# Costs of perturbations and feedbacks in the CO2 and methane cycles

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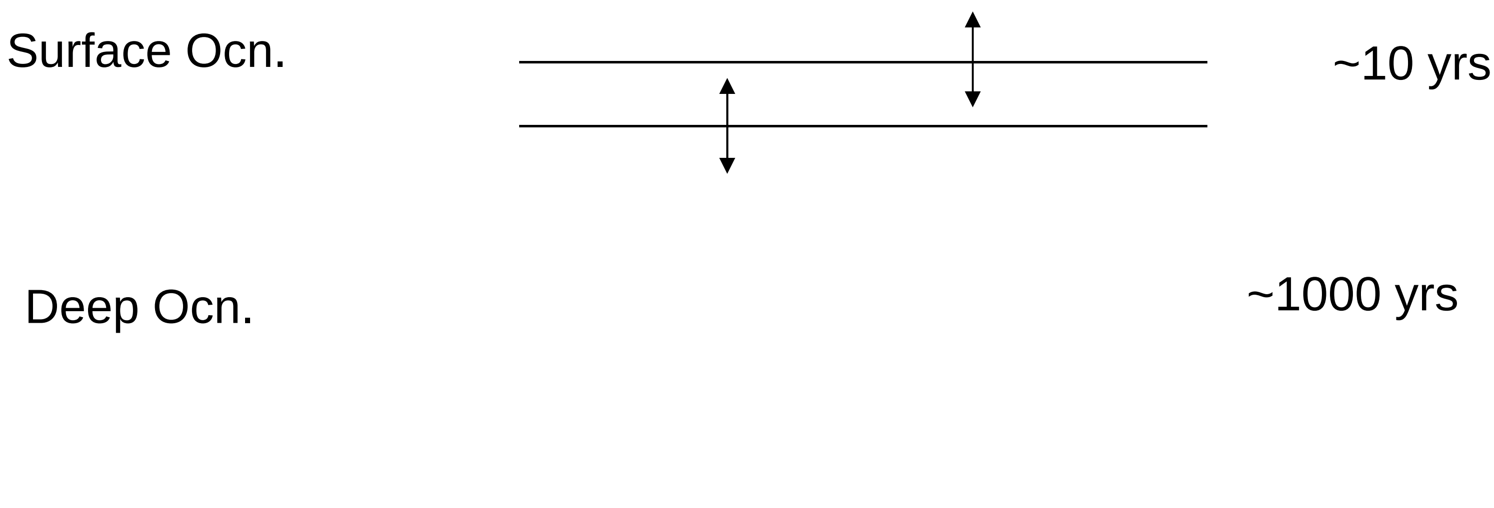
# Your queries

1. Simplest model of ocean $CO_2$ and pH evolution
2. Permafrost carbon feedback? (Methane?)
3. Ocean hydrate feedback?
4. Tipping points of above?
5. Ocean acidification tipping point or feedbacks?
6. Valuing above?

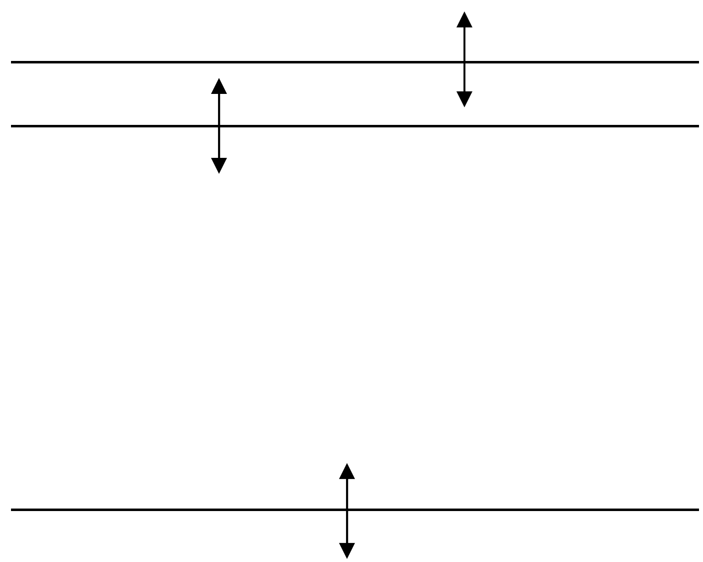
# My outline

1. Simple model of ocean $CO_2$ and heat
2. Impacts of methane vs. $CO_2$ on Peak T
3. Permafrosts and ocean hydrates within the global methane cycle
4. Ocean acidification impacts (?)
5. Immediate vs. ultimate social cost of carbon

# Simplest Model for Earth’s Thermal Inertia and Carbon Cycle



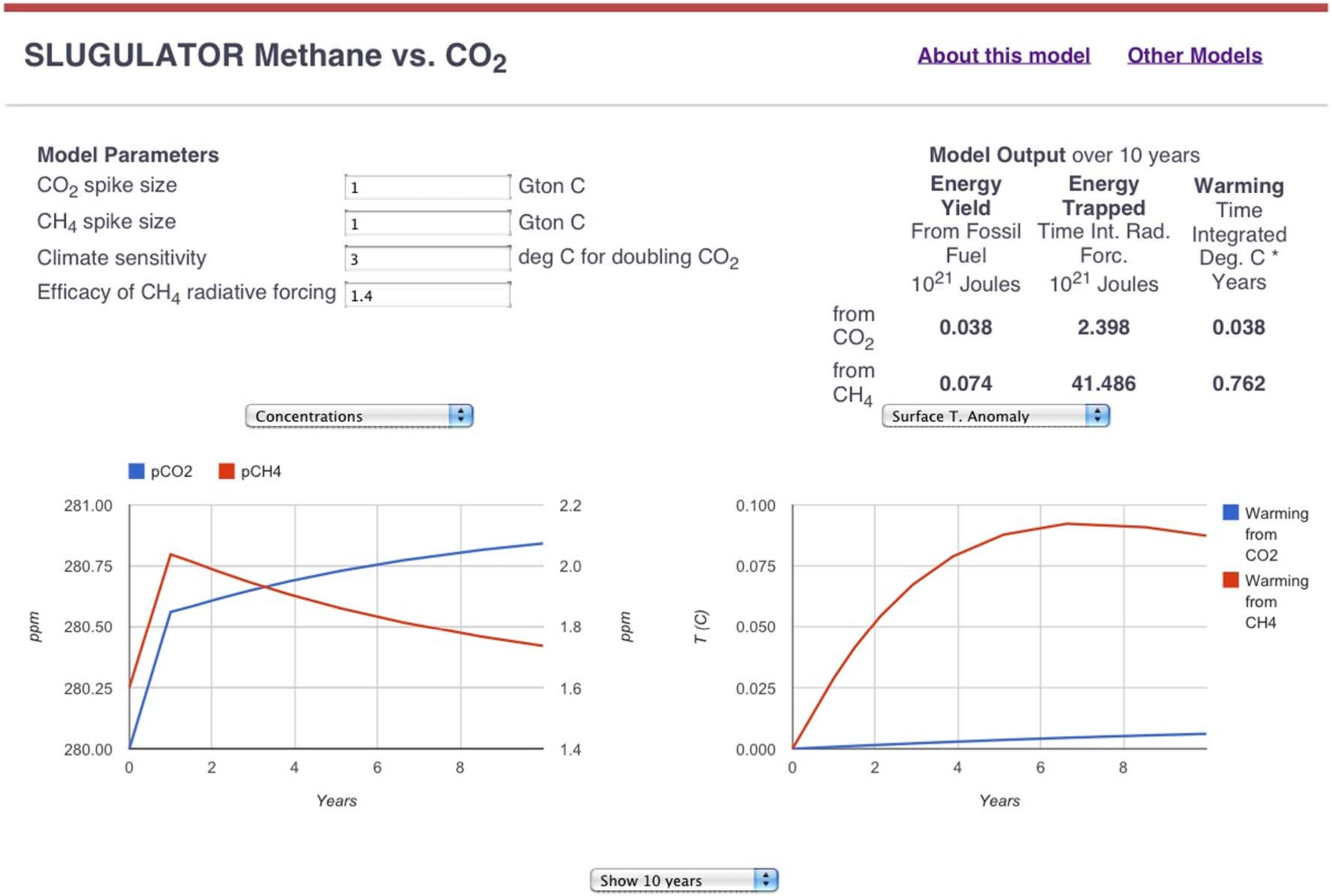
# Time scale for Atmospheric $CO_2$ Uptake



