The Climate Ocean and Sea Ice Model (COSIM) project
Computational and Theoretical Science Divisions

Marine Methane Cycle Simulations For the Period of Early Global Warming:

Arctic Emphasis

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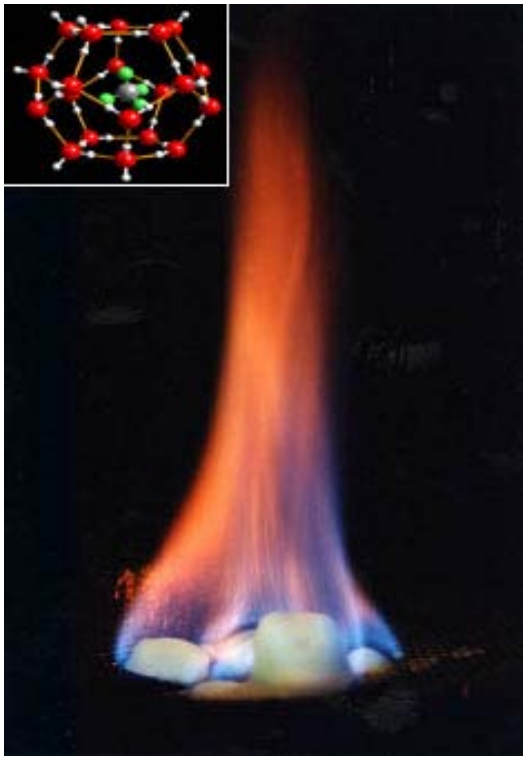
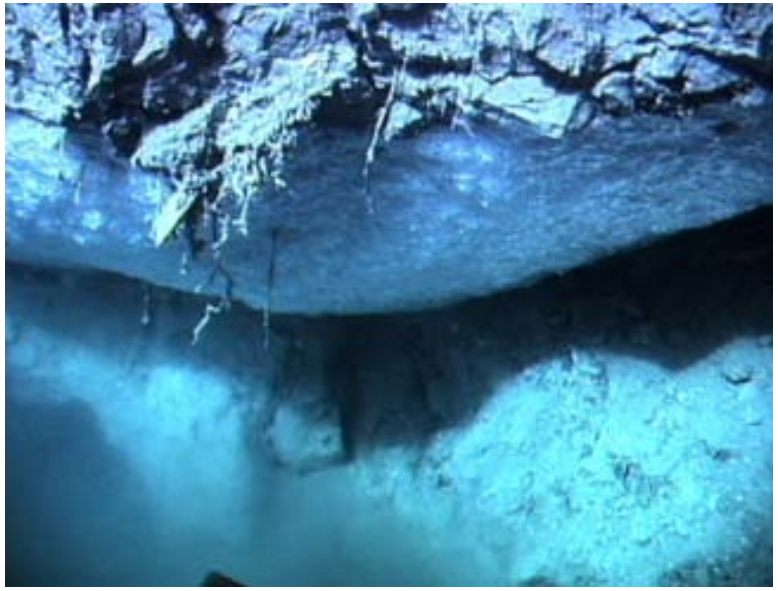
Sponsorship: Department of Energy IMPACTS, NETL

DOE Impacts and CCSM Polar Climate Group meetings, June 2009

INTRODUCTION

- Ocean now a small CH_4 source to atmosphere
- As sea floor warms, buried Arctic clathrate melts
- The greenhouse, polar biogeochemistry at stake
- Simulate behavior in POP for early warming era
- Natural cycle, then decomposition/fate of hydrate





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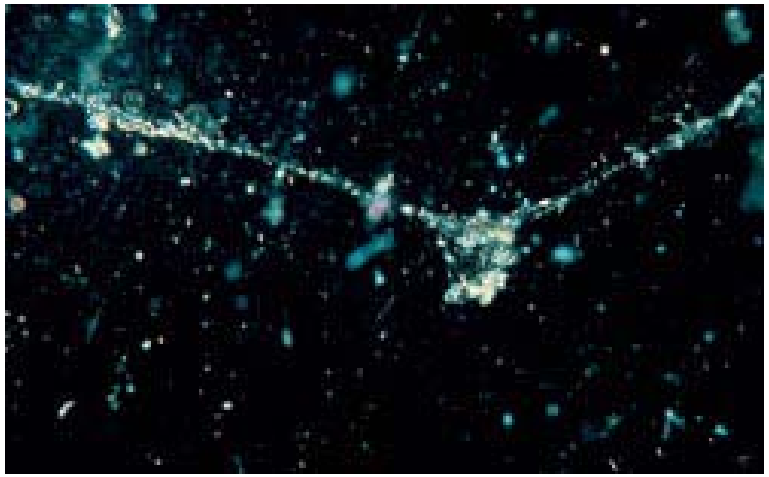
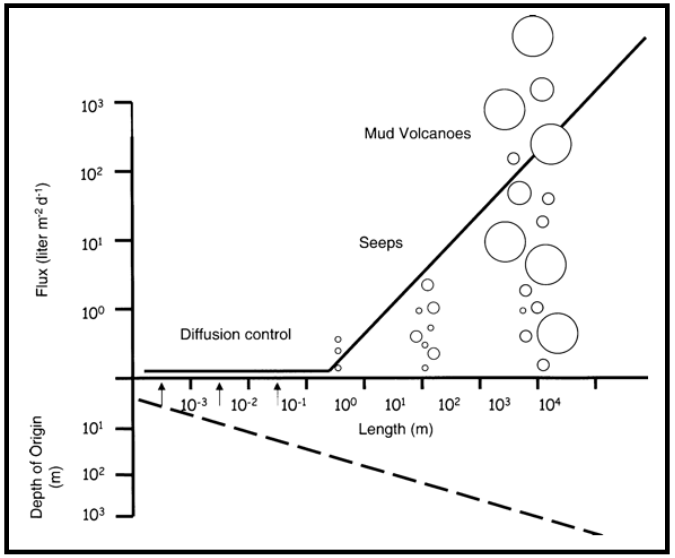
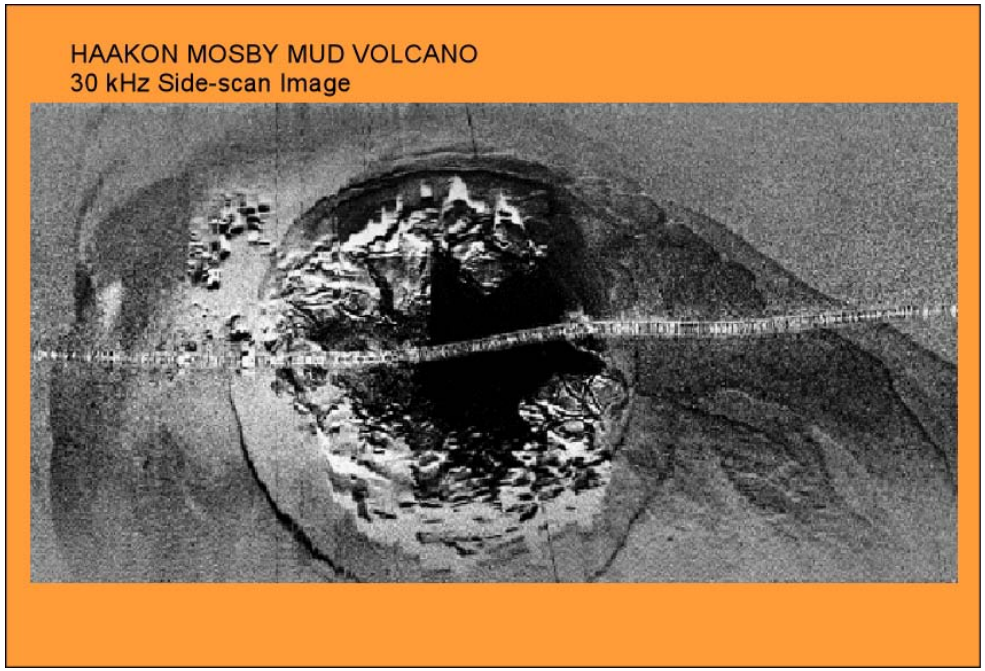
Background Marine CH_4 Dynamics



