3. Projections of Climate Change: 2100 and beyond

- Projections taken from the most recent consensus report from Intergovernmental Panel on Climate Change.
- Focus on those changes that are “very likely” (i.e., those that are either deemed to have a greater than 90% chance to occur “based on quantitative analysis or an elicitation of the expert views”)

How much Carbon Dioxide will be released into the atmosphere?

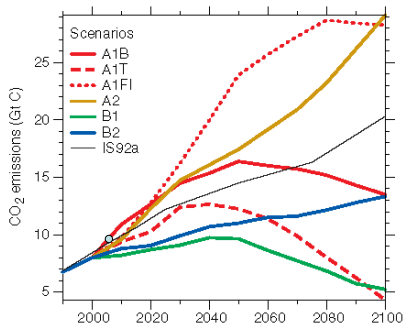
The Emission Scenarios

- **The A2 storyline and scenario family** describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
- **The A1 storyline and scenario family**: very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.
  - fossil intensive (A1FI), non fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source)
- **The B2 storyline and scenario family**: emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Emission scenarios provided by economists, policy makers, etc.

How much Carbon Dioxide will be released into the atmosphere?

Scenarios provided by economists, policy makers, etc.



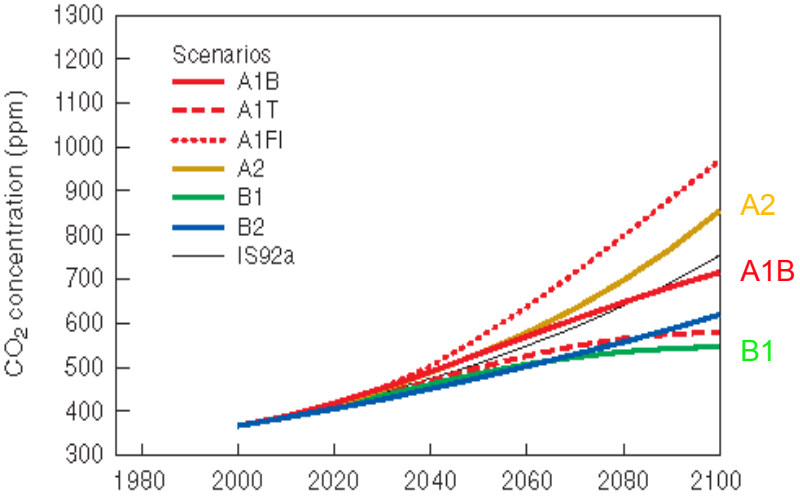
A2 (business as usual)

A1B

B1 (utopia)

Estimates depends on population and economic projections, future choices for energy, governance/policy options in development (e.g., regional vs. global governance)

How much Carbon Dioxide will go into the atmosphere?



A2

A1B

B1

Scenarios also for emissions of other GH gases and aerosols

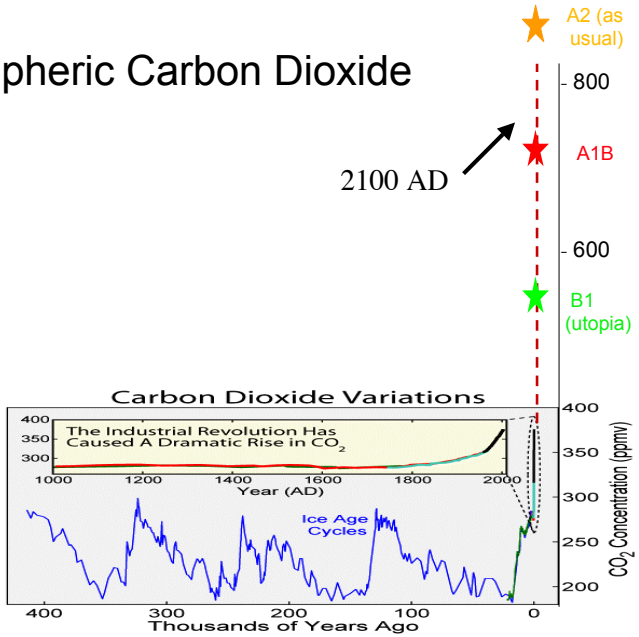
How much CO_2 will in the atmosphere?

