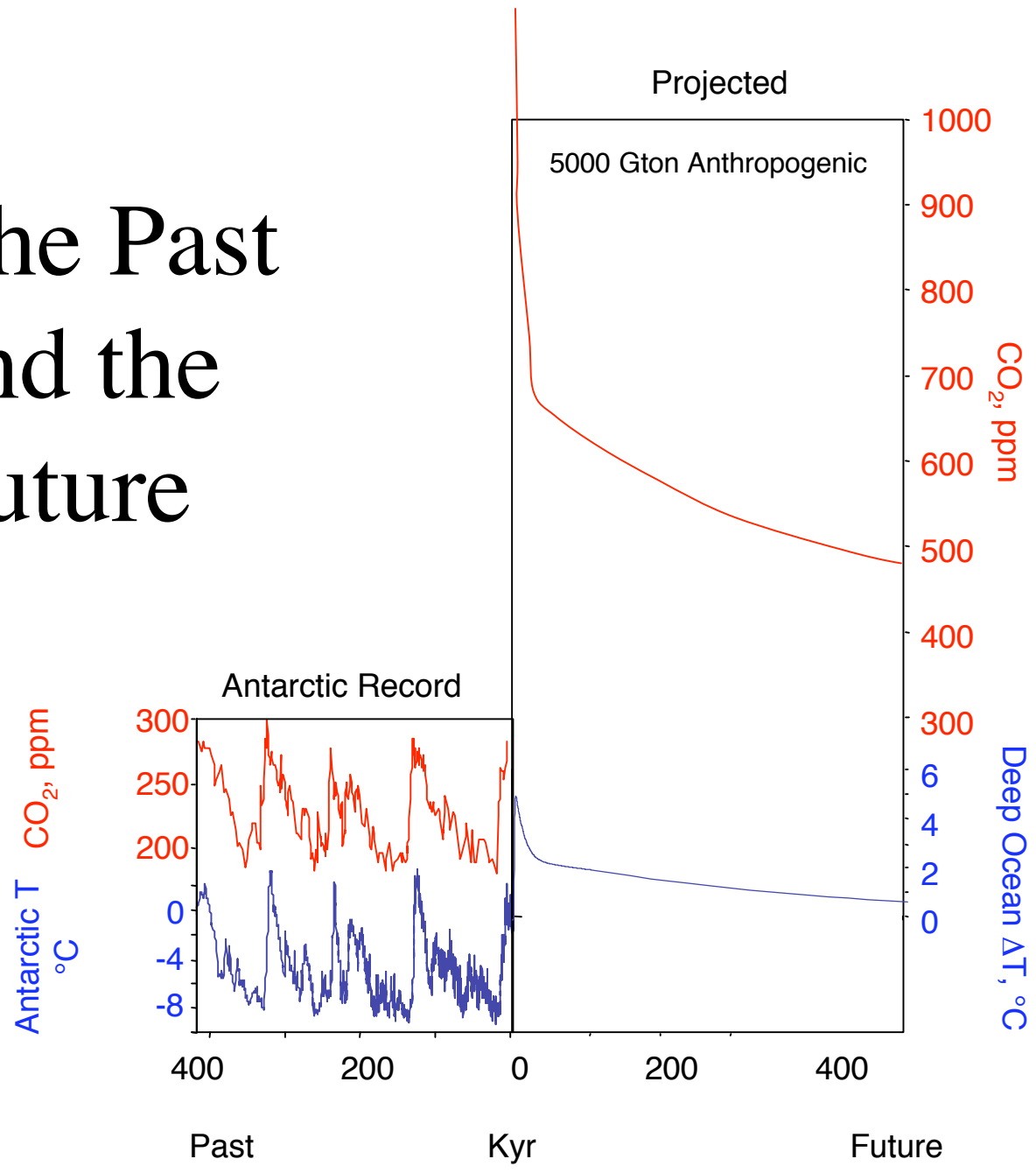


Long lifetime of
anthropogenic C release
and
Response of the ocean
clathrate reservoir