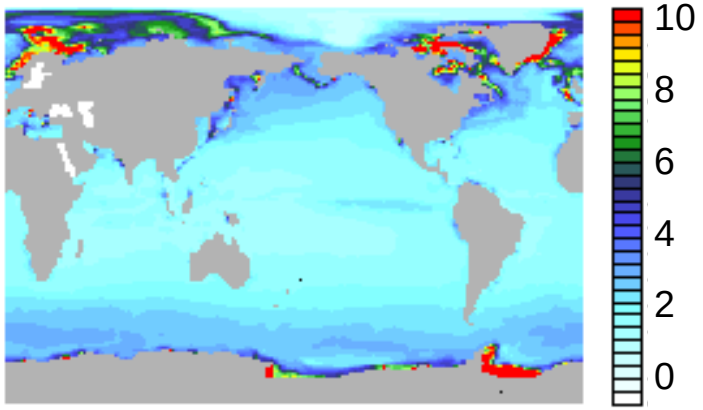
Central ocean - microzones, other
Multiple scales at sea floor
$Log_{10}(\tau,d) = 1 - Log_{10}(CH_4,\mu M)$



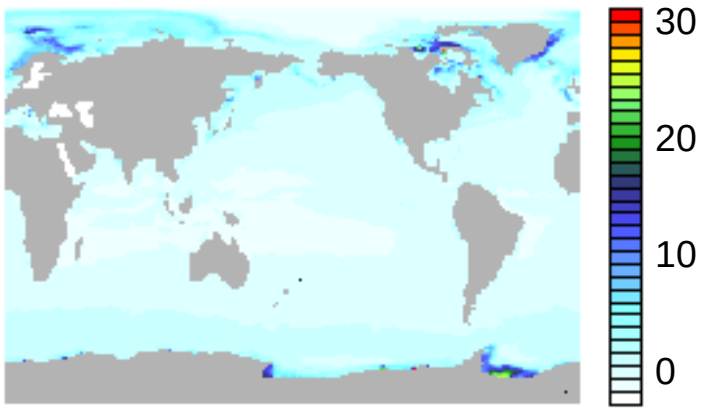


Background Methane Distribution at Surface

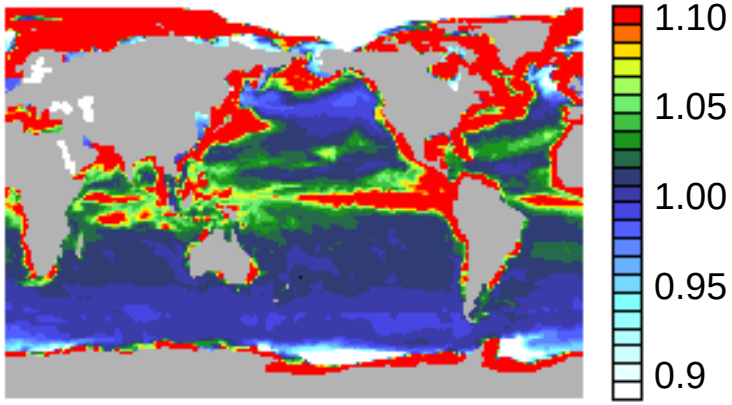
Concentration to 10 nM



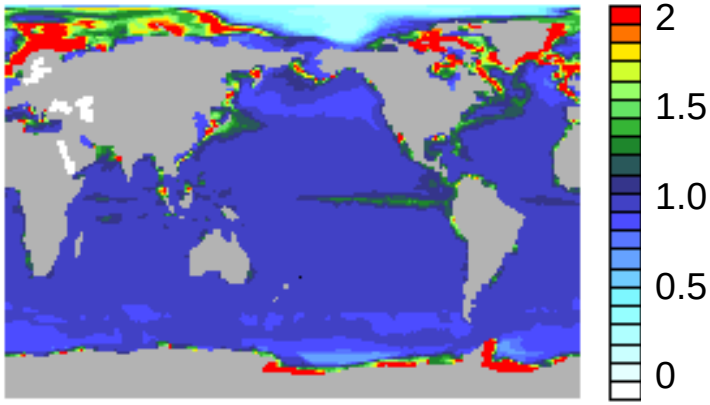
Concentration to 30 nM



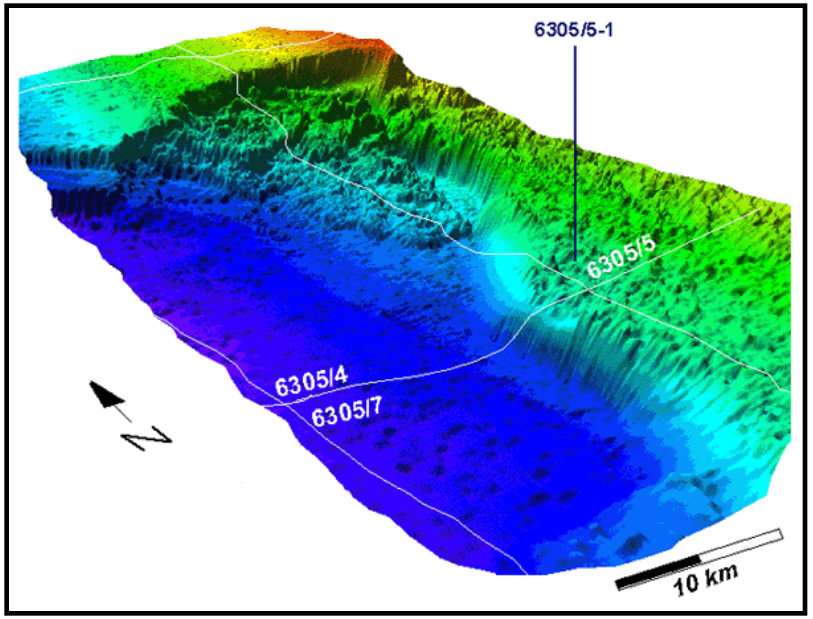
Saturation Ratio +—10 Percent



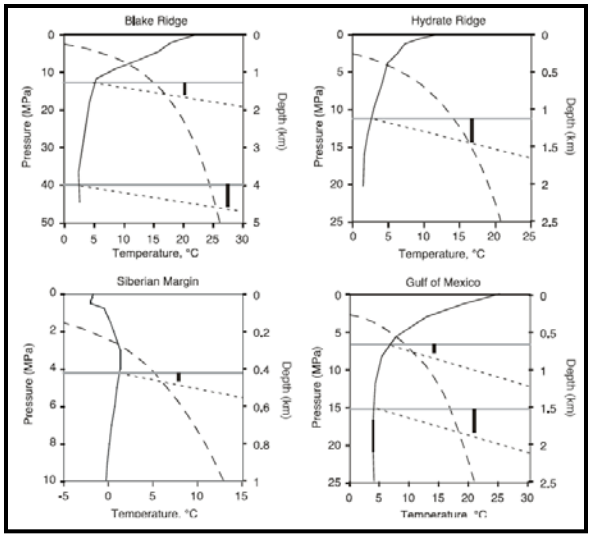
Saturation Ratio +—100 Percent

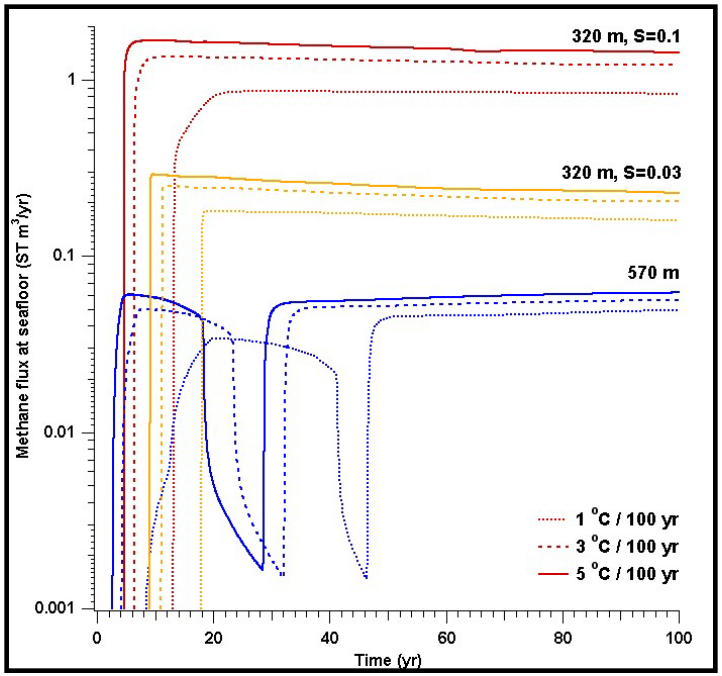


Clathrate Sources



Deposits real, vast, Arctic
Sensitive and already unstable
Apply Reagan-Moridis fluxes
Early in warming era so sparse
Retain log linear removal





