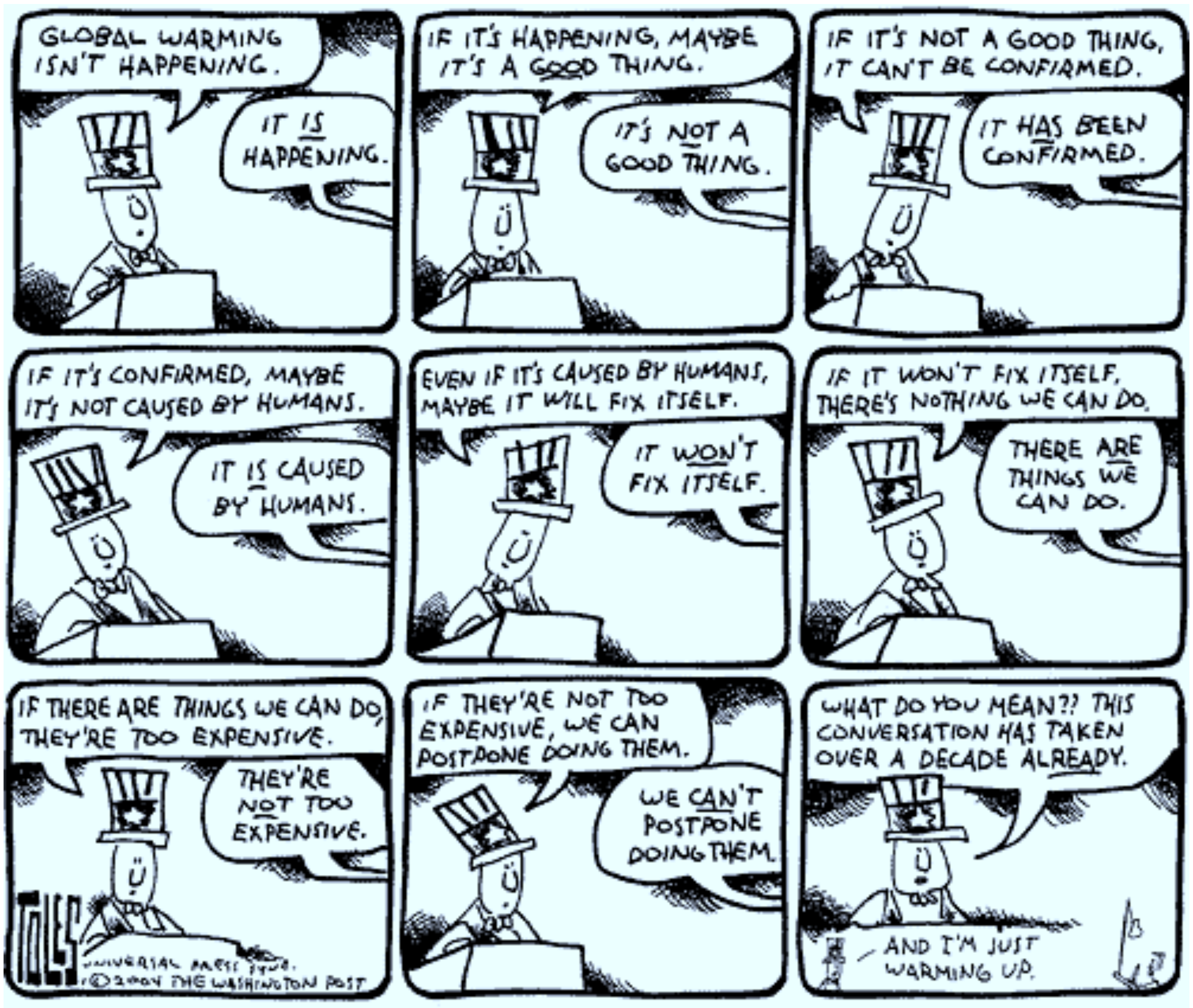
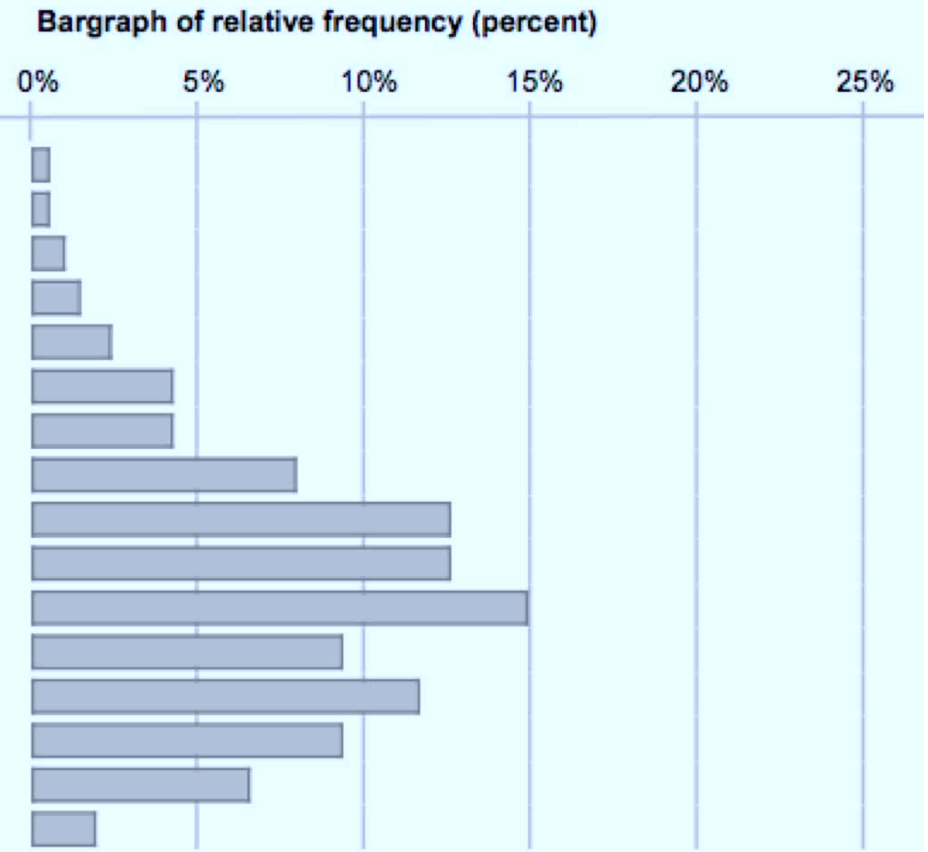
Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111



Quiz #3

Score	Freq	Percent	Cum. Percent
5	1	0.46	0.46
6	1	0.46	0.93
7	2	0.93	1.85
8	3	1.39	3.24
9	5	2.31	5.56
10	9	4.17	9.72
11	9	4.17	13.89
12	17	7.87	21.76
13	27	12.50	34.26
14	27	12.50	46.76
15	32	14.81	61.57
16	20	9.26	70.83
17	25	11.57	82.41
18	20	9.26	91.67
19	14	6.48	98.15
20	4	1.85	100.00



1 student = 0.46% of the group.

Score Name	Number of Students	Average Score	Standard Deviation	Largest Observed Score
Quiz3	216	14.57	2.95	20.00

How dropping the quiz will work

Imagine you have four quiz scores that look like this:

18   18   15   19

Total after dropping one quiz is 55

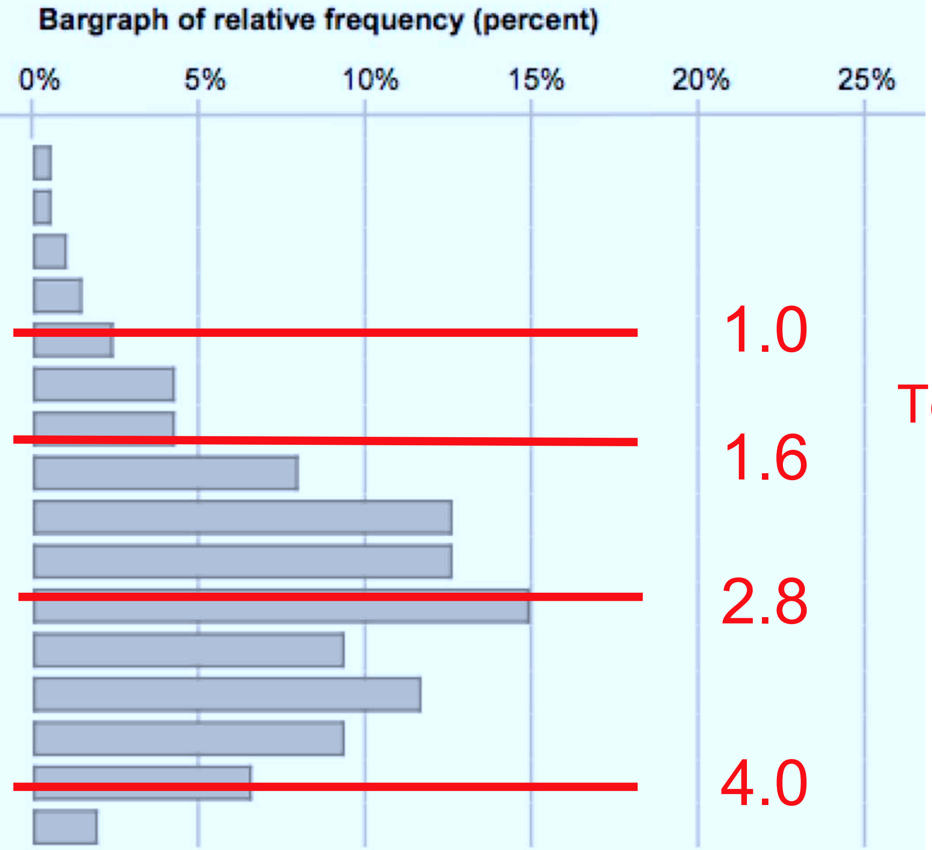
Now divide by 3 to get quiz average 18.33

Hypothetical student

Quizzes are 40% of the grade for quiz average of 18.33, multiply by 2	36.67
Homework are 20% of the grade for homework average of 8.7, multiply by 2	17.40
Clicker points are 15% of the grade for clicker average of 4.2, multiply by 3	12.60
Final points are 25% of the grade for final of 48 (out of 50), multiply by 1/2	24.00
TOTAL	90.67%

Now imagine this is the distribution for all grades out of 100

Score	Freq	Percent	Cum. Percent
5	1	0.46	0.46
10	1	0.46	0.93
15, 20	2	0.93	1.85
25	3	1.39	3.24
30	5	2.31	5.56
35	9	4.17	9.72
40, 45	9	4.17	13.89
50	17	7.87	21.76
55	27	12.50	34.26
60, 65	27	12.50	46.76
70	32	14.81	61.57
75	20	9.26	70.83
80	25	11.57	82.41
85, 90	20	9.26	91.67
95	14	6.48	98.15
100	4	1.85	100.00



Tentative Curve

Extra credit added after the curve is set

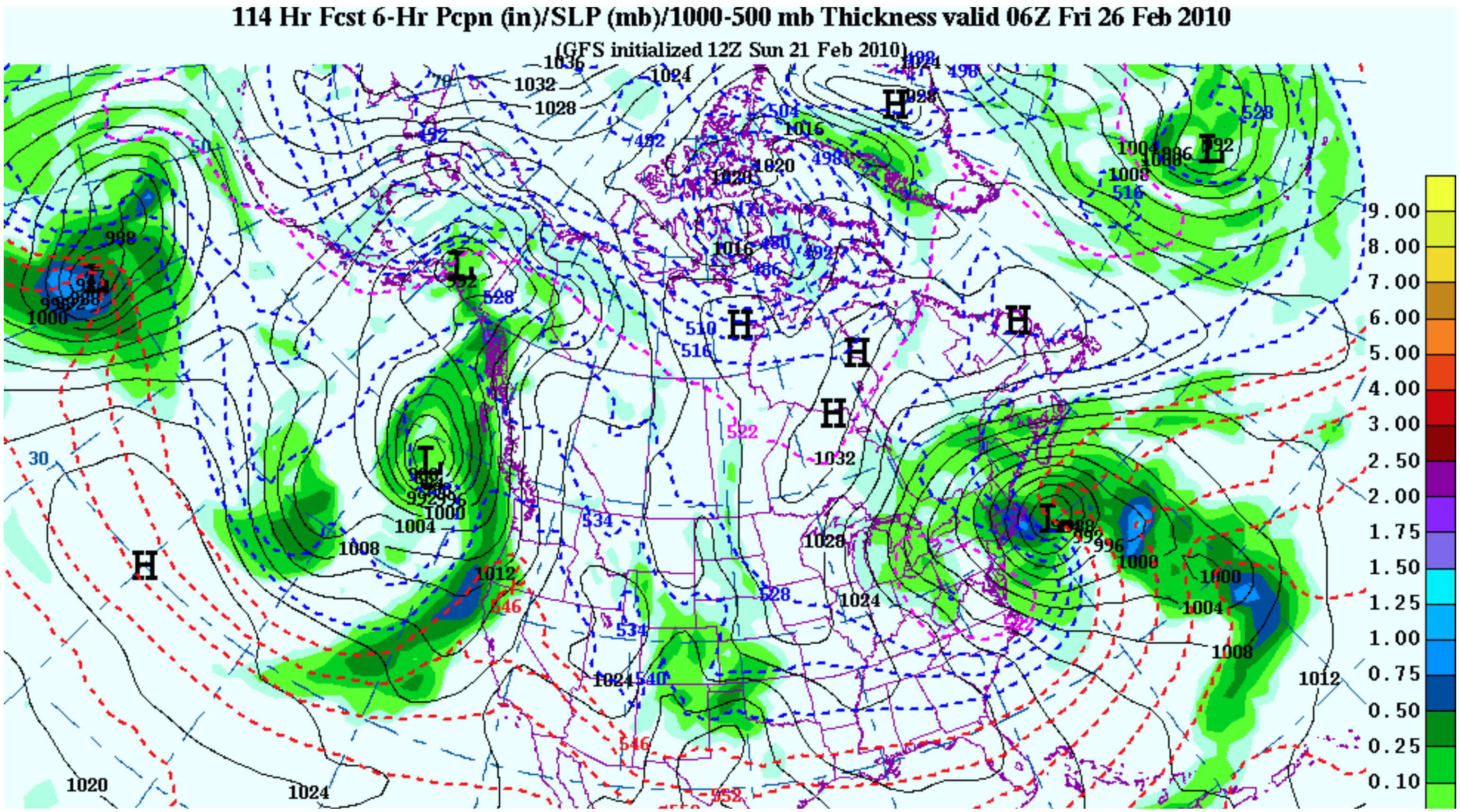
New extra credit survey

Very quick, but must be done by midnight tomorrow, so I can use the data on Thursday.

