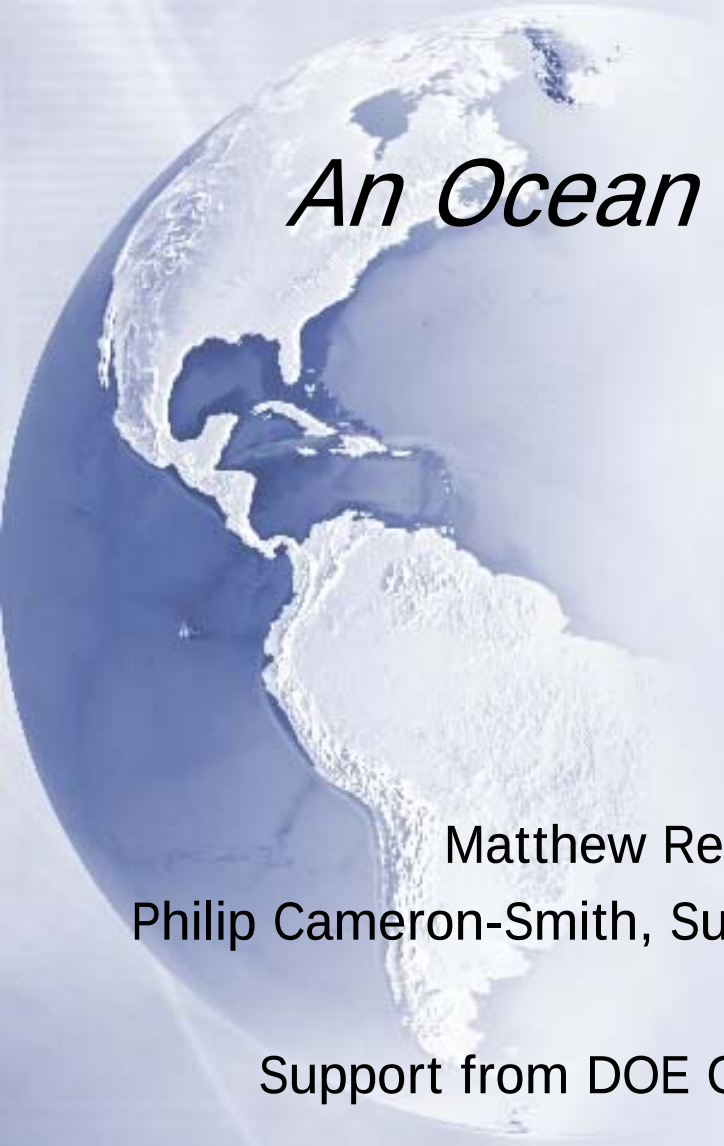

An Ocean Methane Cycle for CESM

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)

