- Sensitivity of biogeochemical models to the treatment of particle dynamics –

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Q1: How should models of ocean biogeochemistry represent particles?

Approach n° 1

identical circulation, sensitivity to process parameterization

short simulations => dissolved tracers not adjusted

observations:

- global integrated numbers
- derived quantities
- particle flux
Sensitivity to model parameterizations

PISCES =>
model of intermediate complexity
24 tracers

standard version
2 particle size classes;
prescribed sinking speed

Exp.1: resolving size
prognostic sinking speed
Exp.2: role of zooplankton
Settling flux: big POC
small POC
biogenic Si
CaCO₃

2 size classes: « small », « big »

Aggregation due to turbulence and
differential settling

- sinking speed is prescribed
PISCES STD version: validation

May

SeaWifs

November

PISCES

Chlorophyll in mgChl/m³

Gehlen et al. (2006)
PISCES STD version: validation

May

November

SeaWifs

SeaWifs

PISCES

PISCES

⇒ PP: independent estimate: 40-60 Gt C per year after Carr et al. (2006)
⇒ this model version: 26 Gt C per year

Chlorophyll in mgChl/m³

Gehlen et al. (2006)
PISCES STD version: validation

Export production (100 m)
PISCES STD version: validation

Export production (100 m)

Laws et al. (2000) 11 Gt C per year
Schlitzer (2000) 11
Model 8

POC export at 100m (molC/m²/y)
PISCES STD version: validation

PE-ratio (depth of euphotic zone)

$r^2 = 0.0863$

Dunne et al. 2005

Gehlen et al. (2006)
PISCES STD version: validation  

Deep fluxes (>1000 m)

modeled POC flux (mmol C/m2/yr)

observed POC flux (mmol C/m2/yr)

Gehlen et al. (2006)
PISCES STD version: validation  

Sediment-water interface

- Independent observations:
  - POC deposition, 0.5 GtC/y*
  - POC burial, 0.002–0.12 GtC/y*
  - O₂ fluxes, Jahnke (1996)
    - 46.8 Tmol O₂/y

- Model: ORCA/PISCES
  - POC deposition d>1000 m, 0.4 GtC/y
  - POC burial, 0.17 GtC/y
  - O₂ fluxes, 22.1 Tmol O₂ per year

* d>1000m; Seiter et al. (2005)

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Jahnke (1996)

Model

Benthic oxygen fluxes (mol/m²/y)

Gehlen et al. (2006)
**PISCES STD version: validation**  
Sediment-water interface

- **independent observations:**
  - POC deposition, \(0.5 \text{ GtC/y}\)^*\(\)  
  - POC burial, \(0.002–0.12 \text{ GtC/y}\)^*\(\)  
  - \(O_2\) fluxes, Jahnke (1996)

- **model: ORCA/PISCES**
  - POC deposition \(d>1000\text{ m}\), \(0.5 \text{ GtC/y}\)  
  - POC burial, \(0.19 \text{ GtC/y}\)  
  - \(O_2\) fluxes, \(26.1 \text{ Tmol O}_2/\text{yr}\) per year

⇒ Model underestimates diffusive oxygen fluxes:  
low deep POC fluxes or low re-mineralization intensity?

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![Map of benthic oxygen fluxes](image)

**Jahnke (1996)**

**model**

benthic oxygen fluxes (mol/m²/yr)

**Gehlen et al. (2006)**
Preliminary conclusions: PISCES STD vs data

- It appears difficult to reconcile surface ocean observations – particles fluxes and oxygen profiles

- Probing model « performance » with different data sets yields contrasting results => data sets integrate varying spatio-temporal information

- Constrains on model results decrease with increasing depth: data from mid- to deep water column are needed, but not without connexion to surface ocean processes

Testing alternative parameterisations ...
EXP1 : Testing the importance of size

Hypothesis : 1. Distribution of particles sizes
\[ P(\theta) = A \theta^{-\varepsilon} \]