Will have another extra credit option by the weekend

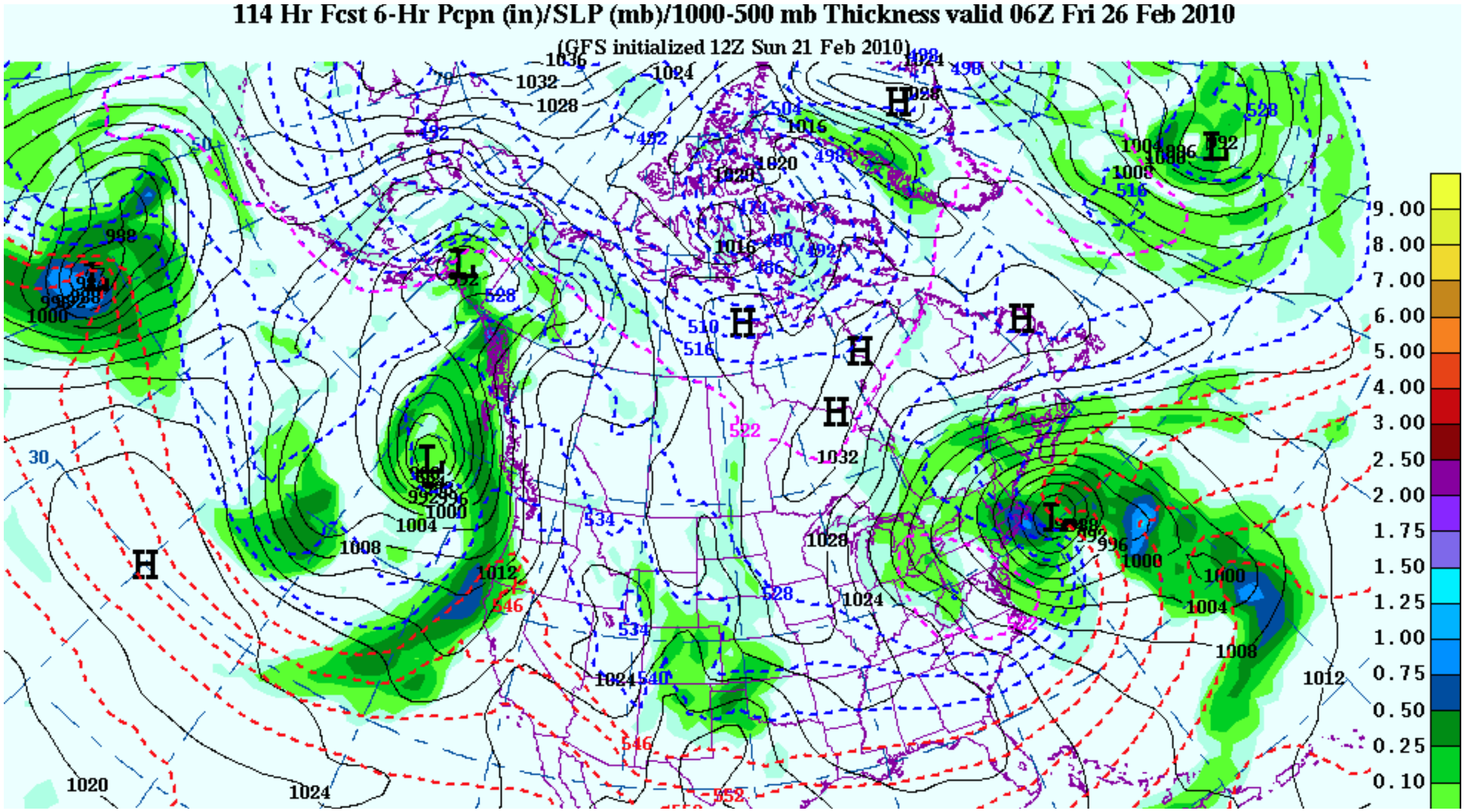
Would you be satisfied if the weather forecast said that we would be experiencing late winter/early spring conditions on Thursday?

OR are you expecting:



What would you expect from a climate model that was initialized in 1850 to tell you about Thursday?

The climate model is predicting weather (like this) but it will be totally uncorrelated with reality

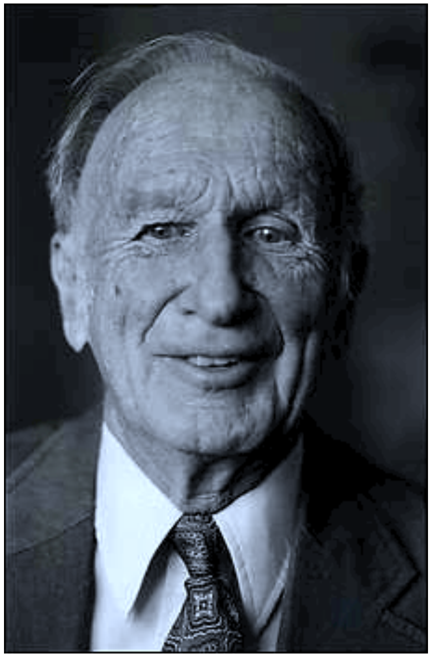


Limit to weather forecast skill: Chaos

"Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" [Lorenz, 1972]

Because weather forecasts depend so sensitively on the initial observations and we can't observe every butterfly flapping its wings, weather forecasts lose "skill" (ability to predict storms, not just the right season) after ~2 weeks.

In contrast, climate models are all about modeling seasons…



Edward Lorenz
(1908 - 2008)
meteorologist, M.I.T.
father of chaos theory

see Rough Guide, p. 228

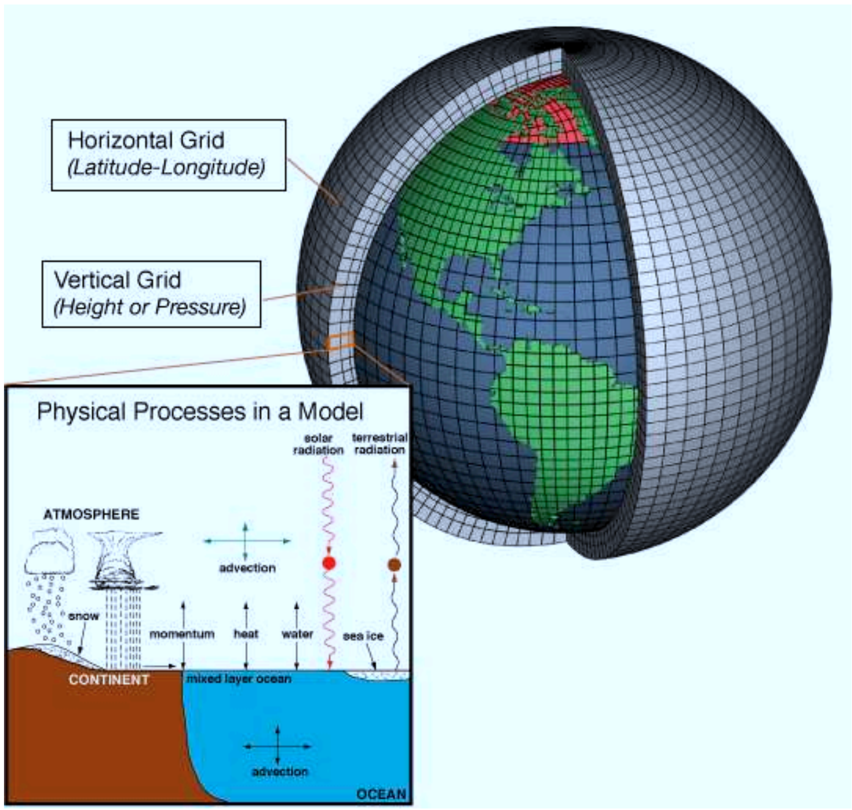
Pioneer in Climate Modeling

"Let the model tell you the answer"
paraphrased from Manabe, 2005

Syukuro Manabe
meteorologist, Princeton

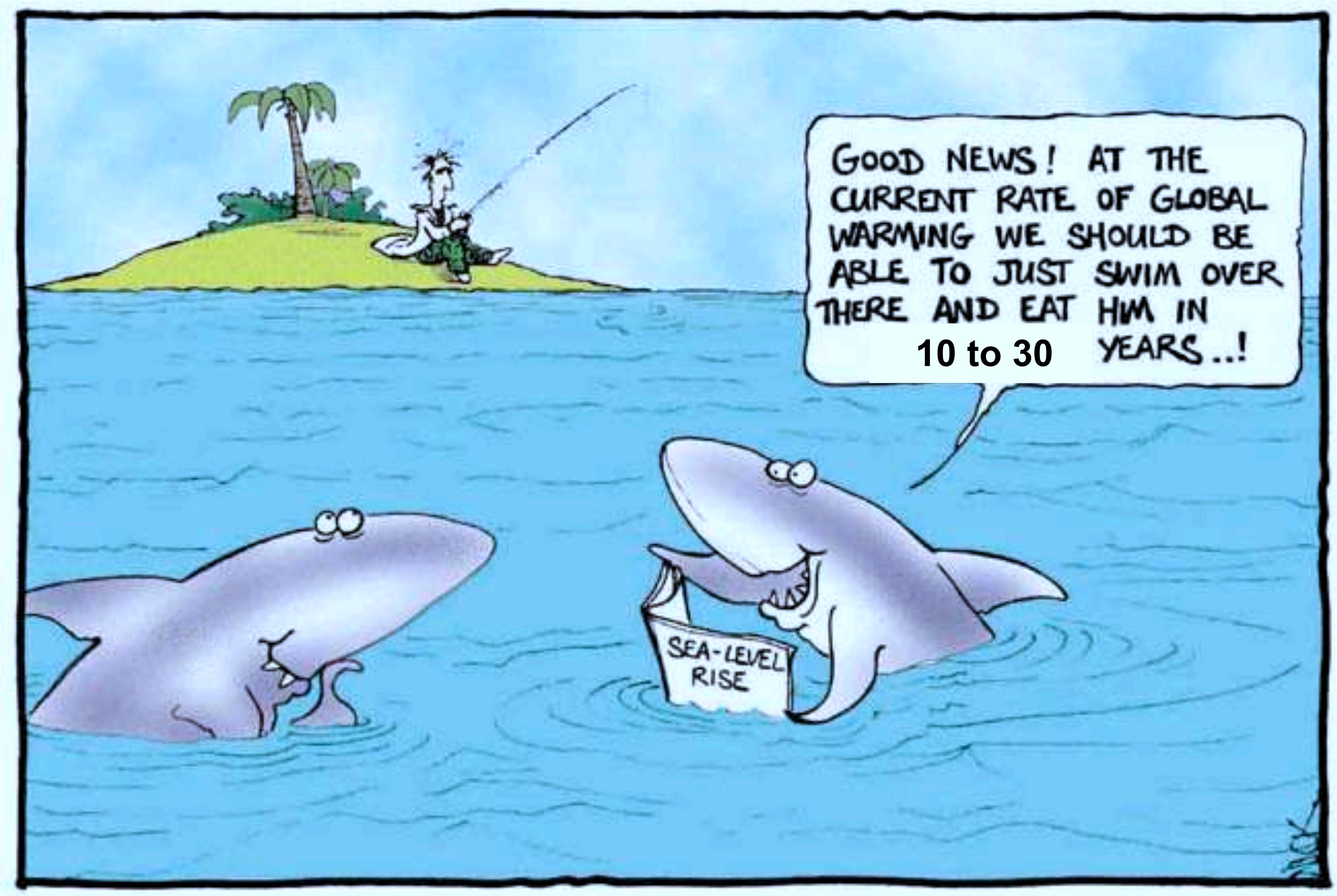
Make the model physics as accurate as you possibly can and it will be better at predicting the climate than you could reason with pencil and paper. (my attempt to describe his philosophy)

How do we test the global warming theory?



OR

Does high uncertainty make the projections worthless?