Support from DOE OBER (*IMPACTS*) and NETL Hydrate program

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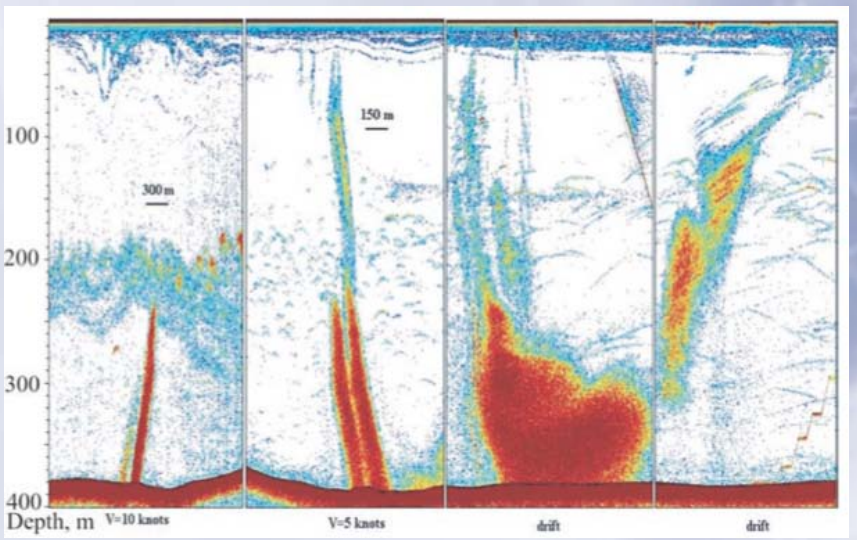
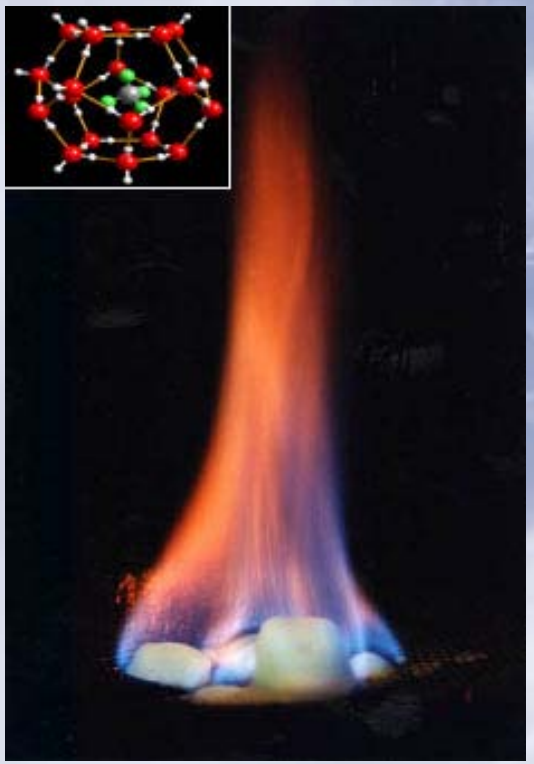
Goals

- 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 clathrates and underwater permafrost



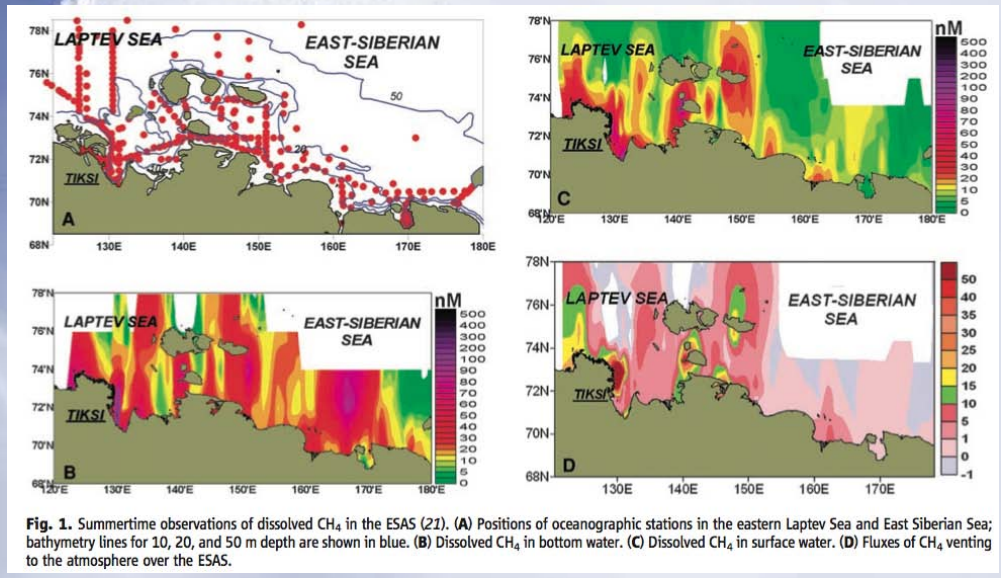


Fig. 1. Summertime observations of dissolved CH_4 in the ESAS (*21*). **(A)** Positions of oceanographic stations in the eastern Laptev Sea and East Siberian Sea; bathymetry lines for 10, 20, and 50 m depth are shown in blue. **(B)** Dissolved CH_4 in bottom water. **(C)** Dissolved CH_4 in surface water. **(D)** Fluxes of CH_4 venting to the atmosphere over the ESAS.