- … in 2100 if global emissions stayed the same as today (no population increase or development)
  - Information needed (rounded):
  - Current world-wide emissions 10Gt/yr
  - About 50% of the CO_2 remains in the atmosphere (the rest goes into the ocean and land)
  - There is 800Gt of carbon in the atmosphere today (389ppm)

- … in 2050 if everyone in the world lived life like an American?
  - 300M people live in the US (1/30 of the world population today) and we emit 2.5Gt/yr
  - 7B people in the world today, 9B by 2050

- If we wanted to stabilize CO_2 concentrations in the atmosphere, how much could the US emit fairly?
  - Information needed:
  - World emissions would must be less than 1Gt/yr

Atmospheric Carbon Dioxide



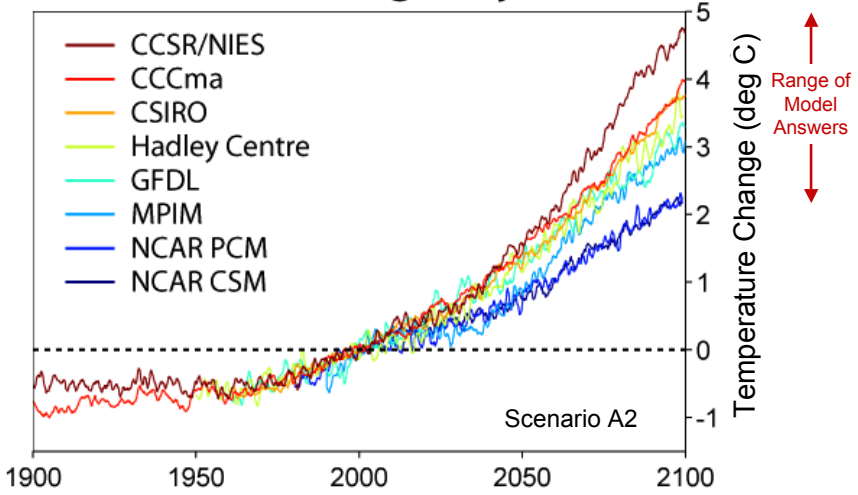
Climate change due to increasing greenhouse gases

Changes that are *highly likely** over the next 100 years include:

- the planet will warm, more so in middle and high latitudes than in the tropics
- the hydrologic cycle will speed up
- the area covered by snow and sea ice in winter will decrease
- the interior of continents will be drier in the summertime
- the sea level will rise
- the surface ocean will become 2-3 times more acidic

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

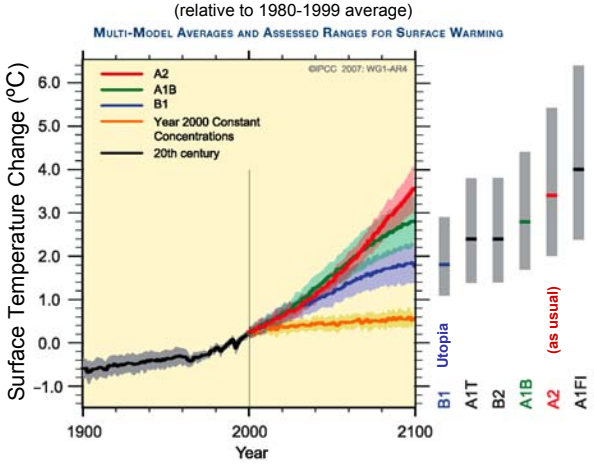
Global Warming Projections



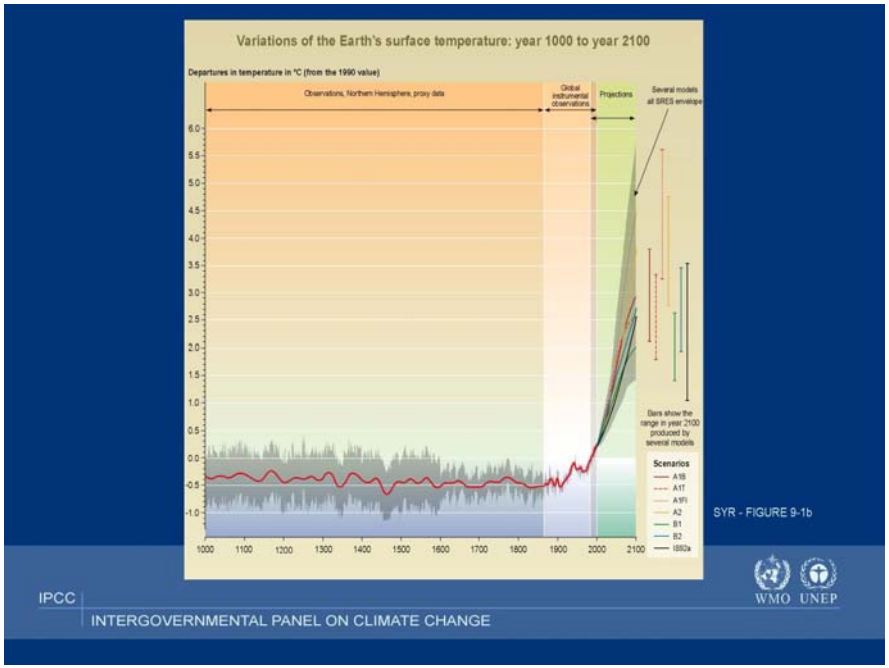
The range in projections is a measure of the uncertainty in the models, given a perfect emission forecast.