Good ways to test a Climate Model

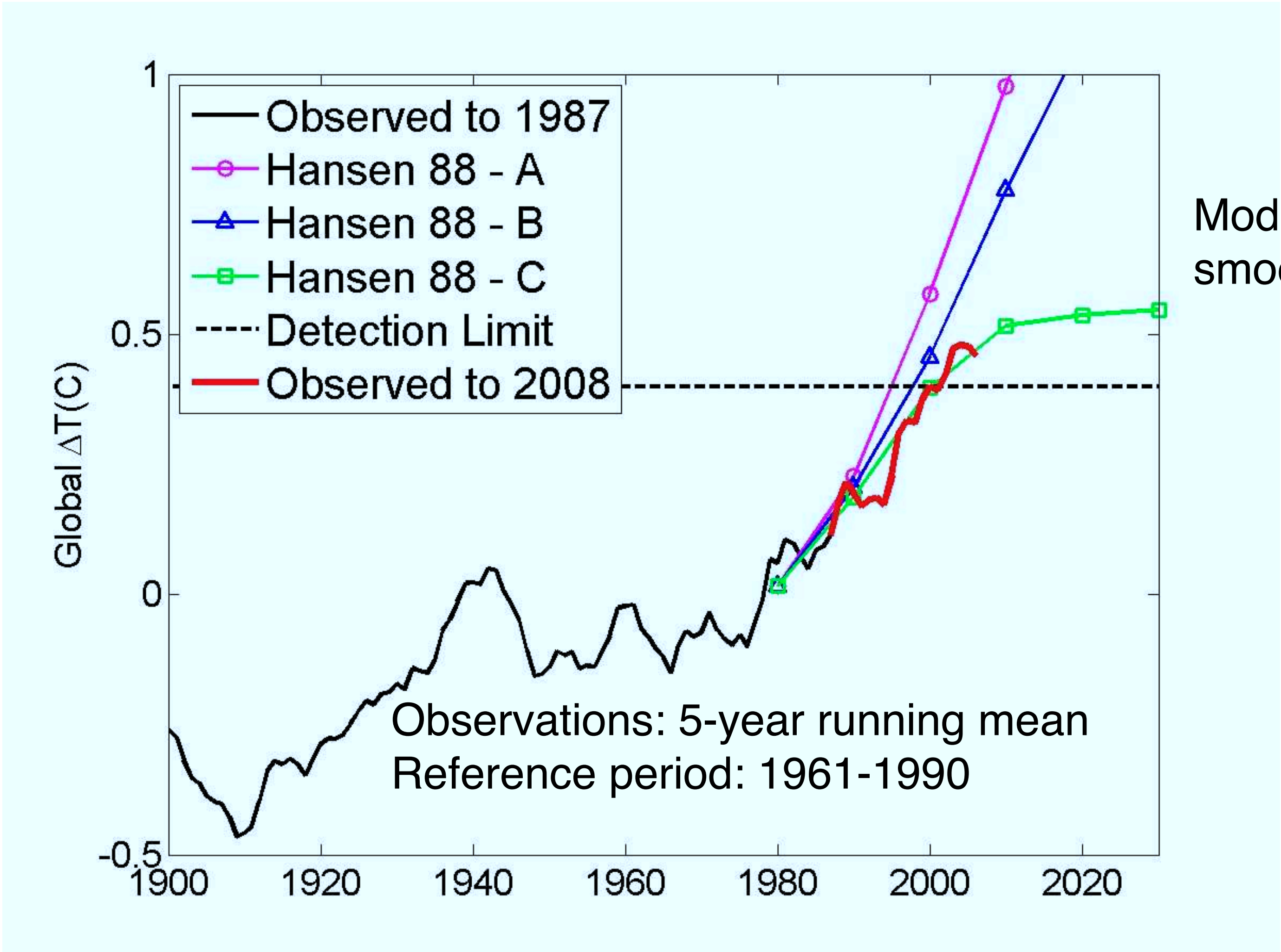
1. Apply them to the climate of Mars
2. Eliminate some processes, like the carbon cycle
3. With ensembles, or many runs with minor parameter differences
4. Compare with other models

5. Compare against observational data, especially long after the forecast

“Prediction is very difficult, especially about the future” Niels Bohr

Niels Bohr with
Albert Einstein

Climate model projection made in 1980: How well did it do?



Models: heavily smoothed

In 1980, little was known about how fast CO2 would rise.
Version C was a more modest assumption.

Summary: Climate Models

- Are complicated codes written by large teams of scientists. There are several dozen different models. Comparing them offers another means of verification.

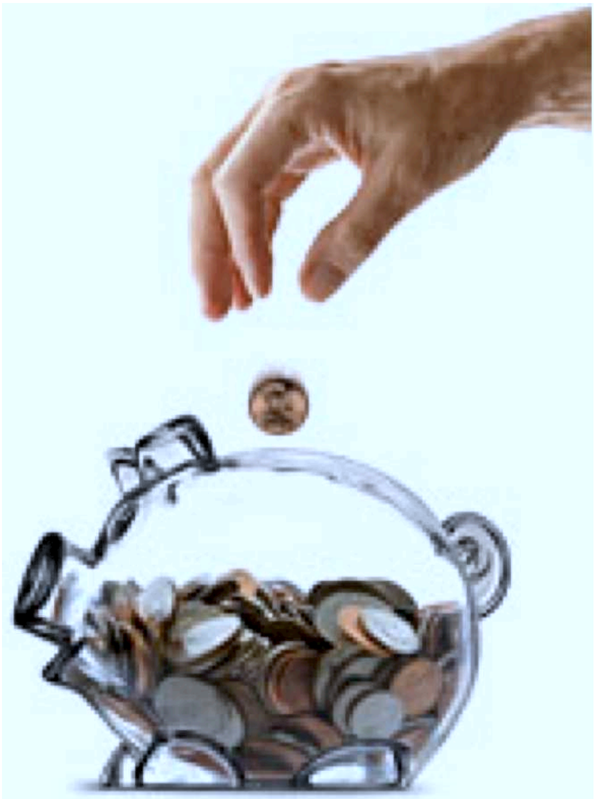
- Are composed of equations that describe fluid motions and have parameterizations of small scale processes involving clouds, glacial calving, plants processing moisture, etc

- Are strenuously tested and have been shown to give reliable forecasts.

- Differ from weather models because the initial conditions are mostly unimportant. Instead energy balance is critical. They produce storms but they are not in sync with reality. Only their statistics are relevant.

What is the right forcing for making a projection?

Emissions versus Concentration

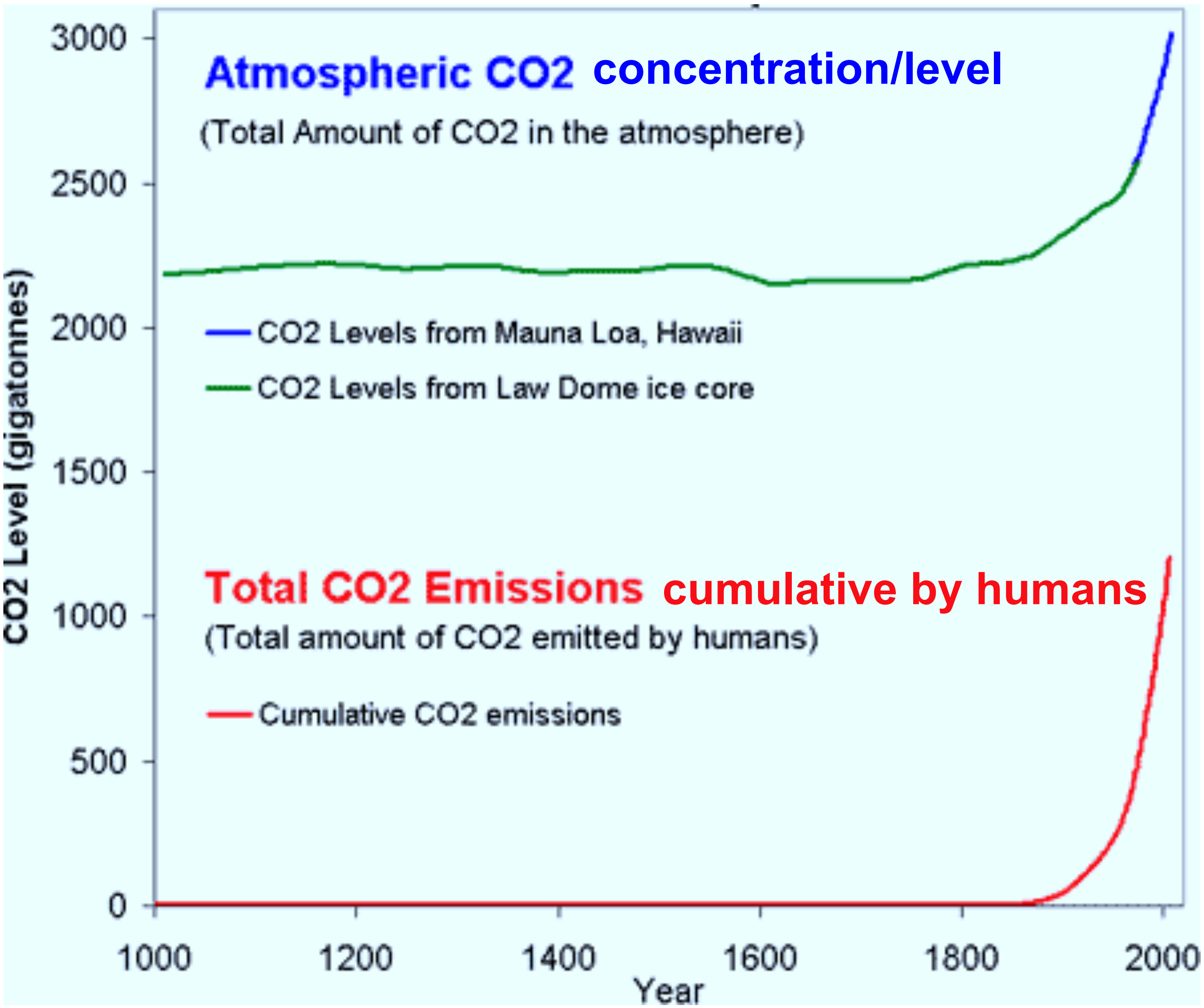


Emissions / Source

Concentration / level / reservoir

Where we are headed…

CO2 Emissions versus Concentration



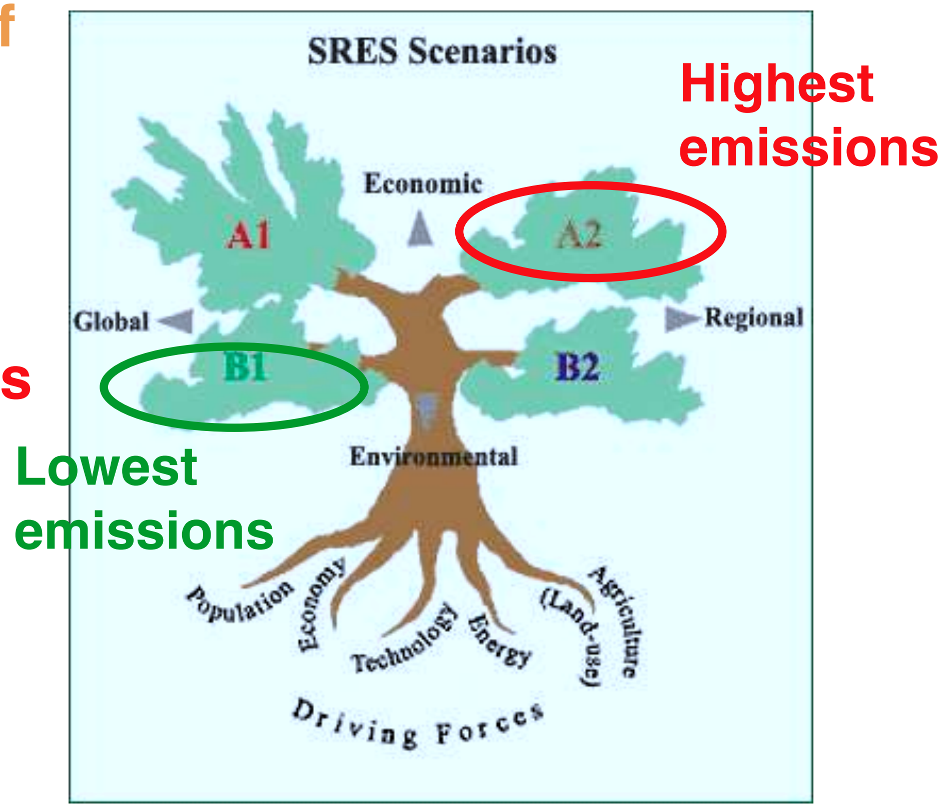
IPCC SRES Emissions Scenarios summarized

A1: Rapid economic growth followed by rapid introductions of new and more efficient technologies

A2: A very heterogenous world with an emphasis on family values and local traditions

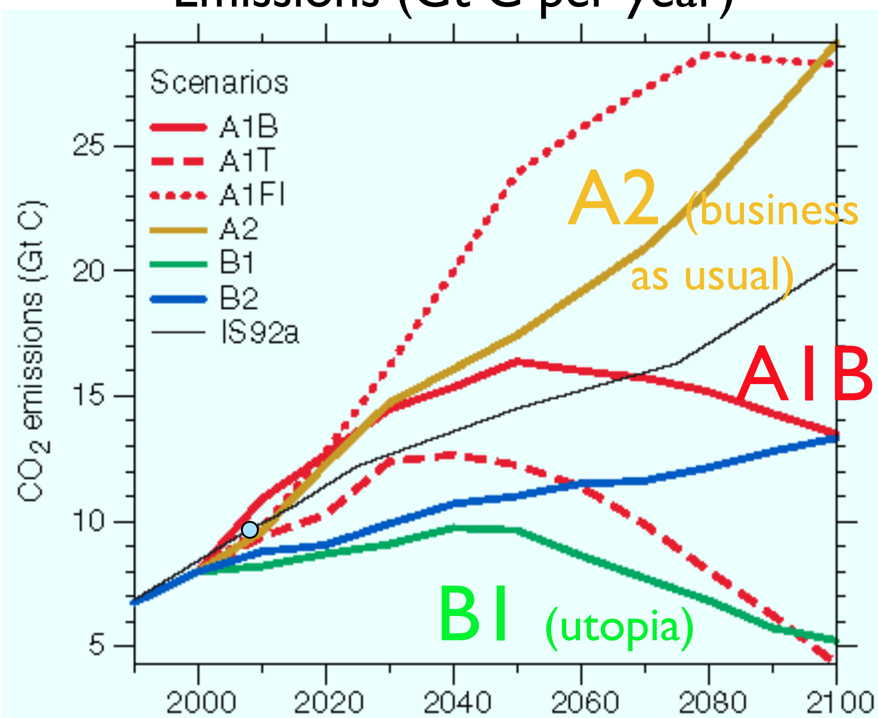
B1: Introduction of clean technologies

B2: Emphasis on local solutions to economic and environmental sustainability

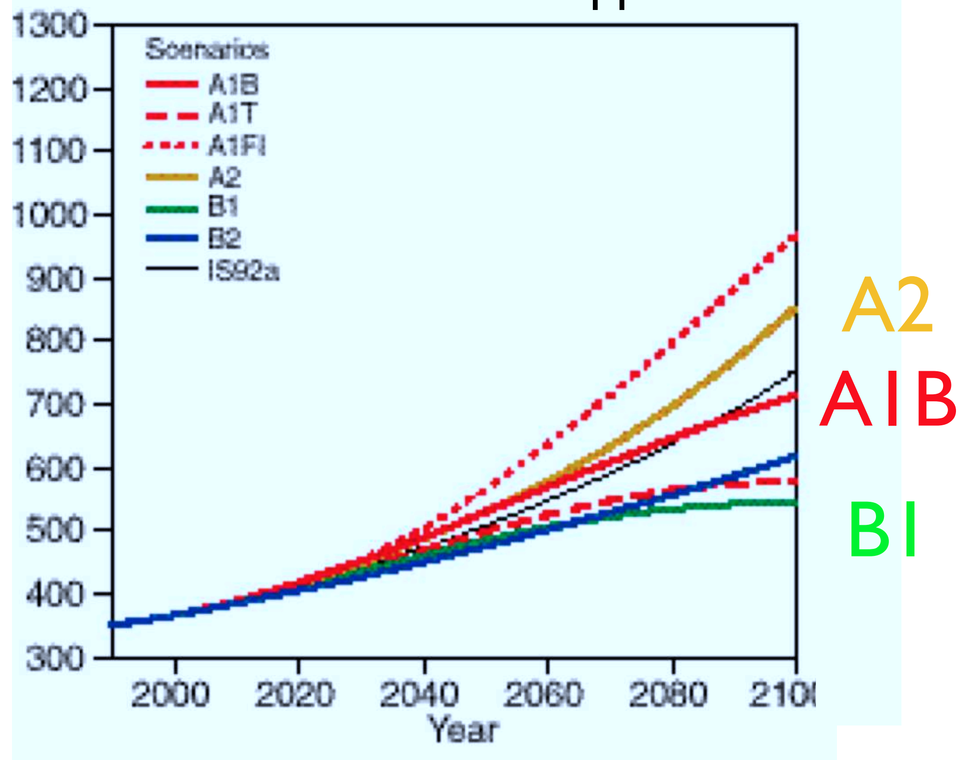


Examples of future IPCC SRES emissions and concentrations

Emissions (Gt C per year)