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The Elusive Sea Heifer

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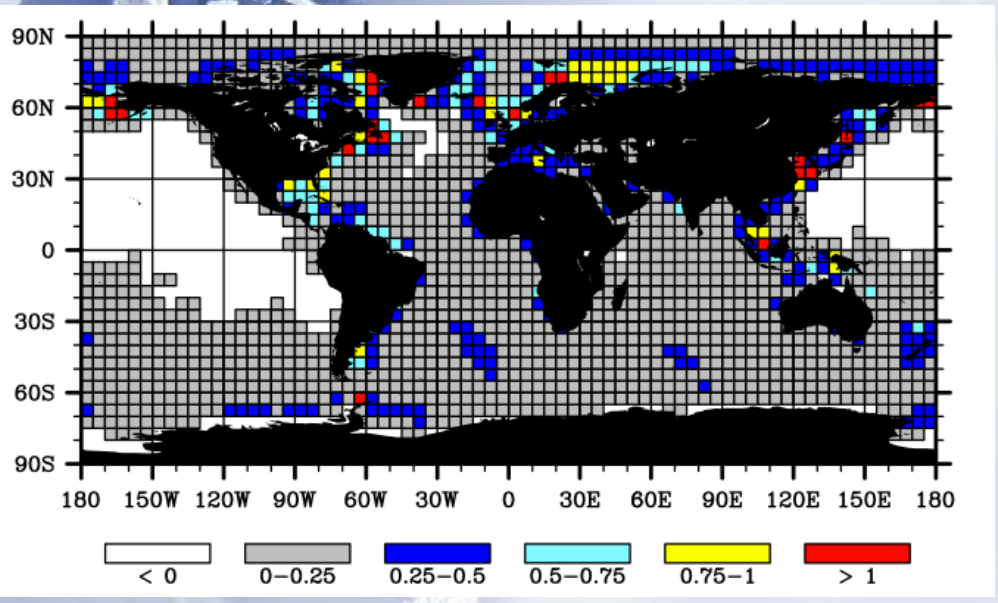
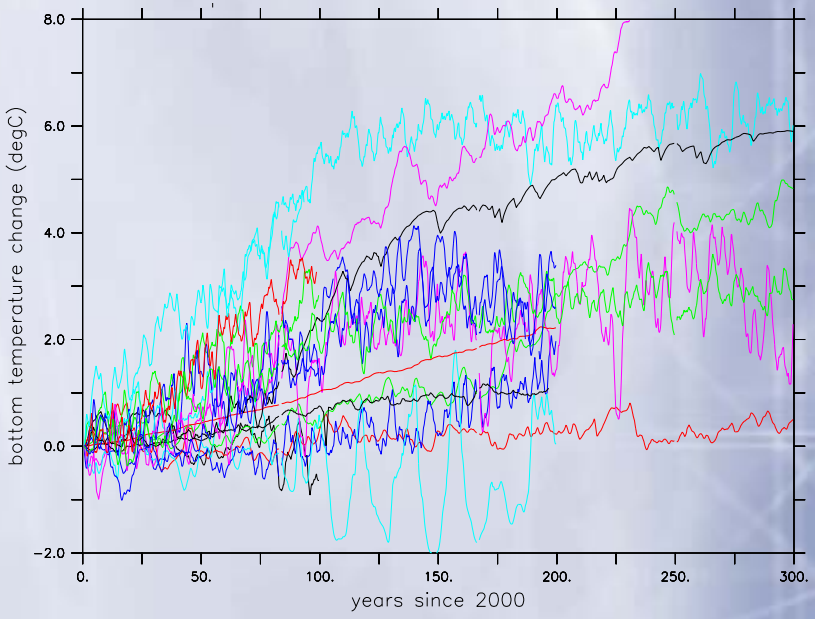
Sea floor (shelf depth) temperatures expected to increase

