Coupling of CESM and MEDUSA: the impacts of a sediment model on ocean biogeochemistry modelling

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MOTIVATION - WHY SEDIMENT MODEL?

Long-timescale climate simulations including biogeochemistry components from a G-IG perspective

(Sigman and Boyle, 2000)
• to have a model including slow processes.
  = marine carbon cycle as an “open” system.

• to have sedimentary “archives” in the model

• to assess the influence on bottom water chemistry
Community Earth System Model v1.2 (CESM1.2) 
the Parallel Ocean Program v.2 (POP2) 
Biogeochemical Elemental Cycling model (BEC) 
[e.g., Moore et al., 2004; Moore et al., 2013; Lindsay et al., 2014]

- low resolution: T31_gx3v7
- carbon isotope components (\textsuperscript{13}C and \textsuperscript{14}C)  [Jahn et al., 2015]
- simplified empirical treatment of sediment processes

Model of Early Diagenesis in the Upper Sediment of Adjustable complexity (MEDUSA) v. 2 [Munhoven, 2020]

- vertically resolved
- oxic and suboxic remineralization of organic matter
- parameterized CaCO\textsubscript{3} and opal dissolution
4 DIFFERENT SEDIMENT APPROACHES

[Hülse et al., 2017]
4 DIFFERENT SEDIMENT APPROACHES

[Figure of sediment approaches, showing various interactions between atmospheric, oceanic, and crustal components]
**“Off-line” coupling**
- separate and sequential model runs
- manageability of model development and maintenance

**Modifying the models**
- new variables
- writing/reading routines
- unit conversion
- source/sink terms
- boundary structure

**Interface**
- one-time/one-way coupling
- automation: a wrapper-level routine to repeat it
Shields et al. (2012) + the prescribed ecosys initial state
"ecosys_jan_IC_gxv7_Nov2012_comO2.nc"
EXPERIMENTS

CESM1.2
SPIN UP
4000yrs–eq.
EXPERIMENTS

- CESM1.2 SPIN UP
  4000 yrs–eq.

Solid flux B-water chem.

- MEDUSA SPIN UP $10^5$ yrs
EXPERIMENTS

CESM1.2 SPIN UP
4000 yrs–eq.

MEDUSA SPIN UP
$10^5$ yrs

EXORG [uncoupled]
2000 yrs–eq.
EXPERIMENTS

CESM1.2
SPIN UP

4000yrs–eq.

MEDUSA
SPIN UP
$10^5$ yrs

EXORG
[uncoupled]

2000yrs–eq.

EXCPL
[coupled]

2000yrs–eq.
AMOC AND MORE

AMOC: 16.6 Sv
Exp Prod: 8.1 GtC
Rain Ratio: 0.13
$pCO_2$: 276.94 ppm

AMOC: 16.7 Sv
Exp Prod: 8.0 GtC
Rain Ratio: 0.13
$pCO_2$: 276.57 ppm

Total inventories in the global ocean

<table>
<thead>
<tr>
<th></th>
<th>EXCPL</th>
<th>EXORG</th>
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</thead>
<tbody>
<tr>
<td>DIC (GtC)</td>
<td>$3.660 \times 10^4$</td>
<td>$3.657 \times 10^4$</td>
</tr>
<tr>
<td>ALK (Peq)</td>
<td>$3.201 \times 10^3$</td>
<td>$3.201 \times 10^3$</td>
</tr>
<tr>
<td>PO$_4$ (Pmol)</td>
<td>2.948</td>
<td>2.923</td>
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The outlines of ocean state was hardly affected by the different ways of sediment-process treatment at a millennial timescale.
UPPER SEDIMENT COMPOSITION

Weight fraction: $\text{CaCO}_3$

- process-based calculation by the model
- more reliable in another climate state

- prescribed spatially-constant lysocline depth
- not necessarily adequate for another climate state

Seiter et al. (2004)
UPPER SEDIMENT COMPOSITION

Weight fraction: org. C

EXCPL

EXORG

Obs.-based data

Seiter et al. (2004)

Weight fraction: opal

EXCPL

EXORG

Obs.-based data

Seiter et al. (2004)
POC & OPAL BURIAL RATIO

POC flux to the ocean floor [mmolC m\(^{-2}\) d\(^{-1}\)]

Opal flux to the ocean floor [mmol m\(^{-2}\) d\(^{-1}\)]
0.2‰ or larger difference in a millennial-scale simulation
→ non-negligible in model-data comparison
EFFECTS ON BOTTOM-WATER CHEMISTRY

[EXCPL - EXORG] \( \Lambda \delta^{13}C \)

due to different flux from the sediment
due to water mass displacement

0.2\% or larger difference in a millennial-scale simulation → non-negligible in model-data comparison
V and $\delta^{13}C$ @ $\sim3900$ m

(a) [EXORG]  (b) [EXCPL]
SUMMARY AND OUTLOOK

- Interactive coupling of CESM1.2 and MEDUSA.

- Much better reconstructed upper sediment properties.
  - Additional measures for model performance by direct comparison with the sedimentary archives.

- Non-negligible effects on the chemical composition of bottom water at a millennial timescale.
  - Influence on model-data comparisons.

- Dynamical CaCO$_3$ diagenesis for future long-term simulations.