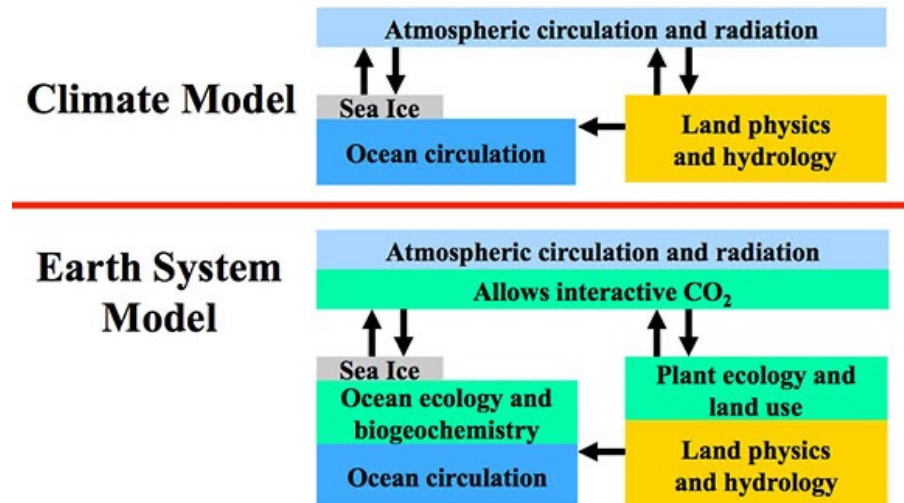# WOMBAT and its alternatives in MOM6

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COSIMA meeting, 14 July 2022

Motivations for ocean BGC modelling

- Carbon climate feedbacks

- Earth system modelling (ESM)

- Ocean acidification and de-oxygenation

- Carbon accounting

- Boundary conditions for regional models

- Ecological relevance (e.g. primary productivity, fisheries)

- Additional fields for assessing model relative to observations

An Earth System Model (ESM) closes the carbon cycle

Climate Model
- Atmospheric circulation and radiation
- Sea Ice
- Ocean circulation
- Land physics and hydrology

Earth System Model
- Atmospheric circulation and radiation
- Allows interactive CO_2
- Sea Ice
- Ocean ecology and biogeochemistry
- Ocean circulation
- Plant ecology and land use
- Land physics and hydrology

https://soccom.princeton.edu/content/what-earth-system-model-esm

Whole Ocean Model with Biogeochemistry and Trophic-dynamics (WOMBAT)

WOMBAT is the BCG model used in

- OFAM3 (Oke et al., 2013)

- ACCESS-ESM 1.0 (Law et al., 2017)

- ACCESS-ESM 1.5 (Ziehn et al., 2020)

And now

- ACCESS-OM2

    - With optional 2-way coupling to sea ice nutrient and algae

    - All 6 configurations in https://github.com/COSIMA/*deg_jra55_* now have 2 branches:

        - **master**: physics only

        - **master+bgc**: physics+BGC

https://www.eurekalert.org/news-releases/474850

WOMBAT in ACCESS-OM2

Each ocean cell carries 10 additional prognostic tracers:

- **N**: nutrient (phosphate)

- **P**: phytoplankton

- **Z**: zooplankton

- **D**: detritus (dead Z, messy eating and poop)

- **ADIC**: anthropogenic + natural dissolved inorganic carbon

- **DIC**: natural dissolved inorganic carbon

- **CaCO3** (calcium carbonate)

- **Fe** (iron)

- **Alkalinity**

- **O2** (dissolved oxygen)

Assumed Redfield ratio of 1:16:106:−172 (P:N:C:O2) with phosphate, nitrate, carbon and oxygen

- Carrying 10 extra tracers slows down MOM5 by about 1.85x at 0.1°
- MOM6 tracers are cheaper due to longer tracer timestep

These tracers **react** with each other in each cell.

They are also are **advected** and **mixed** by the ocean physics just like any other tracer.