David Archer
University of Chicago

The Past and the Future



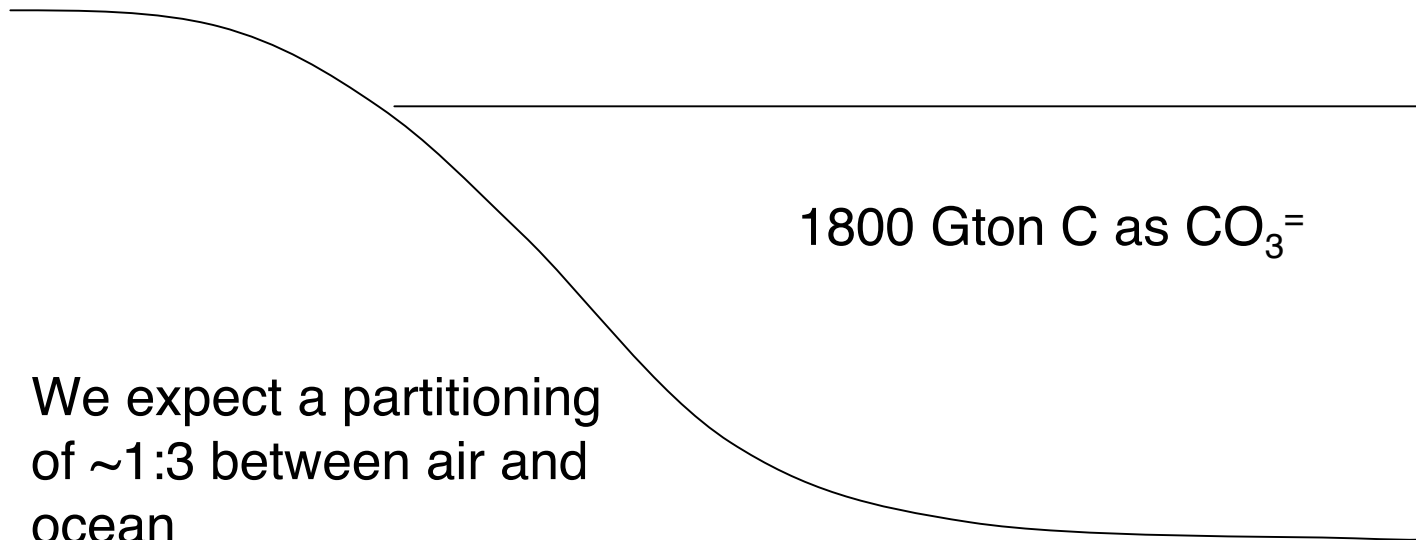
Air / Seawater CO₂ Partitioning

600 Gton C

1800 Gton C as CO₃⁼

We expect a partitioning
of ~1:3 between air and
ocean

Gton C = 10¹⁵ g

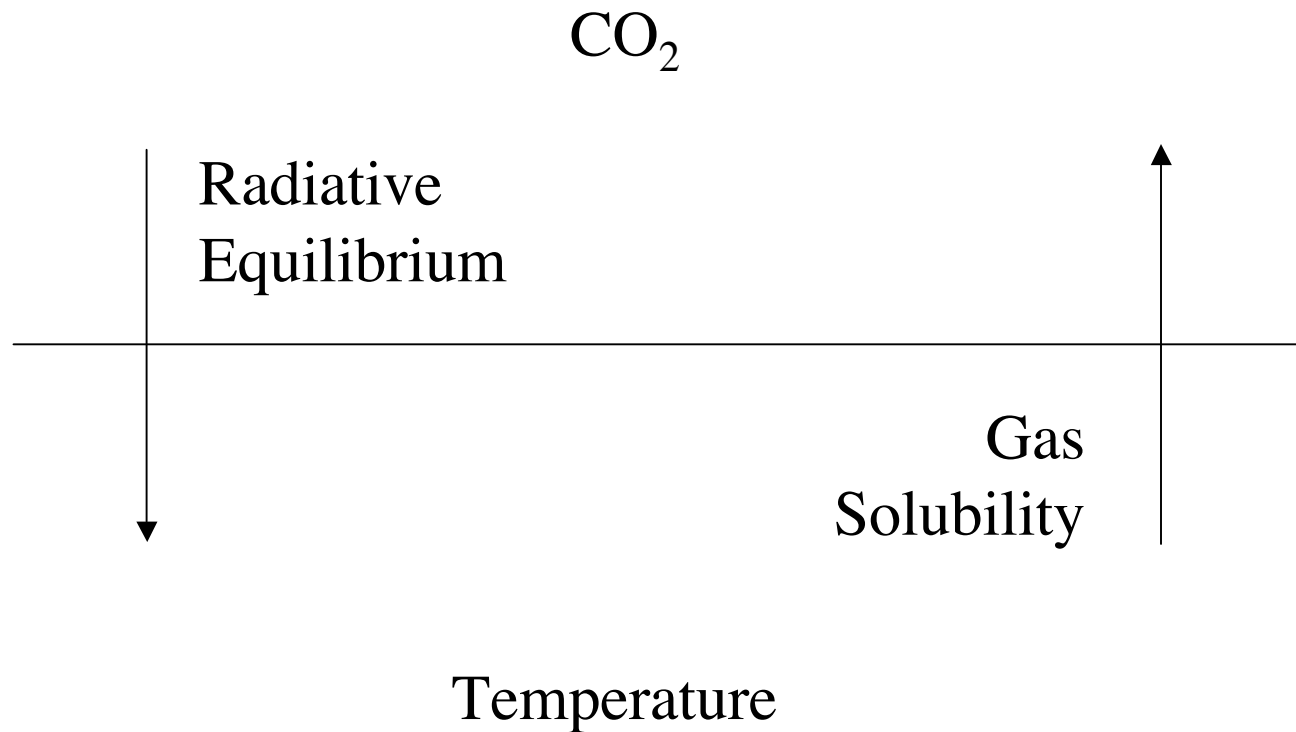


Air / Seawater CO₂ Partitioning

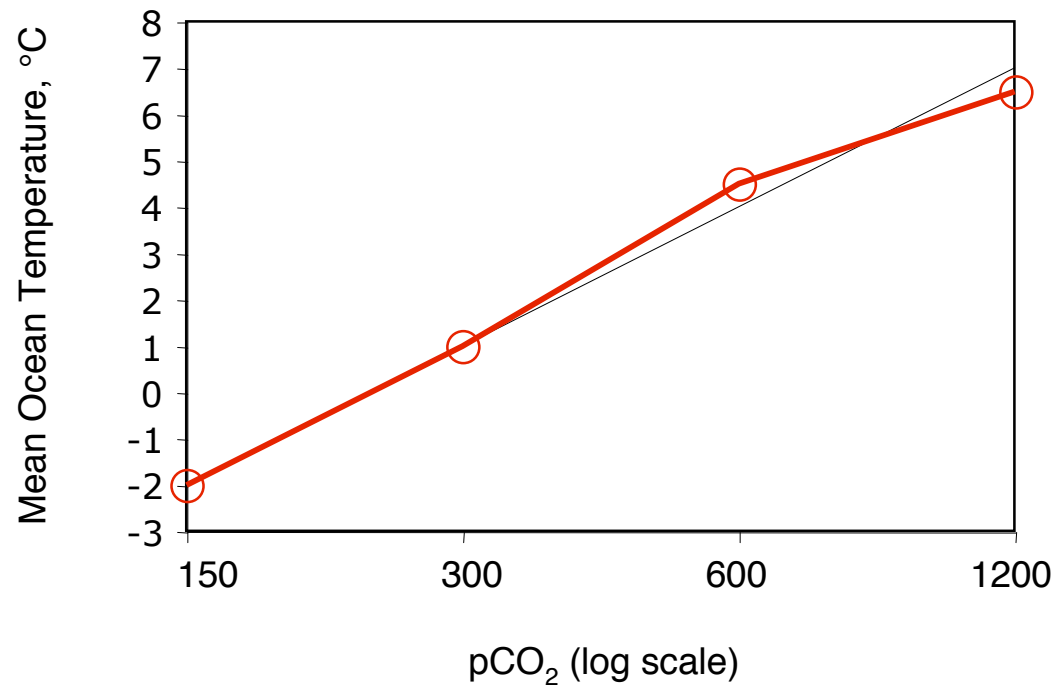
Gton C Added	Equilibrium Atmospheric Fraction
300	13.9%
1000	15.9%
2000	19.7%
5000	30.4%

Hamocc off-line tracer advection code
with ocean-only carbon cycle

Interplay between deep ocean temperature and $p\text{CO}_2$



Stouffer and Manabe 2003
Mean Ocean T Sensitivity to pCO₂



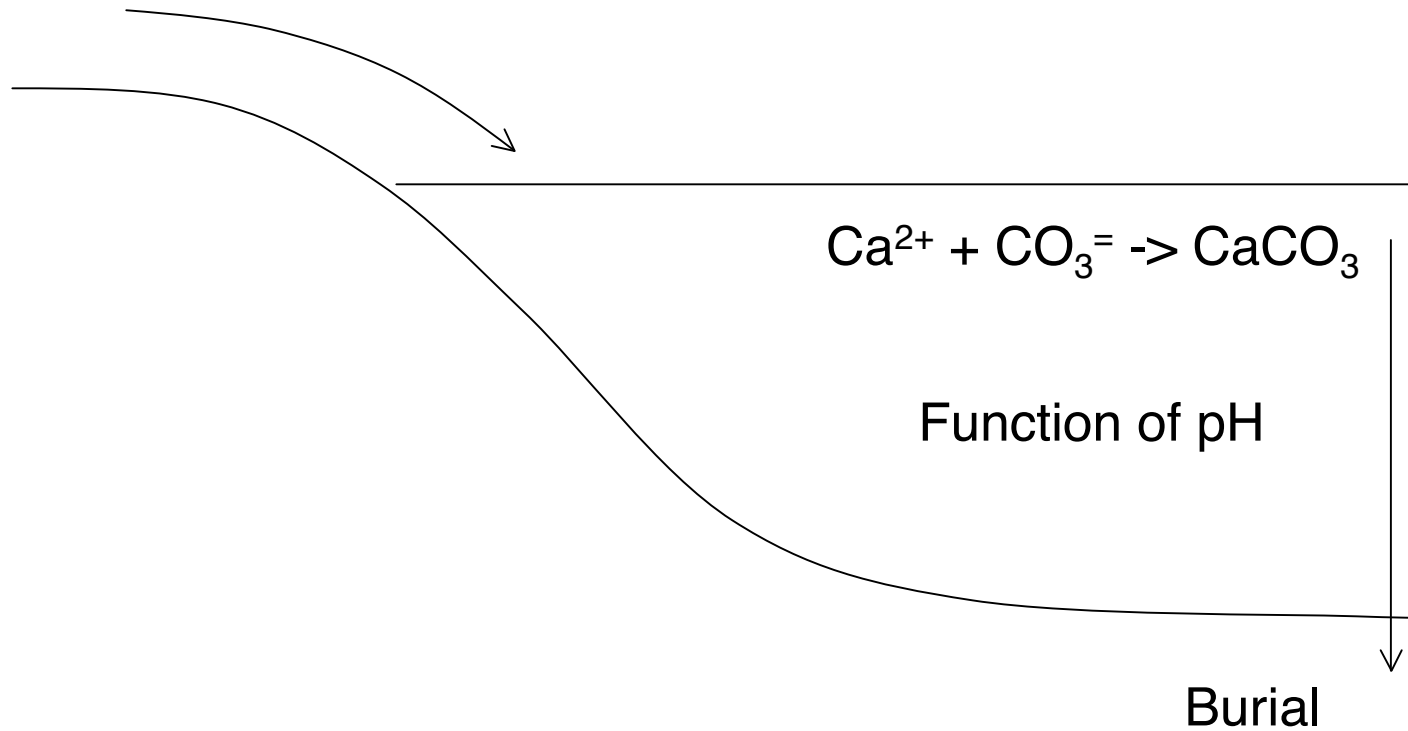
Air / Seawater CO₂ Partitioning

Gton C Added	Chemical Equilibrium Atmospheric Fraction	Add T- Feedback
300	13.9%	15.8%
1000	15.9%	18.0%
2000	19.7%	22.2%
5000	30.4%	33.7%

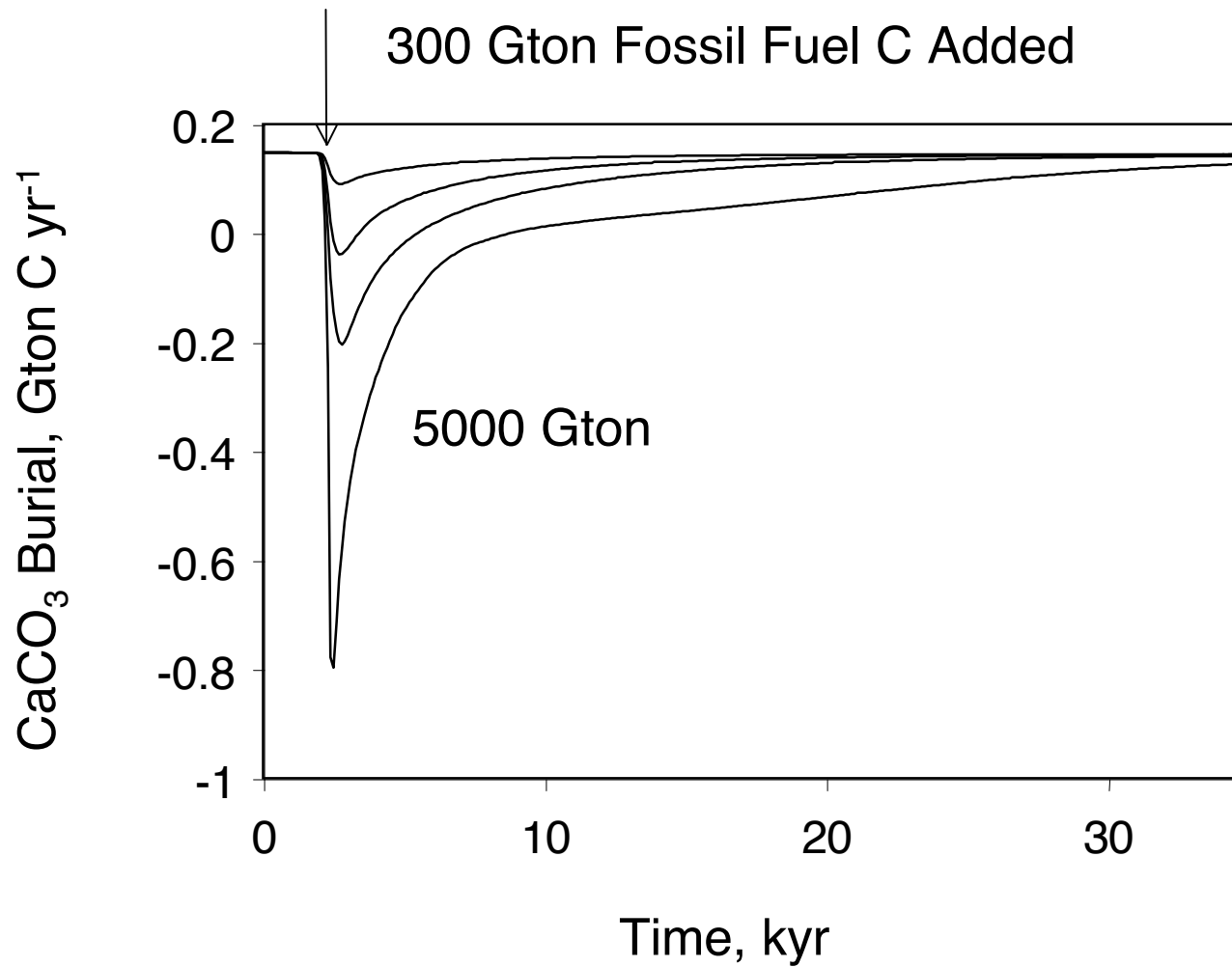
Amplifies any temperature or CO₂ perturbation by ~20%