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

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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)

  $Source = S_0[O_2^{max} - O_2]/O_2^{max}$ for $O_2 < O_2^{max}$ (only if > 0)

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

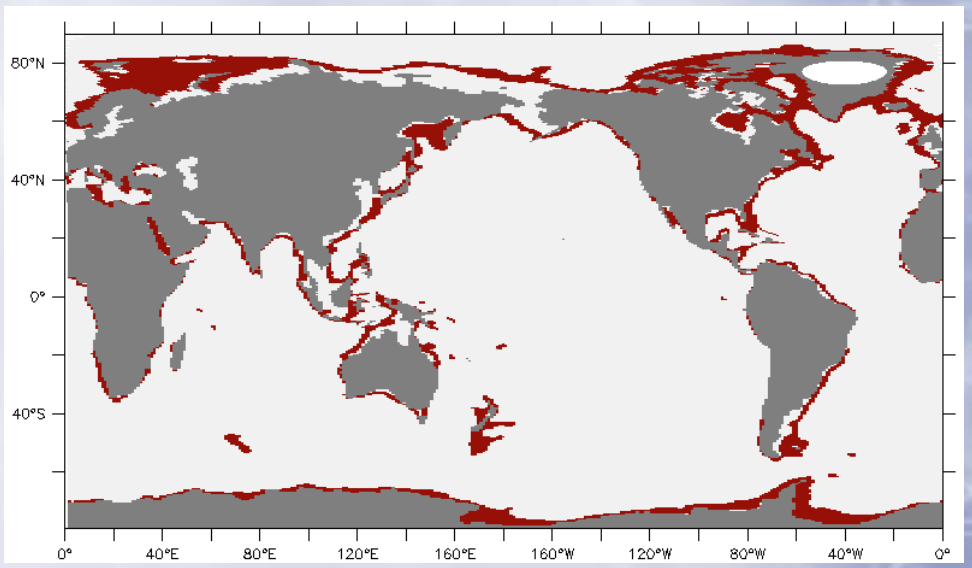
- Consumption (empirical fit to data)

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

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

Model Mechanism

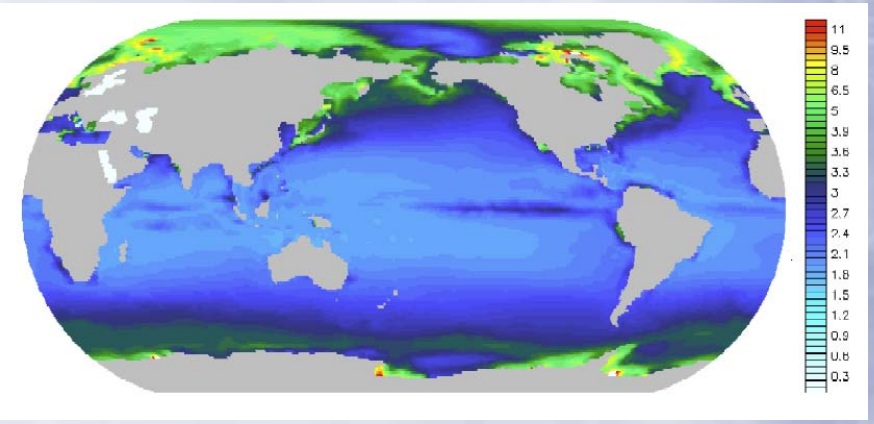
- Background sea floor
  - Imposed bottom flux
  - $3x10^{-10}$ mole/m^2s for 100m < depth < 1000m
- Atmospheric
  - Into undersaturated water
- Same consumption relation as biological