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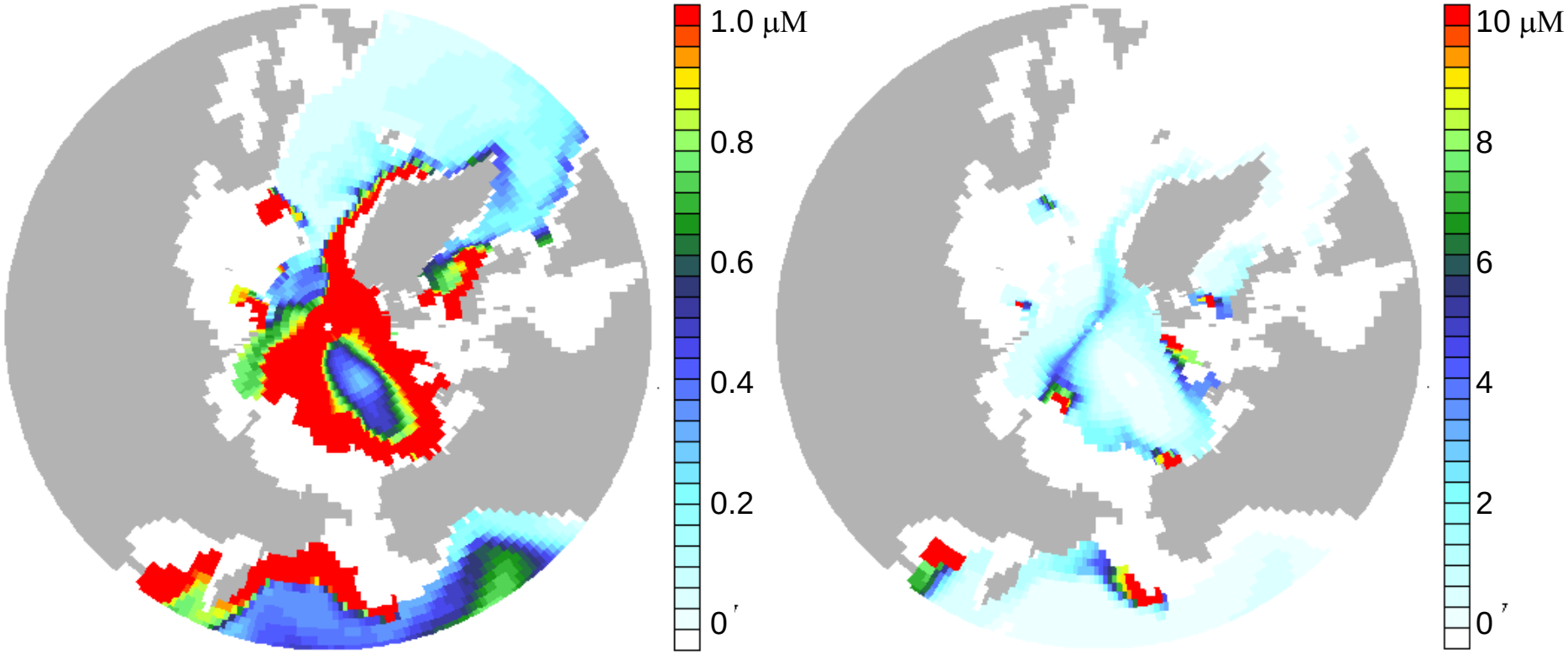
CH_4
300 m
30 years
Scale μM
1.0 μM
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Product Concentration (negative CH_4), 300 meters for 30 year injections



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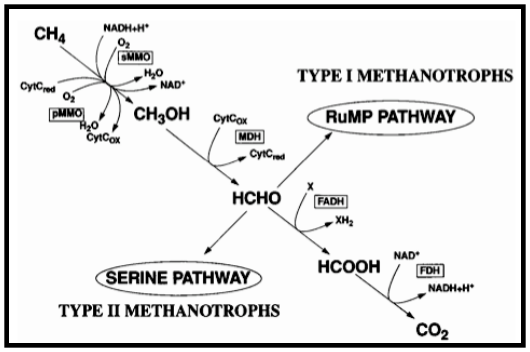
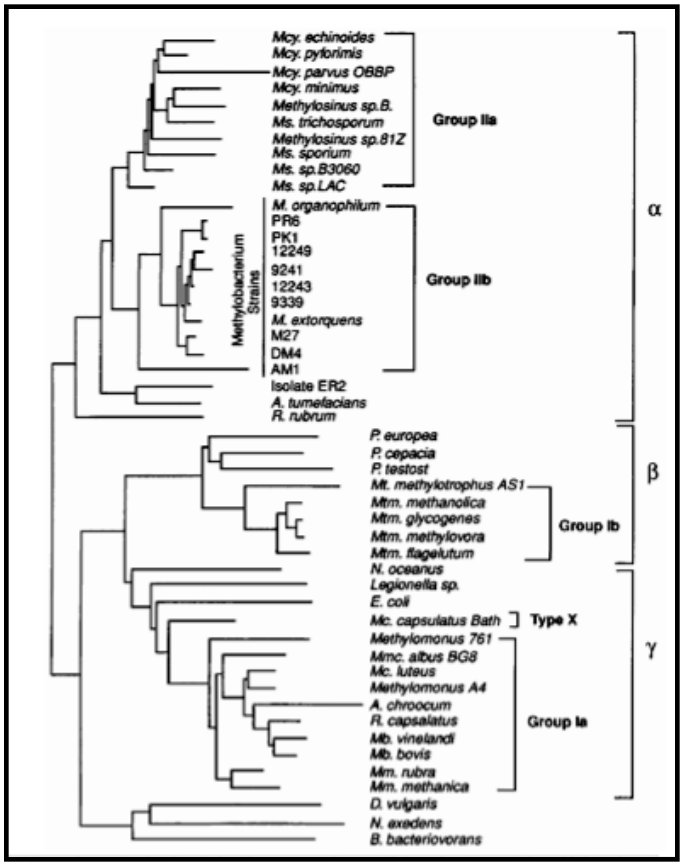