CaCO₃ Equilibrium

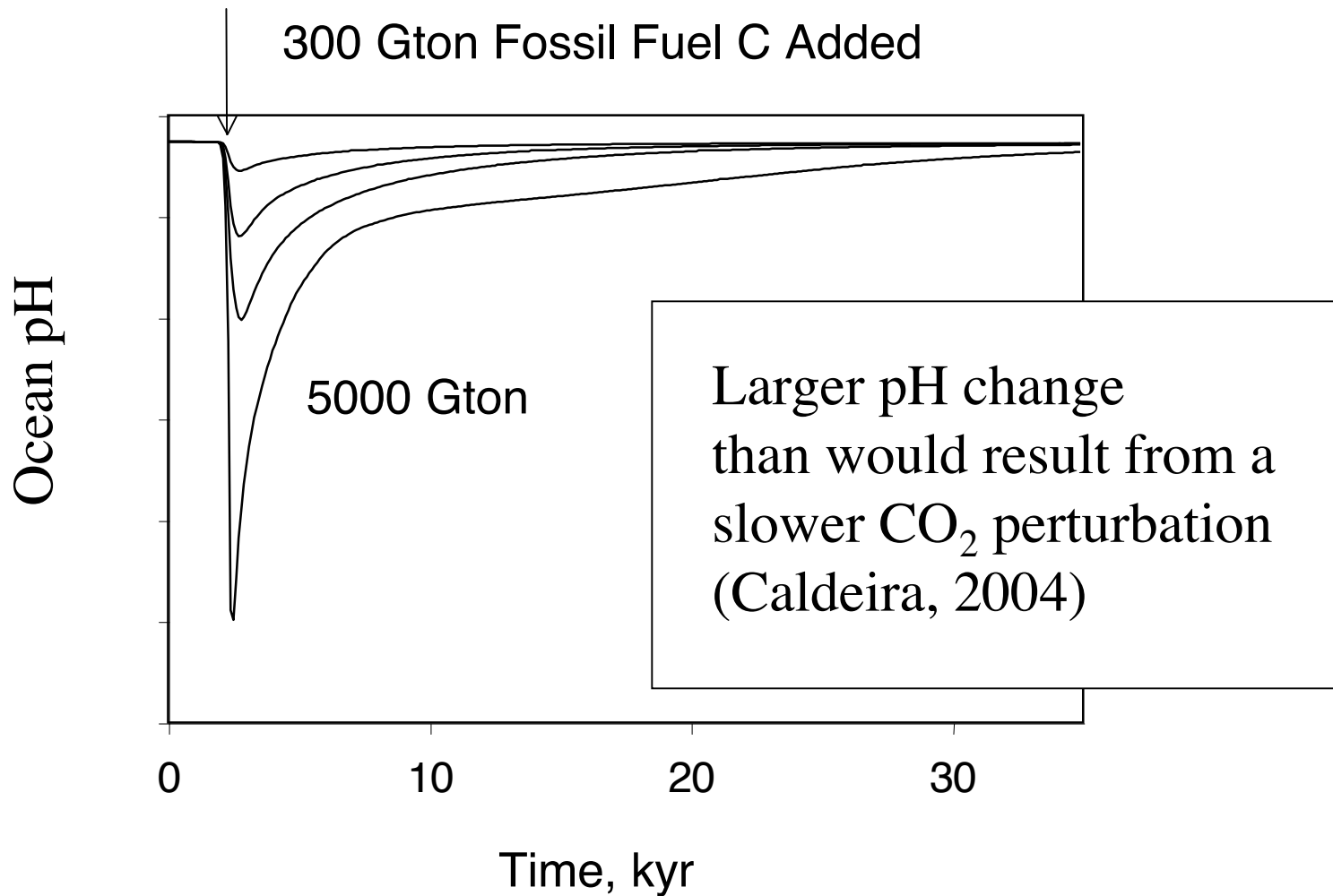
Weathering



CaCO₃ Equilibrium



CaCO₃ Equilibrium



Air / Seawater CO₂ Partitioning

Gton C Added	Air/Water Equil. with T-Feedback	Add Weathering Feedback		
		1 kyr	10 kyr	100 kyr
300	15.8%	16.8%	9.8%	6.7%
1000	18.0%	19.2%	9.9%	6.5%
2000	22.2%	23.8%	10.7%	6.5%
5000	33.7%	32.9%	15.1%	6.7%

Hamocc off-line tracer advection code
with ocean-only carbon cycle

Long lifetime of anthropogenic C release

Compare to nuclear waste

Melt the ice sheets

Melt the clathrate deposits in the ocean

Long-term response of the
ocean clathrate reservoir
to anthropogenic
climate forcing

