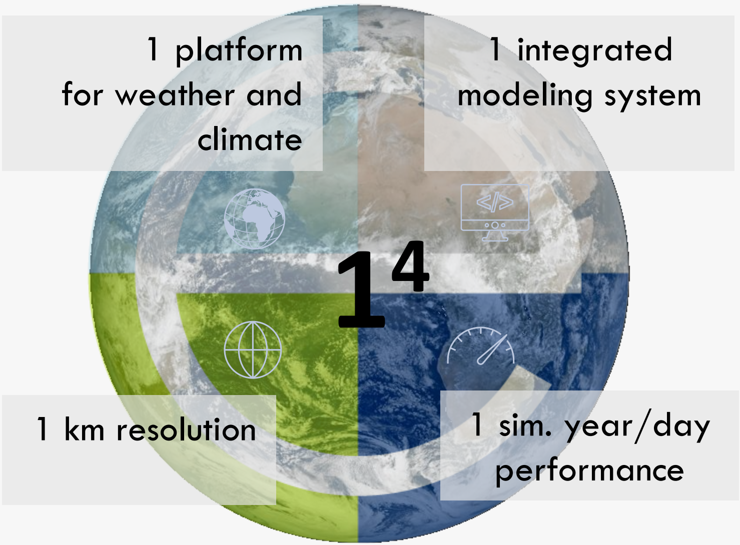
Extreme-scale computing and data platform
for cloud-resolving weather and climate modeling

# What is EXCLAIM?

Extreme-scale computing and data platform
for cloud-resolving weather and climate modeling

EXCLAIM is a six year (2021-2027) open ETH project that aims to develop an - model based infrastructure that is capable of running kilometer- scale climate simulations at both regional and global scales.

## Objectives




ICON

It should fulfil the following design criteria:

(i) broad usability and high transferability,

(ii) smooth integration along the entire work/dataflow,

(iii) adhere to the performance goals of 1 SYPD at 1 km resolution.



https://exclaim.ethz.ch

# The EXCLAIM approach

## Software refactoring

*Separation of concern:*

Lower level intensive compute pattern
→ Libraries (GT4Py)

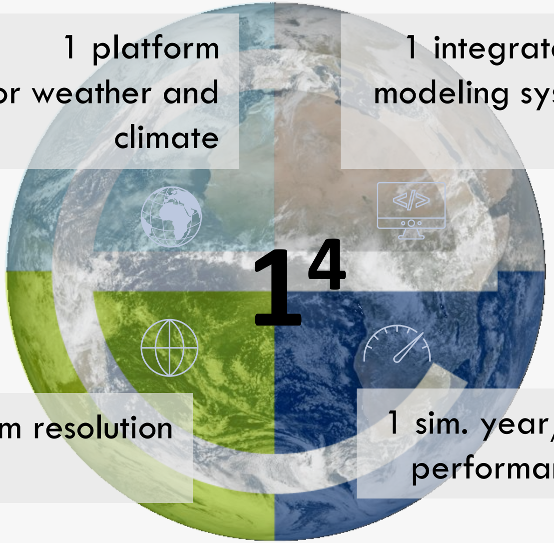
Higher level user driven instructions
→ Python

*Enables optimization* →

## Objectives

1 platform for weather and climate

1 integrated modeling system




1 km resolution

1 sim. year/day performance

*Acceleration: Order of factor 20*

## Hard/Software optimization

Automatic optimization of libraries on mixed hardware systems

Optimal use of CSCS Alps Infrastructure (NVIDIA GPUs)