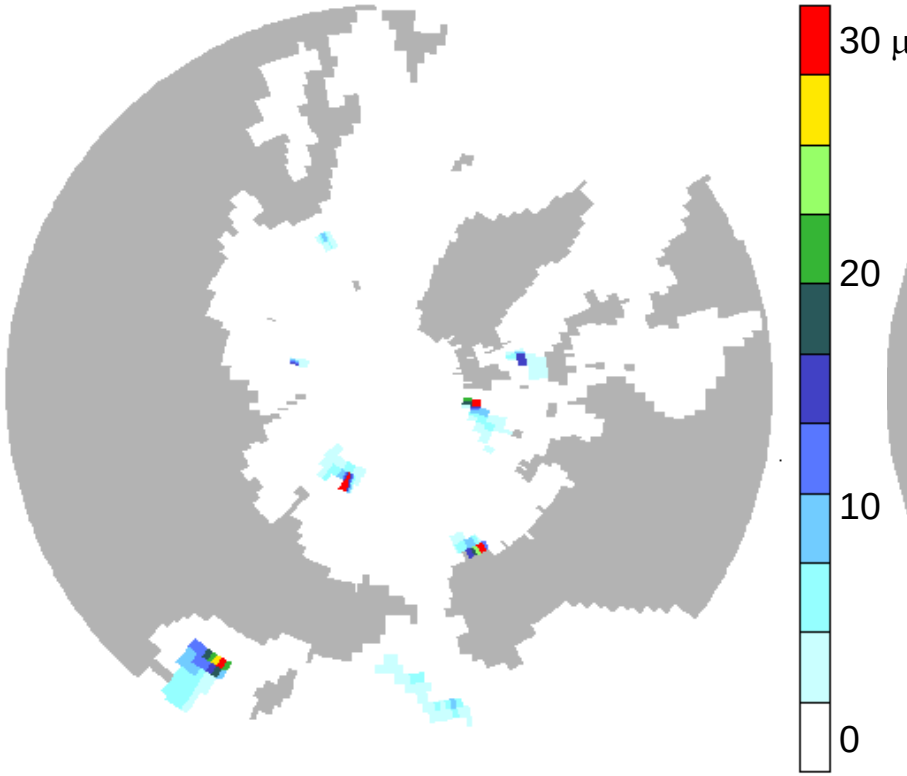


LINK TO BIOGEOCHEMISTRY

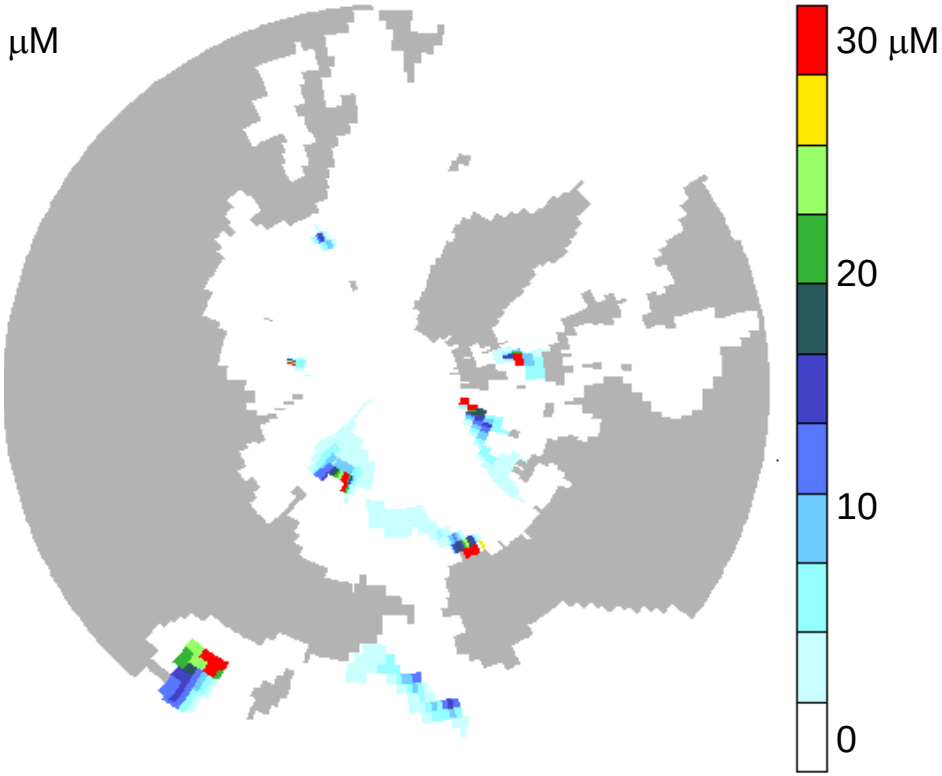
- Above assumes contemporary removal
- Now couple methanotrophs to POP DML
- Carbon-oxygen interactions
- Multiple nitrogen states
- Trace metals, others as inerts

C/O Metabolism Added
ΔDIC and ΔO_2, 300 meters at 10 years

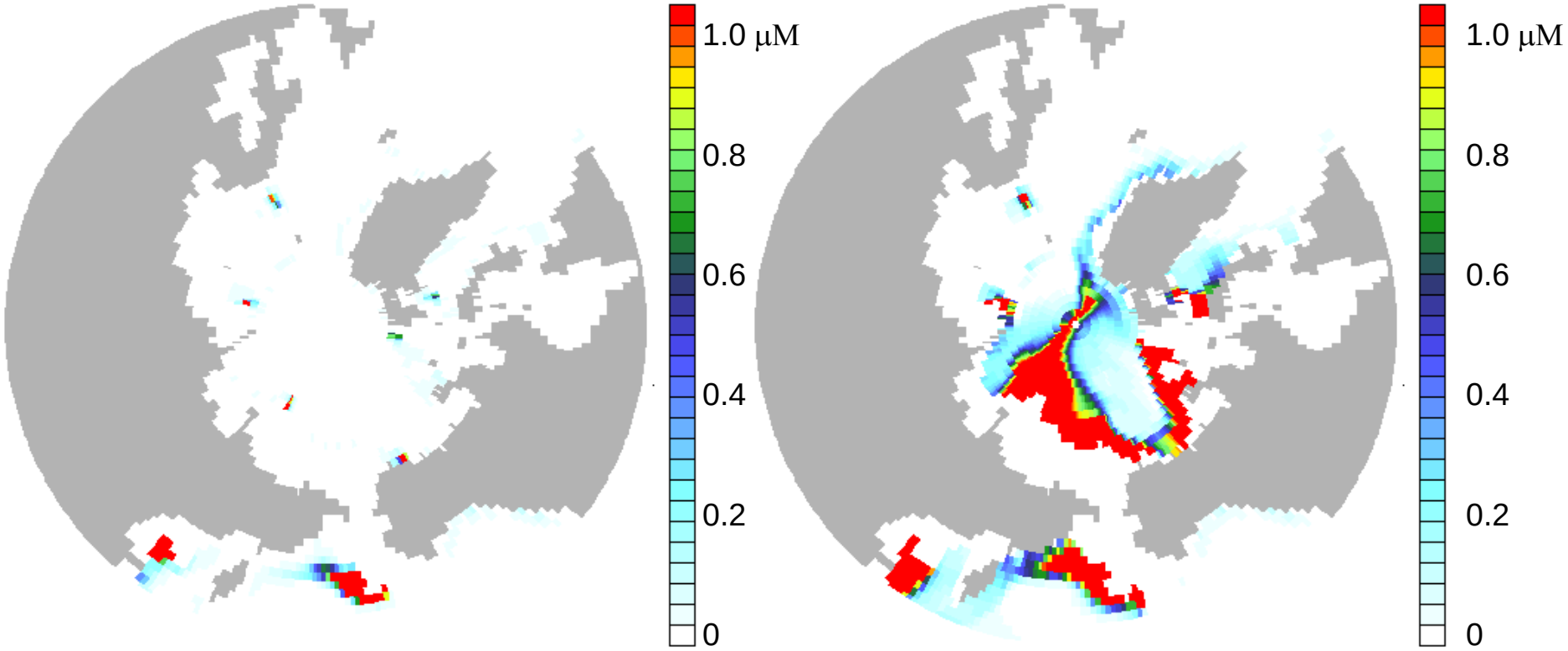
$+\Delta DIC$



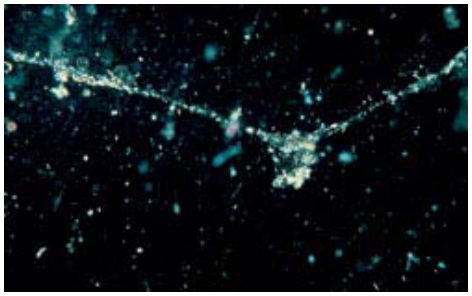
$-\Delta O_2$

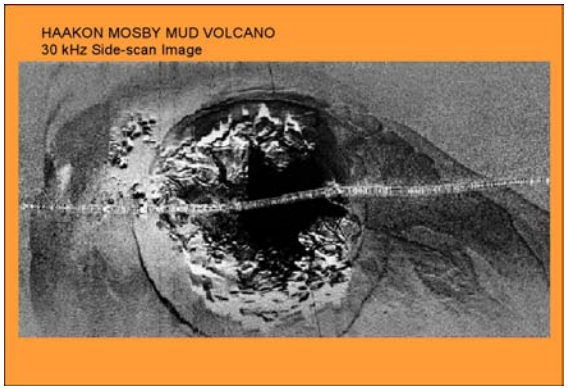


CH_4 under Oxygen versus Ammonia Limitation, 300 meters at 10 years



CONCLUSIONS (TO DATE)