Concentration in ppm



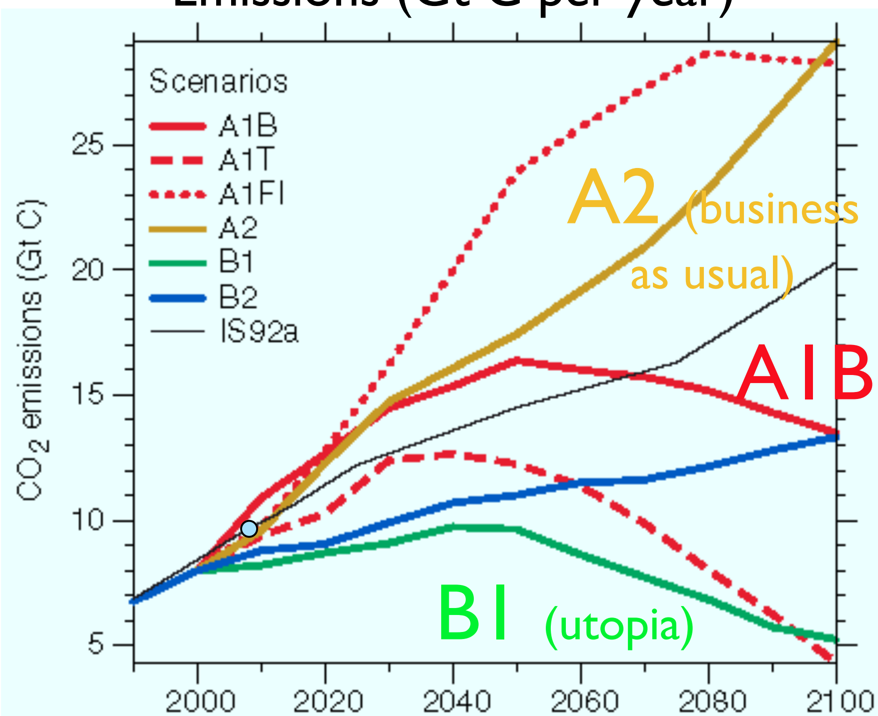
The 4 perspective on the previous slide are the basis for the naming scheme.

The concentrations are estimates from carbon cycle models.

The concentration is input to the climate model.

Examples of future IPCC SRES emissions and concentrations

Emissions (Gt C per year)

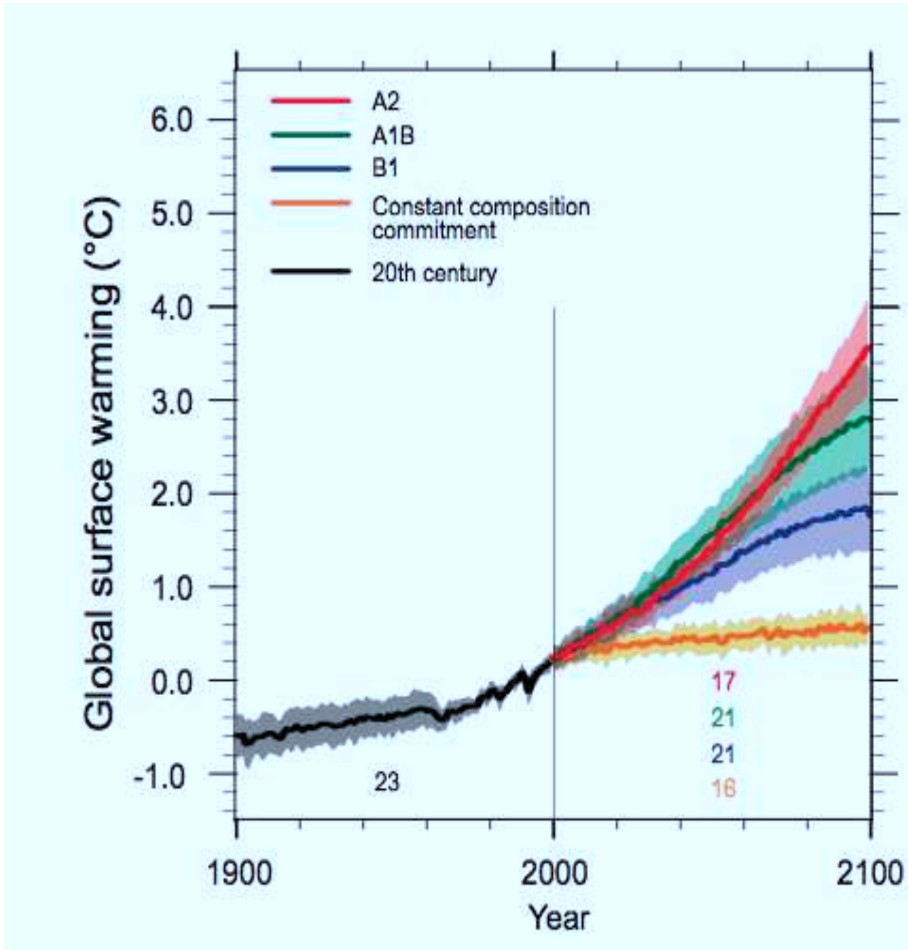


The spread among scenarios is modest until about 2020, so in the near term the scenario doesn't matter.

Business as Usual (BAU) is originally an IPCC term, now loosely used to mean the higher scenarios

Utopia is an informal term

Climate model projections



Yet another scenario called “commitment”, has GHGs held fixed. “Warming in the pipeline”

2007 IPCC Figure

How is the uncertainty illustrated?

IPCC confidence levels

Scientific Uncertainty

- "uncertainty," to a scientist, does not connote "ignorance"
- "uncertainty is a key component of scientific *knowledge*
- quantifying uncertainty is a critical part of the scientific method

IPCC conventions*

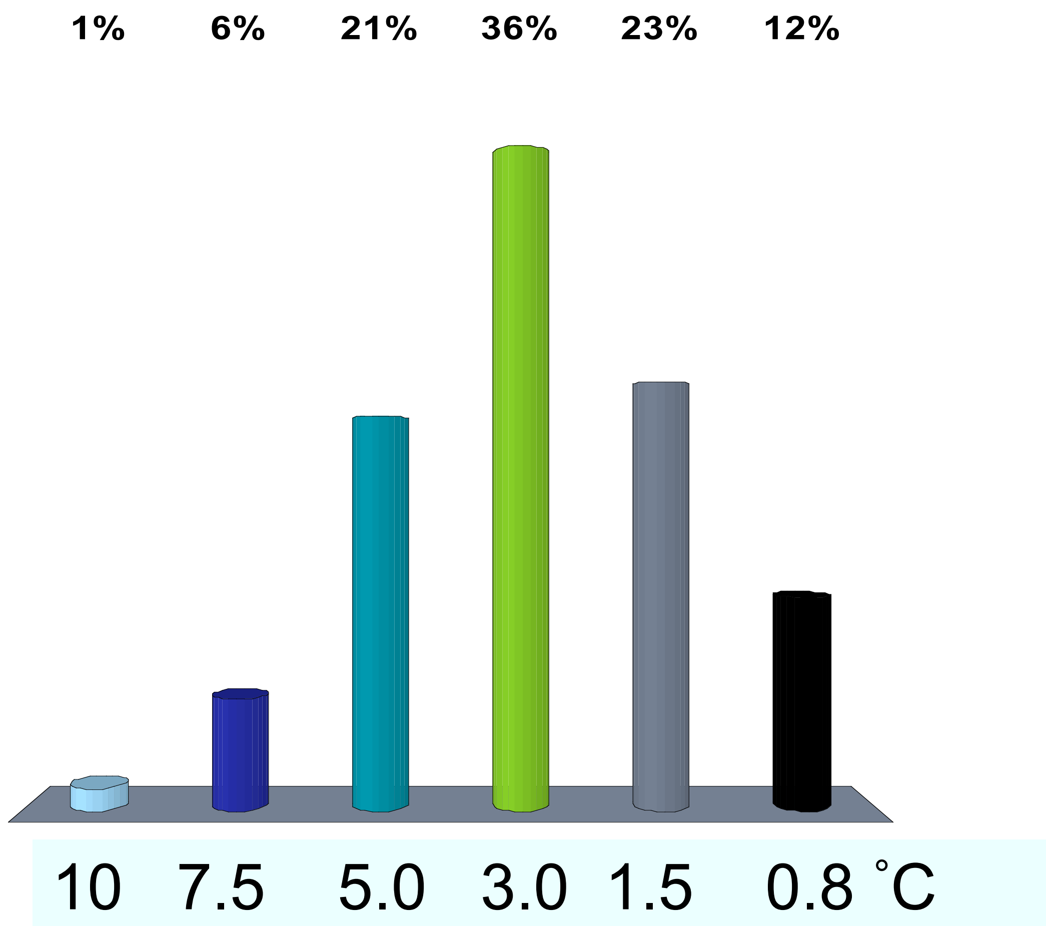
virtually certain:	>99% probability of being true
extremely likely:	>95%
very likely:	>90%
likely:	>66%
more likely than not:	>50%
unlikely:	<33%
very unlikely:	<10%
extremely unlikely:	< 5%

**page 3, footnote 6 of IPCC 2007, WG1, Summary for Policymakers (SPM)*

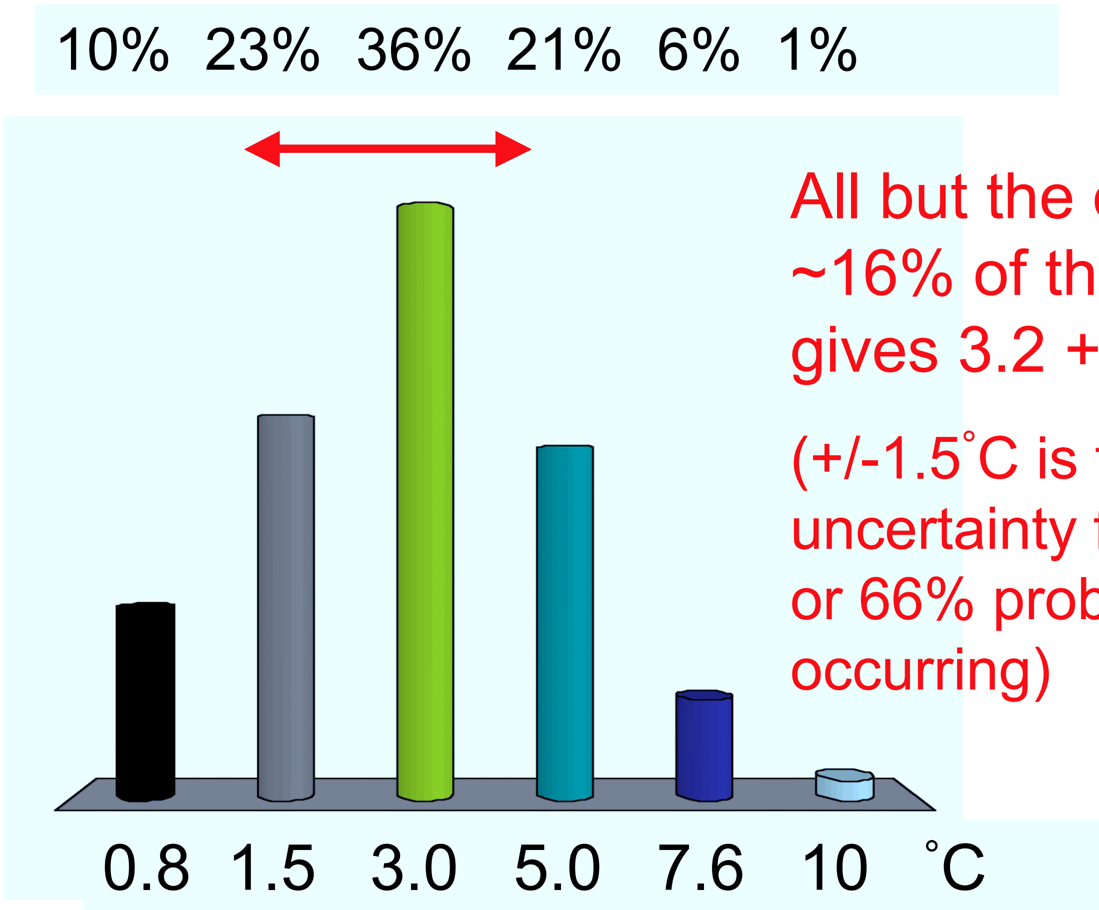
Example: If an assertion is given as "likely" that means it has about a 33% chance of being wrong.