Ocean dissoln. ~300 yrs

$CaCO_3$ neut. ~5000 yrs

Solid earth ~400,000 yrs




http://climatemodels.uchicago.edu/slugulator

# $CO_2$ vs $CH_4$ Abatement Impacts

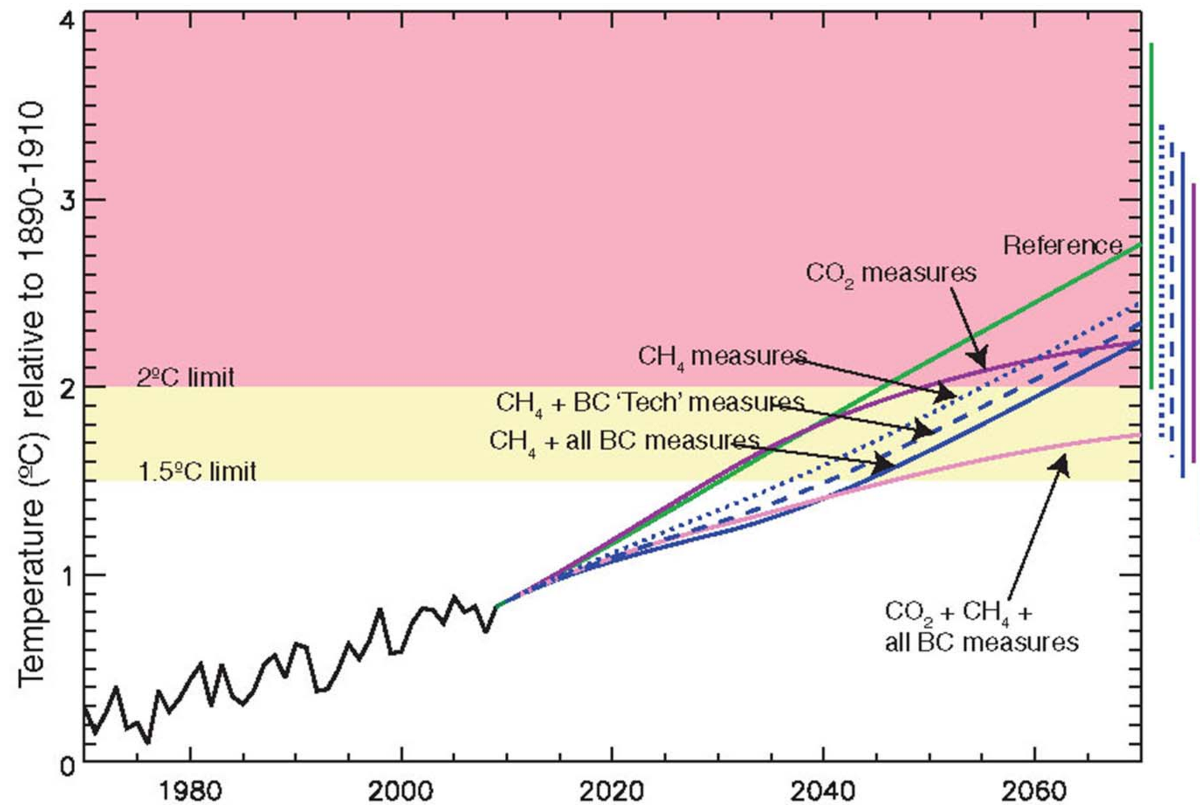



**Fig. 1.** Observed temperatures (*42*) through 2009 and projected temperatures thereafter under various scenarios, all relative to the 1890–1910 mean. Results for future scenarios are the central values from analytic equations estimating the response to forcings calculated from composition-climate modeling and literature assessments (*7*). The rightmost bars give 2070 ranges, including uncertainty in radiative forcing and climate sensitivity. A portion of the uncertainty is systematic, so that overlapping ranges do not mean there is no significant difference (for example, if climate sensitivity is large, it is large regardless of the scenario, so all temperatures would be toward the high end of their ranges; see www.giss.nasa.gov/staff/dshindell/Sci2012).

Shindell et al 2012

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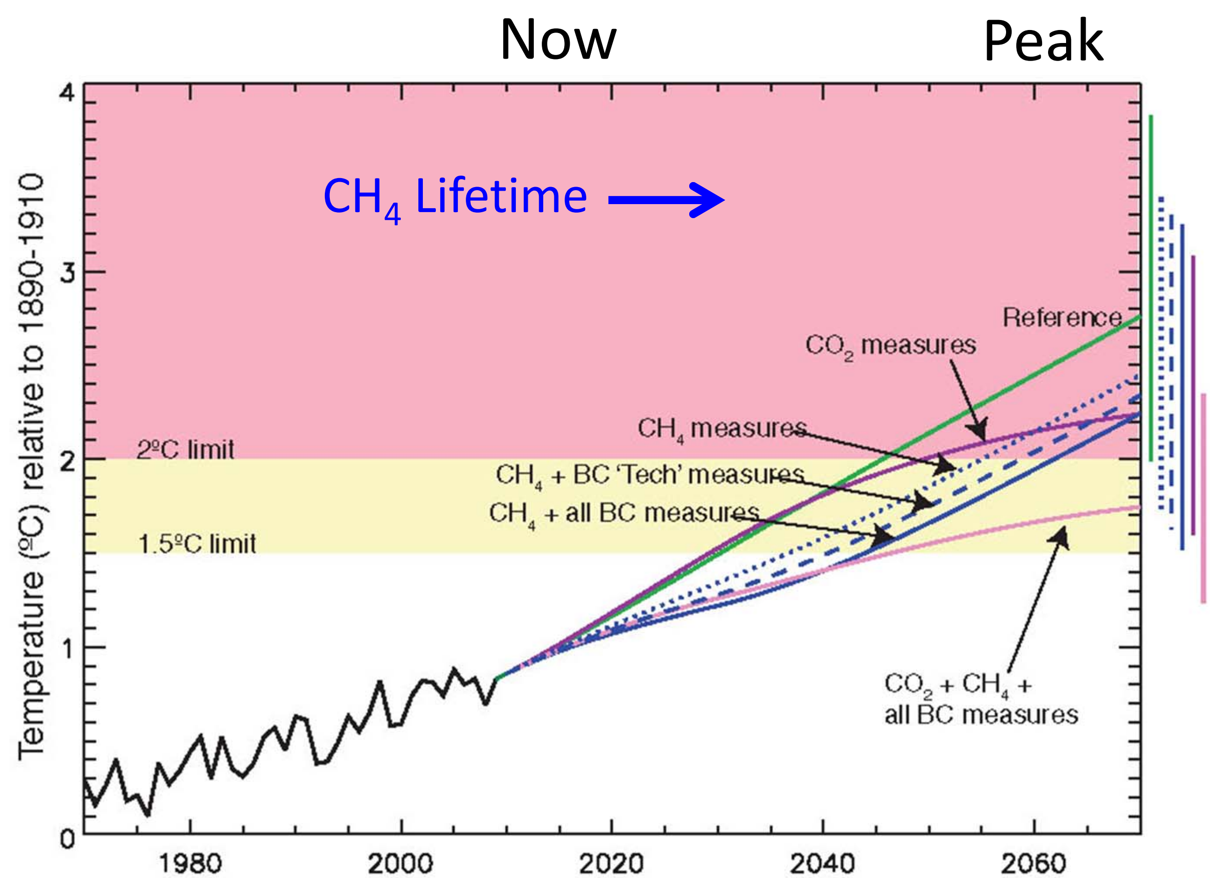


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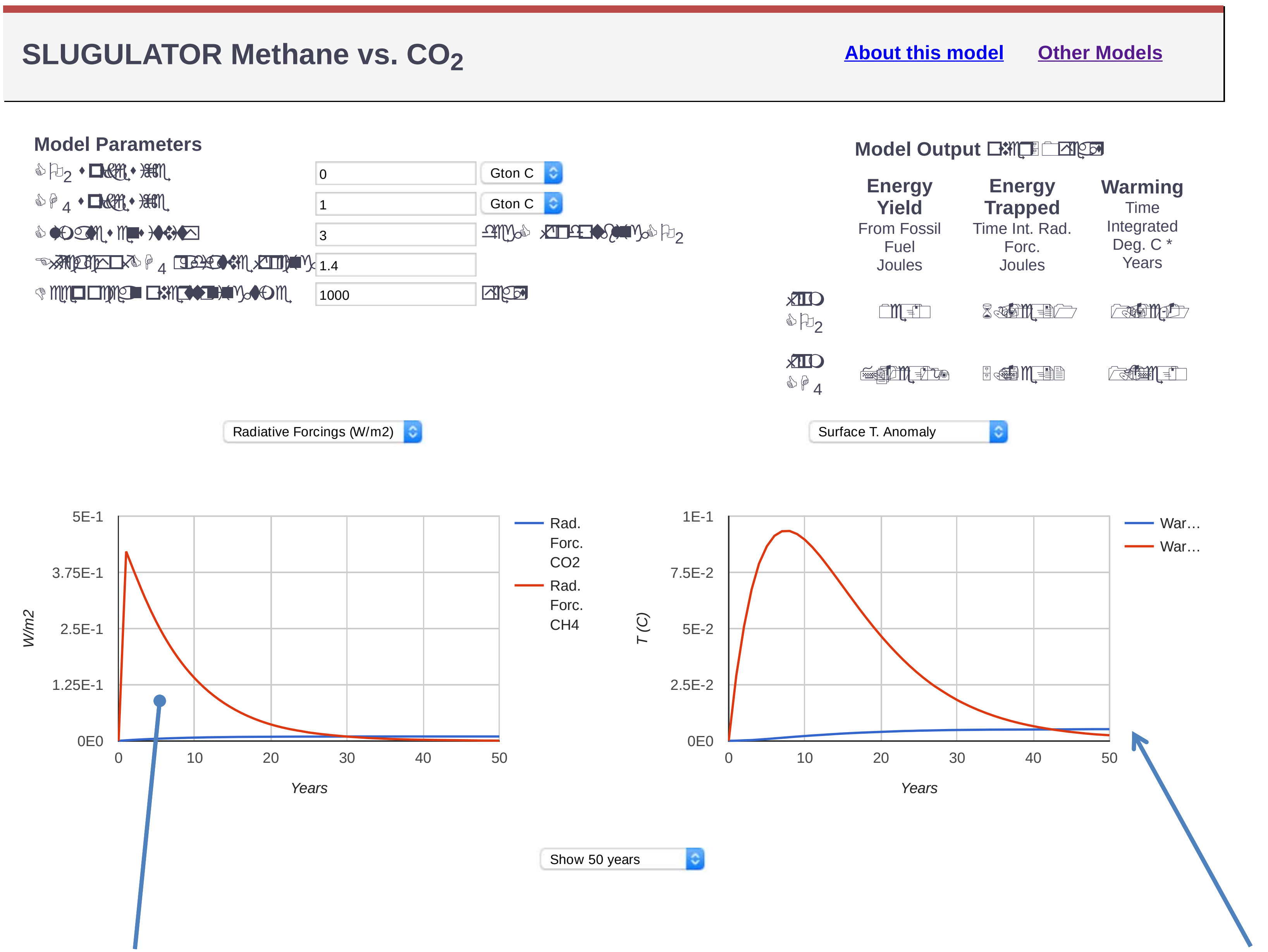
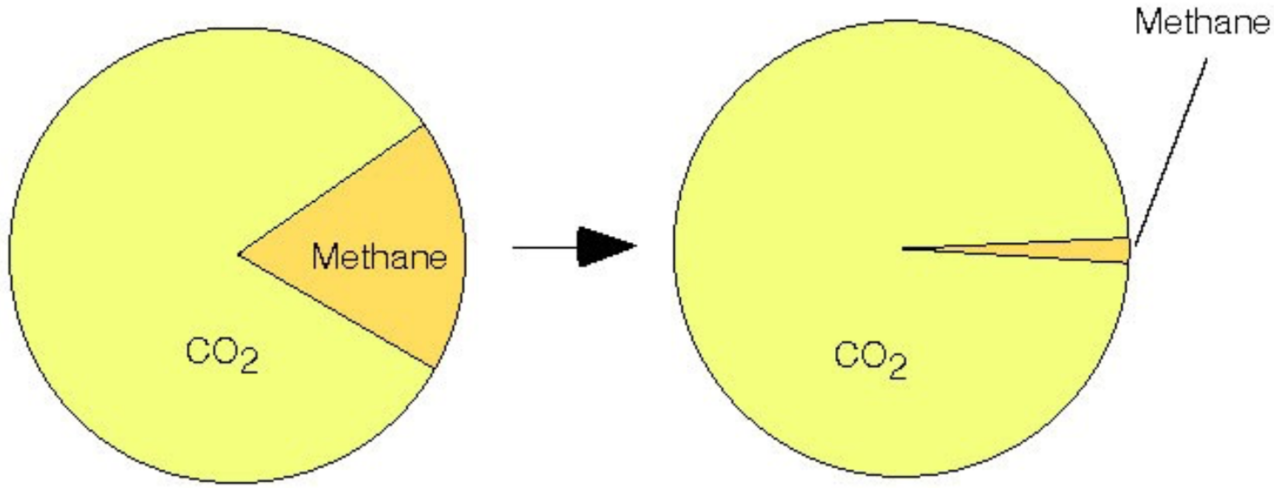