2. Mass of a particle
\[ m(\theta) = C \theta^{\xi} \]

3. Sinking speed
\[ w(\theta) = B \theta^{\eta} \]

B, C, \eta and \xi are constant

Aggregation and disaggregation due to turbulent shear and differential settling

Model traces evolution of particle mass and number distributions

\[ \Rightarrow \text{sinking speed of particles is predicted} \]  

Kriest and Evans (1999, 2000)
Testing the importance of size

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Kriest and Evans (1999, 2000)
Export production (100 m)

Schlitzer (2000)
PISCES STD
PISCES Ballast
PISCES K&E, low FF
Export production (100 m)

Laws et al. (2000) 11 Gt C per year
Schlitzer (2000) 11
Model STD 8
K&E low FF 5

POC export at 100m (molC/m2/y)
• independent observations:

POC deposition, 0.5 GtC/y  *
POC burial, 0.002–0.12 GtC/y  *
$F_{O_2}$, Jahnke (1996) 46.8 Tmol $O_2$/y  *
  * d>1000m; Seiter et al.(2005)

• model: PISCES/K&E

POC deposition d>1000m, 0.5 GtC/y
POC burial, 0.19 GtC/y
$F_{O_2}$, 26.1 Tmol $O_2$ per year
Preliminary conclusions: resolving size

- Difficulties in reconciling surface ocean observations – particles fluxes and oxygen profiles: rapid decrease below surface, close to constant fluxes at depth – What is missing?

- Probing model « performance » with different data sets yields contrasting results:
  
  PE-ratios:
  - resolution of particle size spectrum is needed

  Deep POC fluxes (trap data):
  - model capability to reproduce yearly mean POC fluxes below 2000m and benthic oxygen demand does at first order not dependent on the resolution of the particle size spectrum
EXP2: the role of zooplankton

Exploring the role of mesopelagic biological processes

Flux feeding = Mesozooplankton Feeding type

controls deep fluxes ...

low = as in STD version

Flux feeding intensity

POC Flux
Changing the flux feeding intensity

**low**

**high**

Chlorophyll in mgChl/m³

POC export at 100m (molC/m²/y)
Changing the flux feeding intensity

low

⇒ PP: independent estimate: 40-60 Gt C per year after Carr et al. (2006)
⇒ STD low FF 26 Gt C per year
⇒ STD high FF 43

high

⇒ EP: Schlitzer (2000) 11 Gt C per year
⇒ STD low FF 8
⇒ STD high FF 11
Changing the flux feeding intensity

- Model POC flux (mmol C/m²/yr)
- Observed POC flux (mmol C/m²/yr)

*Low flux feeding intensity*
*High flux feeding intensity*

Large impact of fluxes
Changing the flux feeding intensity

- independent observations:
  POC deposition, $0.5 \text{ GtC/y}^*$
  POC burial, $0.002–0.12 \text{ GtC/y}^*$
  $O_2$ fluxes, Jahnke (1996)

  $46.8 \text{Tmol } O_2/\text{y}$
  $^* \text{ d}>1000m; \text{Seiter et al.}(2005)$

- model: ORCA/PISCES
  POC deposition $d>1000 \text{ m}$, $0.4 \text{ GtC/y}$
  POC burial, $0.17 \text{ GtC/y}$
  $O_2$ fluxes,

  $22.1 \text{Tmol } O_2 \text{ per year}$

⇒ starved benthos!

[Map showing benthic oxygen fluxes (mol/m$^2$/y)]
Zooplankton

PISCES
2 size classes:
- micro- and
- mesozooplankton

Limitations

- no life stages, biomass varies instantaneously with preys
- no vertical migrations
- mortality of mesozoo is a closure term
NMFS global mesozooplankton distribution ($\mu$molCm$^{-3}$), 0-200 m

CPR mesozooplankton distribution ($\mu$molCm$^{-3}$), 0-10 m

Zonal averaged mesozooplankton distribution ($\mu$molCm$^{-3}$) modeled and observed
Bridging the gap from ocean models to population dynamics of large marine predators: A model of mid-trophic functional groups

Patrick Lehodey, Raghu Murtugudde, Inna Senina

The model has:

**Zooplankton**: 1 functional group

**Micronekton**: 6 functional groups in 3 vertical layers; 3 groups with daily vertical migrations

**Forcing**: Temperature, currents and Primary Production.

Relationship between temperature and development time of post-embryonic (hatching to adult) zooplankton species (rotifers, copepods and cladocerans) incubated at different constant temperatures. From Gillooly et al. (2002)
Q1: How should models of ocean biogeochemistry represent particles?