They don't affect the physical model (velocity, temperature, salinity) at all (we omit the phytoplankton control on shortwave penetration, which is instead governed by seasonal climatological chlorophyll data)

ADIC, DIC, Fe, O2 also have **surface fluxes**

Sediment pools for CaCO3 and detritus

WOMBAT

$$\bar{J}(z,t,T,N,Fe) = J_{\max}(T)$$

Phyto growth rate depends on temp, light, nutrient and iron

$$\times \min\left[\frac{J(z,t,T)}{J_{\max}(T)}, \frac{N}{N+k_N}, \frac{Fe}{Fe+k_{Fe}}\right]$$

$$J(z,t,T) = J_{\max}(T)\left(1 - \exp\left(\frac{-\alpha I(z,t)}{J_{\max}(T)}\right)\right)$$

$$I(z,t) = PAR \times I(0,t) \times Frac(z)$$

$$J_{\max}(T) = ab^{cT},$$

$$\frac{dN}{dt} = \mu_D D + \gamma_2 Z + \mu_P P - \bar{J}(z,t,T,N,Fe)P$$

$$\frac{dFe}{dt} = 0.02\frac{dN}{dt}$$
$$- \tau_{scav}\max(0, Fe - 0.6)$$

$$\frac{dDIC}{dt} = \frac{106}{16}\frac{dN}{dt} - \frac{dCaCO_3}{dt}$$

$$\frac{dALK}{dt} = -\frac{dN}{dt} - 2\frac{dCaCO_3}{dt}$$

ADIC, DIC, Fe, O2 also have surface fluxes

DIC and ADIC differ only in atmospheric CO2 concentration

$$\frac{dO_2}{dt} = -\frac{172}{16}\frac{dN}{dt}$$

Oke et al., 2013
Kearney et al., 2021

nutrient — uptake / mortality — phyto.
nutrient ← excretion
Fe — scavenging
DIC
Alk
grazing
egestion
zoo
mortality
remineralization
detritus
CaCO3

$$\frac{dP}{dt} = \bar{J}(z,t,T,N,Fe)P - G(P,Z) - \mu_P P$$

$$G(P,Z) = \frac{g\epsilon P^2}{g + \epsilon P^2}Z, \quad \text{Grazing of phyto by zoo}$$

$$\frac{dZ}{dt} = \gamma_1 G(P,Z) - \gamma_2 Z - \mu_Z Z^2$$

$$\frac{dD}{dt} = (1-\gamma_1)G(P,Z) + \mu_Z Z^2 - \mu_D D - w_D\frac{dD}{dz}$$

$$\frac{dCaCO_3}{dt} = \frac{0.08 \times 106}{16}\left((1-\gamma_1)G(P,Z) + \mu_Z Z^2\right)$$
$$- \mu_{caco3}CaCO_3 - w_{caco3}\frac{dCaCO_3}{dz}$$

Other BGC models

- Large variety – there's no standard BGC equation set
- Different sets of state variables, governing equations, parameters, etc
- Different degrees of complexity
- Tradeoff between model detail and speed
- Many empirical parameterisations and parameters, often poorly constrained

BGC models already available in MOM6

https://github.com/NOAA-GFDL/ocean_BGC

- **BLING** – much simpler than WOMBAT; used in GFDL's CM4.0

- **COBALT** – much more complex than WOMBAT, used in GFDL's ESM4.1

- **TOPAZ** – superseded by COBALT? Apparently not maintained?