SINGLE CELLS ALTER LOCAL CHEMISTRY

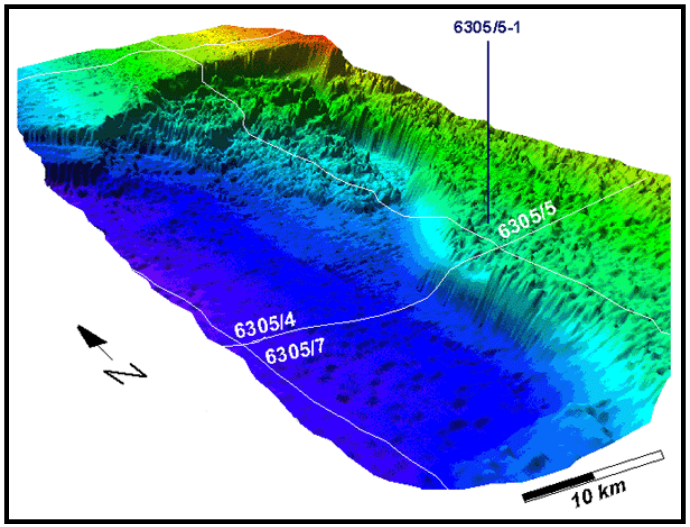
- But detailed limitation necessary
- Too disperse to affect atmosphere

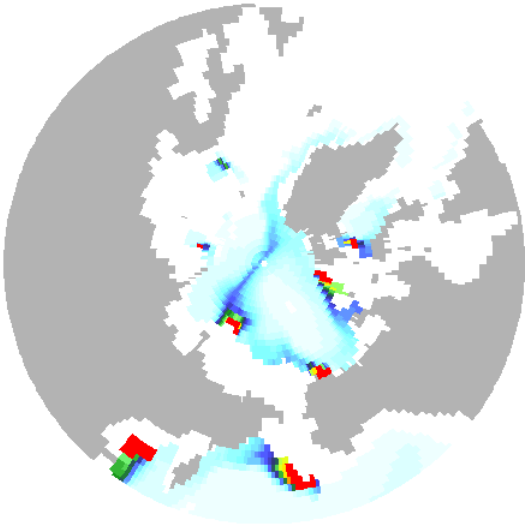
NEXT STEPS

- Scale global resolution down
- Scale Arctic release areas up
- Real microbes especially Fe, Cu

ULTIMATELY INTO CCSM

- Clathrate to climate feedbacks





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EXTRAS

APPROACH

DEVELOP A CONTEMPORARY OCEAN CH_4 CYCLE

- Coarse, stand alone biogeochemical POP
- Estimate natural production
- Surface behavior well-known
- Biology must be parameterized

ADD EARLY CLATHRATE RELEASE AT HIGH LATITUDES

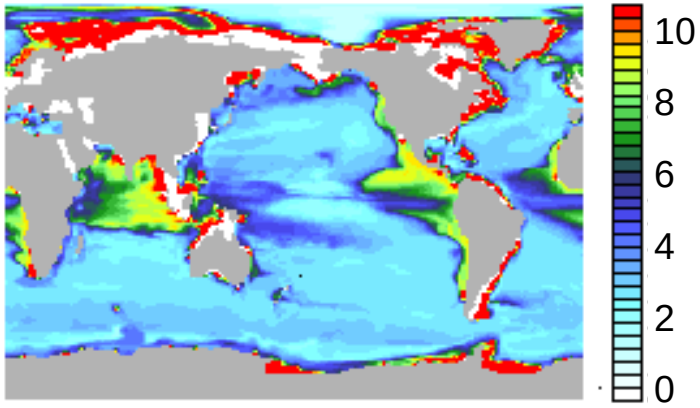
- Decomposition one cell and one dimensional
- Sample Arctic locations around shelf break
- Start with observed removal, dial in ecodynamics
- Chart influences on C, O, other geocycles

IDENTIFY UNCERTAINTIES

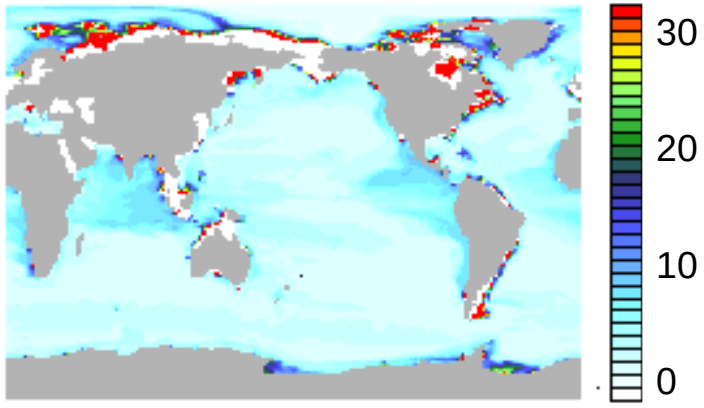
- Microbial limits/seeding, hydrate structure, plume rise
- Regional marine/atmospheric effects cannot exclude