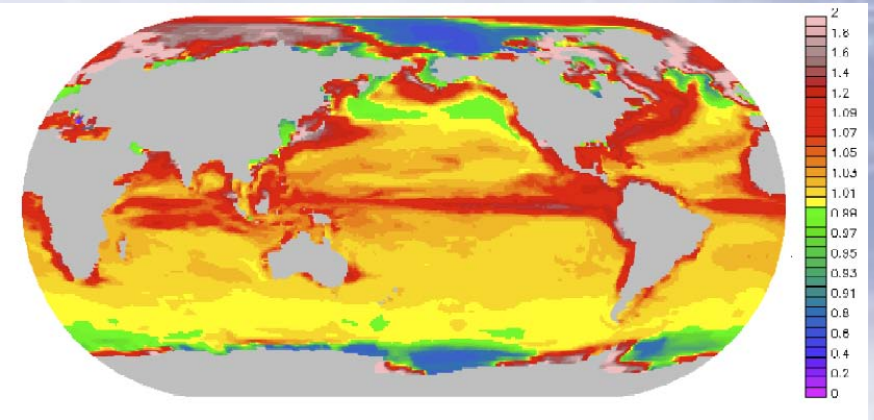
Results from "background" cycle

- gx1v3 (40 levels)
  - GM, KPP
  - LW advection
- CESM-BEC (~2008)
- 6-hourly normal year

- 0.5 Tg CH_4/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/m^2s
  - Computed by Reagan and Moridis (JGR, 2008) from detailed sub-floor clathrate model

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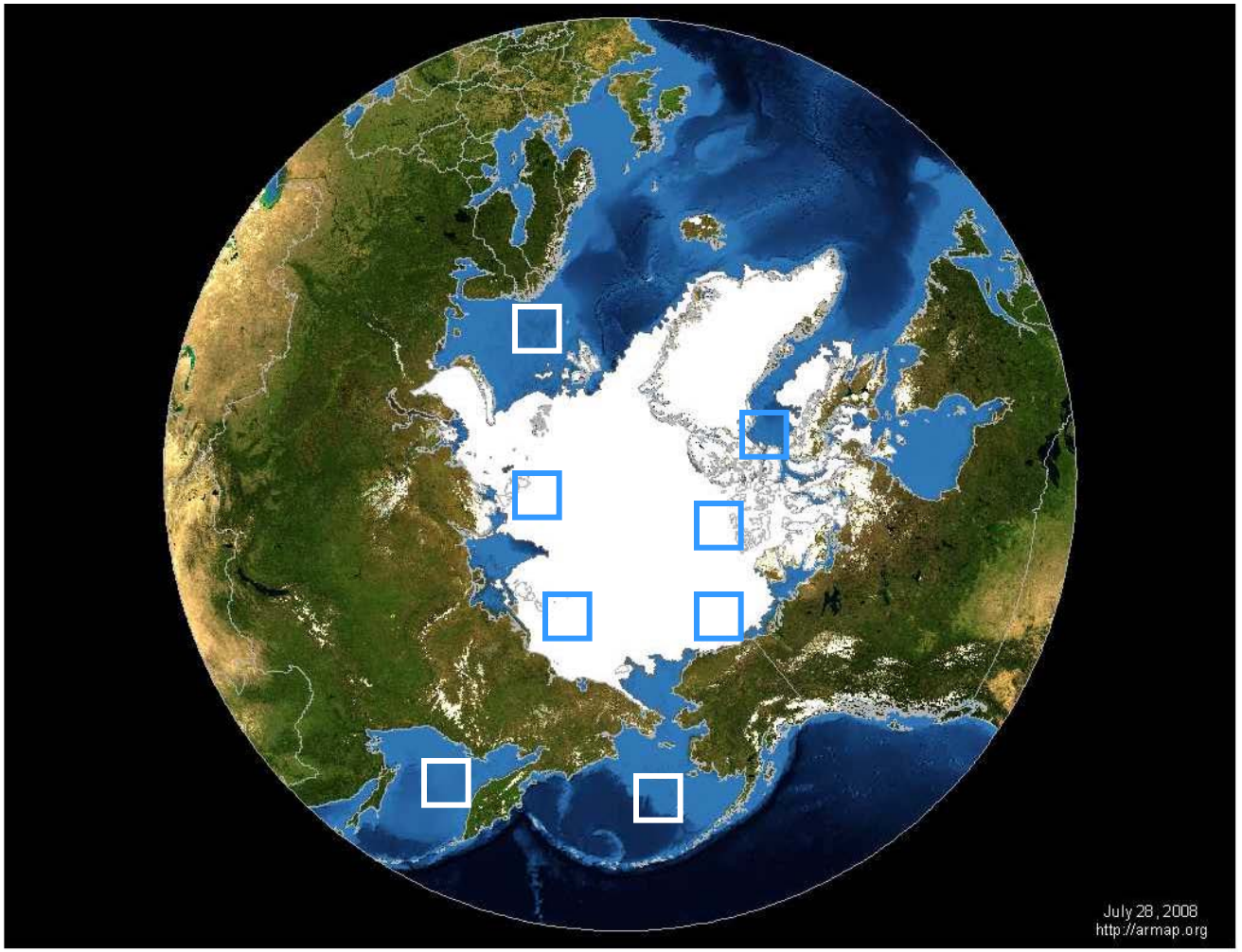
Locations of Methane Clathrate Release