With Bruce Buffett
University of Chicago

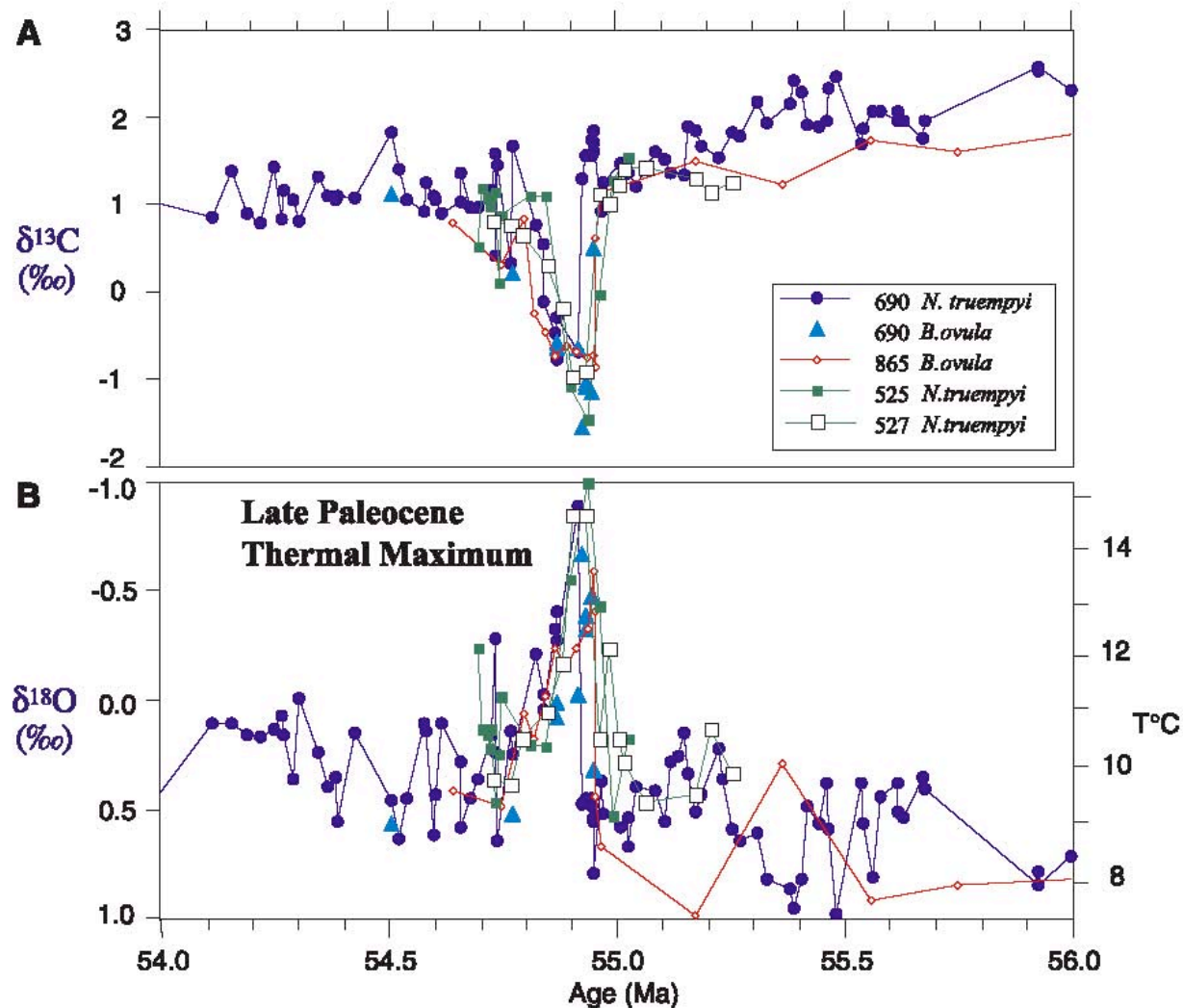
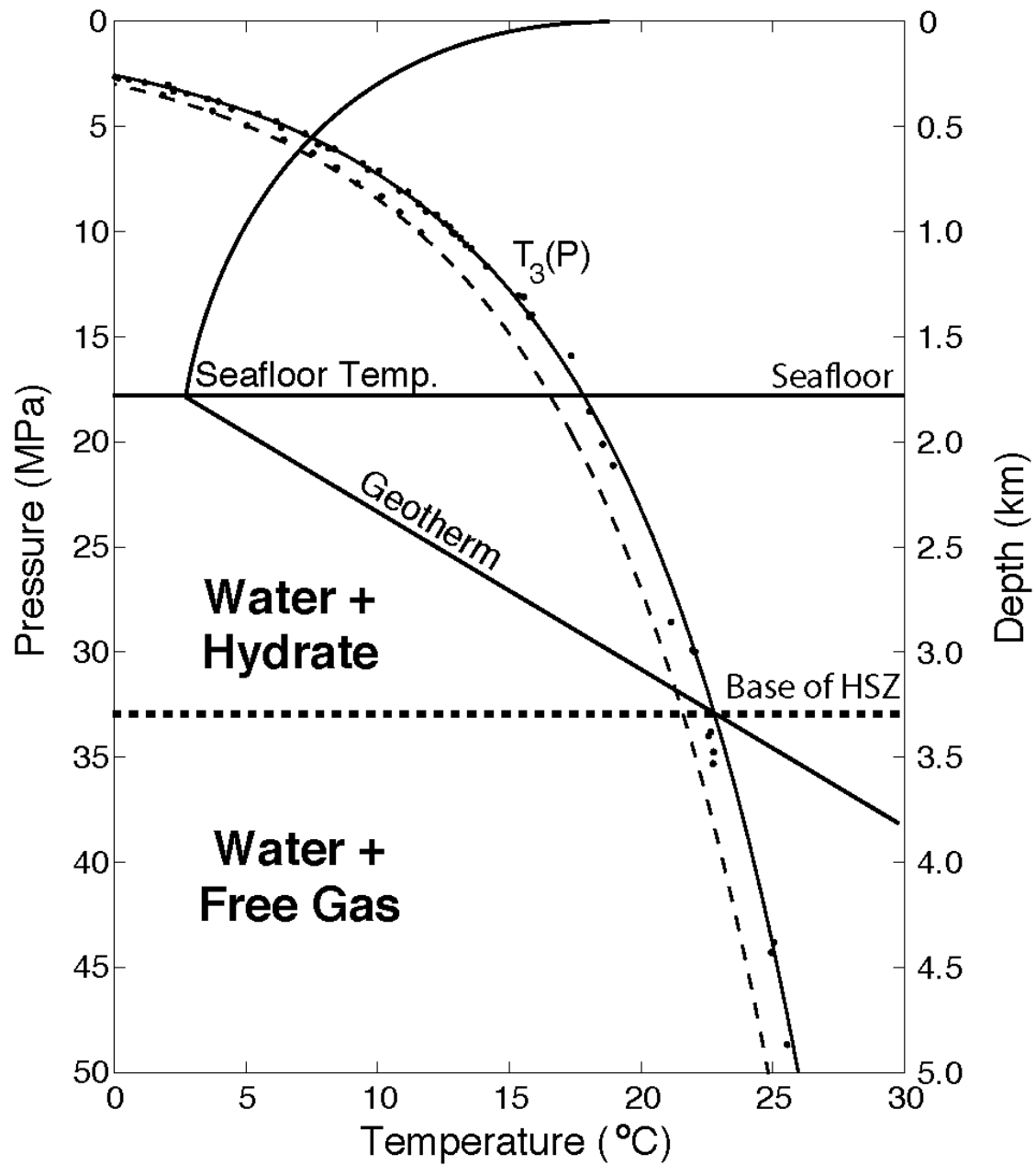
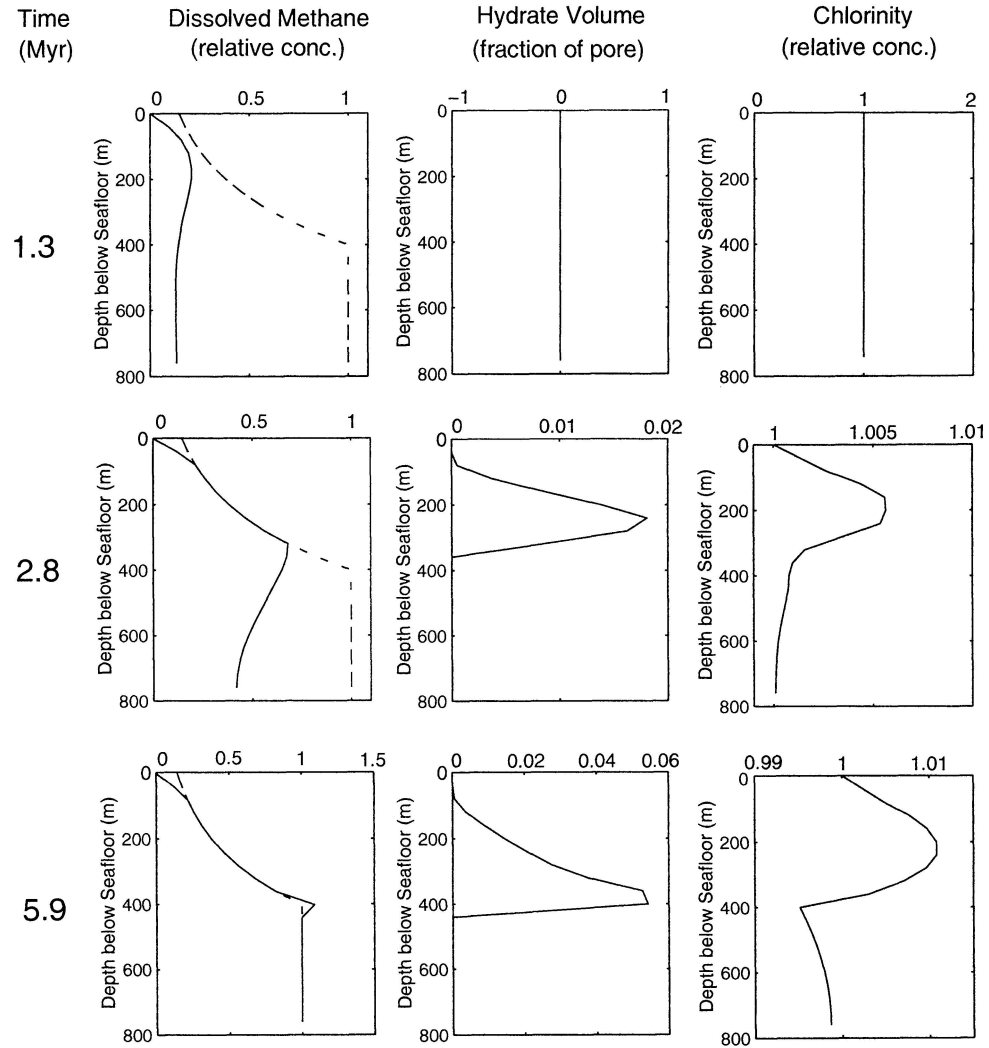


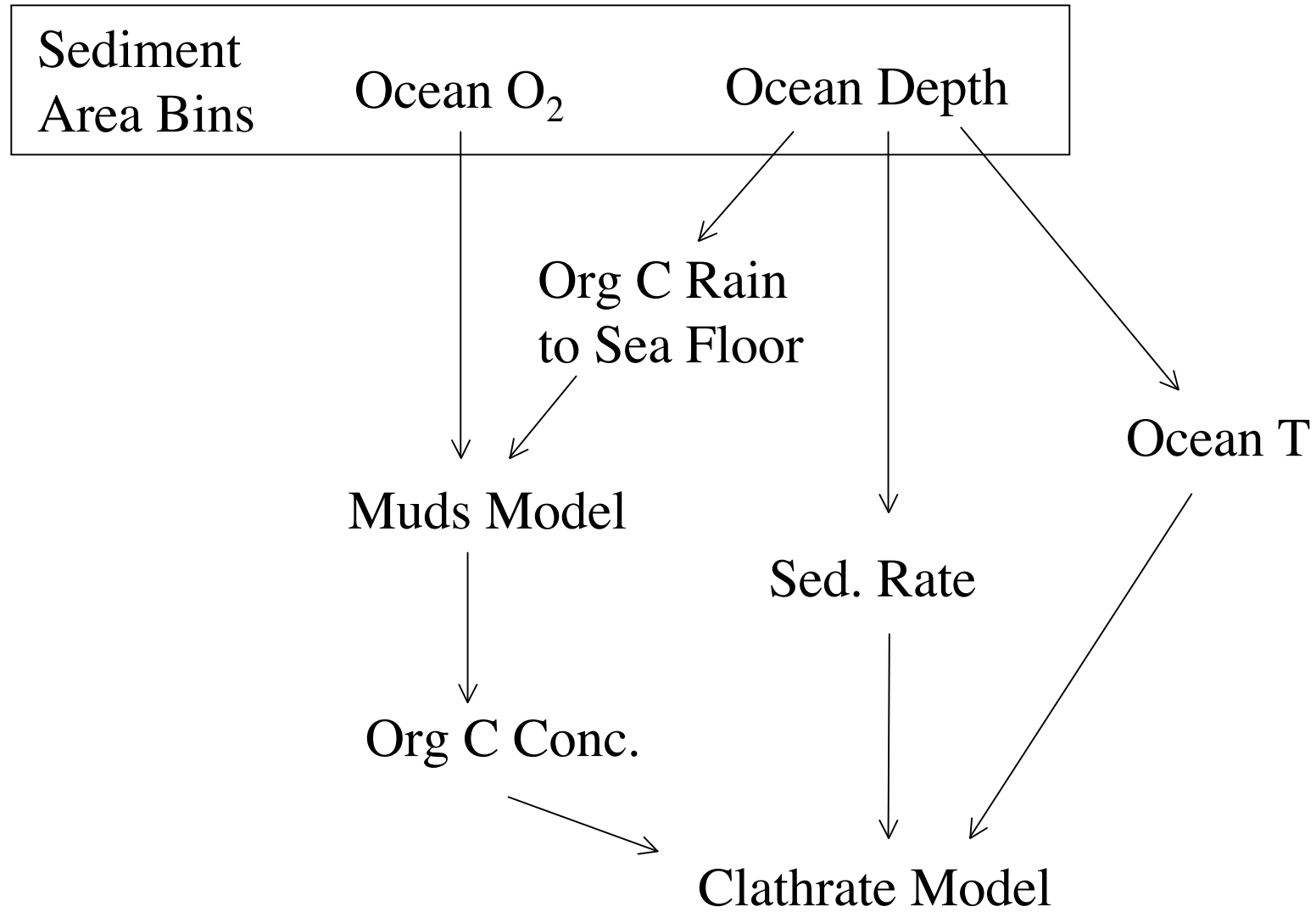
Fig. 5. The LPTM as recorded in benthic $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ records (A and B, respectively) from Sites 527 and 690 in the south Atlantic (73), and Site 865 in the western Pacific (26). The time scale is based on the cycle stratigraphy of Site 690 (30) with the base of the excursion placed at 54.95 Ma. The other records have been correlated to Site 690 using the carbon isotope stratigraphy. Apparent leads and lags are artifacts of differences in sample spacing. The oxygen isotope values have been adjusted for species-specific vital effects (118), and the temperature scale on the right is for an ice-free ocean. The negative carbon isotope excursion is thought to represent the influx of up to 2600 Gt of methane from dissociation of seafloor clathrate (111).



