An advanced representation of the oceanic biological carbon pump: M^4AGO in HAMOCC

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Representations of POC fluxes in ESMs

Sinking of particulate organic carbon (POC) is represented via:

→ Martin curve (e.g. standard HAMOCC; Mauritsen et al. 2019, following Kriest & Oschlies 2008)

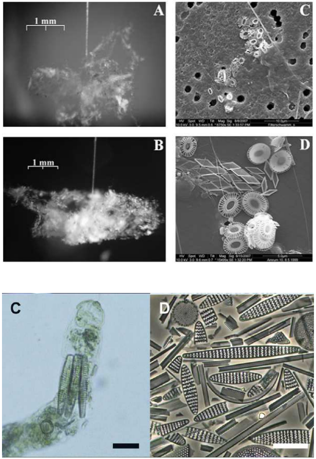
→ POC fractions: 'slow' and 'fast' sinking (e.g. MEDUSA; Yool et al. 2020)

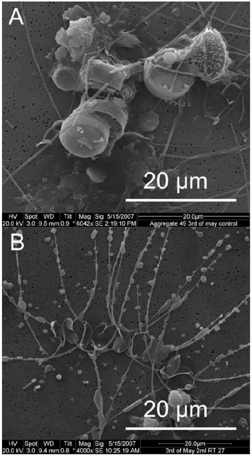
→ Aggregation of POC (e.g. PISCES, NorESM; Gehlen et al. 2006, Schwinger et al. 2016, following Kriest & Evans 2000)

→ Ballasting schemes (e.g. GFDL; Stock et al. 2020, following Armstrong et al. 2002)

With the Microstructure, Multiscale, Mechanistic, Marine Aggregates in the Global Ocean (M^4AGO) sinking scheme, we aim at explicitly representing marine aggregates and their mean sinking velocity, including 'ballasting effects', to advance HAMOCCs representation of the biological carbon pump.

Aggregate composition & microstructure





Aggregates of variable sizes are composed of heterogeneous primary particles with different size and density

Affects:

→ excess density and porosity of aggregates

→ Sinking velocity & eventually POC transfer efficiency

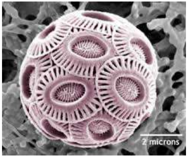
Assmy et al. 2013, Iverson et al. 2010

Aggregates' sinking velocities
→ range from $\approx 1\,\mathrm{m\,d^{-1}}$ to $\gg 200\,\mathrm{m\,d^{-1}}$

Representing poly-dense, poly-sized primary particles

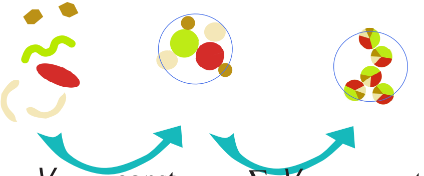
M⁴AGO model core represents heterogeneous aggregate composition by POC, $CaCO_3$, silicate and dust:

Coccolithophores & Diatoms



http://earthguide.ucsd.edu http://joidesresolution.org

→ feature dense $CaCO_3$ and silicate structures

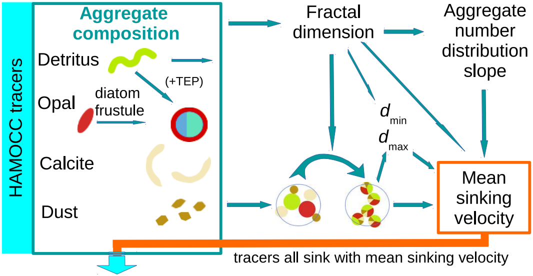


$V_{p,i} = \mathrm{const},\ \rho_{p,i} = \mathrm{const}$

$\sum_i V_{p,i} = \mathrm{const}$
$m = \mathrm{const}$

→ Fractal representation of aggregate microstructure

M^{4}AGO schematic



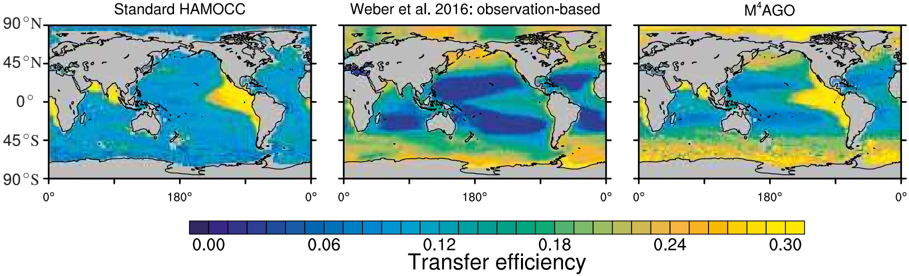
M^{4}AGO captures relevant aggregate properties and

→ explicitly represents heterogeneously composed marine aggregates and their measurable properties (e. g. size, microstructure, porosity, excess density) in HAMOCC

→ implicitly represents aggregation and remineralization-dependent fragmentation

→ includes temperature- and oxygen-dependent remineralization

Improved latitudinal transfer efficiency pattern



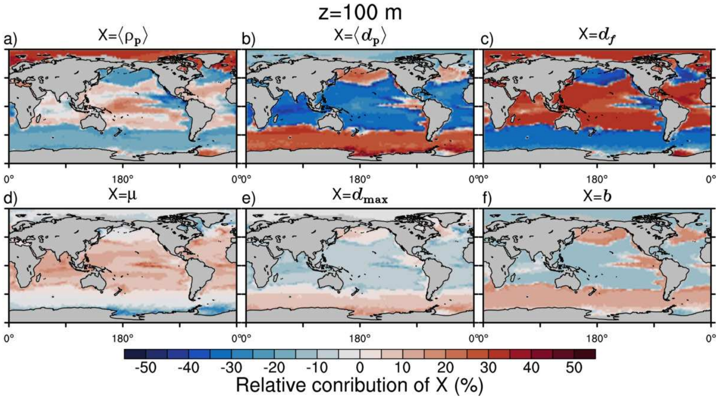
$$\text{Transfer efficiency} = \frac{\text{POC flux at } z \approx 1000\,\text{m}}{\text{POC flux at } z = 100\,\text{m}}$$

Transfer efficiency as a measure, how efficient POC can become sequestered

→ Temperature- and oxygen-dependent remineralization is a strong driver for the transfer efficiency pattern.

→ Spatio-temporally variable sinking velocity contributes to latitudinal transfer efficiency pattern.

Relative contributions of driving factors to $\langle w_s \rangle$

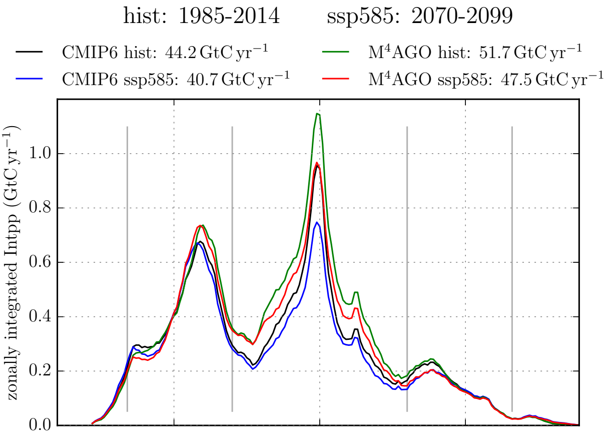


Mean settling velocity, $\langle w_s \rangle$, is primarily driven by

→ mean primary particle density, $\langle \rho_p \rangle$, and size, $\langle d_p \rangle$, and

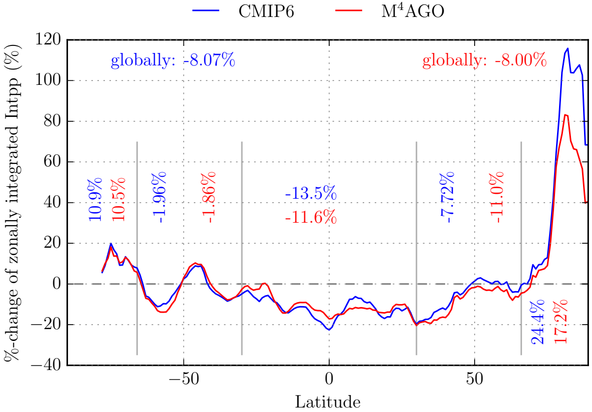
→ potentially the microstructure, d_f, of marine aggregates.