Integral = GWP

Peak T Impact

# $CO_2$ vs. Methane

- Global Warming Potential (GWP)
  integral of radiative forcing
  methane more powerful by 20-40x
  Peak Temperature Impact
  methane by only 3-4x (today)
  Methane = 1% of C emissions, 3% of impact

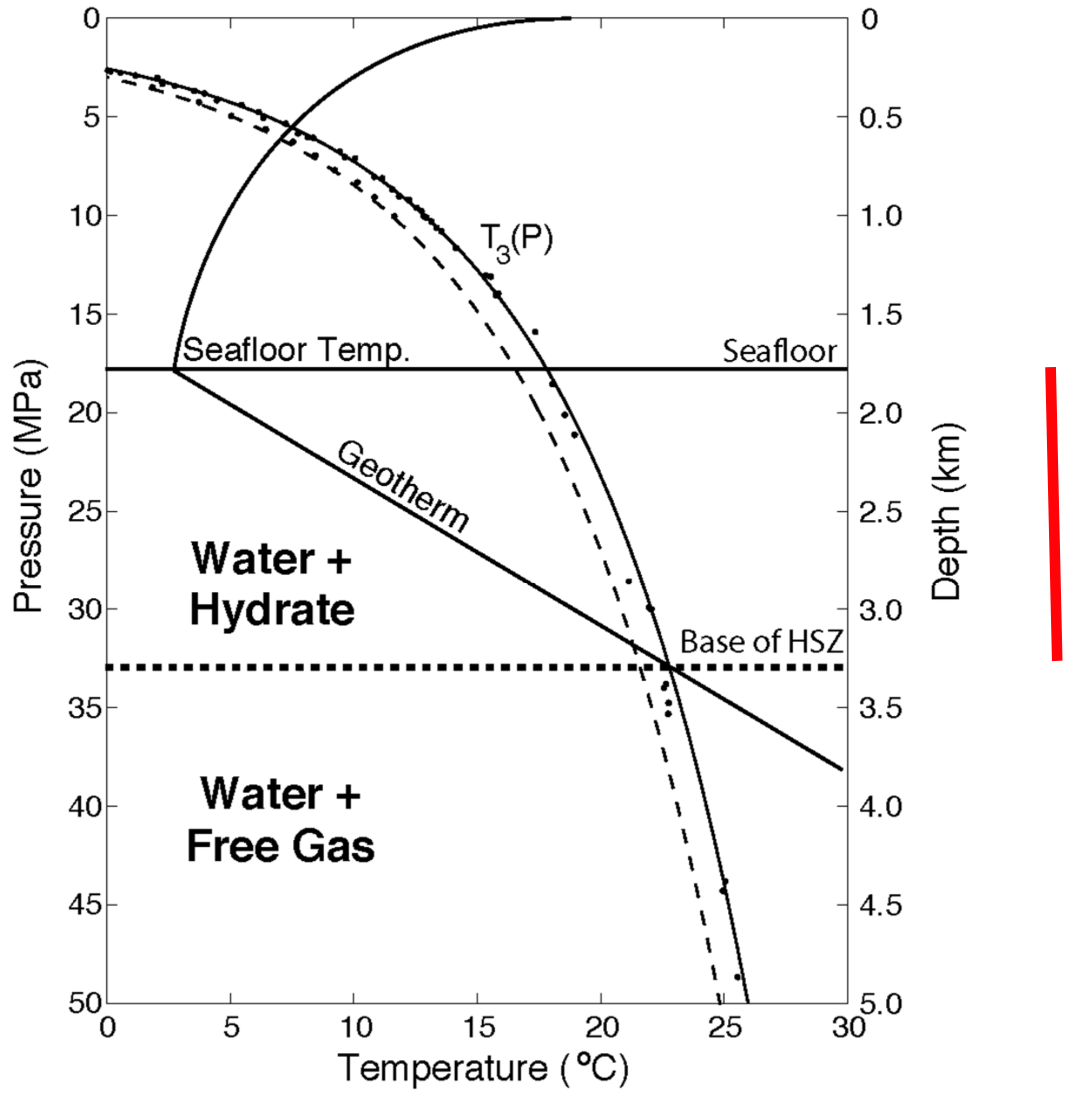



Radiative Forcing
change over the last 30 years[1]

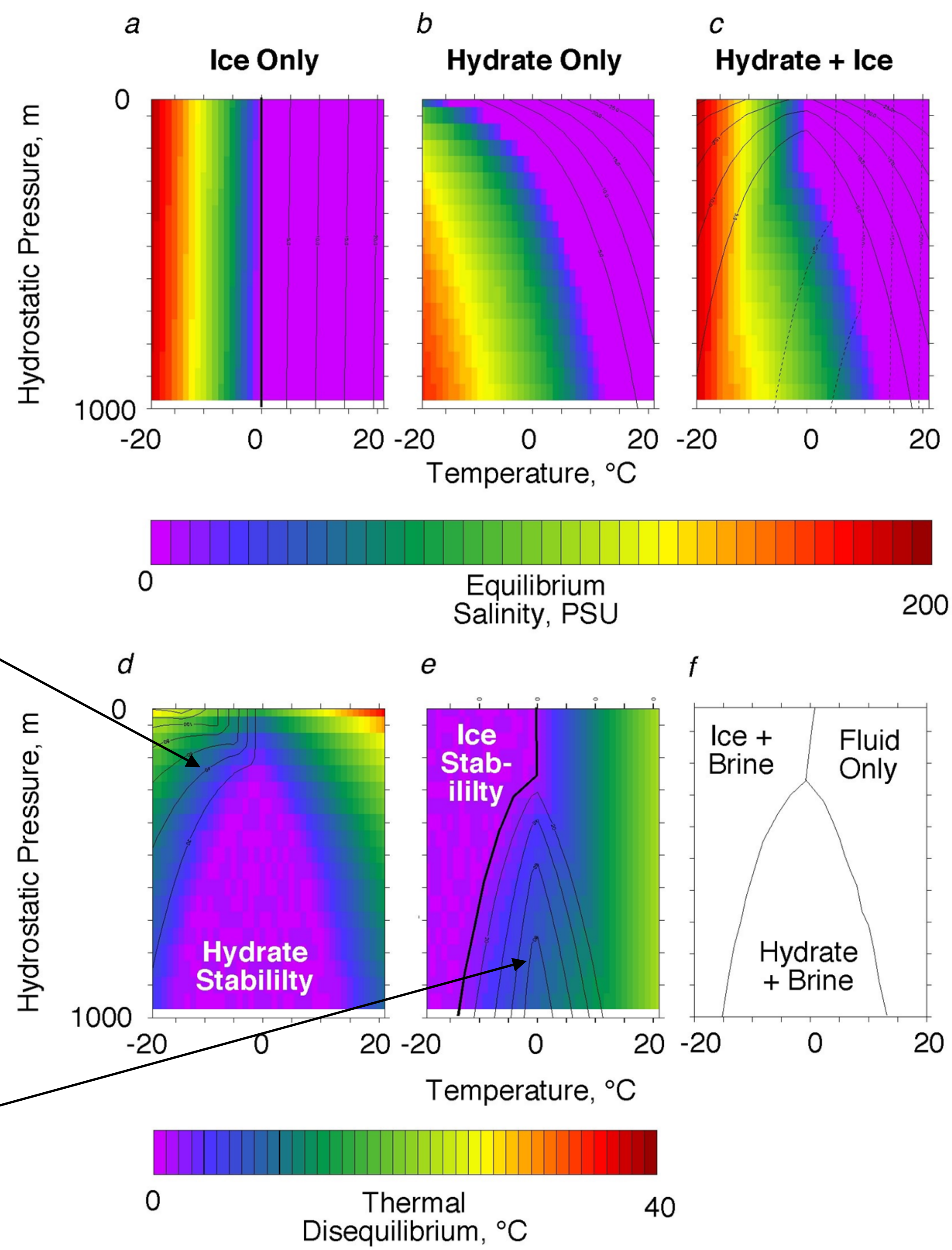
Our impact 30 years from now[2]