- **miniBLING** – the original, even simpler BLING? Apparently not maintained?
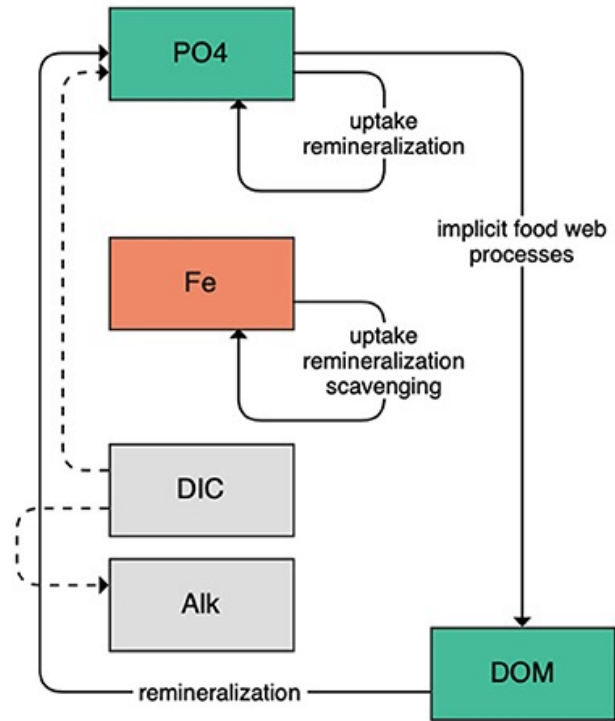
The model zoo

Size scale

pm   nm   um   mm

BLING

Or miniBLING?