Clicker Question from Last Week

How much do you think the global mean temperature will rise by 2050 relative to pre-industrial (1850)?



Clicker Question from Last Week



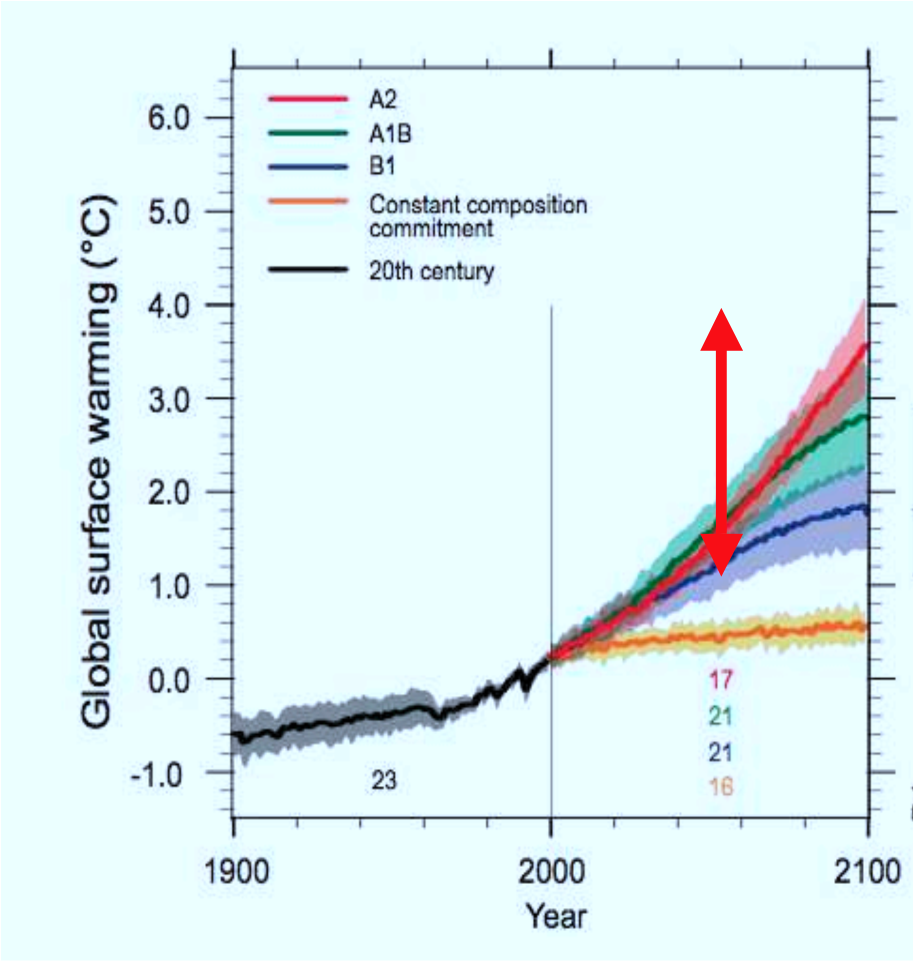
All but the outer ~16% of the tail gives 3.2 +/- 1.5˚C

(+/-1.5˚C is the uncertainty for a likely or 66% probability of occurring)

What is the difference between uncertainty and probability?

Is this objective or subjective probability?

Class compared to climate model projections



This class predicts 3.2 +/- 1.5 ˚C by 2050 relative to 1850

Note the vertical axis on this graph is relative to 2000

The class's *likely* uncertainty exceeds that of the models at 2050

Equilibrium climate sensitivity - Reduce the realism of the scenario to gain insight

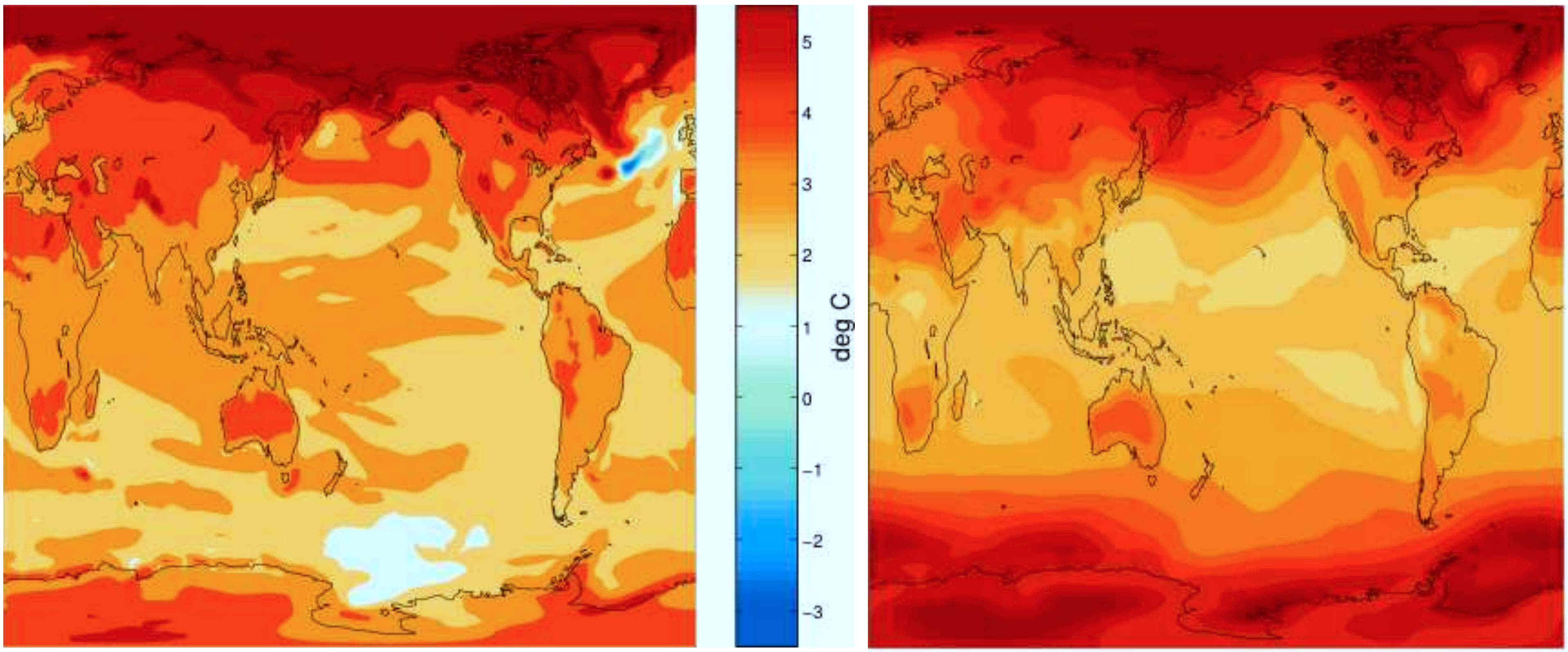
Method:

1. Run models without deep ocean - replace ocean component with shallow mixed layer only (about 100 m is fine)
2. Instantly double CO_2
3. Wait about 10 yrs to get equilibrium response

Transient versus Equilibrium warming

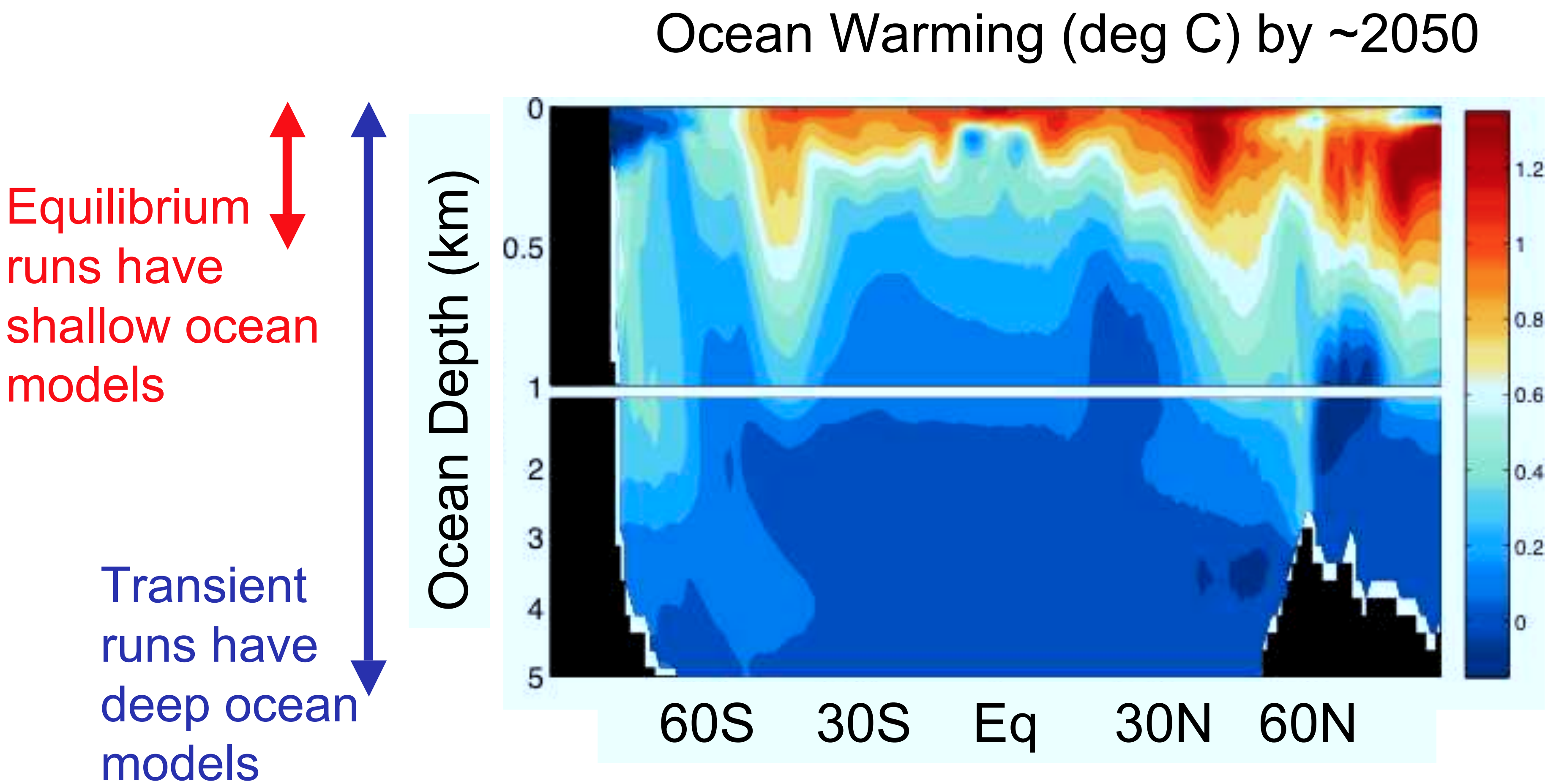
Warming at 2100
relative to end of last century

Warming from 2XCO2

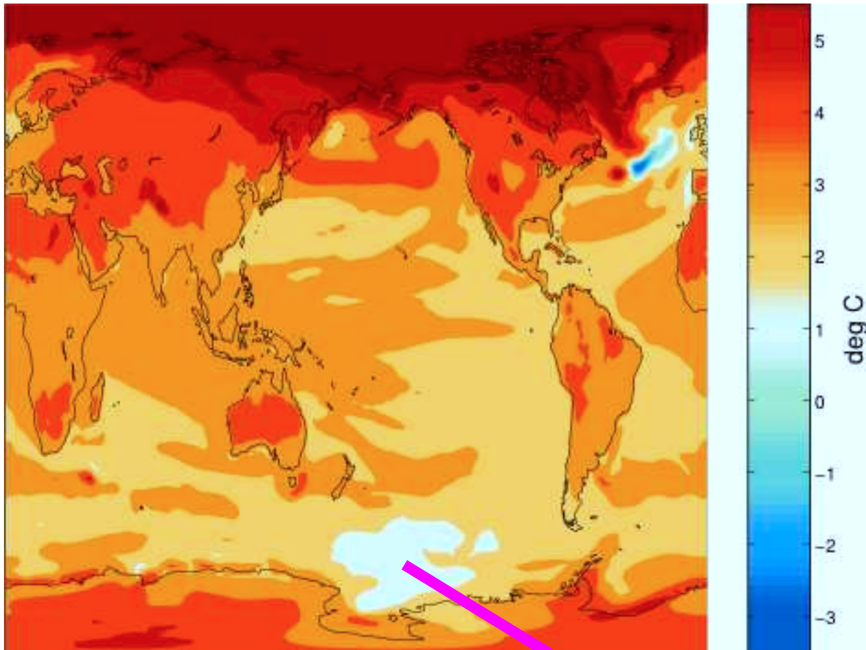


- Transient warming is smaller, yet forcing is much larger
- Transient warming is asymmetric across hemispheres
- Transient warming is modest in the northern North Atlantic

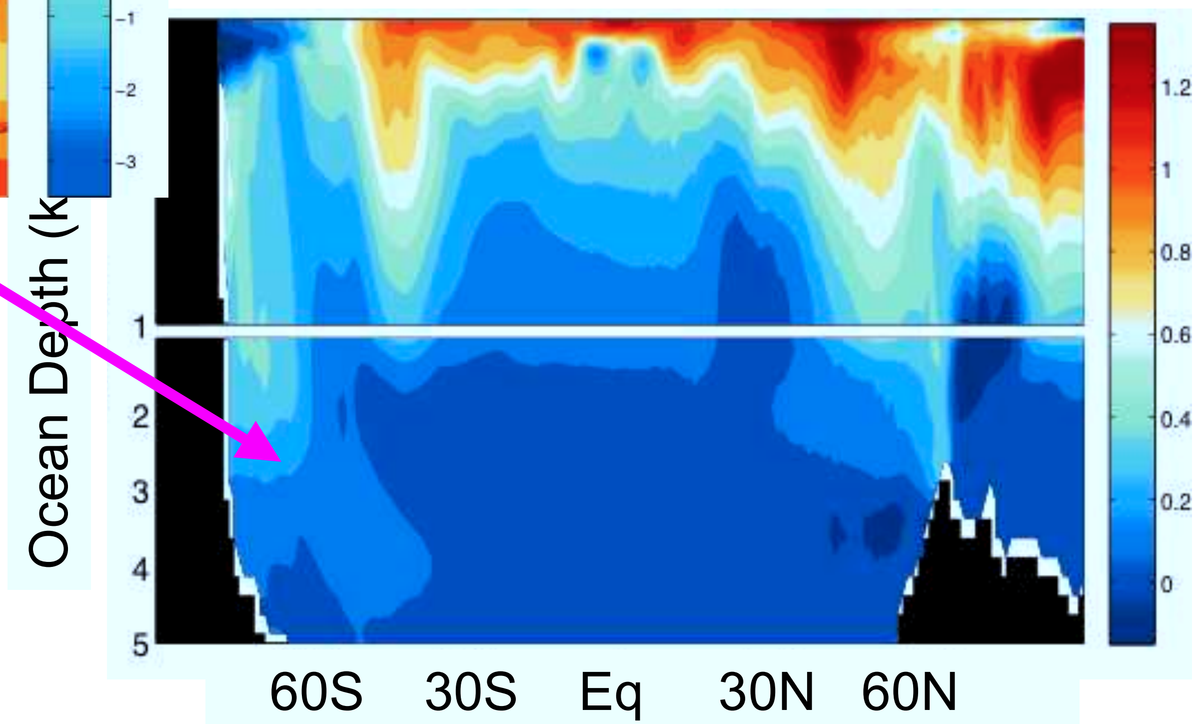
Most of the ocean warming is in the upper ocean. In a transient warming experiment there is deep ocean warming in a few key places. Pumping heat down there delays the surface warming in exactly the blue/white splotches on the previous slide.