# The Siberian Continental Margin

# Methane Hydrate Stability Zone

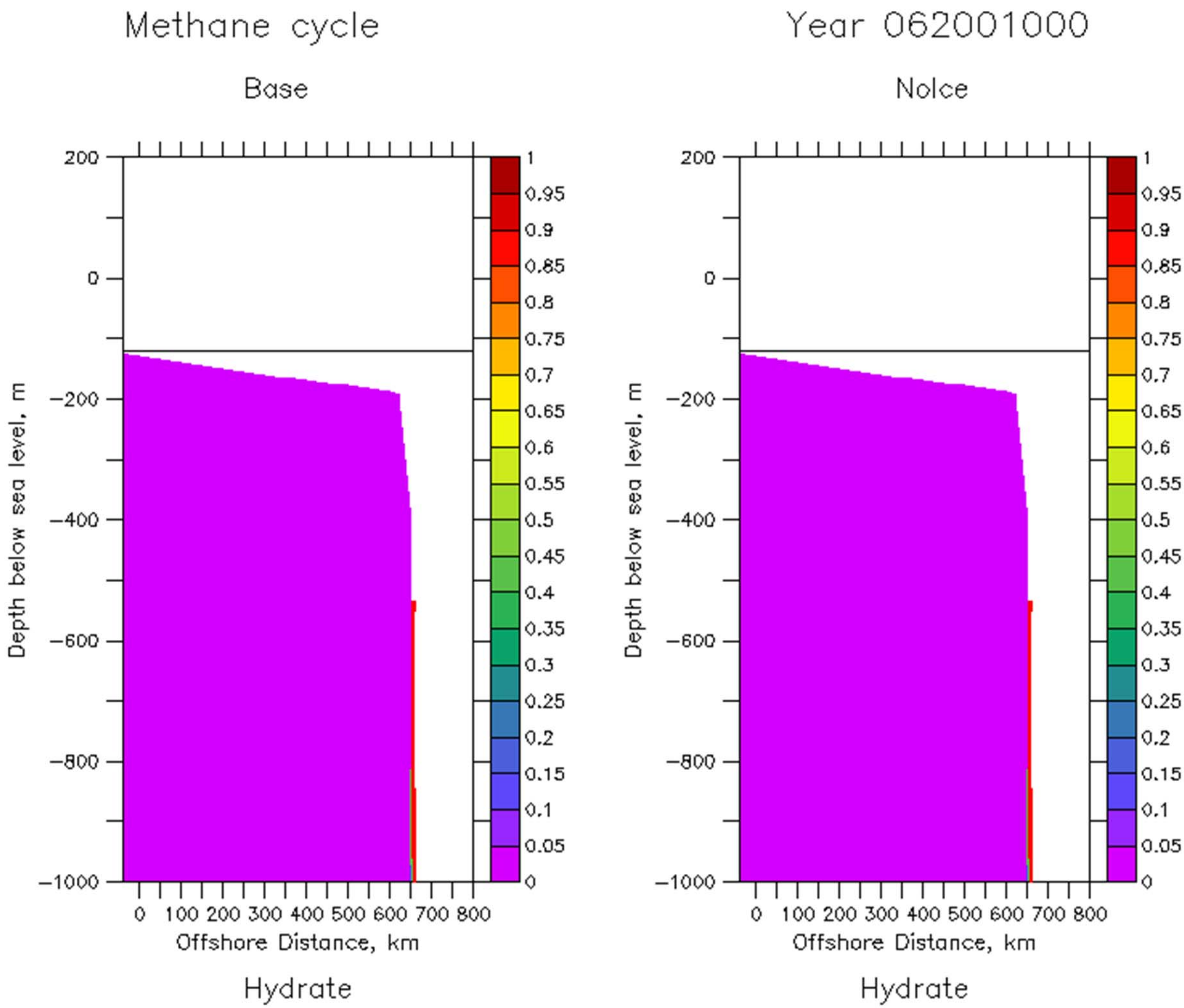


# Ice vs. Hydrate

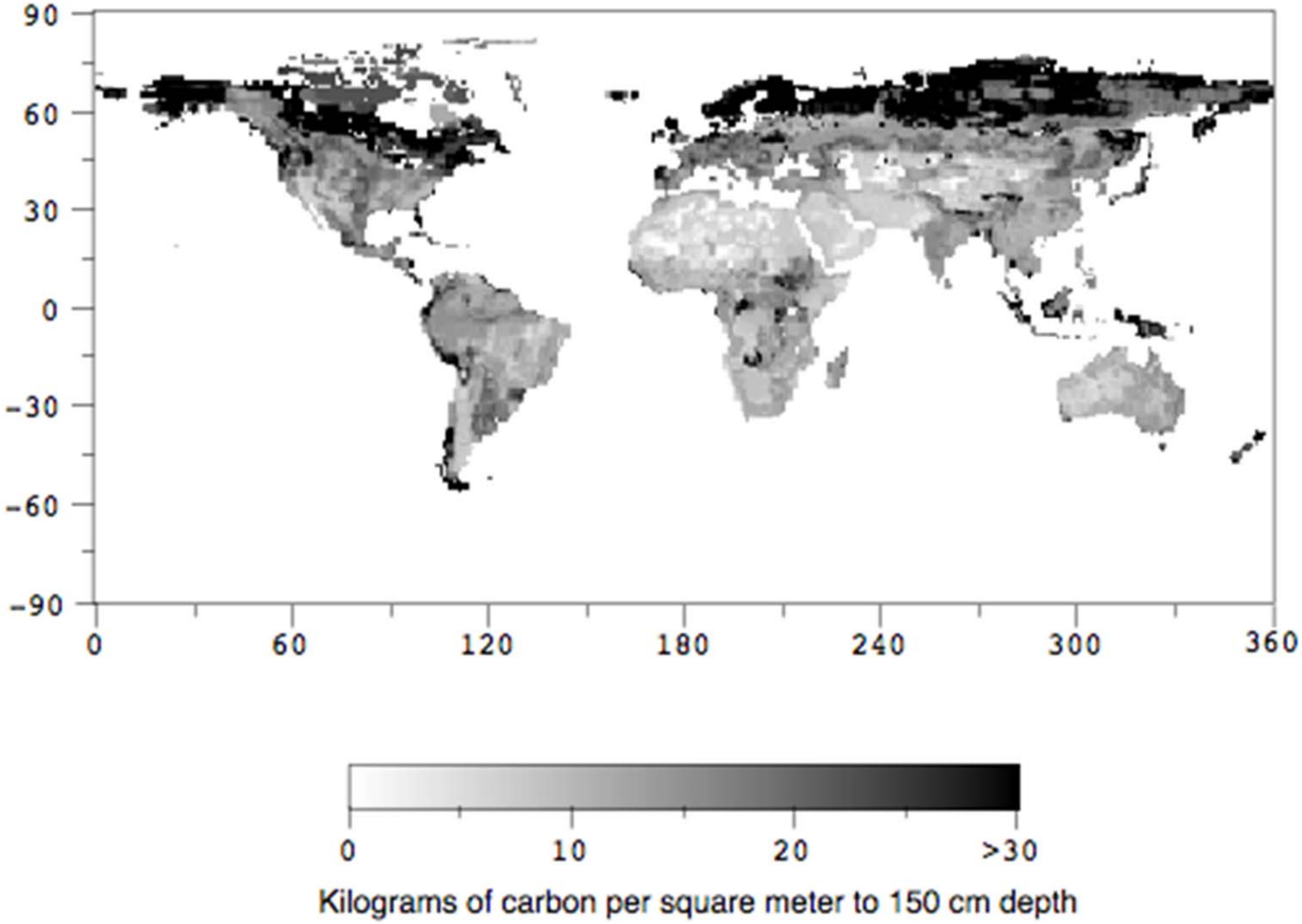



Hydrate excluded from permafrost zone

Ice excluded from hydrate zone if there is sufficient $CH_4$


Methane cycle
Year 062001000
Base
NoIce
Depth below sea level, m
Offshore Distance, km
200
0
-200
-400
-600
-800
-1000
0 100 200 300 400 500 600 700 800
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Hydrate
Hydrate