1. Link between surface ocean productivity and POC export at the base of the euphotic zone: particle size spectrum has to be resolved (PISCES-K&E) yielding a prognostic sinking speed.

2. Fate of POC fluxes in the twilight zone: evolution of fluxes most sensitive to the intensity of zooplankton flux feeding (composition of zooplankton community).

3. Capability of model to reproduce yearly averaged POC fluxes below 1000 m and benthic oxygen demand: independent of the resolution of the particle size spectrum.
Q2: What measurements of particles should GEOTRACES make?

Approach n° 2

extending standard biogeochemical model to TEI long simulations => dissolved tracers in equilibrium

observations:

dissolved distributions
particle fields
Simulation of $^{231}\text{Pa}$ and $^{230}\text{Th}$ w/NEMO-PISCES

Kd from Siddall et al, 2005

Courtesy to Jean-Claude Dutay (LSCE)

Dutay et al, 2009
Constraints from global budget

Global Source = Global Sink

\[ \int [\beta - \lambda (A_d + A_p) \, dv] = \int - (w_s \, A_p)_{fond} \, ds \]

\[ \beta \cdot z_{oc} \cdot \text{surf} = A_p \text{ (bottom)} \cdot W_s \text{ surf} \]

Constraint from Observations: \( A_p \) (Th) \((0.1) \) dpm/m3 \( \rightarrow \) \( w_s \sim 1000 \) m/an

Small particles are controlling the vertical profile

Constraint on Kd from Observations

Observations: \( A_p/A_d \sim 1/10 \)

\[ K_p = A_p/(A_d \cdot C_p) \]

PISCES Model: \( C_p \sim 10^{-8} \) gr/gr(sea water)

\( \rightarrow \) \( K_p \sim 10^9 \)
Simulation of $^{231}\text{Pa}$ and $^{230}\text{Th}$ w/NEMO-PISCES

Kd as a function of particle size classes

<table>
<thead>
<tr>
<th>Kd</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>POCs</td>
<td>$1.0e+7$</td>
<td>$1.0e+9$</td>
</tr>
<tr>
<td>KPOCs</td>
<td>$1.0e+7$</td>
<td>$1.0e+9$</td>
</tr>
<tr>
<td>KPOCb</td>
<td>$1.0e+7$</td>
<td>$1.0e+6$</td>
</tr>
<tr>
<td>POCb</td>
<td>$1.0e+7$</td>
<td>$1.0e+6$</td>
</tr>
<tr>
<td>BSi</td>
<td>$0.17e+7$</td>
<td>$0.17e+7$</td>
</tr>
<tr>
<td>BSi</td>
<td>$0.05e+7$</td>
<td>$0.05e+7$</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>$0.025e+7$</td>
<td>$0.025e+7$</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>$1.0e+7$</td>
<td>$1.0e+7$</td>
</tr>
</tbody>
</table>

Siddall et al, 2005
EMIC

Thorium 230
Dutay et al, 2009

improved model fit, but Kd values are too large compared to obs.
Simulation of $^{231}$Pa and $^{230}$Th w/NEMO-PISCES

Assessment of model particle fields

Estimation derived from satellite data, loisel et al, 2007

Data along the W. Atlantic GEOSECS section (brewer et al., 1976), units µg/kg.
Q2: What measurements of particles should GEOTRACES make?

Every measurement is valuable!
1. particle concentration from surface to deep
2. particle characterization (e.g. size, composition, specific surface)
3. particle flux and sinking speed
4. lab experiments needed in order to constrain reaction rates!

if possible integrated data sets ...

be aware of match/mismatch between scales when comparing model output to data