Why Antarctic sea ice is not retreating:



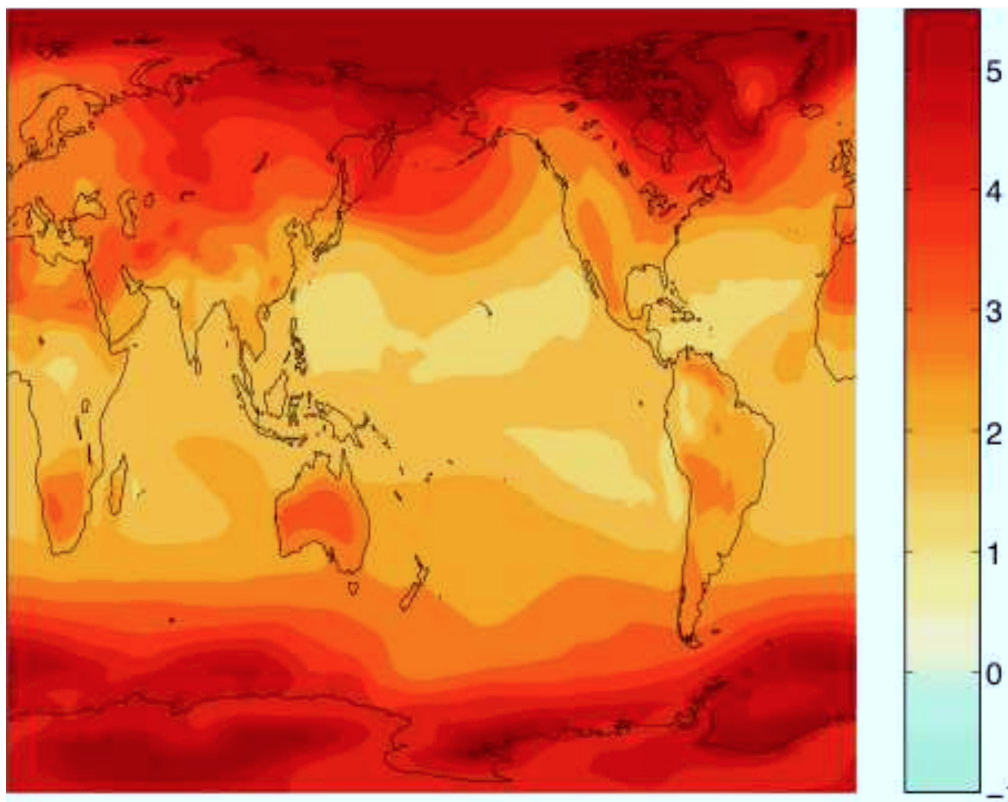
Ocean Warming (deg C) by ~2050



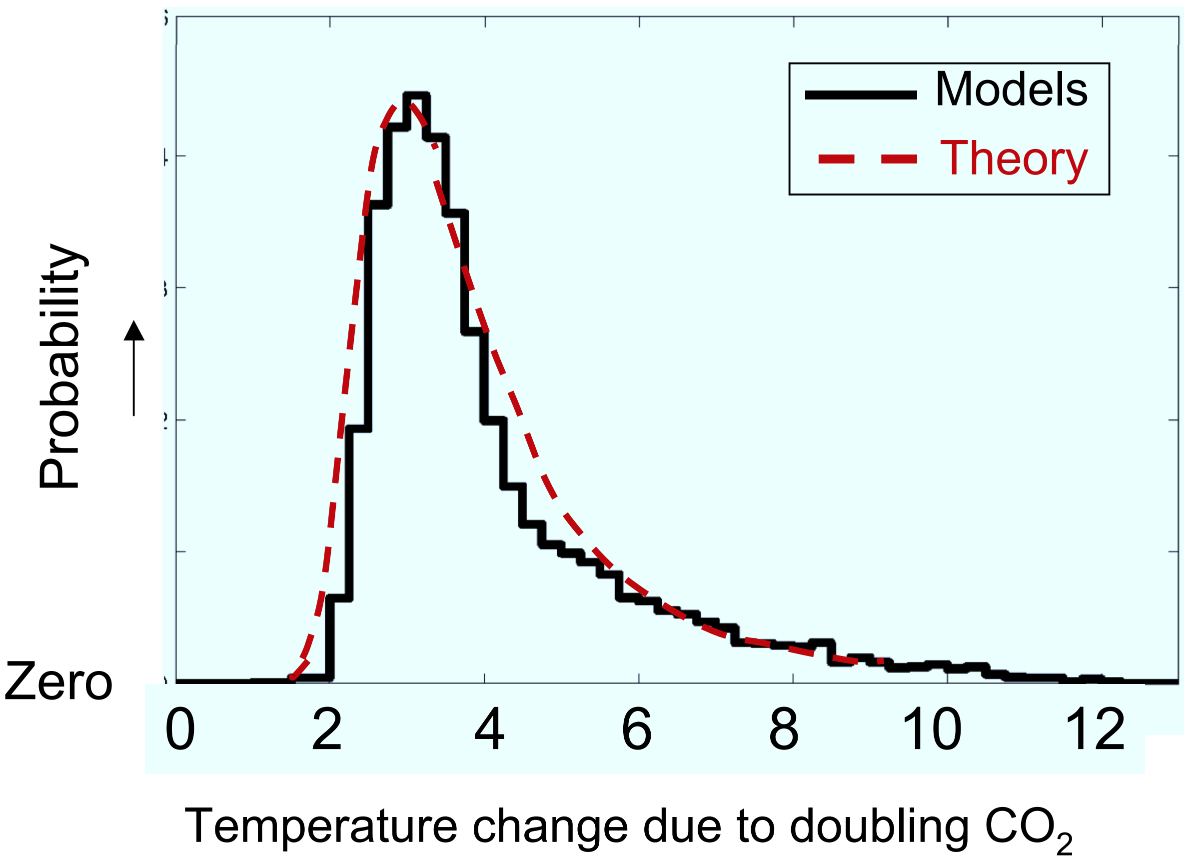
In a transient run, the warming missing at the surface went down here

When we run a model with a shallow "bath tub" style ocean, Antarctic sea ice retreats a lot. So we know heat circulating to the deep ocean is important there. The fact that the Antarctic sea ice is not retreating is not a failure of the global warming theory.

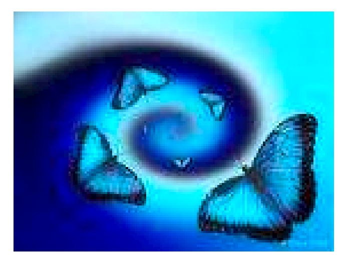
Equilibrium Warming from 2XCO2



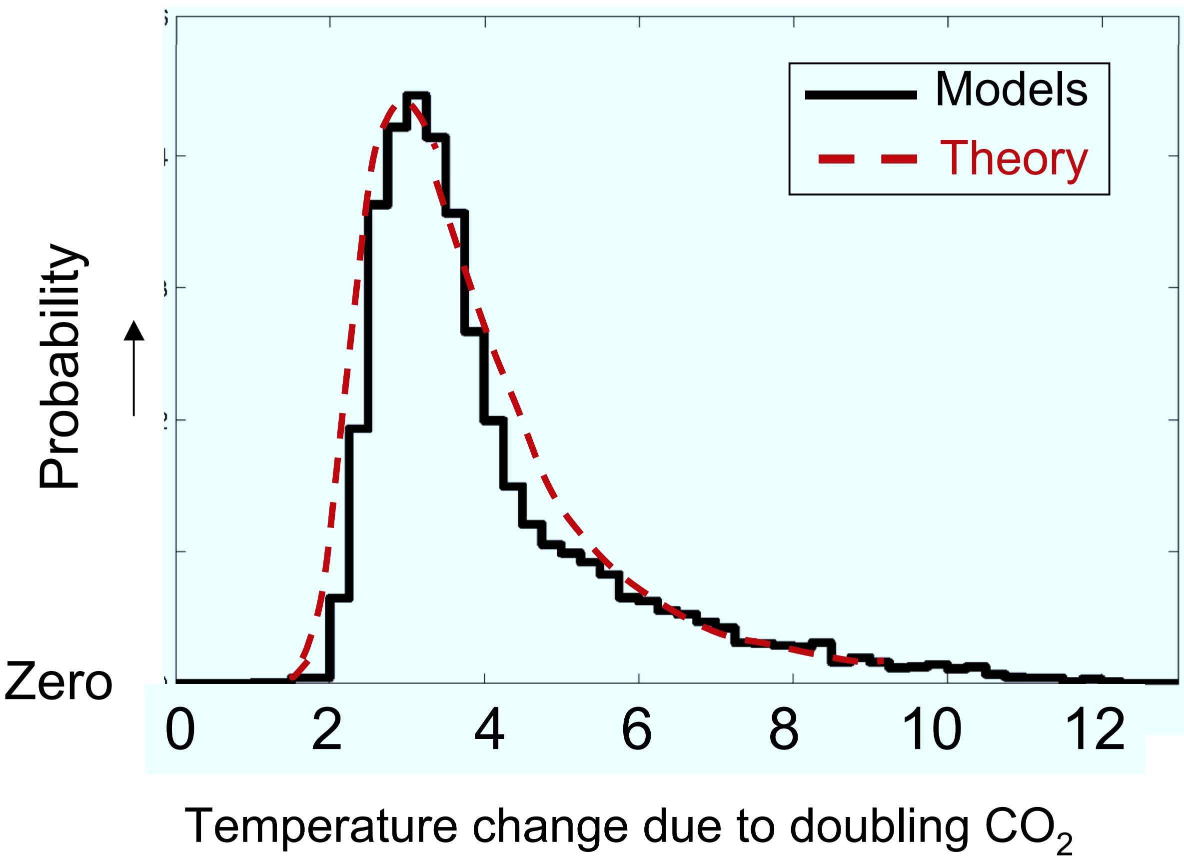
Uncertainty of Equilibrium Climate Sensitivity from a very large ensemble



UW profs Roe and Baker (2007) provide a simple theory that agrees very well with 200,000 climate runs from ClimatePrediction.net (RG p 236-7)

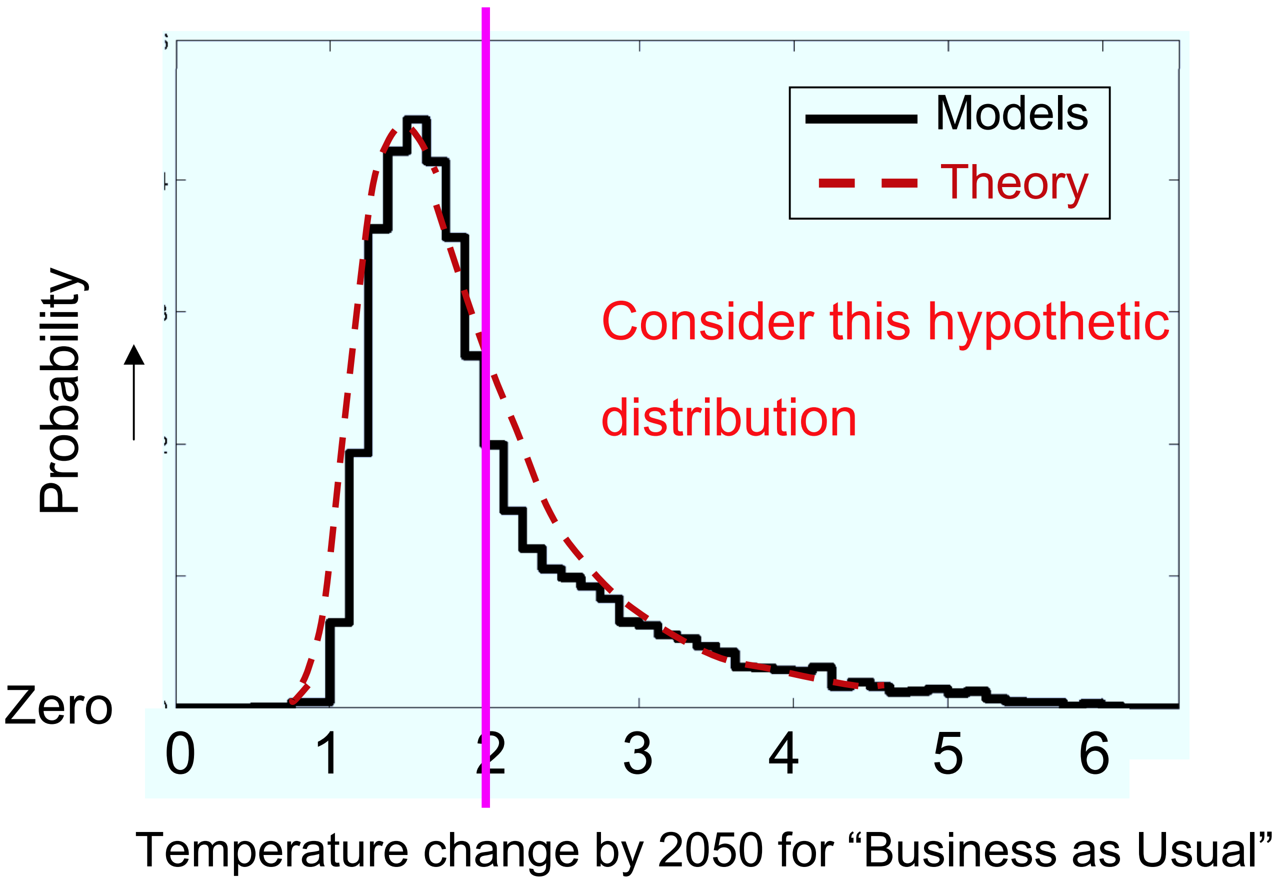


What is the probability that global warming will be dangerous (2 deg C)?