← *Acceleration*

# The EXCLAIM approach

## Software refactoring

*Separation of concern:*

Lower level intensive compute pattern
→ Libraries

Higher level user driven instructions
→ Python

## Partners

Partners:
MPI-M, DWD, KIT, DKRZ

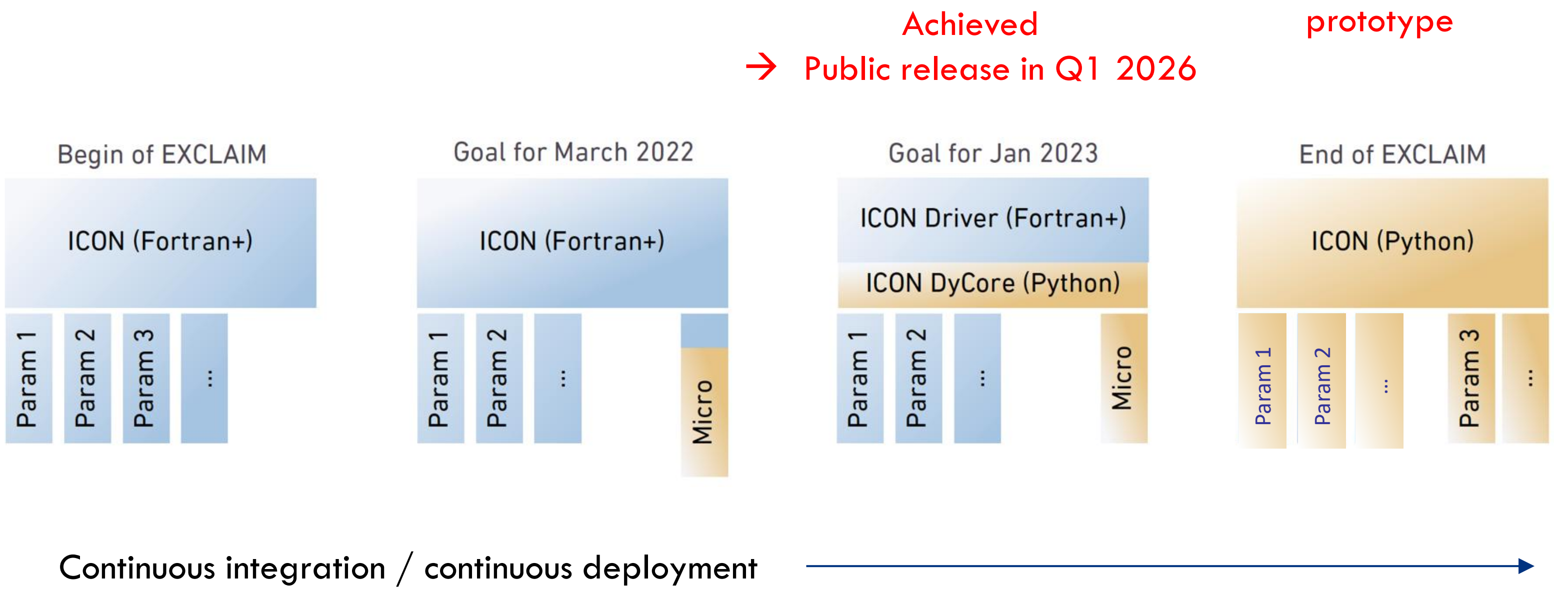
## Hard/Software optimization

Automatic optimization of libraries on mixed hardware systems

Optimization of work- and dataflow/structures

Optimal use of CSCS Alps Infrastructure (NVIDIA GPUs)

# Refactoring our climate & weather codes




The aim is to ensure a non-disruptive evolution of the software.

# Science Roadmaps: Core scientific use cases

| | Simulation | Setup | Resolution | Duration |
|---|---|---|---|---|
| completed | Aqua Planet | Global atmosphere only, no land | 10 km, 5 km, 2.5 km, 1 km | 2 years |
| completed | Global Uncoupled | Global atmosphere and land, prescribed SSTs | 10 km, 5 km, 2.5 km | 5-10 years |
| running | Global Coupled | Global, ocean, sea-ice, land, atmosphere | 10 km, 5 km, 2.5 km | 3 decades to century |
| completed | Regional Climate Europe (Scenarios CH202X) | Europe (CORDEX domain) | 12 km<br>1 km | century |

Upcoming (2026) with carbon cycle

The use cases provide milestones and guide the technical developments. They also ensure community engagement along the way.

# THE END.

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www.exclaim.ethz.ch