Boxes: state variables

Solid lines: fluxes

Dotted lines: linked in proportion

Functional role

N-fixers

producers

Si

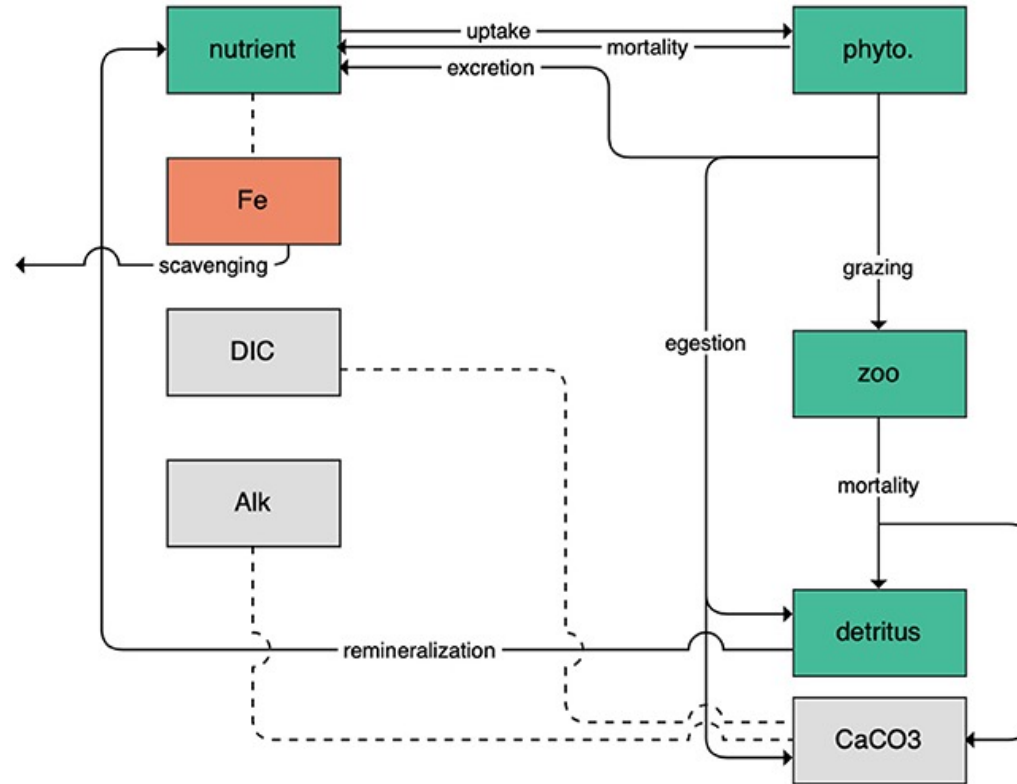CaCO3

consumers

detritus

Kearney et al., 2021

The model zoo

Size scale

Boxes: state variables

Solid lines: fluxes

Dotted lines: linked in proportion

Functional role

Kearney et al., 2021

The model zoo

Size scale
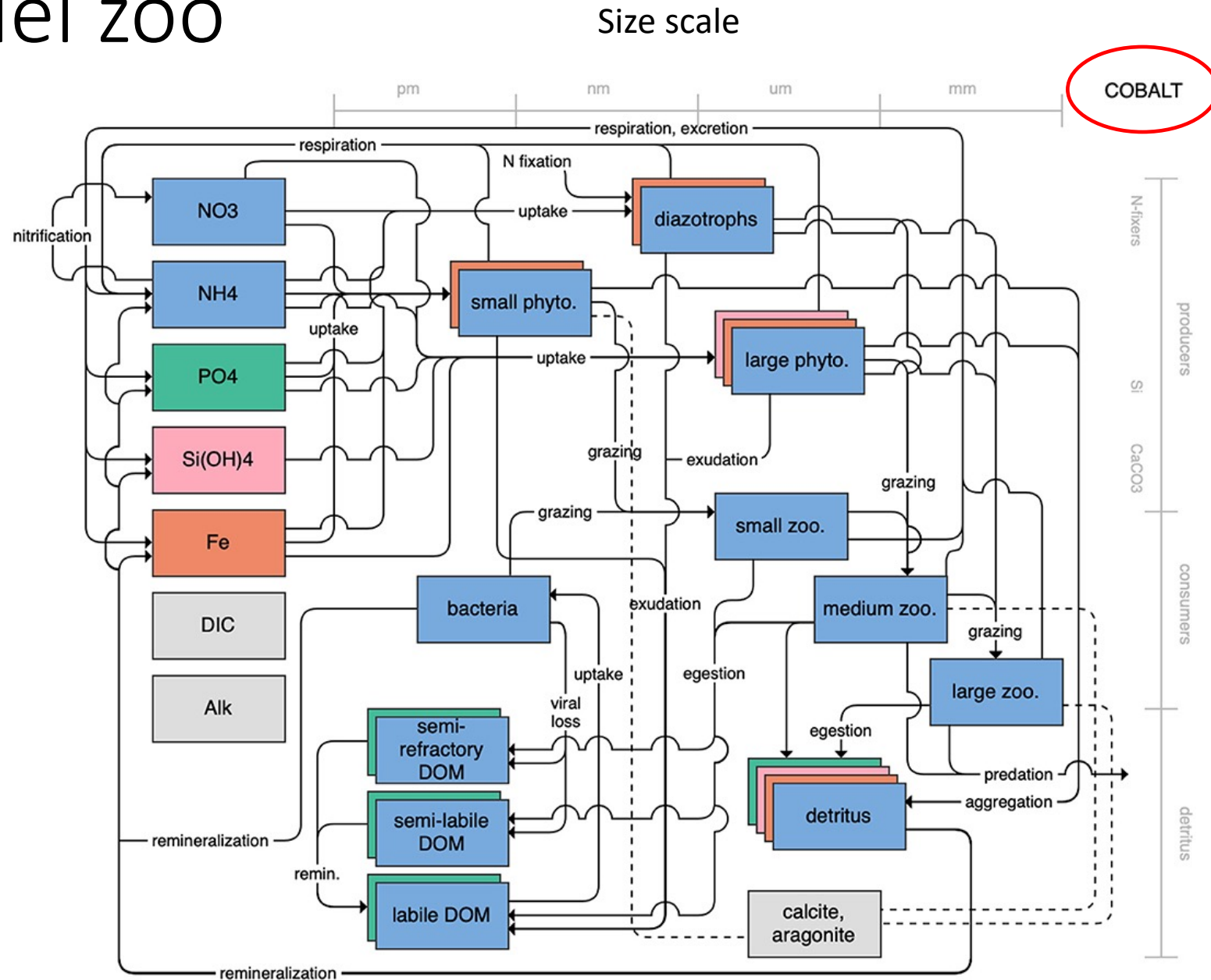
Boxes: state variables

Solid lines: fluxes

Dotted lines: linked in proportion

Functional role

Kearney et al., 2021