- Single grid points
- 300m depth
- 8 locations



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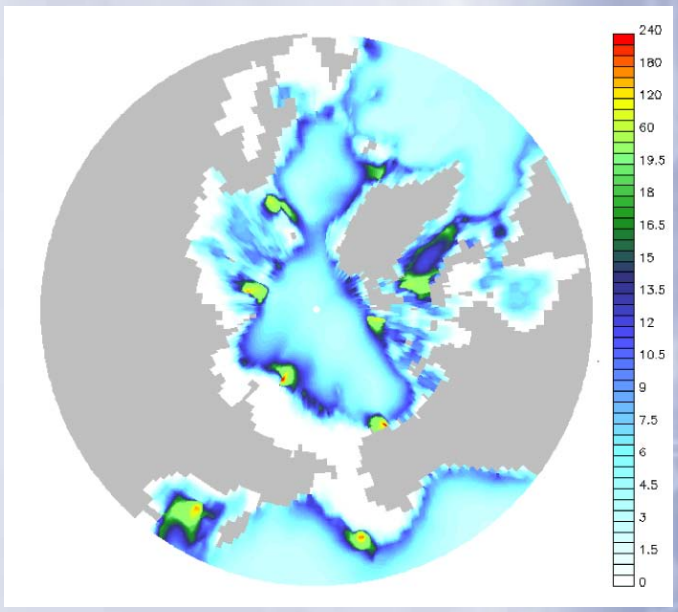
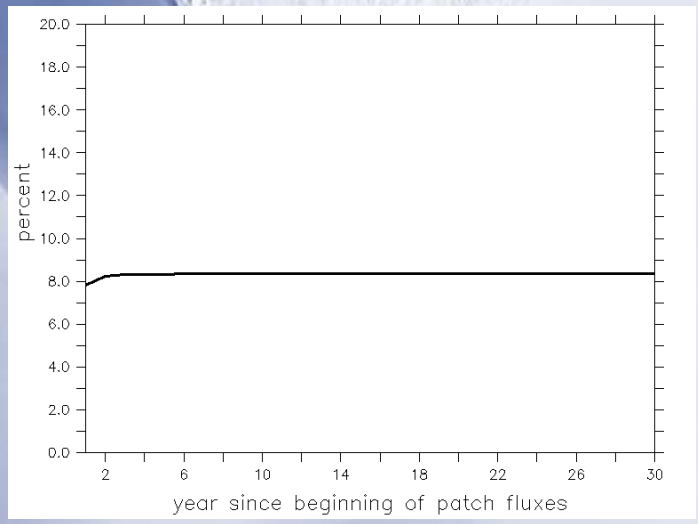
Clathrate Results