# Long-term carbon cycle feedbacks: soil carbon



Yedoma

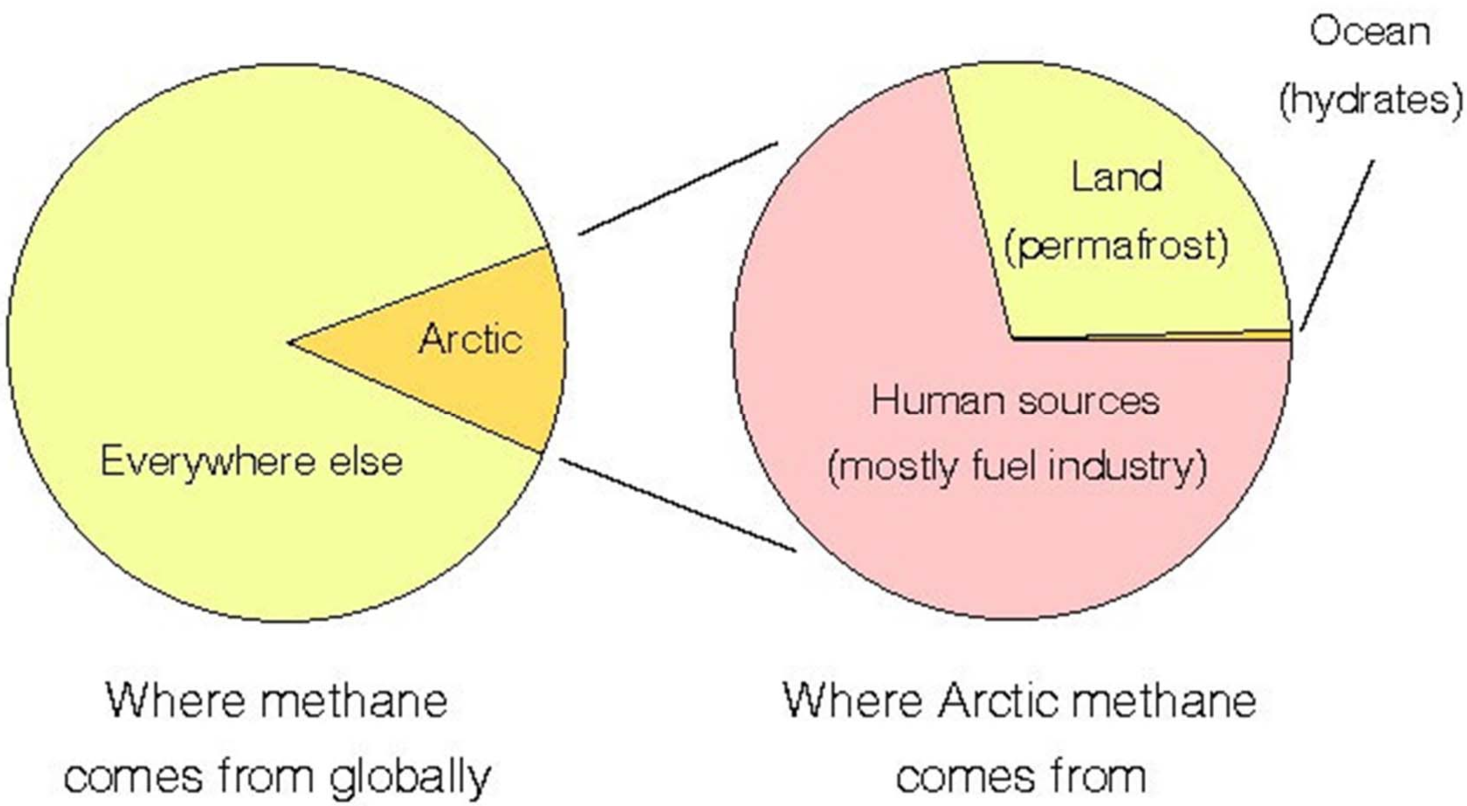
**Ancient soils. (Left)** Exposed carbon-rich soils from the mammoth steppe-tundra along the Kolyma River in Siberia. The soils are 53 m thick; massive ice wedges are visible. **(Right)** Soil close-up showing 30,000-year-old grass roots preserved in the permafrost.

Frozen grass roots accumulated in wind-deposited glacial flour (loess)

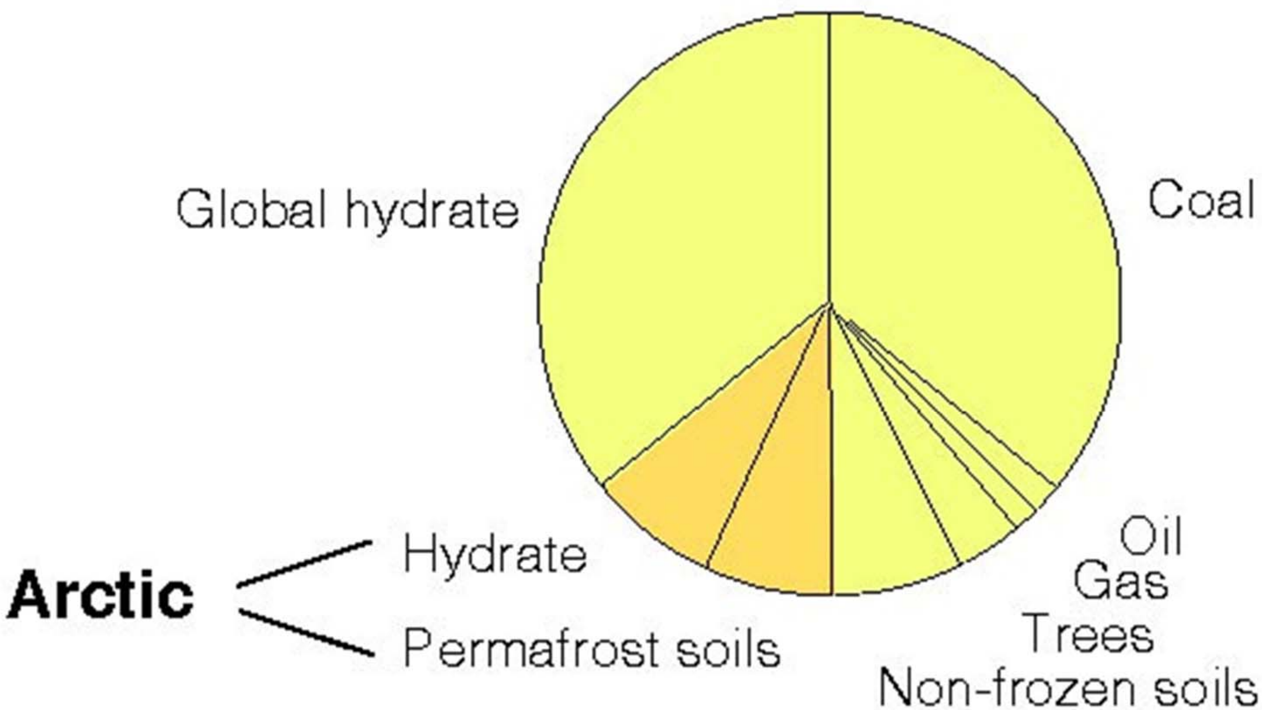
Degrades quickly upon thawing.

Can produce some $CH_4$ in waterlogged soils and lakes

# Arctic Hydrates Are a Minor Component of the Global Methane Budget



# Long-term potential climate impact from Arctic carbon[4]

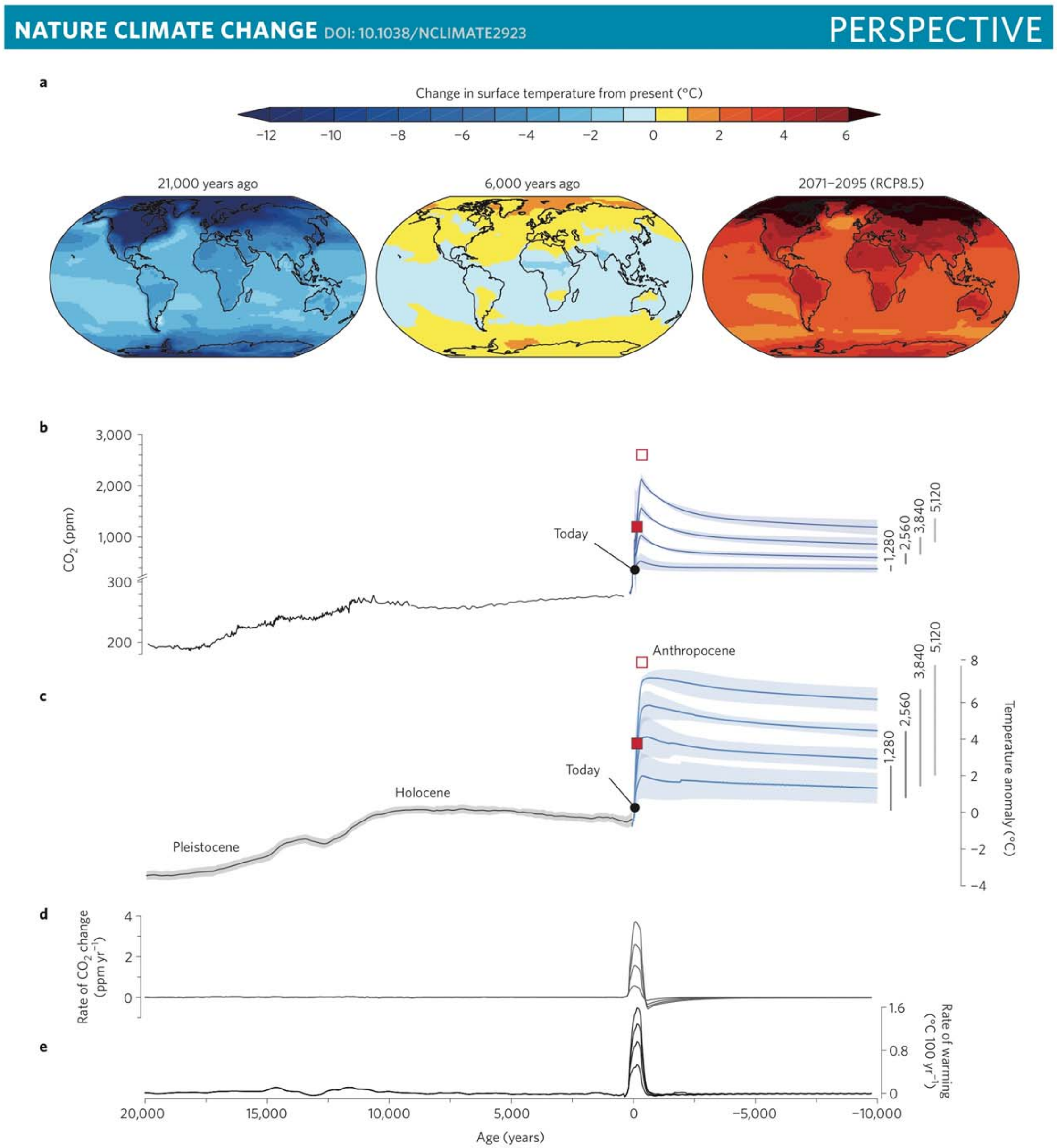


# Ocean Acidification Impacts

- Shellfish hatcheries
  - juveniles more sensitive mineralogically
  - near-shore pH changes larger than expected
- Pteropods
  - cold-dwelling, aragonitic shells
  - eaten by salmon etc.
- Carbon cycle feedbacks
  - mesocosm experiments contradictory
  - small atmospheric $CO_2$ impact by 2100