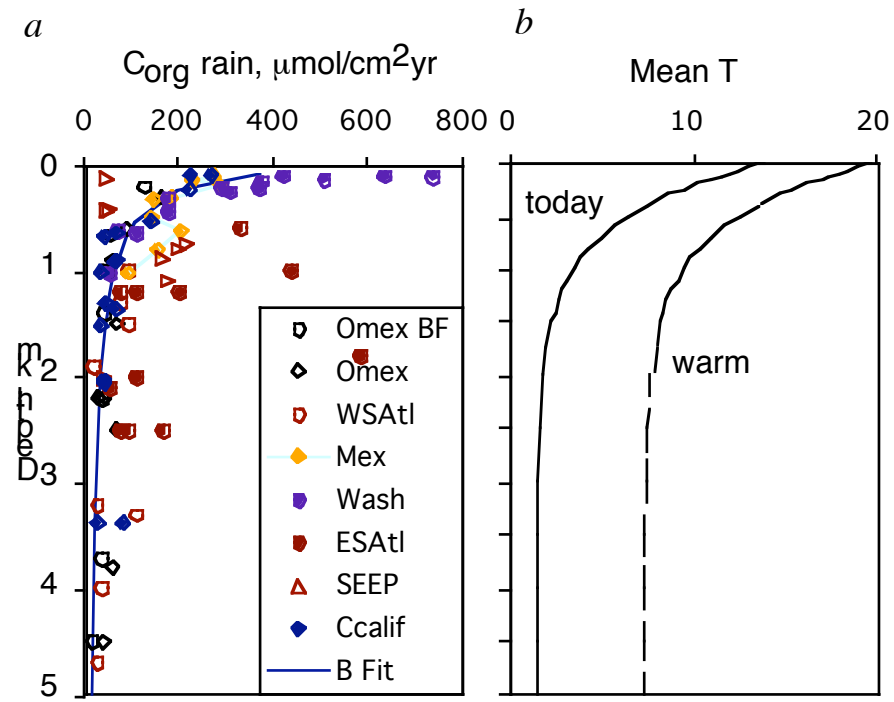
DAVIE AND BUFFETT: HYDRATE FORMATION BELOW THE SEAFLOOR



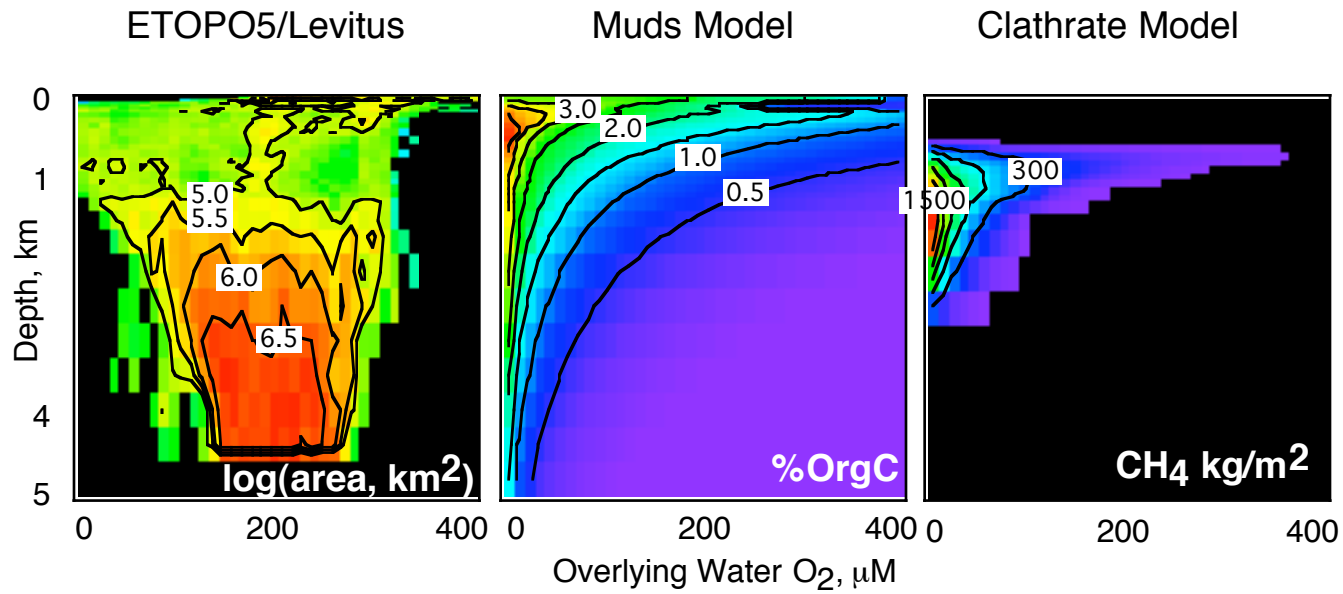
Data Flow



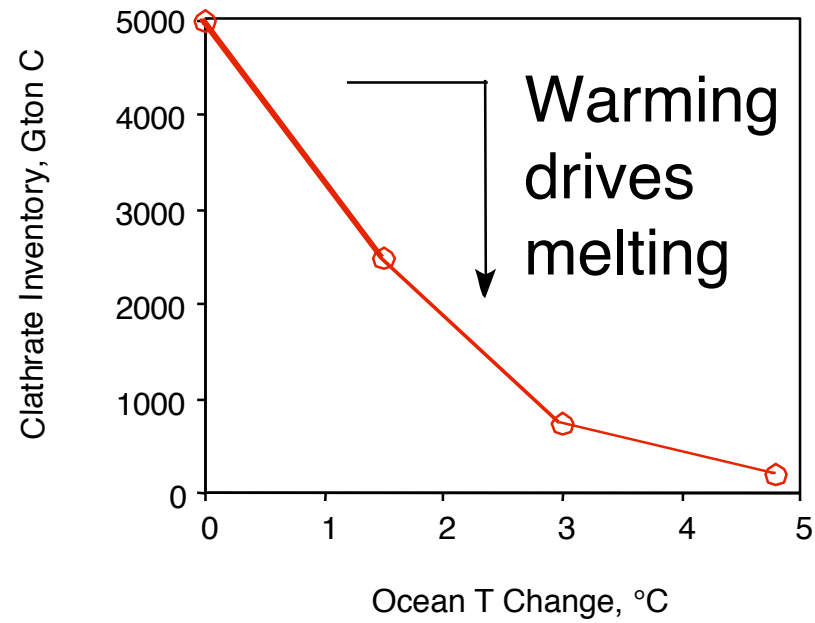
Organic rain, T as fn(depth)