Background Methane Distribution Depth Slices

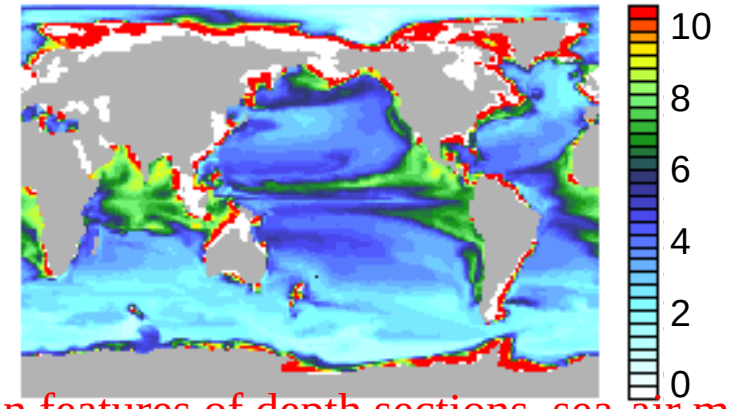
Concentration at 100 m, to 10 nM



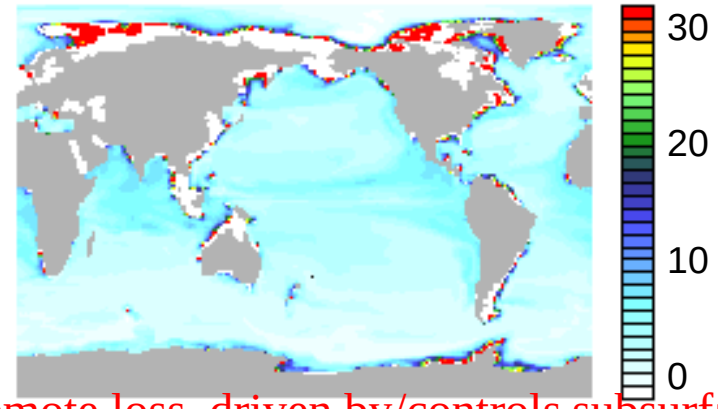
Concentration at 100 m, to 30 nM



Concentration at 200 m, to 10 nM

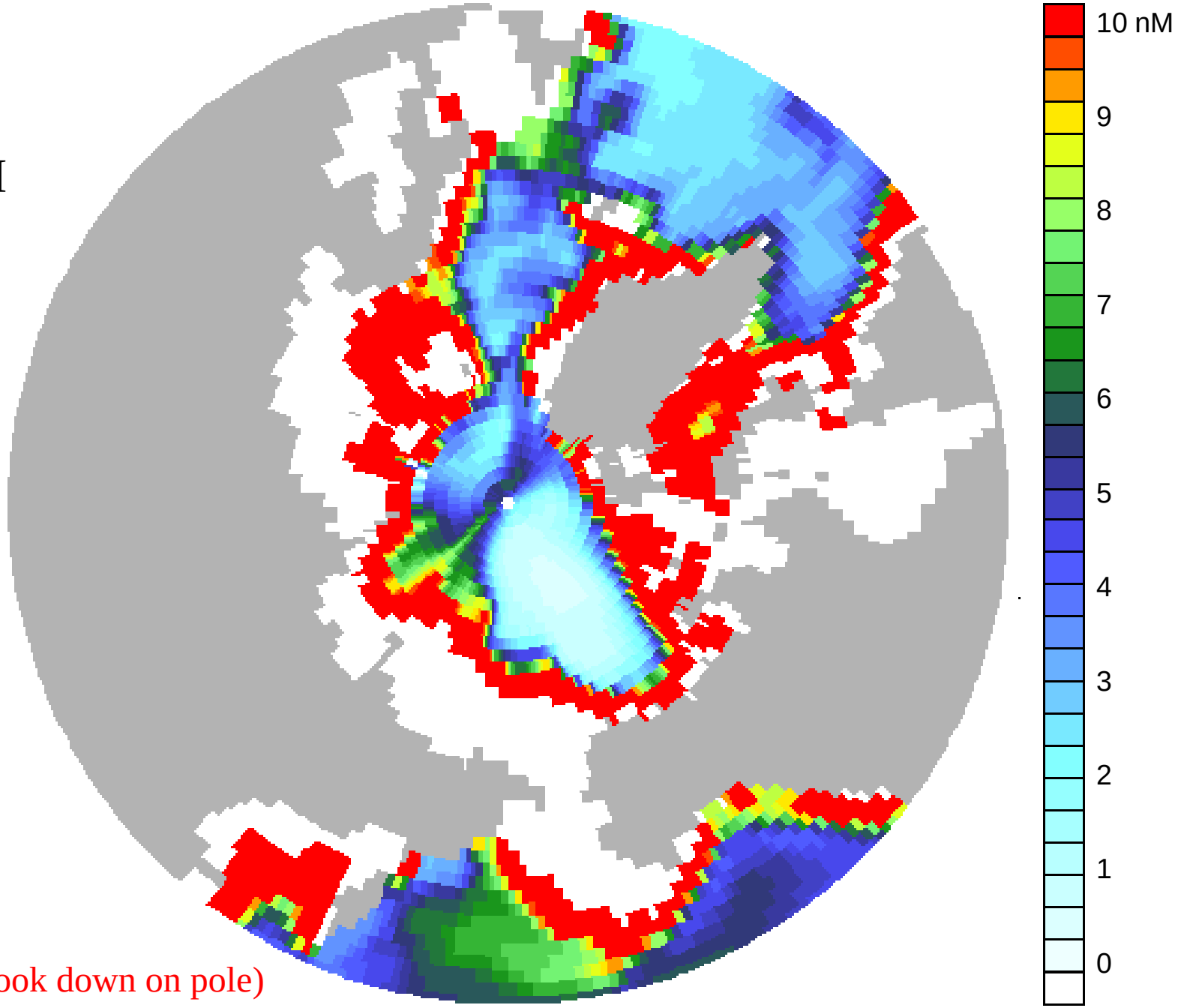


Concentration at 200 m, to 30 nM



(Pick up main features of depth sections, sea-air main remote loss, driven by/controls subsurface)
(Agreement with sparse slope data places modest constraints global sea floor source)
(Log linear lifetime gives quadratic dependence on injection, useful guide and check)

CH_4
200 m
30 years
Scale nM

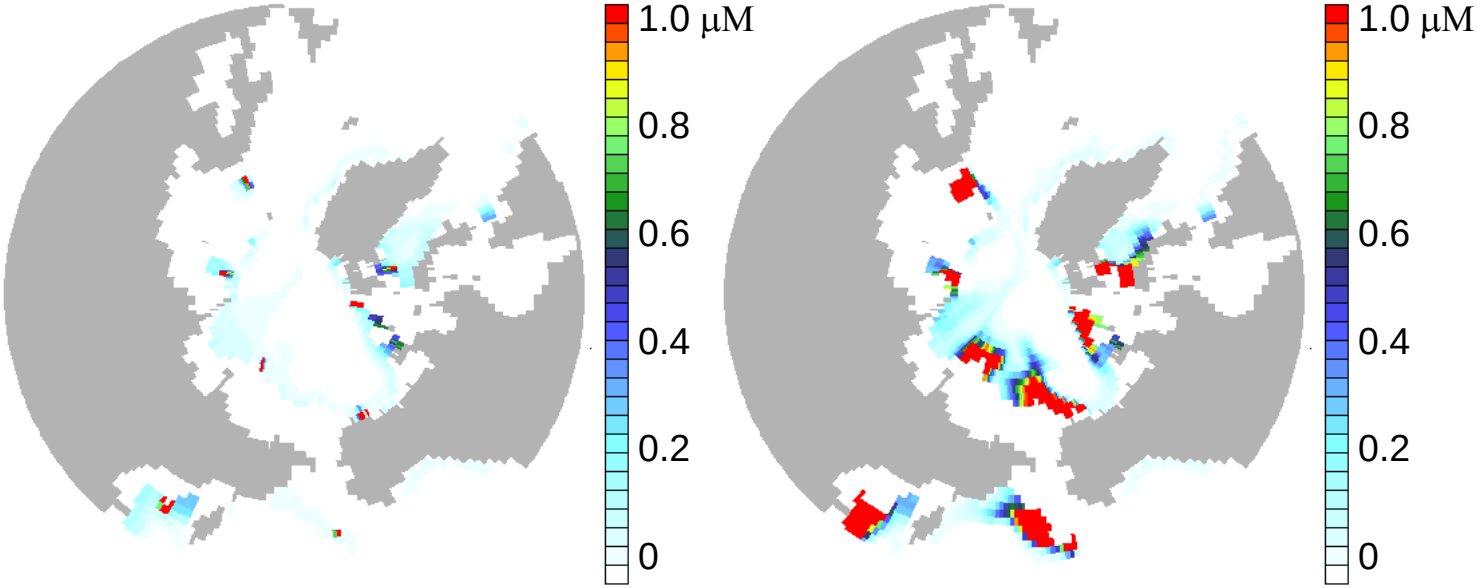


(Henceforth look down on pole)
(Background to start, see shelf intensity, dispersion, coarseness of initial work)

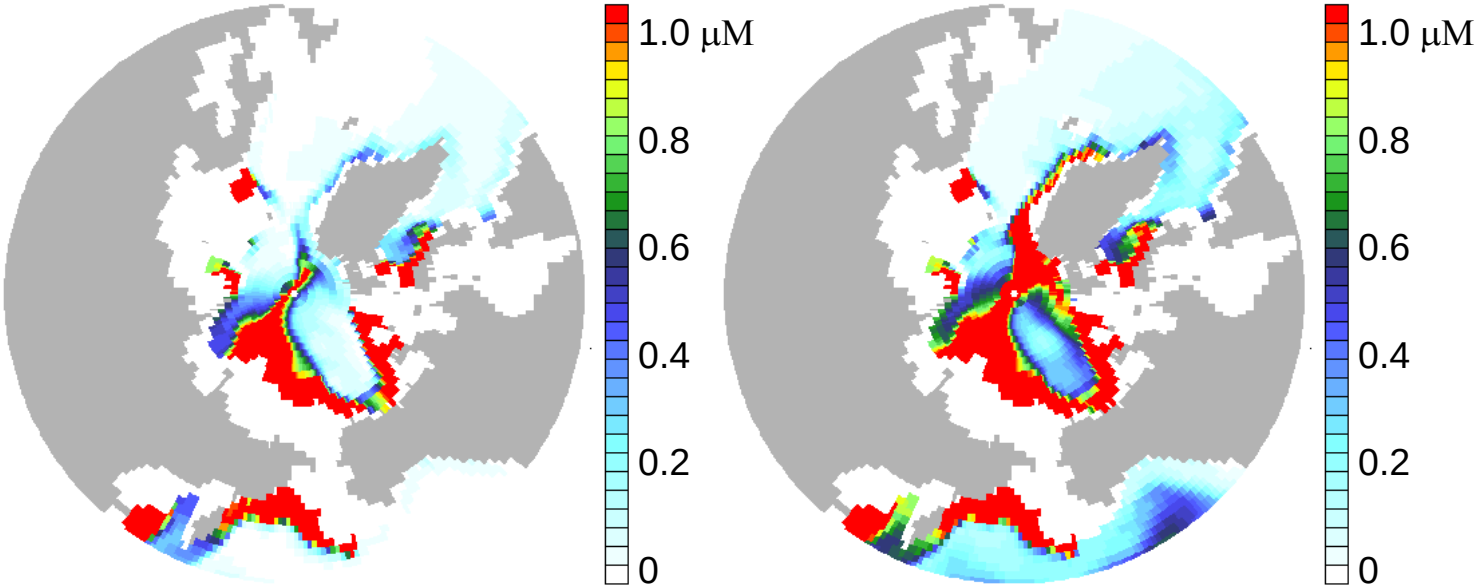
Evolving Product Concentrations, 300 meters 1 μM scale

(Watch Arctic Ocean and outflow regions fill)