# Your queries

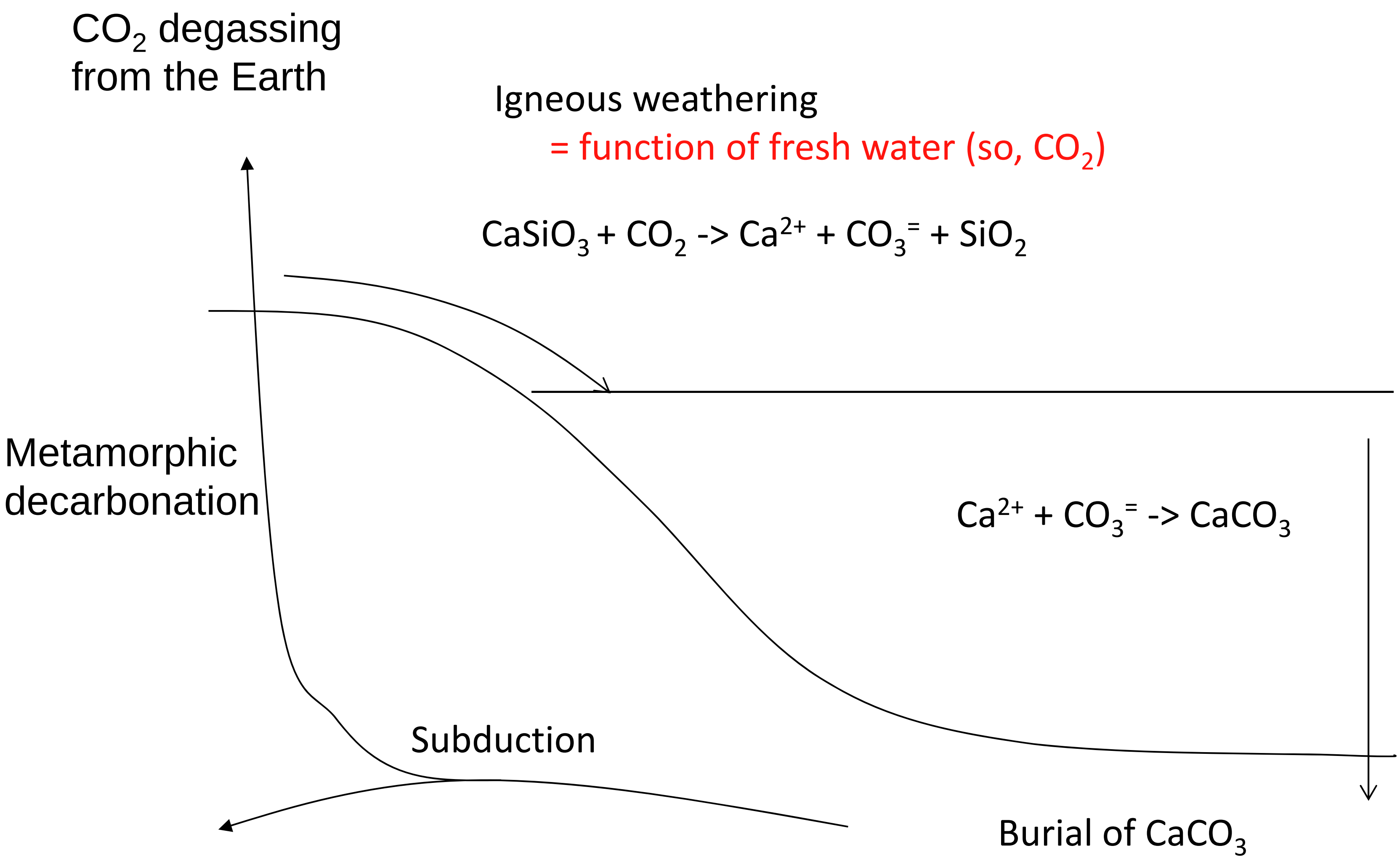
1. Simplest model
   Two layers, two timescales
   http://climatemodels.uchicago.edu/slugulator
2. Permafrost carbon feedback? (Methane?)
   100's Gtons C over 1-2 centuries
   $CH_4$ up to 50%, depending on water saturation
3. Ocean hydrate feedback?
   Time scale > 1000 years due to thermodynamic exclusion of hydrate from permafrost zone
4. Tipping points of above?
   Yes, in that they won't reform if it cools back down
   No, in that no sudden acceleration
5. Ocean acidification tipping point or feedbacks?
   Impacts difficult to gauge
   Carbon cycle feedbacks probably slow
6. Valuing above?