Global Average Temperature Change

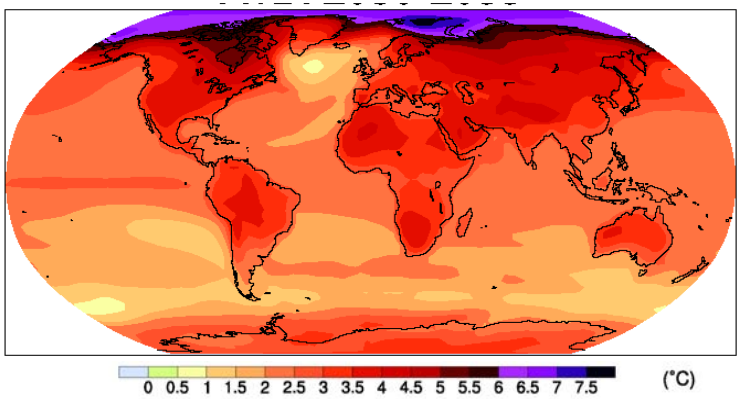
(relative to 1980-1999 average)



For a mid-range emission scenario, model project an global average warming over the next 100 years of 2.8 ºC: 3 to 4 times the warming over the past century.

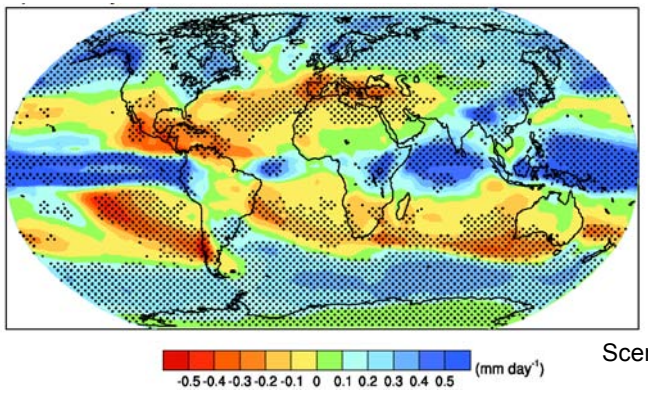


Projected Annual Average Surface Temperature Change:
"2080-2099" minus "1980-1999"



Average of 21 climate models forced by Scenario A1B.
Multiply by ~1.2 for A2 and ~0.7 for B1

Projected Annual Average Precipitation:
"2080-2099" minus "1980-1999"

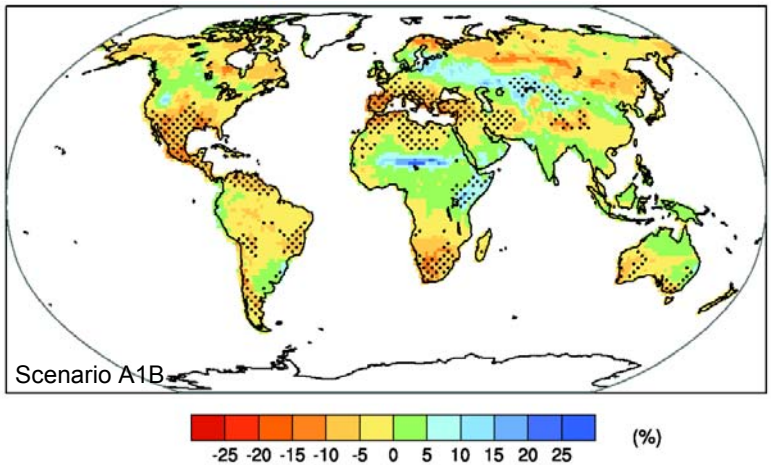


Scenario A1B

There is a *robust* drying of the subtropics, 20-35N&S.