We need this kind of information but for a more realistic transient distribution. These are equilibrium warming.

What is the probability that global warming will be dangerous (2 deg C)?



Proportion of area under curve to the left of pink line is the probability of avoiding 2 deg C by 2050, or about 66%

Equilibrium warming from 2XCO2

Used to compare models without worrying about there deep ocean heat uptake.

But still
ΔT_{EQ} ranges from 1.5-4.5 C among models

- **The range is awfully large (factor of three!)**
- **Hasn't narrowed in 30 years - but models have a lot more features now and old estimates were subjective.**
- **Are predictions even useful for policy-making purposes? Yes, policy makers absolutely need to know the uncertainty though.**

Source of Model Uncertainty?

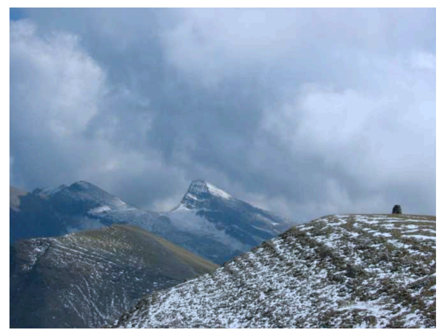
Mainly things that we don’t explicitly model (we have to parameterize them in terms of the ‘resolved physics’)

- Physics of individual clouds
- Calving from glaciers
- Moisture cycling in plants
- Aerosol effect on albedo
- Turbulence

The largest uncertainty in the current models is clouds.

Which Clouds Warm?

High (thin) Clouds

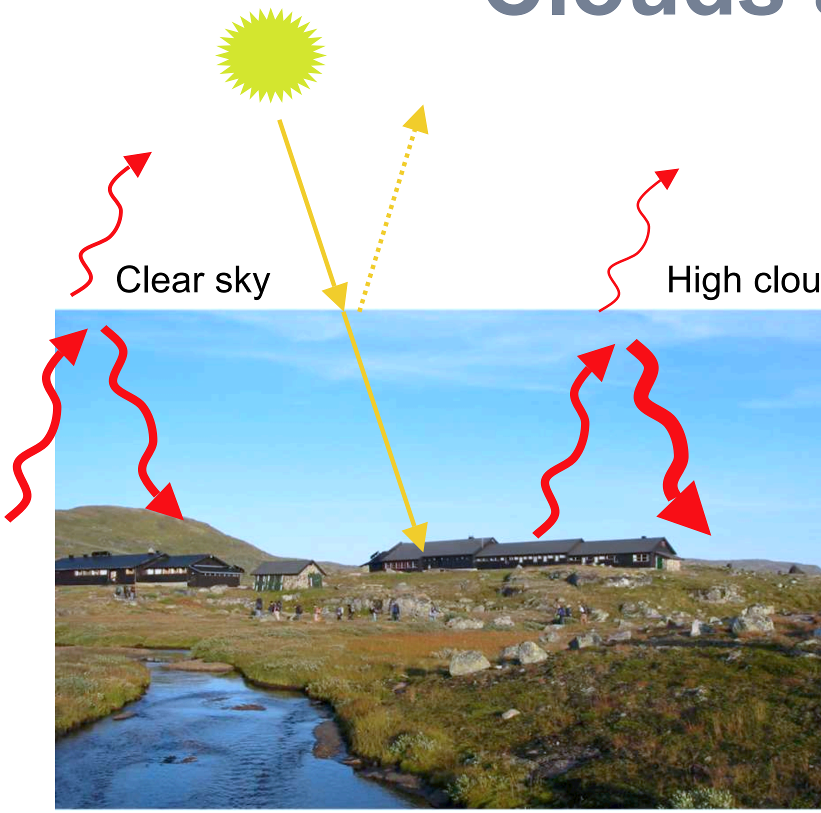


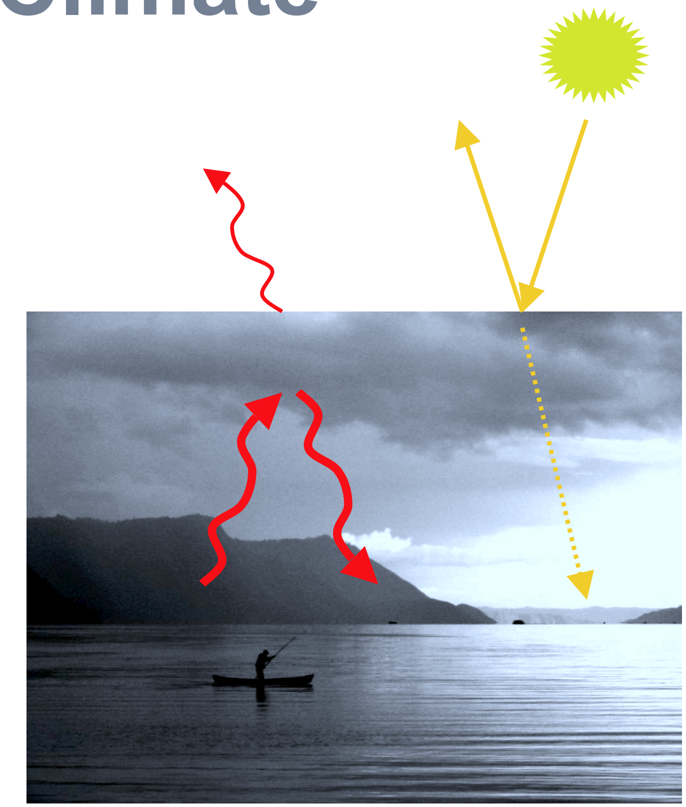
Low (thick) Clouds

Albedo effect – is a cooling, mainly low clouds

Longwave (greenhouse-like) effect – is a warming, greater for high clouds

Clouds and Climate





High (thin) Clouds Warm

Low (thick) Clouds Cool

In today's climate, *the net effect of clouds is to cool the planet* (albedo affect wins over greenhouse effect)

Clouds are the major source of uncertainty in the models

What happens at equilibrium when you double CO_2 ?

- With no feedbacks: 1.2ºC
- With all feedbacks except clouds: +1.9ºC +/- 0.25ºC
- With all feedbacks (incl. clouds): +3.0ºC +/- 0.9ºC

These uncertainties are 66% confidence level, or “likely”

Most models predict less low cloud when there is warming.

Gives a positive feedback

Global Warming Theory – we can make a model to solve with pencil and paper

$$\Delta T = \lambda \, \Delta F$$

Note:
Δ: common symbol to refer to change in some quantity

ΔF: radiative forcing (change in energy balance)
ΔT: response (change in surface temperature)
λ: climate sensitivity parameter (everything else)

λ: does not represent the wavelength of light here!

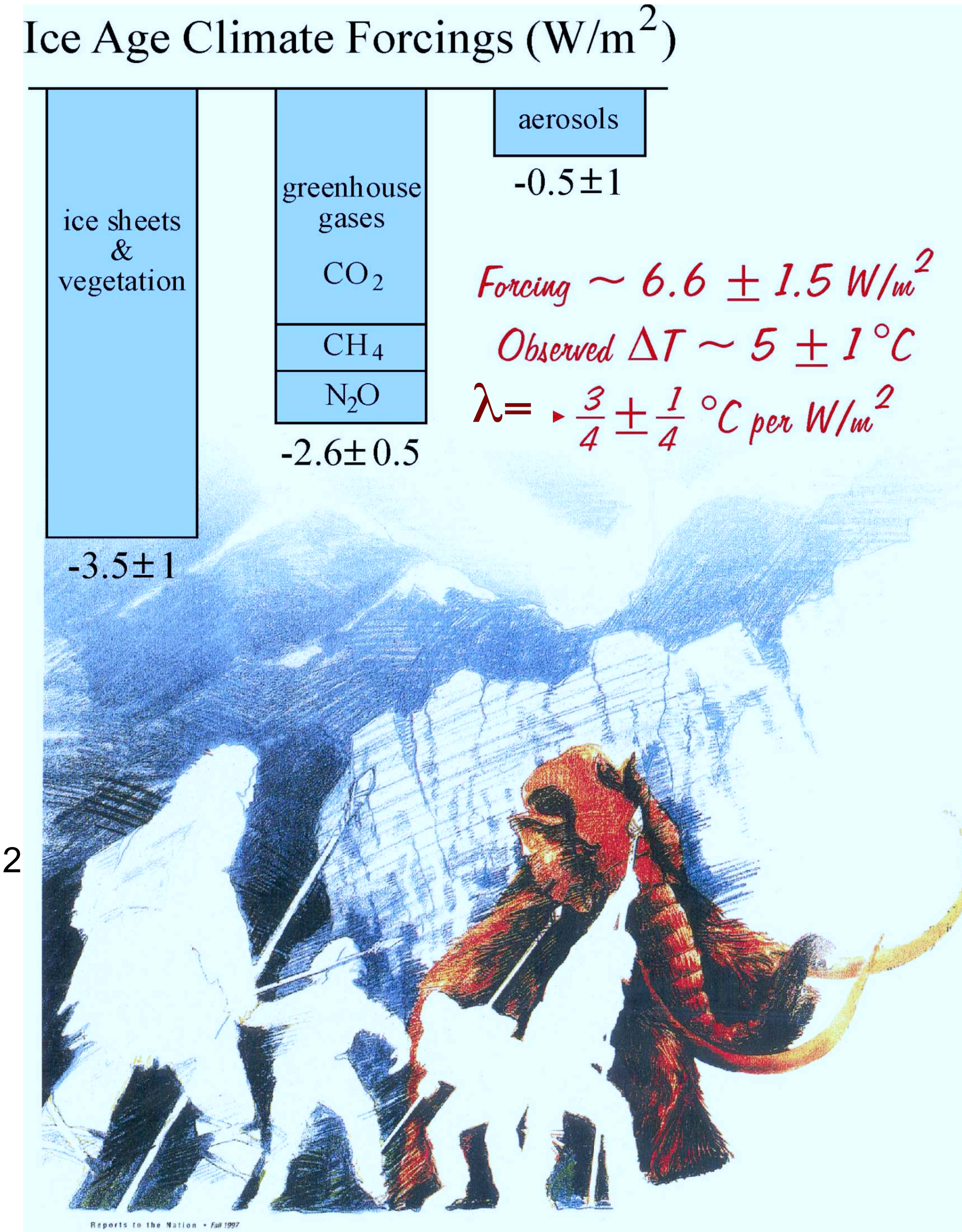
Example by James Hansen
all numbers are relative to pre-industrial

Source: Hansen et al., *Natl. Geogr. Res. & Explor.*, **9**, 141, 1993.

$$\lambda = \Delta T/\Delta F$$

high ΔT/ low ΔF:
6ºC/5.1W/m^2 ≈ 1ºC per W/m^2

low ΔT/ high ΔF:
4ºC/8.1 ≈ 1/2ºC per W/m^2



Except we usually run a Climate Model to estimate λ

Recall ΔF = 3.7 W/m2 for doubling of CO_2

Run model until the ocean comes into equilibrium with the atmosphere and find ΔT is about 2-4.5 °C.

So λ is ?