- 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

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Effects of Clathrate release

- Possible hypoxia in Sea of Okhotsk and Bering Sea
- Increase in acidity

O_2 concentration ($mmol/m^3$) at 300m

change in pH at 300m

-0.01

-0.05

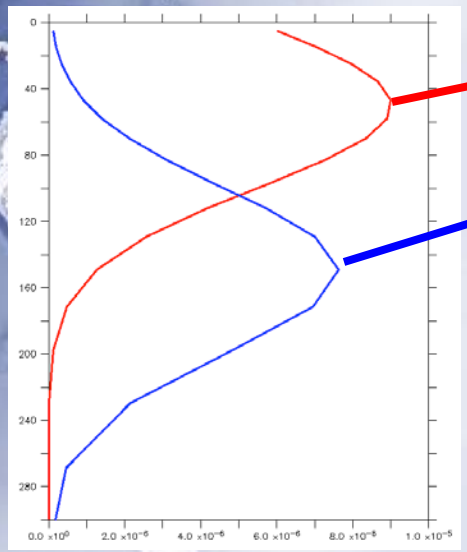
-0.17

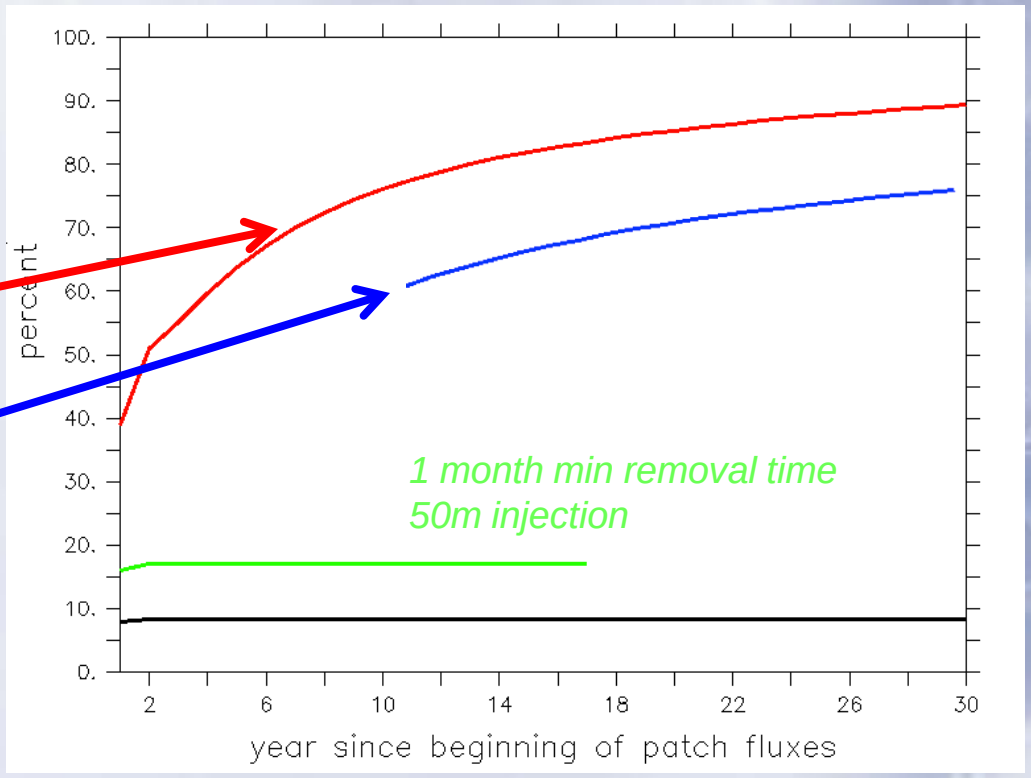
Methane Removal Limitation

- 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





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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