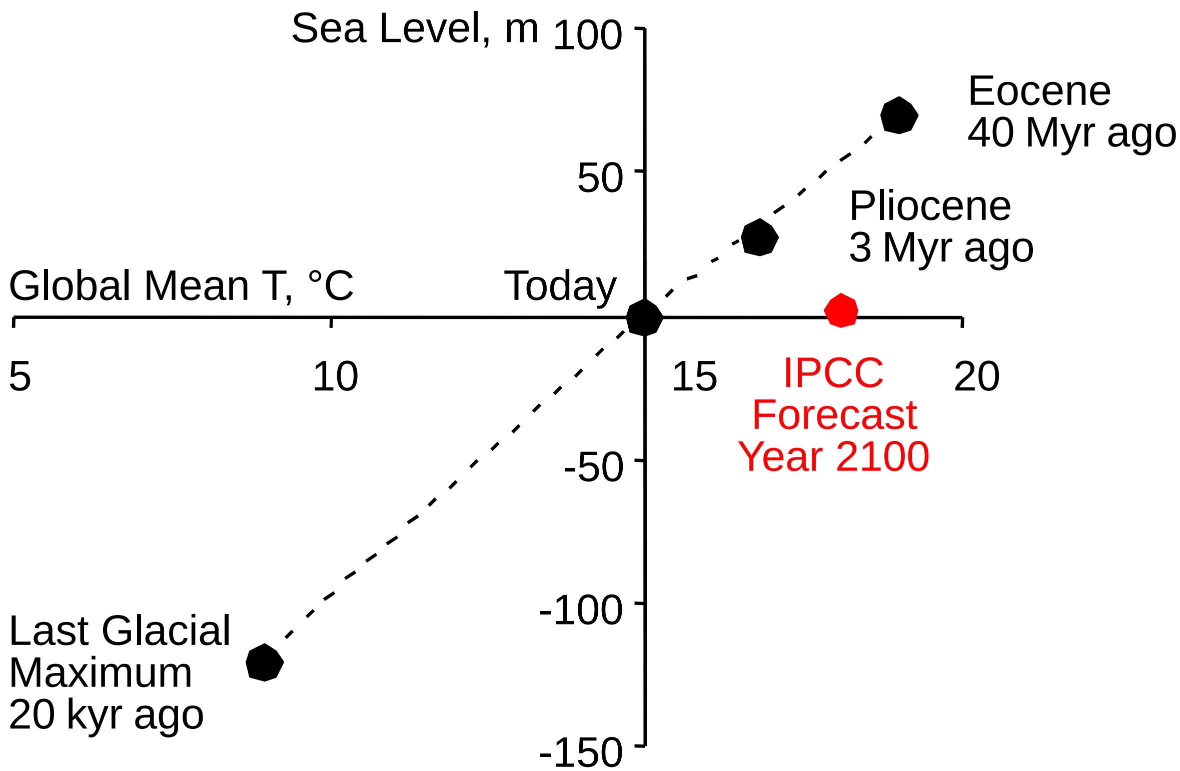

# $CO_2$ and Temperature plateau at a new normal

Clark et al 2015

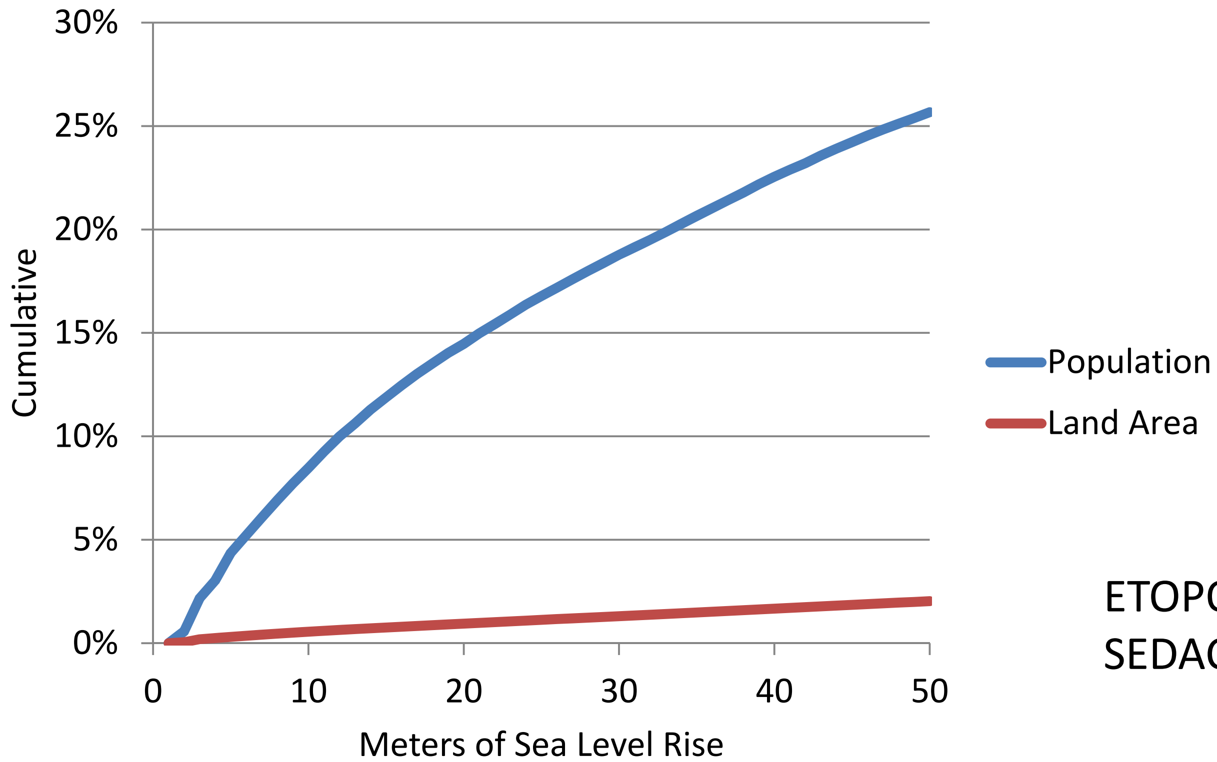
# How long will it last?



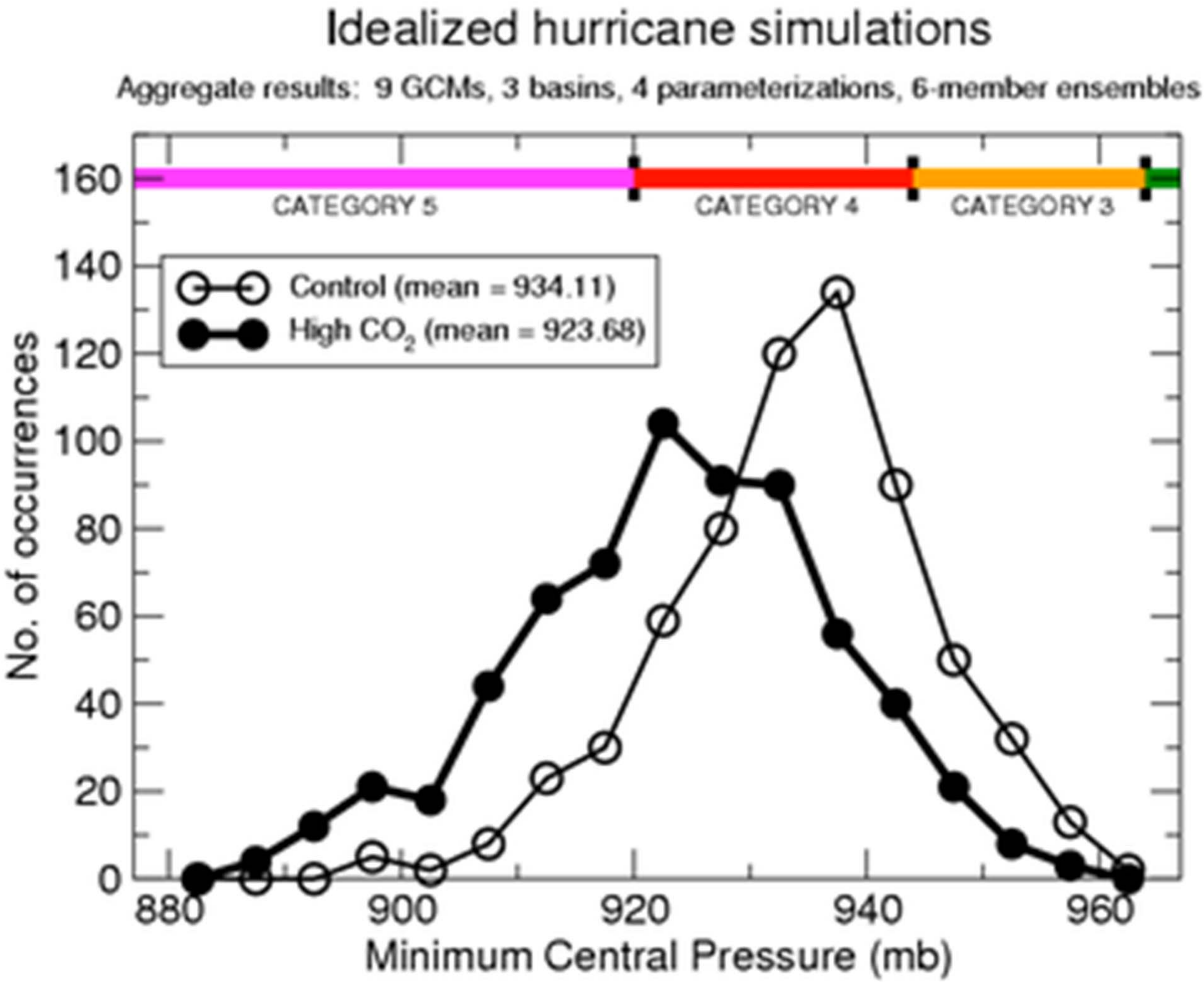
# Long-Term Sea Level Rise



# People live close to sea level




ETOPO2 Bathymetry 2’ grid
SEDAC Population Density 2.5’



Idealized hurricane simulations
Aggregate results: 9 GCMs, 3 basins, 4 parameterizations, 6-member ensembles
CATEGORY 5
CATEGORY 4
CATEGORY 3
Control (mean = 934.11)
High CO2 (mean = 923.68)
No. of occurrences
0
20
40
60
80
100
120
140
160
880
900
920
940
960
Minimum Central Pressure (mb)

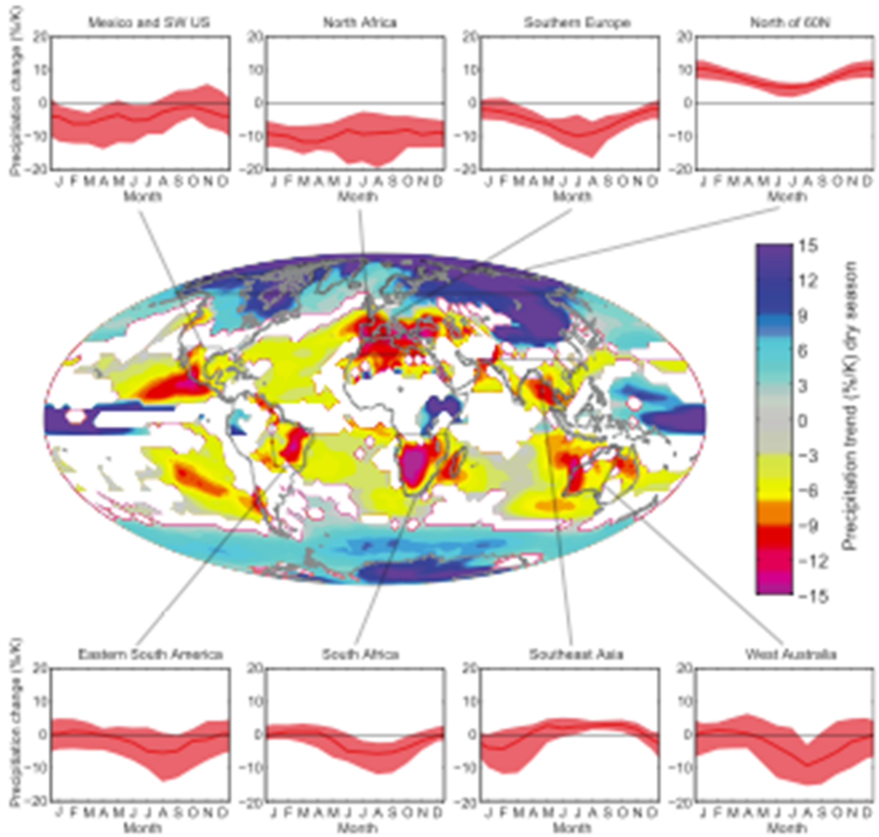



**Fig. 3.** Expected decadally averaged changes in the global distribution of precipitation per degree of warming (percentage of change in precipitation per degree of warming, relative to 1900–1950 as the baseline period) in the dry season at each grid point, based upon a suite of 22 AOGCMs for a midrange future scenario (A1B, see ref. 5). White is used where fewer than 16 of 22 models agree on the sign of the change. Data are monthly averaged over several broad regions in *Inset* plots. Red lines show the best estimate (median) of the changes in these regions, while the red shading indicates the $\pm 1$-$\sigma$ likely range (i.e., 2 of 3 chances) across the models.

Solomon et al., 2009

# What is it Worth?

**Scenario:** 10% decrease in carrying capacity that lasts 100,000 years

**Postulate**: Each generation values its existence in the world the same amount (as us)

**Propose**: Absolute unit of value through time: a **generation-value**

How much is 10% of our world worth to us?