$\lambda = \Delta T / \Delta F = 2/3.7$ to $4.5/3.7$

$= 0.54$ to 1.2 °C per (W/m^2)

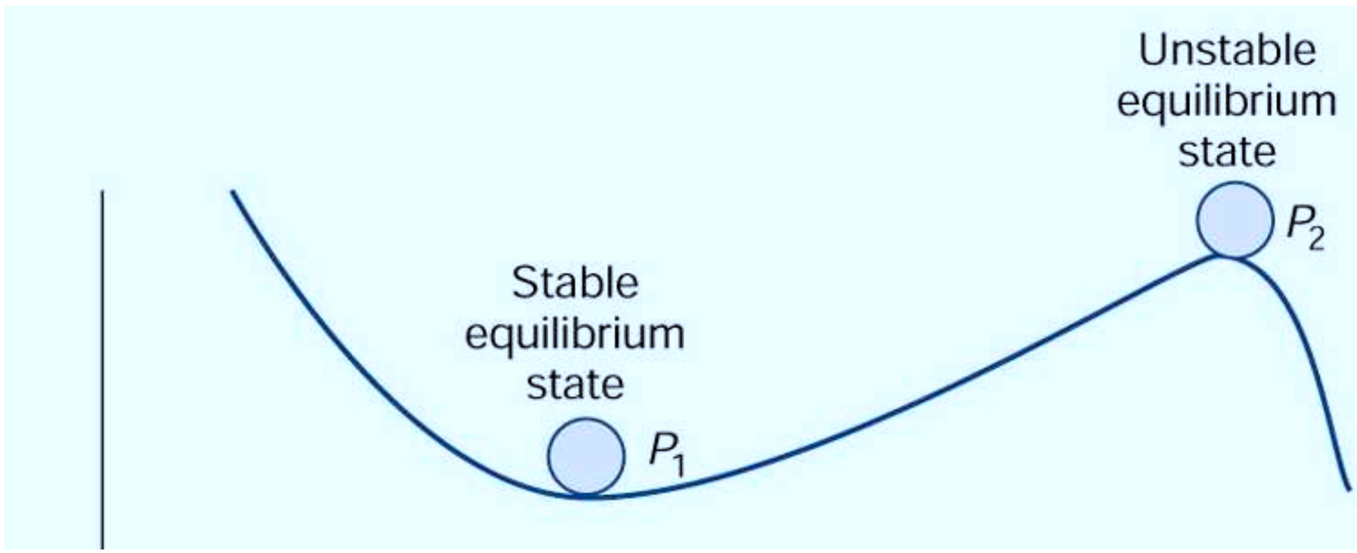
But now apply the model to solar variations

Where last week we learned
$\Delta F = 0.2\ W/m^2$

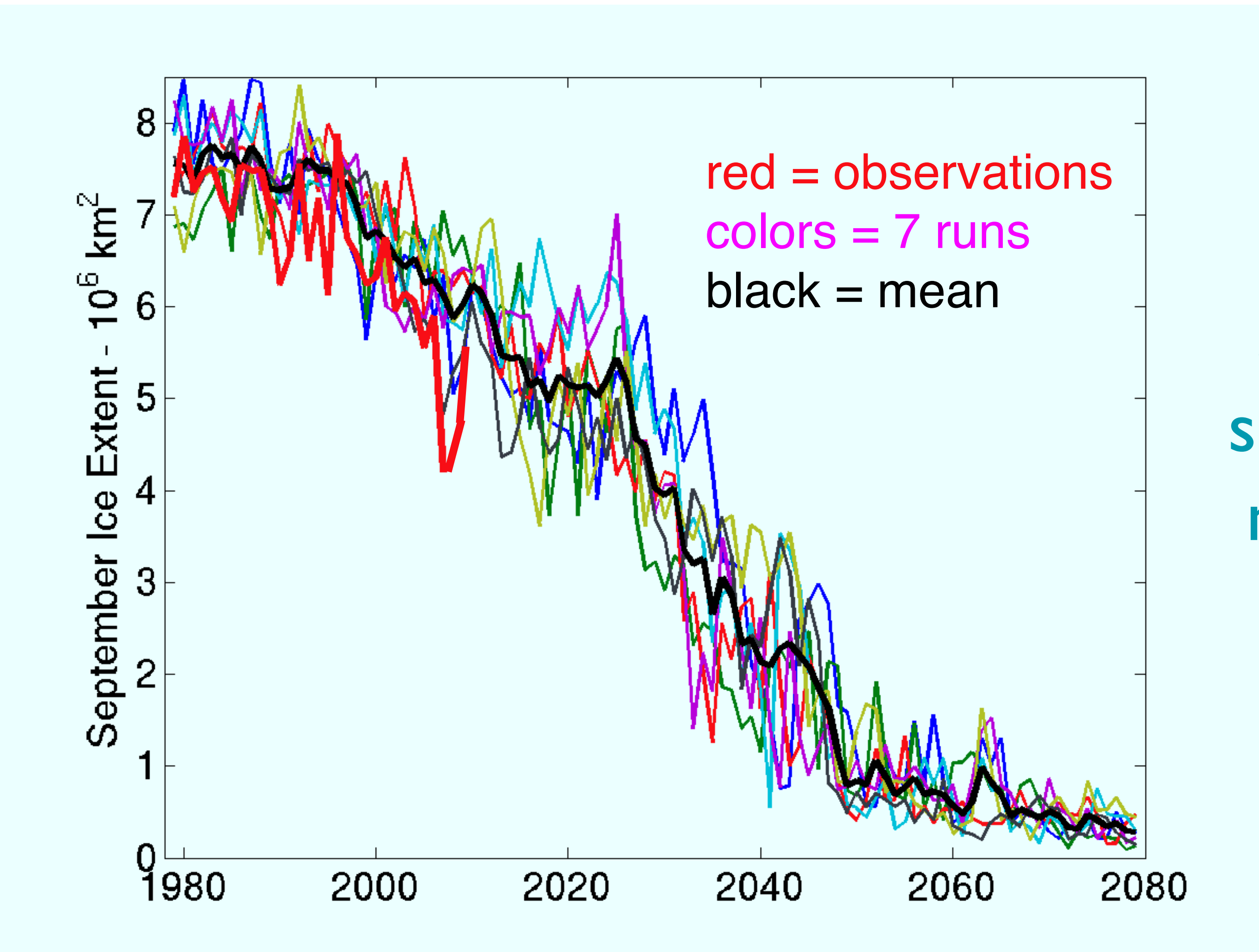
$\Delta T = \lambda\ \Delta F$
Where if $\lambda = 0.5\ ^{o}C$ per W/m^2 then
$\Delta T = 0.5 \times 0.2 = 0.1\ ^{o}C$

if $\lambda = 1\ ^{o}C$ per W/m^2 then
$\Delta T = 1 \times 0.2 = 0.2\ ^{o}C$

Does the climate have a tipping point?

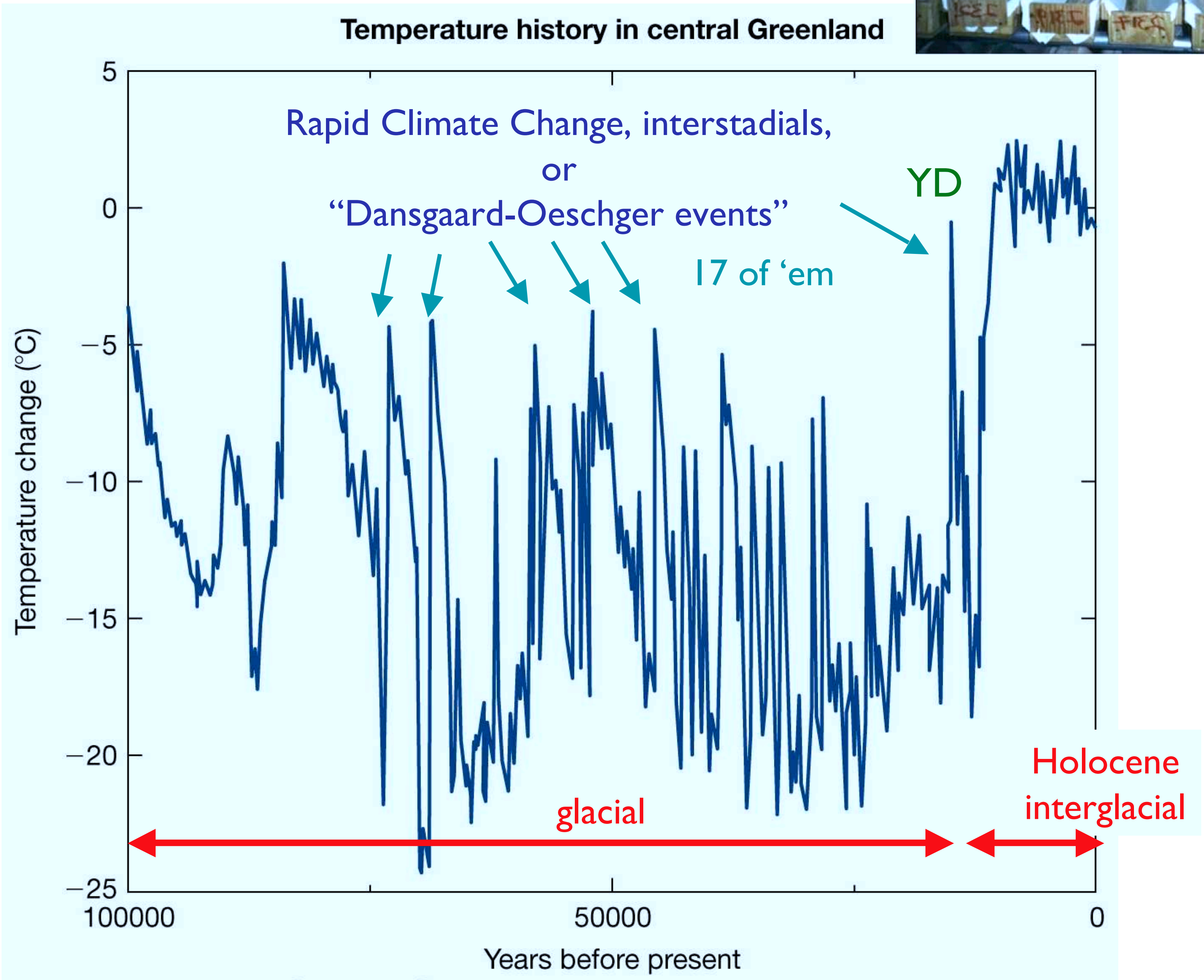


CCSM3 Arctic September Sea Ice Projections
7 runs from one climate model



The observations appear to fall sharply but the model does it at times too. Sometimes "falling" up

The last ice age appeared to have real tipping points

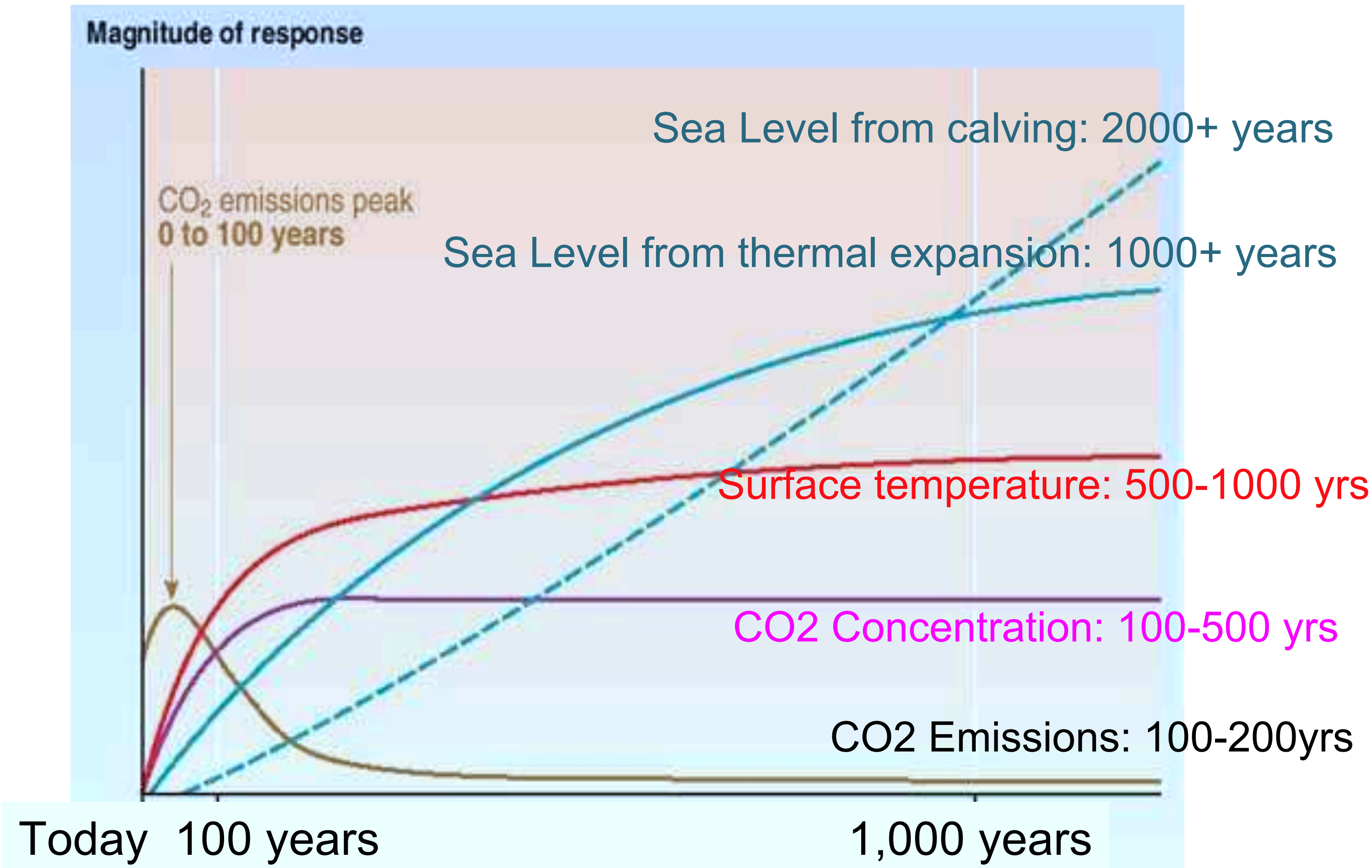


Climate surprises/tipping points?

My opinion: high risk low probability

The long term outlook: 2000-3000AD

If -- in the next 200-300 we reduce CO_2 emissions to a modest constant rate, the climate will eventually equilibrate. How long will it take to reach the new equilibrium?



Summary: Climate in the 21st Century

- The climate is projected to change over this century because of human-induced changes in greenhouse gases (CO_2, CH_4, SO_2, etc)
- The global, annual averaged temperature will likely increase by 2.4 to 6.4ºC
- The uncertainty in the climate projections is roughly equally due to
  - Uncertainty in emissions
  - Uncertainty in models

Summary

- Warming will not be uniform in space or time. It is very likely that
  - Warming -- more over continents than oceans; more in high latitudes than in tropics; more in winter than summer, more at night than day
- Other climate changes that are *very likely** over the next 100 years include:
  - the hydrologic cycle will speed up
  - the area covered by snow and sea ice will decrease
  - the subtropics will be drier (less precipitation/more evaporation)
  - the sea level will rise
  - the ocean will become more acidic.

(* very likely: defined by the IPCC as greater than 90% chance)

Summary (cont)

•The changes over the next 100 years will be much, much greater than the changes seen over the past 150 years that have been attributed to increased greenhouse gases and aerosols.

•The rate of change is 100 - 1000 times faster than nature

•The changes in climate will have a significant and increasing effect on temperature, precipitation, snow pack, river flows (amount and timing), and soil moisture.

-> **agriculture**, fisheries, forestry, aquaculture …
-> ecosystems and biodiversity
-> flood control policy, hydropower, vector borne diseases, …

•We now understand the range in the warming projected for 2100 by the various models, and can better quantify the likelihood of a very large warming (compared to average warming, used by IPCC)