0 y, 3y



10 y, 20 y

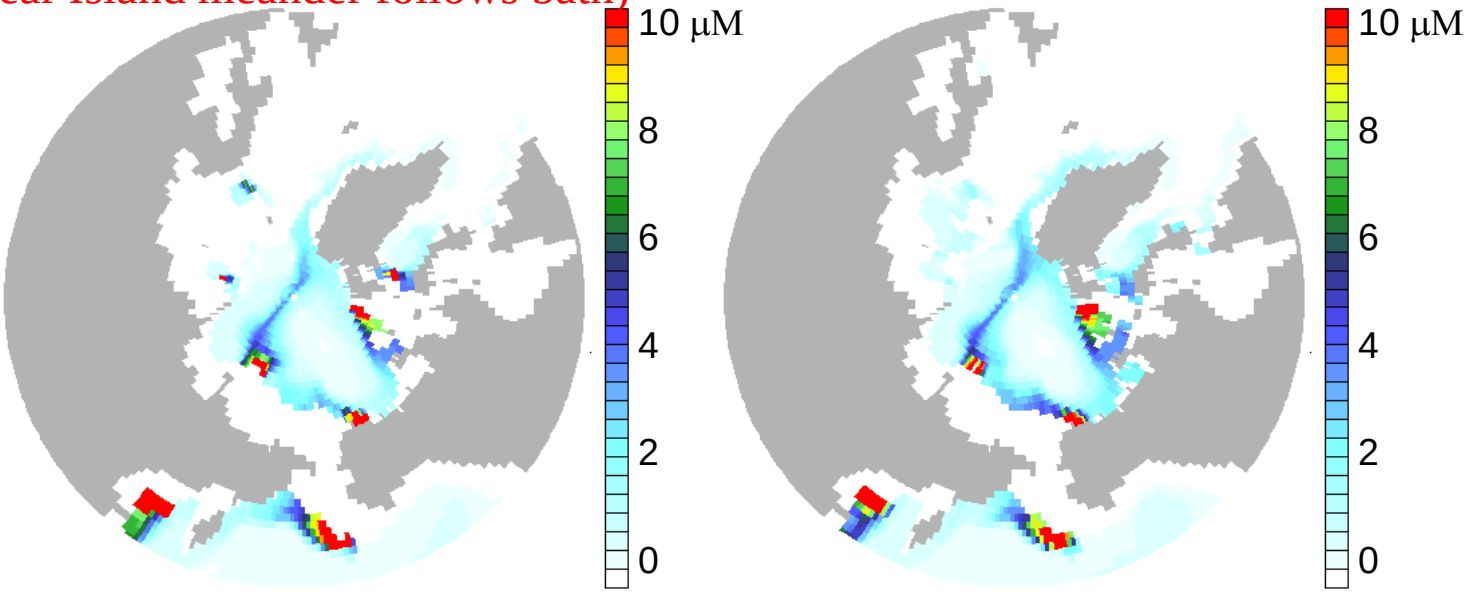


Product Concentration Slices, 30 year injections

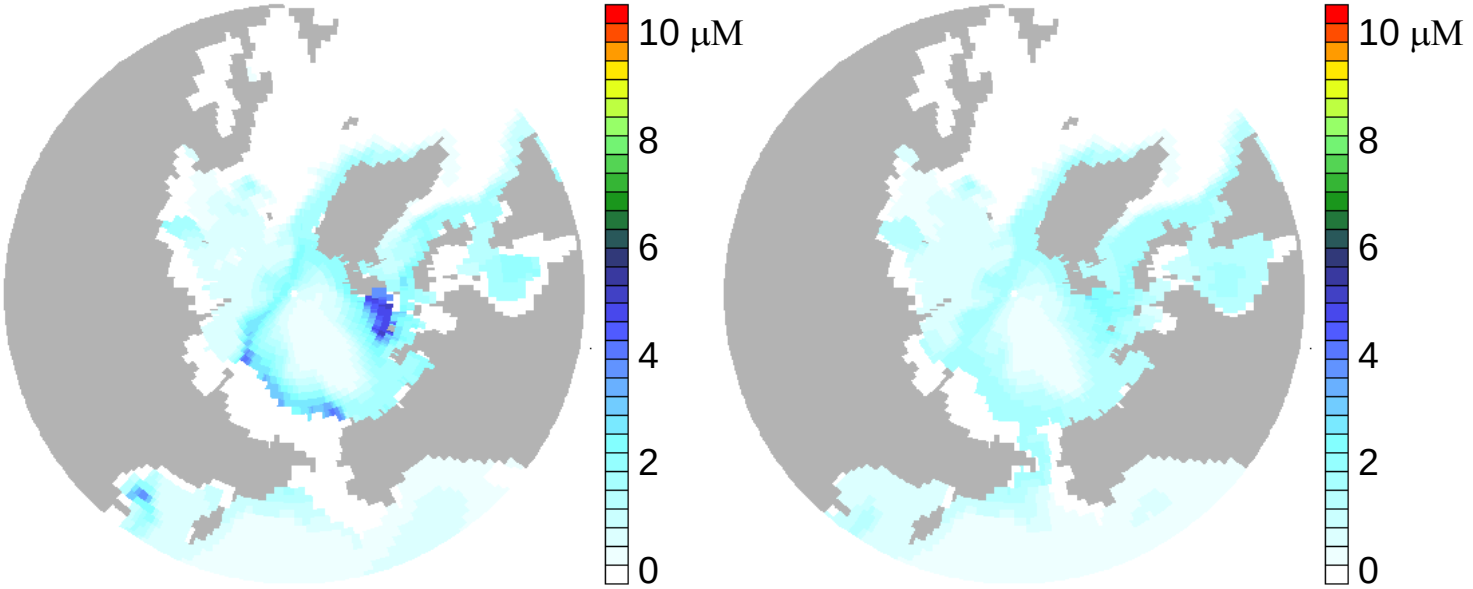
(See dilution and note area of early releases too small for atmospheric effects)

(Bear Island meander follows bath)

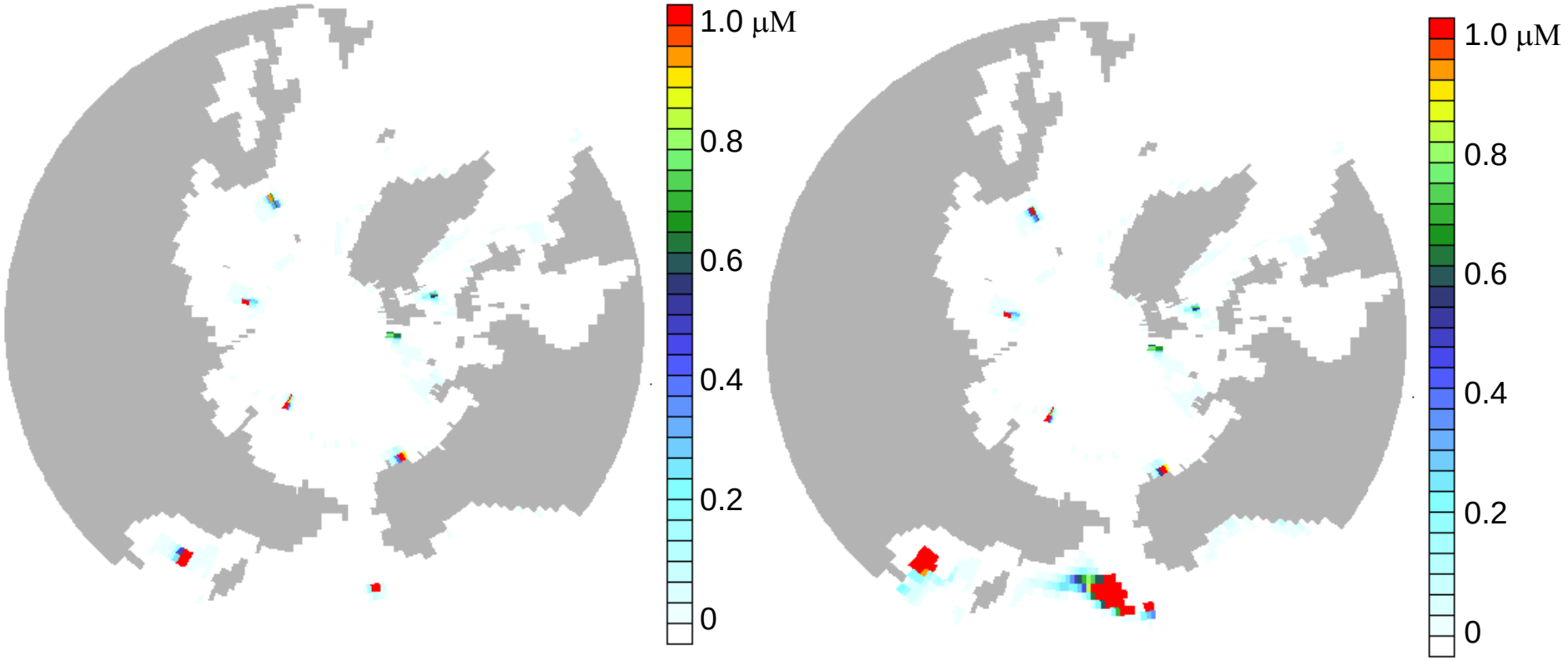
300, 200 m



100, 50 m



Methane Distribution, Original then C/O Metabolism Added 300 meters at 10 years, O_2 limitation at Black Sea value