Net primary production (NPP) under ssp585 scenario



→ M^{4}AGO with the temperature-dependent remineralization increases NPP particularly in the equatorial regions compared to standard HAMOCC

NPP under ssp585 scenario



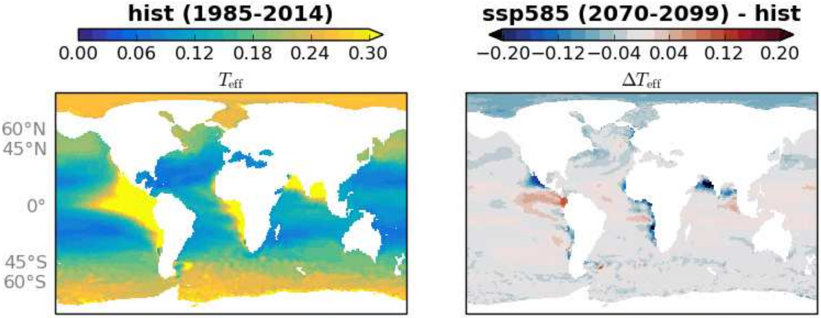
M^4AGO

→ slightly reduces %-decrease of NPP in the equatorial regions

→ weakens NPP %-increase in the Arctic region ($> 66\,^\circ$N)

compared to the standard HAMOCC (CMIP6).

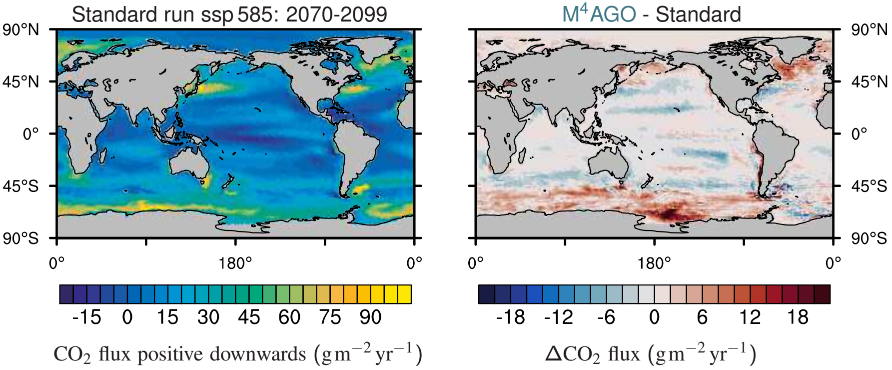
M^4AGO transfer efficiency under ssp585 scenario



→ Strongest future regional changes in transfer efficiency associated to changes in oxygen minimum zones.

→ Transfer efficiency significantly reduced in the Arctic Ocean by the end of the century (still higher than in the standard HAMOCC).

Air-sea CO_2 fluxes under ssp585 scenario



- → Higher transfer efficiency in high latitudes in M^4AGO imprints on CO_2 uptake compared to standard HAMOCC.
- → Global CO_2 fluxes in M^4AGO remain within the standard HAMOCC ensemble spread.

