An Ocean Methane Cycle for CESM

Mathew Maltrud
COSIM
Los Alamos National Laboratory

Scott Elliott (LANL)
Matthew Reagan, George Moridis, William Collins (LBNL)
Philip Cameron-Smith, Subarna Bhattacharyya, Dan Bergmann (LLNL)

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Goals

- Ocean Component of IMPACTS
  - Background methane
  - Enhanced sea floor fluxes
- Tracegas module
  - Also a DMS module
- Inclusion into CESM release
  - Requirements document?
  - Leaves ecodynamics unchanged
  - How much support?
Why do we care about ocean methane?

- Strong greenhouse gas
- Global contribution (0.4 Tg CH$_4$/yr) much smaller (< 1%) than terrestrial
- High latitude clathrrates and underwater permafrost
The Elusive Sea Heifer
Sea floor (shelf depth) temperatures expected to increase

Change in bottom temperature (K) after 100 years from 16 different models (1 realization each) for 1%/year
J.-F. Lamarque, GRL 2008

Change in bottom temperature (K) averaged over the Barents Sea (100 to 1000m) from A1B scenarios
Model Characteristics

- 4 types of methane
  - Natural background due to biological activity
  - Background sea floor (seeps, etc)
  - Atmospheric
  - Enhanced background (clathrates, permafrost)
Model Mechanism

- Each type is standard source/sink

\[
\frac{\partial [CH_4]}{\partial t} + \mathbf{u} \cdot \nabla [CH_4] = Source - Removal + Diffusion
\]

- Source (only for background biological in top 250m)

\[
Source = S_0 \frac{O_2^{max} - O_2}{O_2^{max}} \text{ for } O_2 < O_2^{max} \text{ (only if } > 0)
\]

\[
S_0 = 10^{-5} \mu M/day ; O_2^{max} = 300 \text{ mmol/m}^3
\]

- Consumption (empirical fit to data)

\[
Removal = CH_4/\tau \quad \log_{10}\tau = 1 - \log_{10}[CH_4]
\]

- Surface flux standard Wanninkhof air-sea transfer with constant 1.75ppb in atmosphere
Model Mechanism

- Background sea floor
  - Imposed bottom flux
  - $3 \times 10^{-10}$ mole/m$^2$s for $100m < \text{depth} < 1000m$

- Atmospheric
  - Into undersaturated water

- Same consumption relation as biological
Results from “background” cycle

- gx1v3 (40 levels)
- GM, KPP
- LW advection
- CESM-BEC (~2008)
- 6-hourly normal year
- 0.5 Tg CH₄/yr

Surface concentration (nM) after 30 years

Saturation ratio
Clathrates

- 2 choices for introducing methane
  - Applied bottom flux
    - Includes vertical transport velocity (can be 0)
  - Source profile
- $10^{-6}$ mole/m²s
  - Computed by Reagan and Moridis (JGR, 2008) from detailed sub-floor clathrate model
Locations of Methane Clathrate Release

- Single grid points
- 300m depth
- 8 locations
**Clathrate Results**

- Methane does not spread very far from source
- Small amount is released into the atmosphere

**Vertically Integrated CH$_4$ Distribution after 30 Years**

Percent of patch methane released into atmosphere
Effects of Clathrate release

- Possible hypoxia in Sea of Okhotsk and Bering Sea
- Increase in acidity
Methane Removal Limitation

- Removal time scale very short (days) at high concentration
- Removal assumes no nutrient (or $O_2$) limitation
  - Methanotrophs require Fe, Cu
- What if no methane is removed?
  - Worst case scenario
- Other sensitivities?
Sensitivities

- Can get a wide range of atmospheric releases

- 1 month min removal time
- 50m injection
- inert
- inert

1 month min removal time
50m injection

year since beginning of patch fluxes

percent
Current and Future Work

- Code ported to CESM1.0.3
  - Fully coupled physics, ocean BGC+methane
  - gx1v6 (60 levels)
  - Ran “background” cycle 30 years
  - Very similar results
- Couple with atmospheric chemistry
- Bubble rise
- Higher resolution
- Include with CESM distribution