(Original plumes similar at t0 years since log linear τ short)
(Plumes expand in hypoxic zones since O_2 can approach or recede to 10 μM)
(But their extent may be over-predicted, compare DML with WOA)

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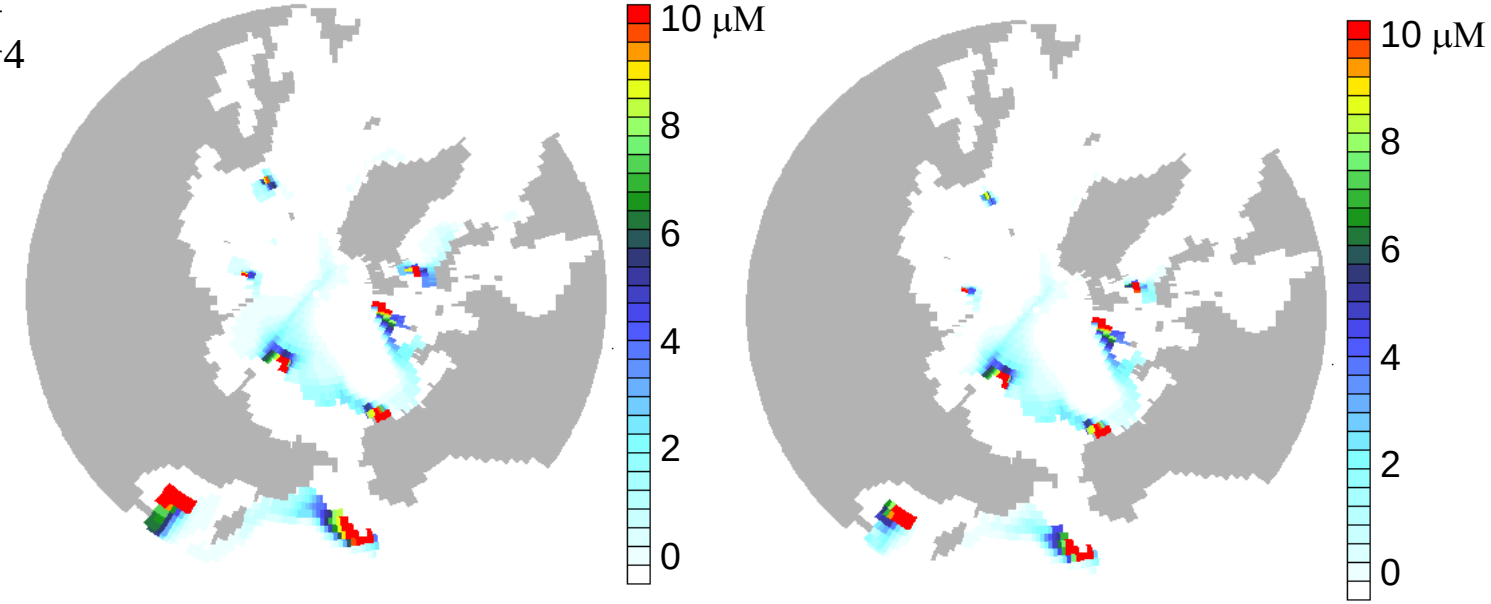
Negative CH_4 and NH_4^+-Limited Slices, July of tenth year

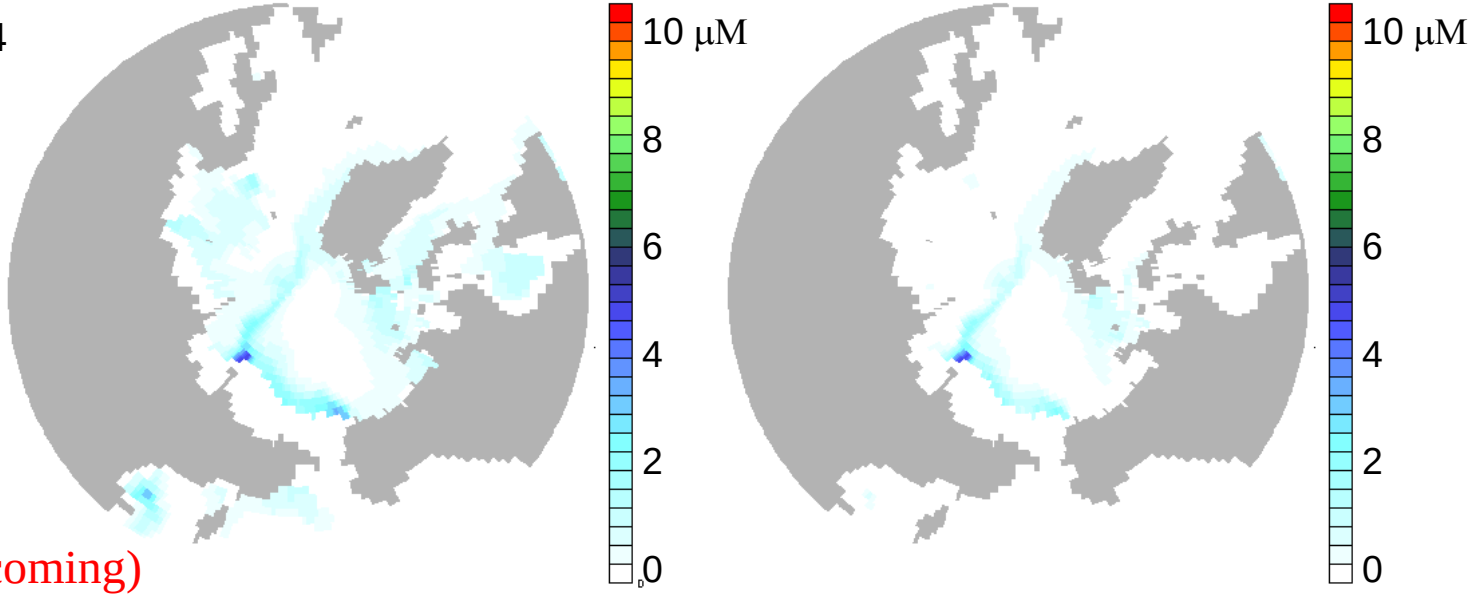
(Summer chosen to allow particle deep penetration -note seasonality issues raised)

(Ammonia requirement does not free methane entirely, but gets close under ice)

Product, CH_4
300 meters



Product, CH_4
100 meters



(Note: ice algae coming)

(pH and E master variables)
(Under reducing conditions, new ecosystems may arise)
(Organic rain from ML may denit, N_2O 10X the GHG)
(Redox sequence on to sulfate as acceptor, methanogenesis…)

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SUMMARY

MOTIVATION

- Warming hydrates amplify marine CH_4 cycle
- Simulate in biogeochemical POP

CONTEMPORARY DISTRIBUTION CAPTURED

- Average central/slope sourcing
- Plus empirical and surface losses

CLATHRATE DESTABILIZATION BEGINS

- Represent disperse initial release as Arctic one-cells
- Maximum fluxes with fast oxidation -regional ΔpH, pE
- Trace element, seed and other limits preserve
- Other unknowns -hydrate distribution, plume rise

POTENTIAL EFFECTS

- If wide spread, Arctic marine biota perturbed
- or regional atmosphere at risk …or both