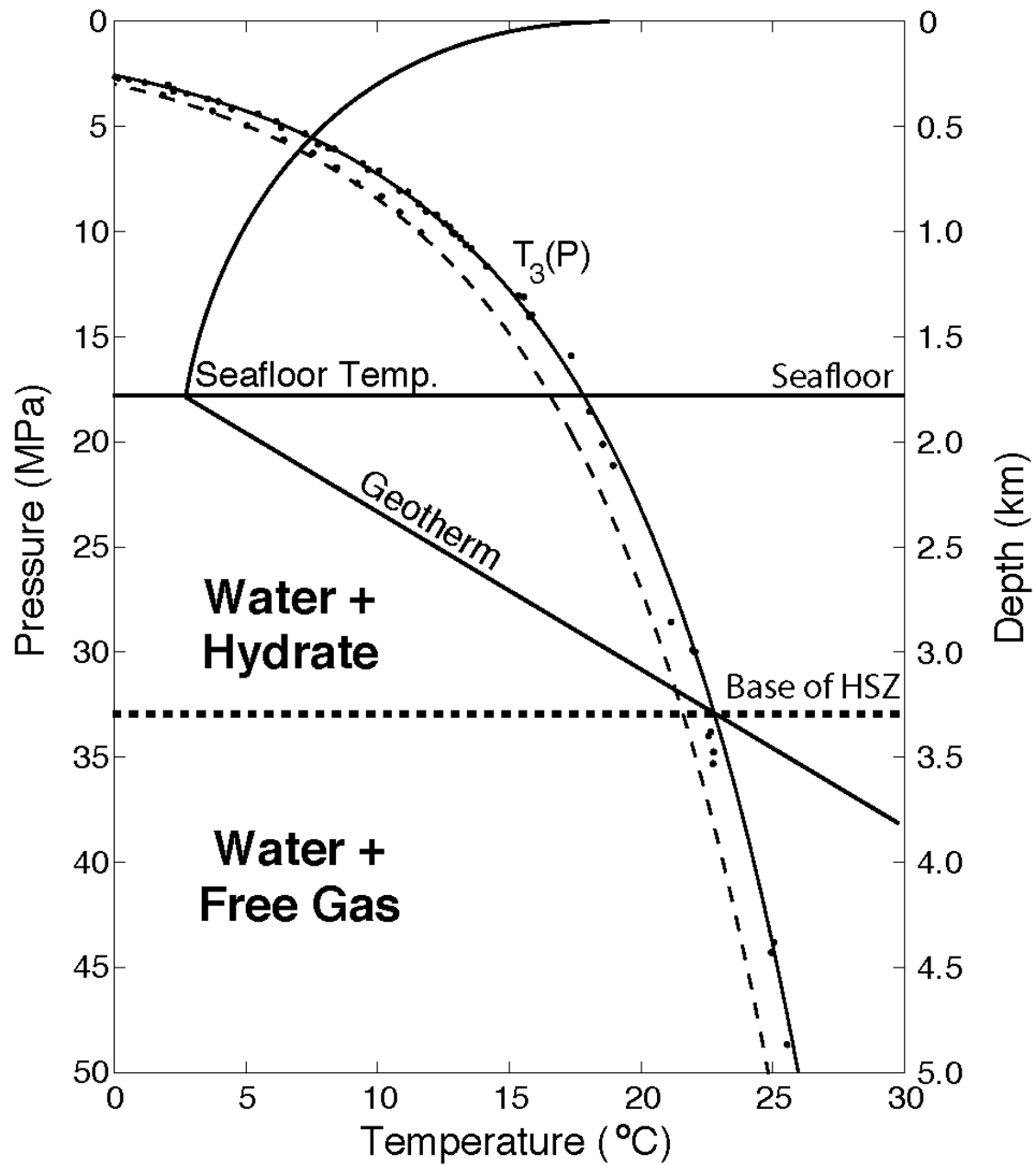


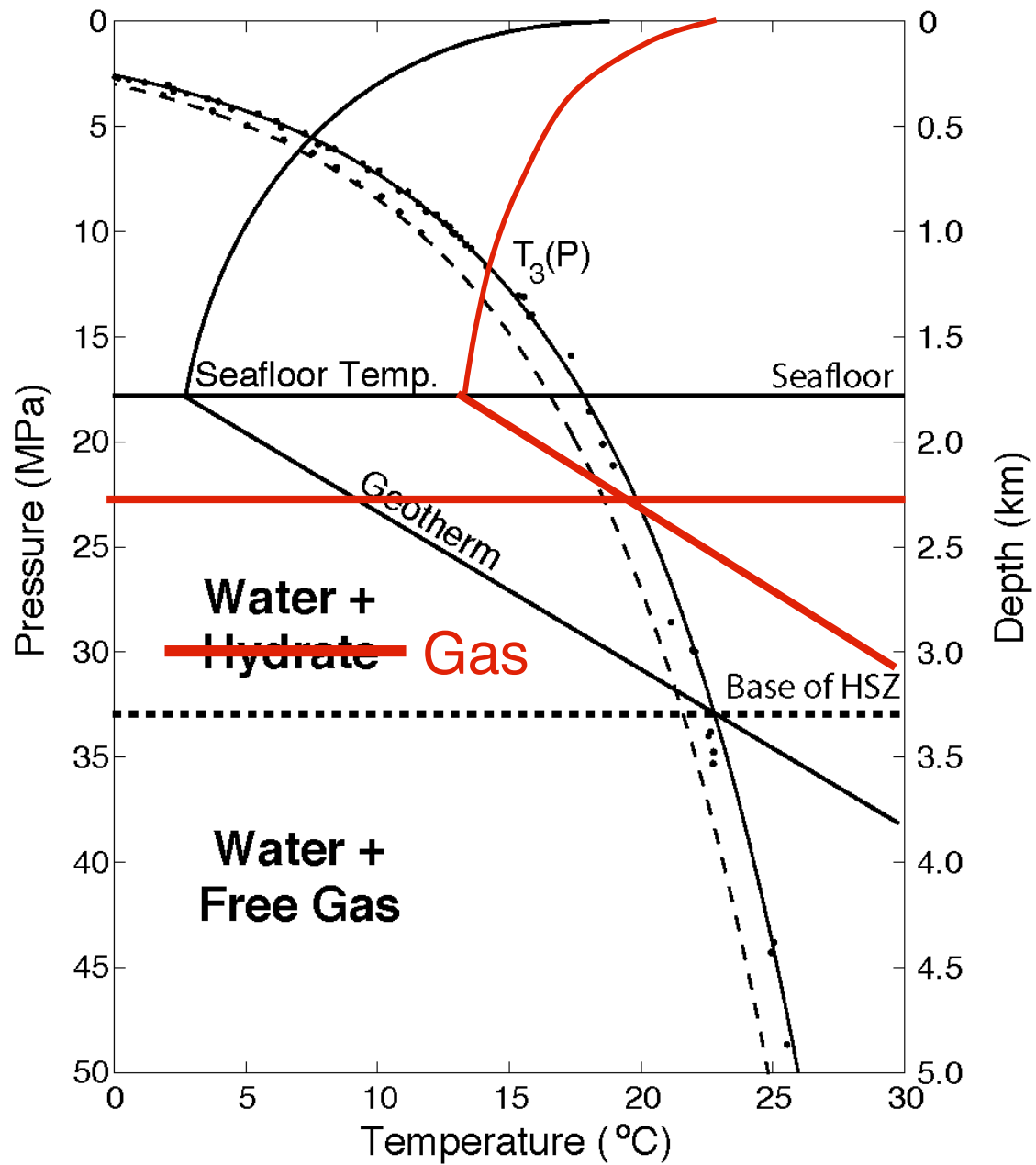
Gridded ocean accounting



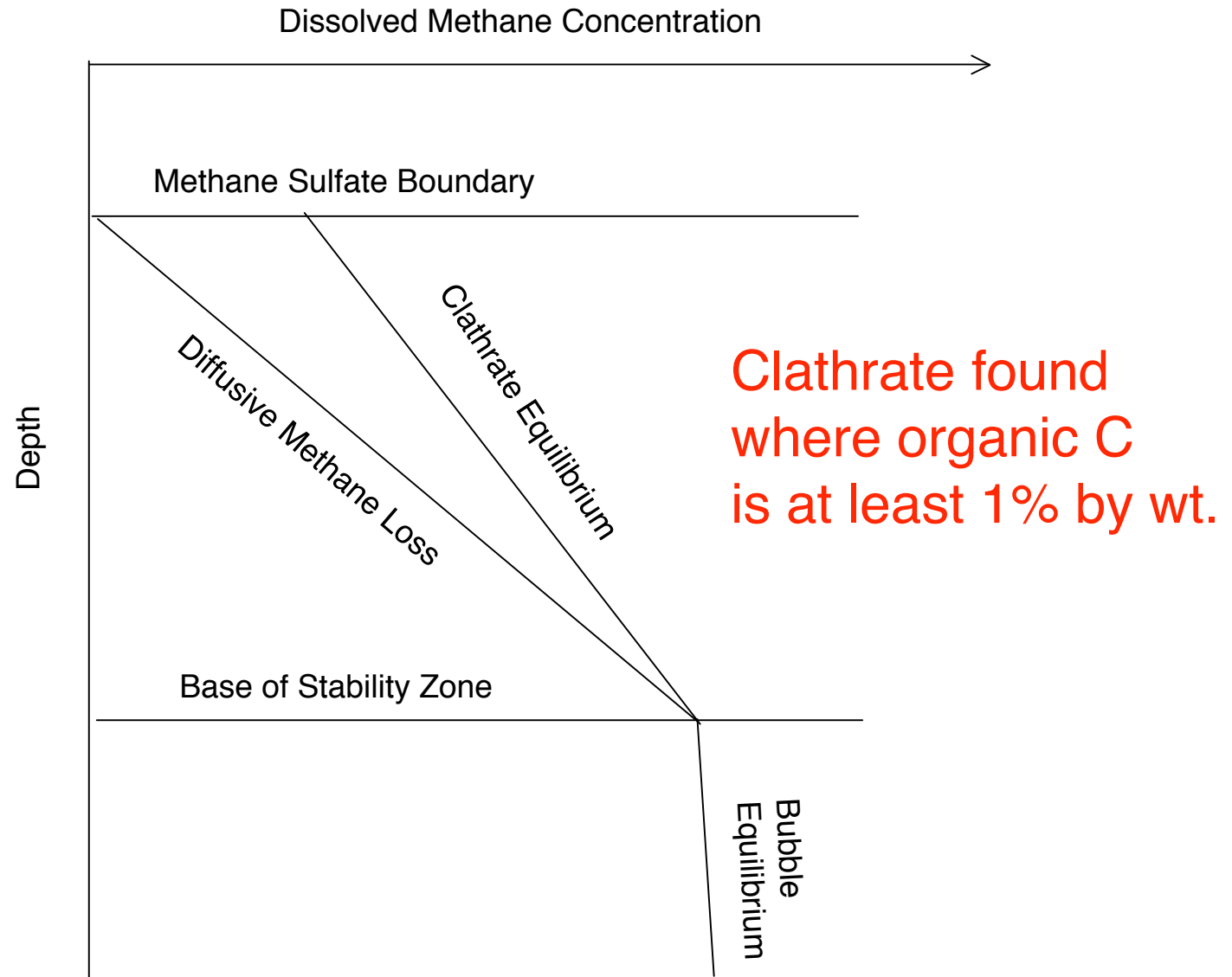
Clathrate Sensitivity to Temperature



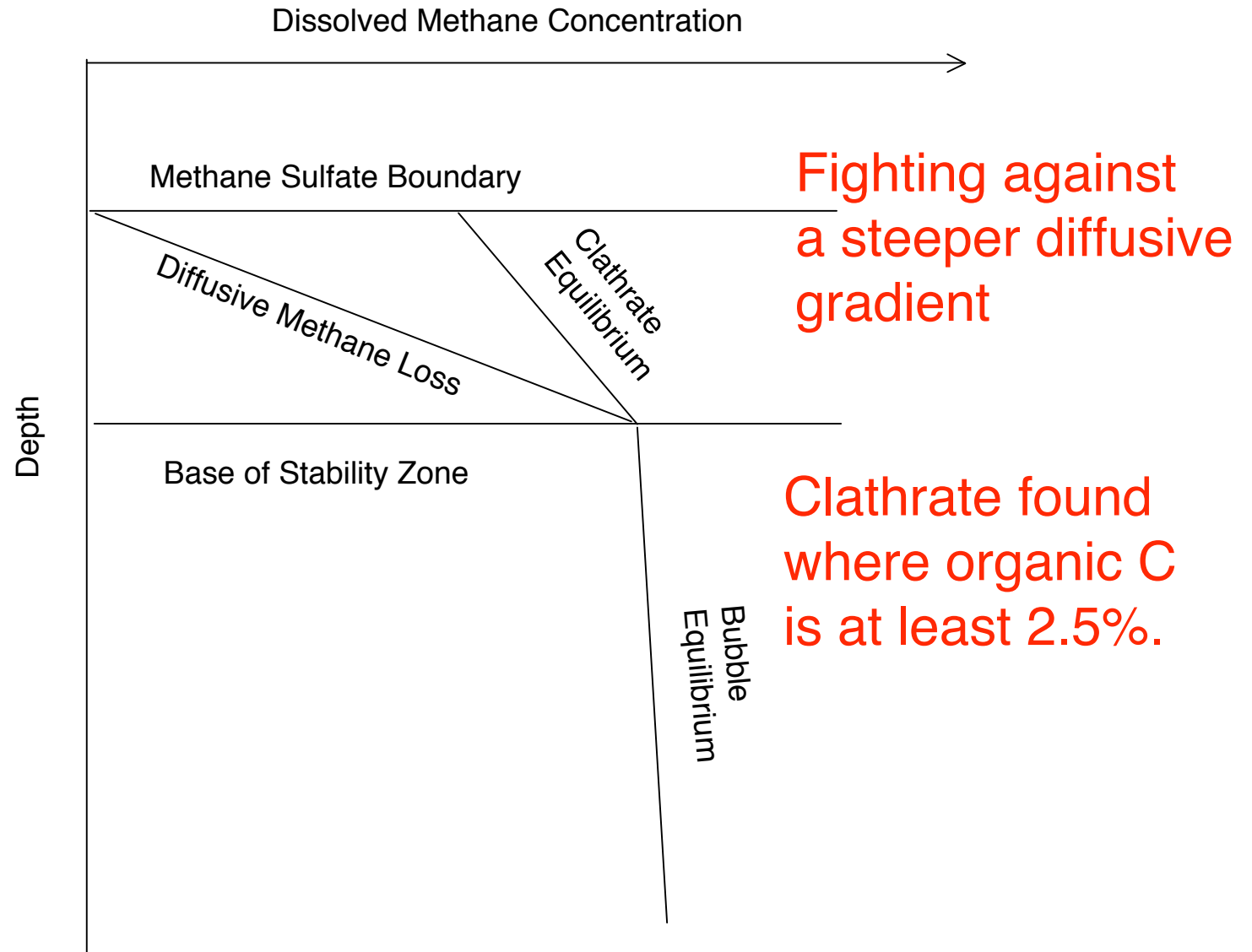




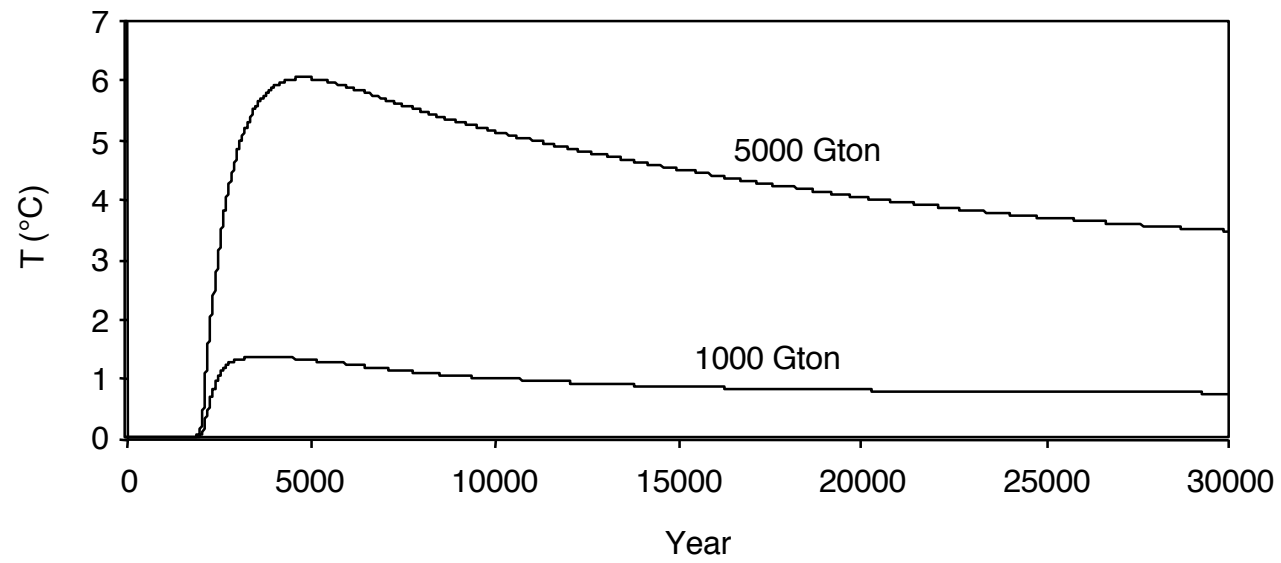
Effect of T on Clathrate Inventory



Effect of T on Clathrate Inventory

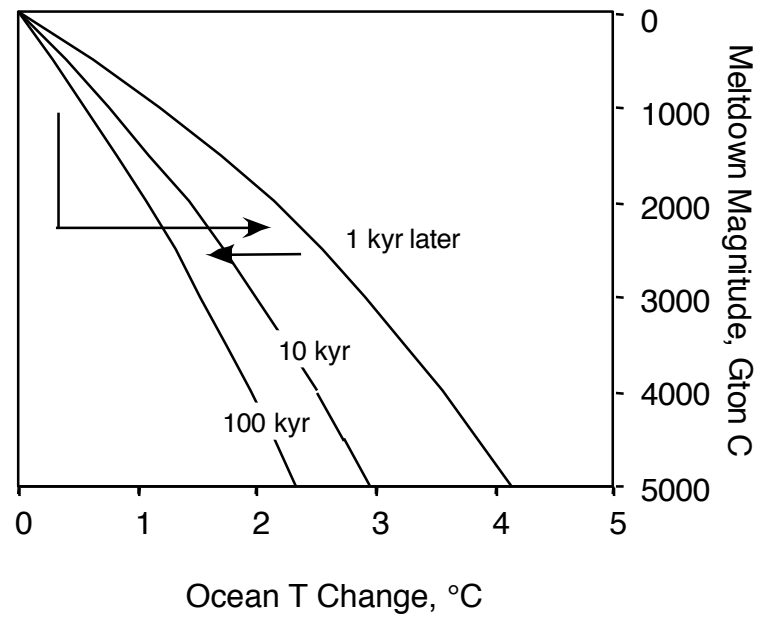


Hamocc Deep Ocean Temperature

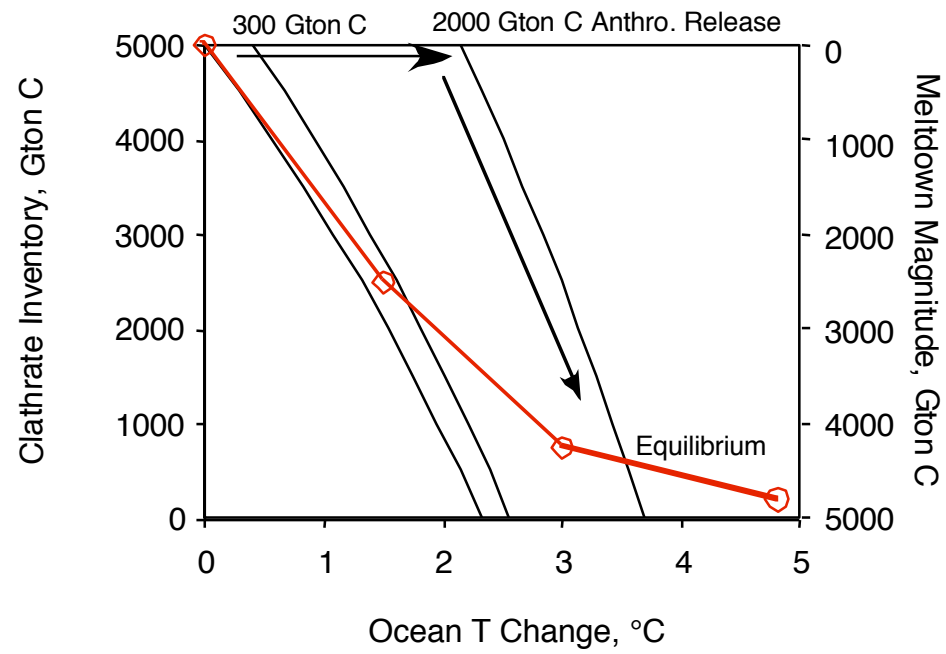


Radiative Impact of a Clathrate Carbon Release

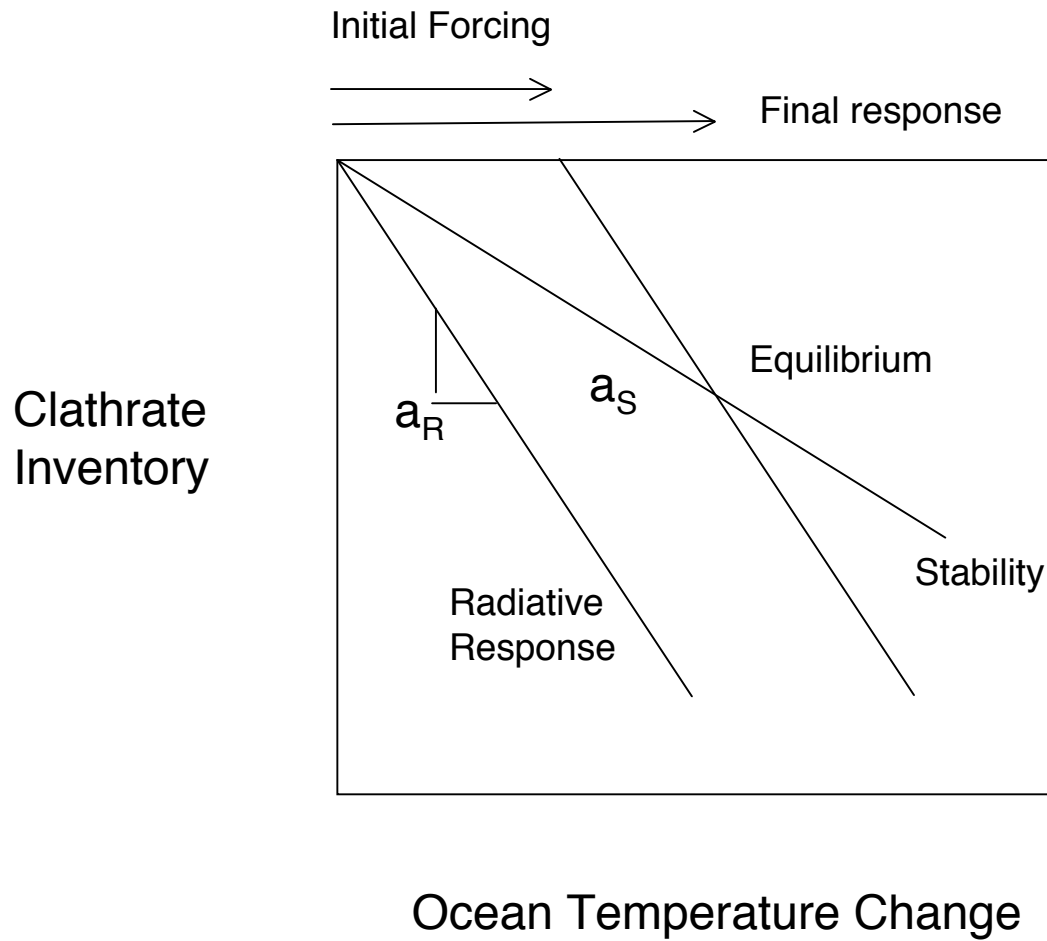