Conclusion

M^4AGO

→ improves the representation of POC transfer efficiency

→ imprints on the latitudinal CO_2 uptake pattern

→ bridges the gap from microscale marine aggregate properties in spatio-temporally variable environments to global impacts on POC and air-sea CO_2 fluxes

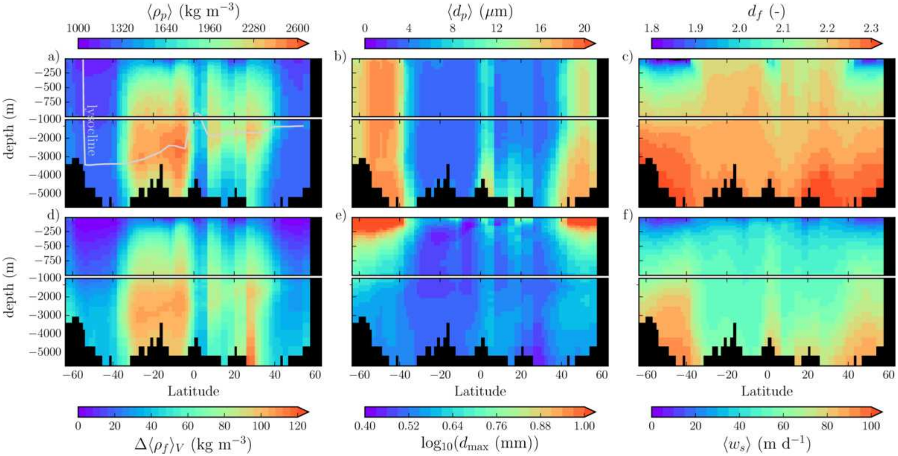
→ provides a link between phytoplankton community & size structure and POC fluxes

→ enables representation of aggregate properties-related processes (e.g. size-dependent remineralization)

Maerz et al. 2020, Biogeosciences (& in prep.)

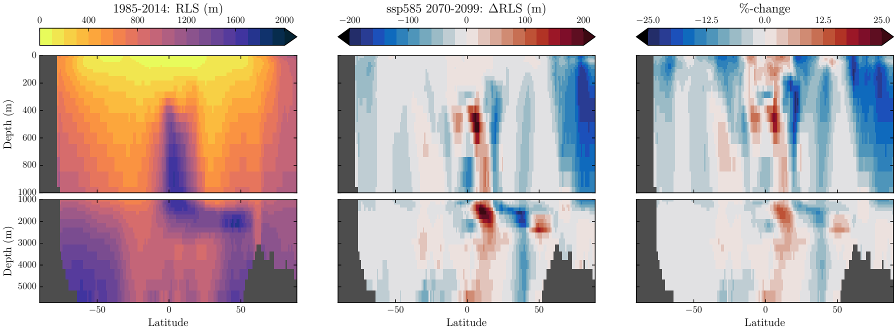
Appendix

M^4AGO aggregate properties (WOA P16, 150°W)



M^4AGO reasonably reproduces the spatio-temporal variability of marine aggregate properties and mean sinking velocity.

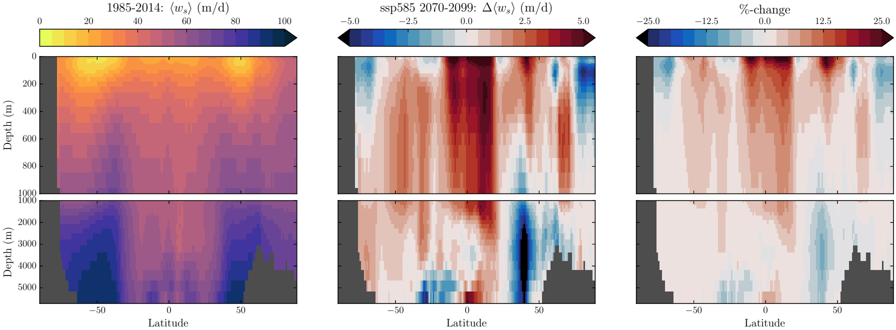
POC remineralization length scale under ssp585



→ Strong changes of POC remineralization length scales in the Arctic region.

→ mesoplegaic changes in the equatorial region linked to OMZ changes

Settling velocity under ssp585



→ Temperature-dependent remineralization enhances $CaCO_3$ ballasting effect on POC.

→ Q_{10}-dependent opal remineralization decreases opal frustule size- effect in high latitude regions.