10% * Global GWP ($100 trillion/yr) * 20 years (generation time)

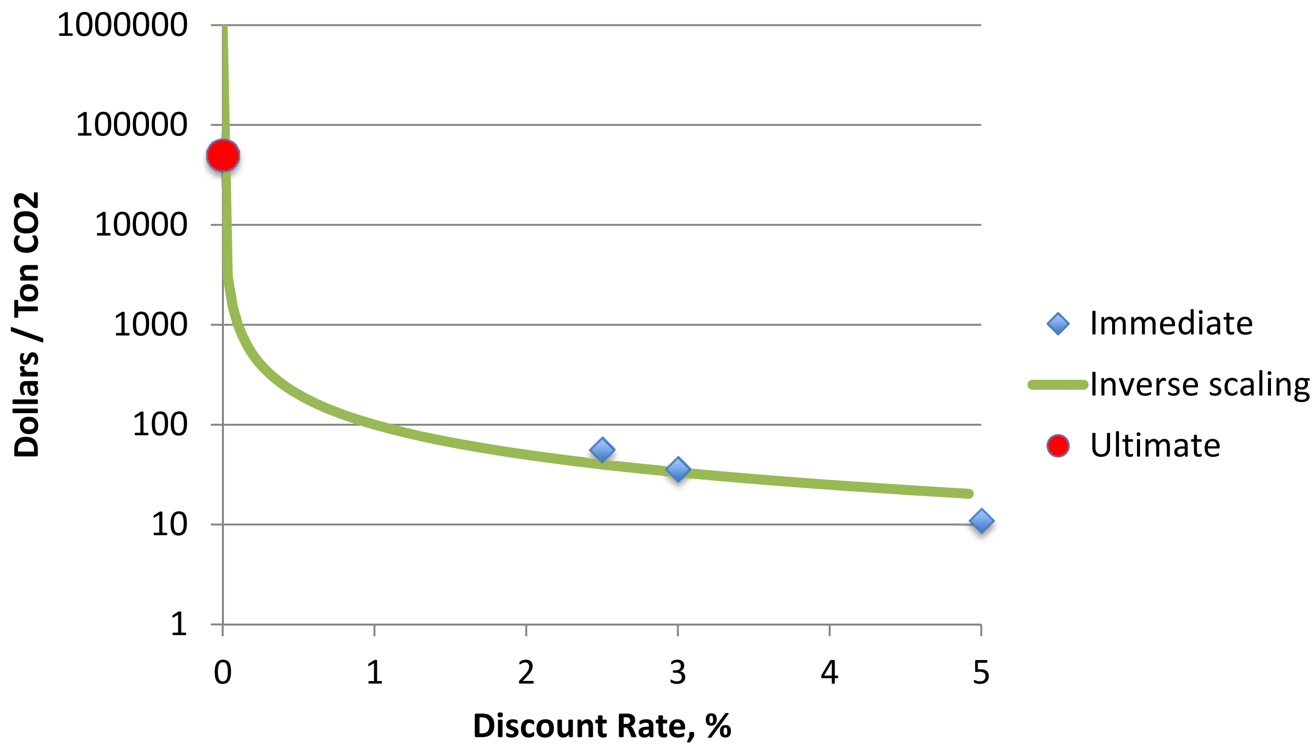
**Conclude:** **= $2E14 = $ 200 trillion**

# The Number

5000 Generations * 10% = 500 generation-values

**total cost** = $ 1E18 or **$1 quintillion**

1E18 dollars / 5E12 tons C * 12 g C / 44g $CO_2$ **= $50,000 / ton $CO_2$**



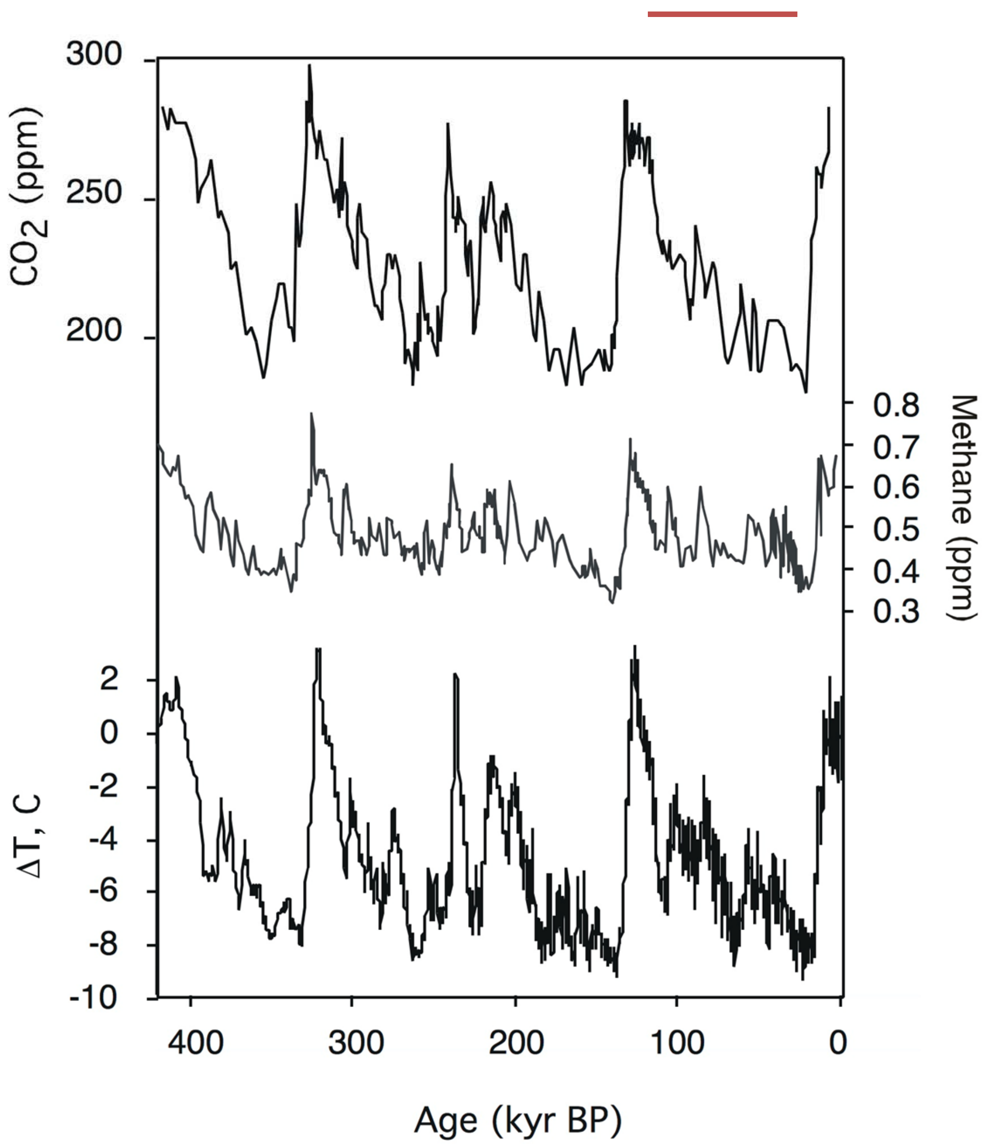
1000000
100000
10000
1000
100
10
1
0
1
2
3
4
5
Dollars / Ton CO2
Discount Rate, %
Immediate
Inverse scaling
Ultimate

# Conclusions

Our generation is walking out on 99.9% of the climate bill.

Using SCC in cost / benefit analysis => our financial self interest

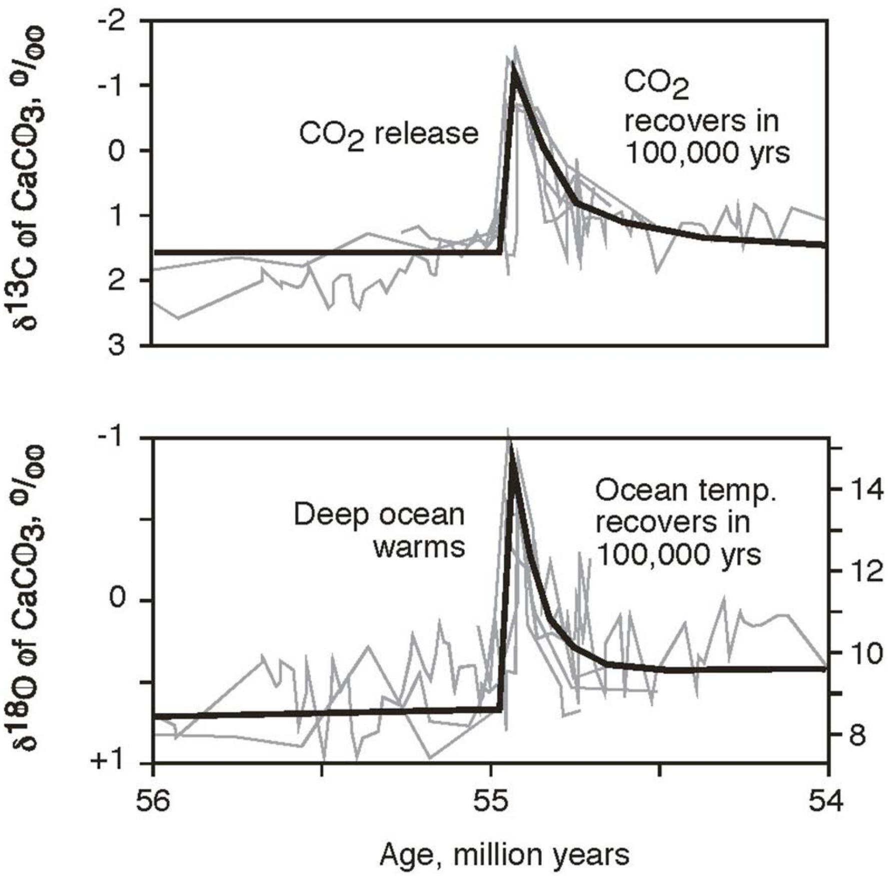
not the same as ethical justification to burn that carbon




Probably longer than the 100 kyr glacial cycles

Figure 8-3

# Paleocene/Eocene Thermal Maximum Event
# 55 Myr Ago




A natural release of $CO_2$, comparable to the potential fossil fuel release.

Warming, with a recovery that took 100,000 years.

Zachos et al. 2001