Melting
warms
ocean



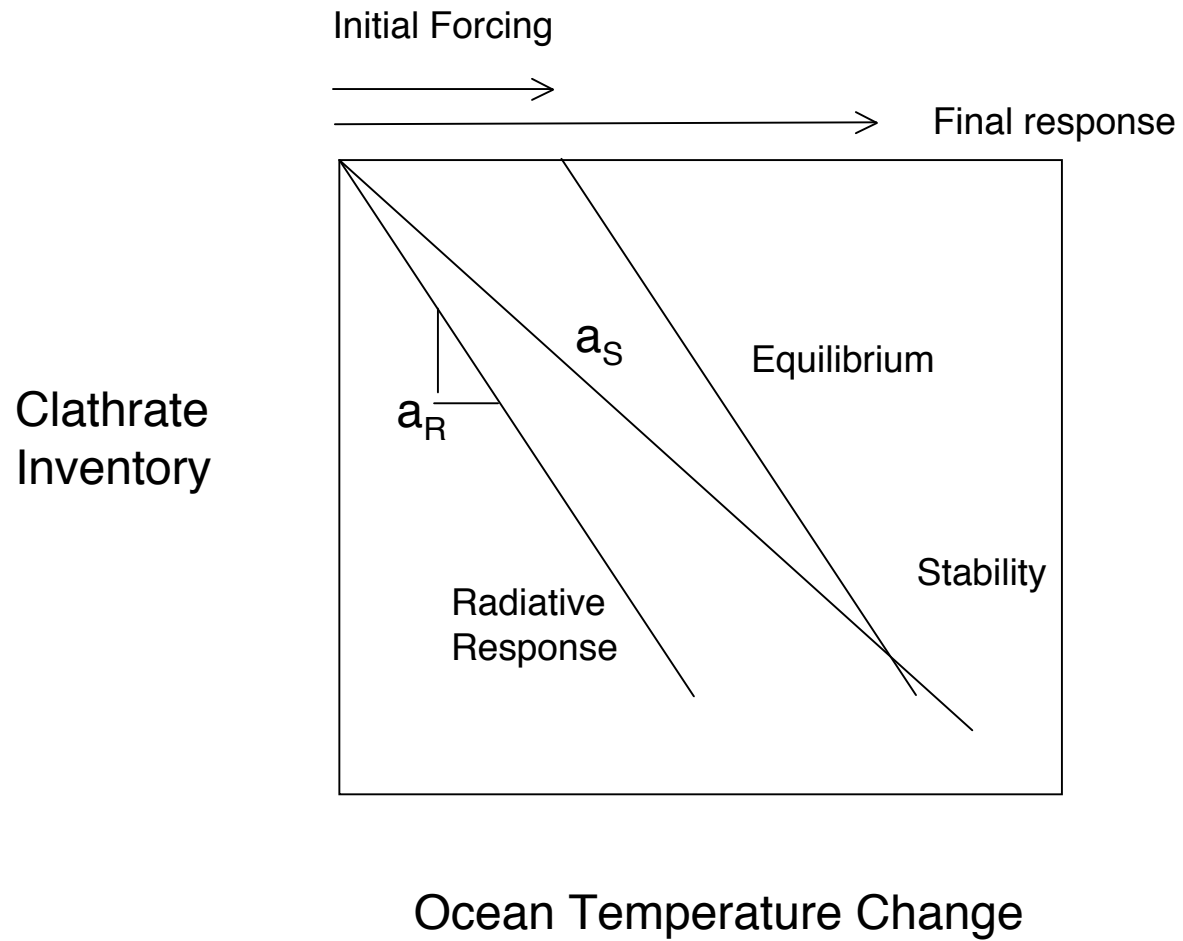
Amplifying Feedback



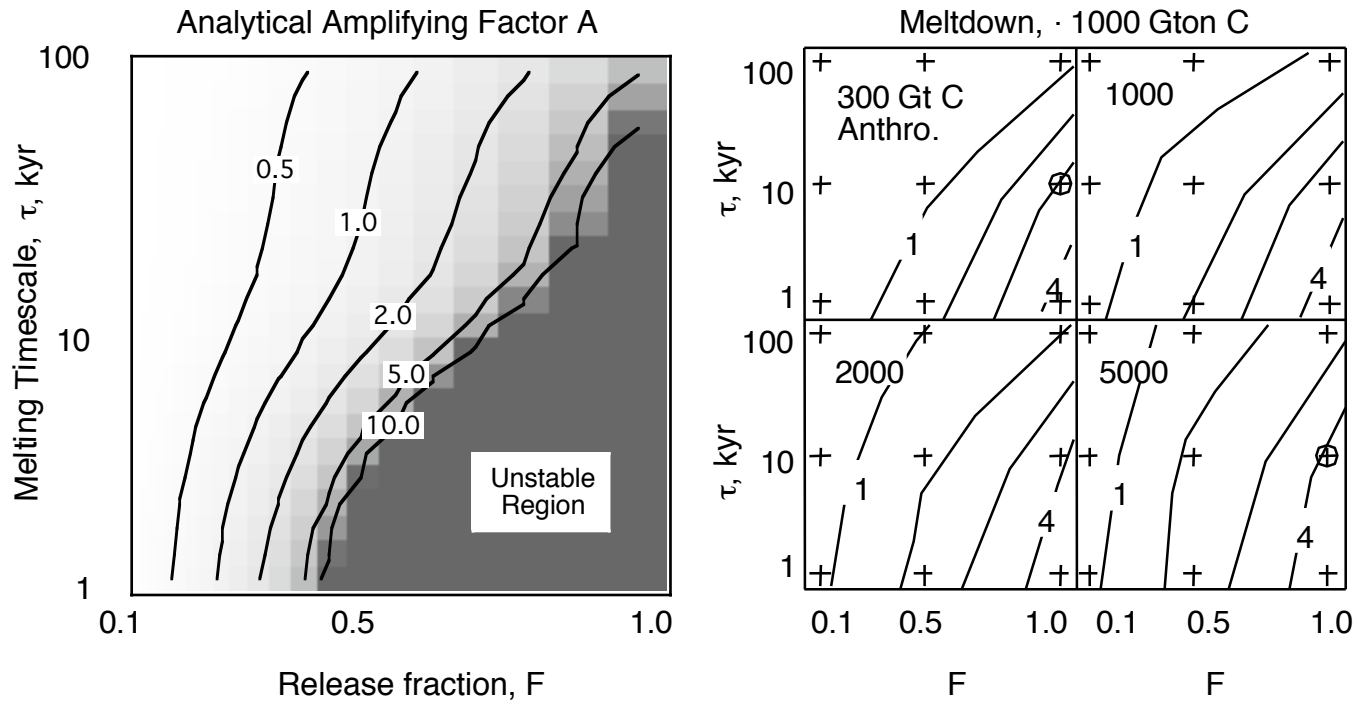
Amplifying Feedback



Amplifying Feedback



Amplifying Feedback



Mechanisms for Meltdown

Methane could react with SO_4 to form CaCO_3 in the sediment.

Methane carbon could escape diffusively to the ocean on a time scale of Myr. Atmospheric pCO_2 would be stabilized by the silicate weathering thermostat (timescale = 400 kyr).

Bubbles could coalesce and escape if bubble fraction $> 10\%$.

Hydrostatic pressure spike upon melting could destabilize sediment column. Timing governed by heat transport to deep sediments, thousands of years.

Clathrate bottom line

The clathrate inventory of the ocean is very sensitive to ocean temperature.

It could easily melt down in the future, in response to fossil fuel CO₂ release. This will take thousands of years, at least.

The extent of the meltdown depends on how quickly and completely the reservoir responds.

The clathrate reservoir has probably grown through geologic time, and therefore gotten more tippy.