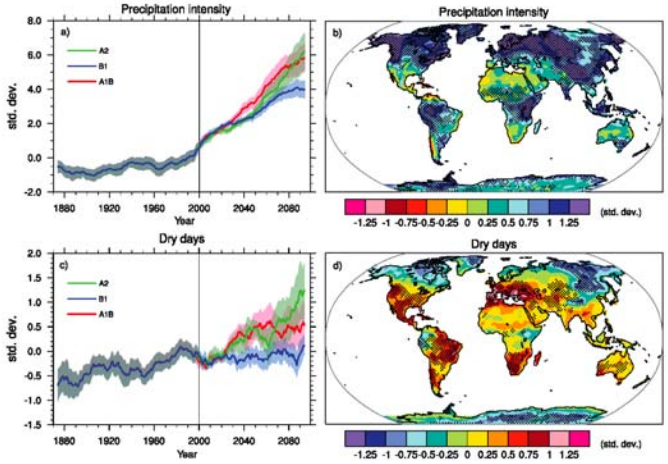
Stippling is where the multimodel average change exceeds the standard deviation of the models

Projected Soil Moisture Change: “2080-2099” minus “1980-1999”

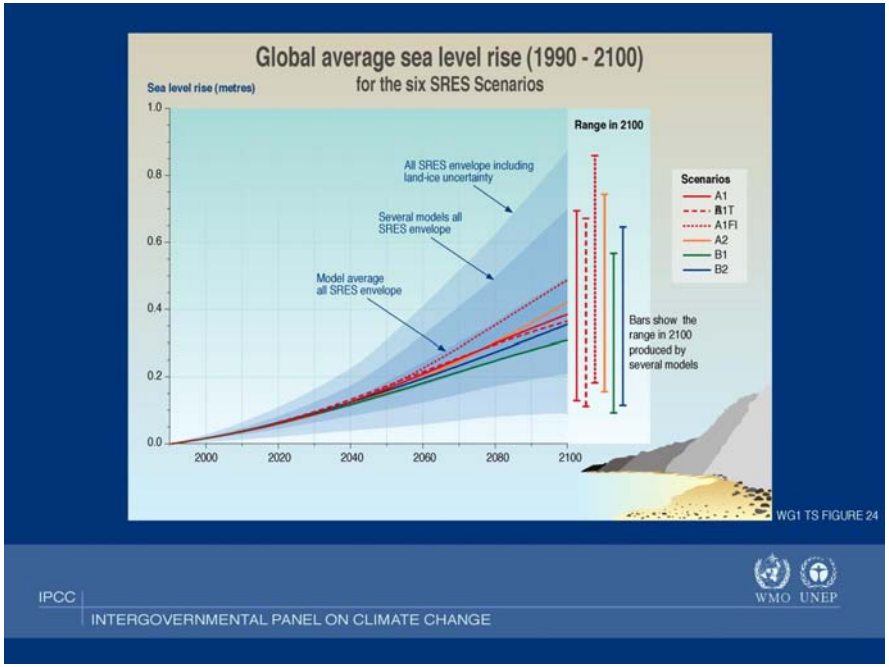


Percent Change

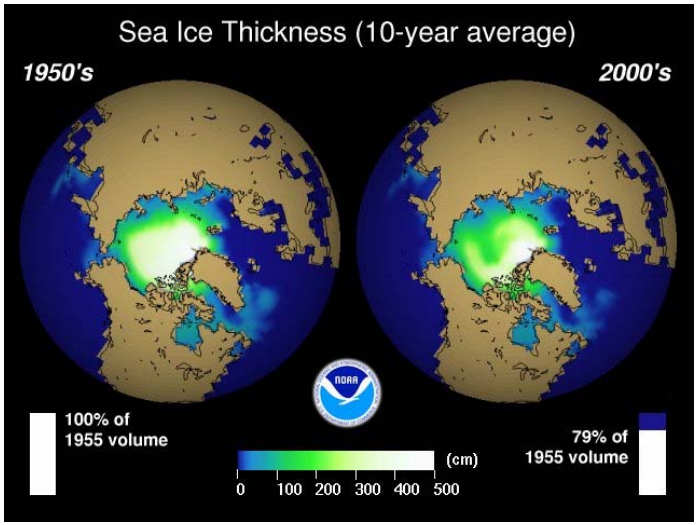
Projected Hydrologic Changes: “2080-2099” minus “1980-1999”



Scenario A1B



Sea Ice Thickness



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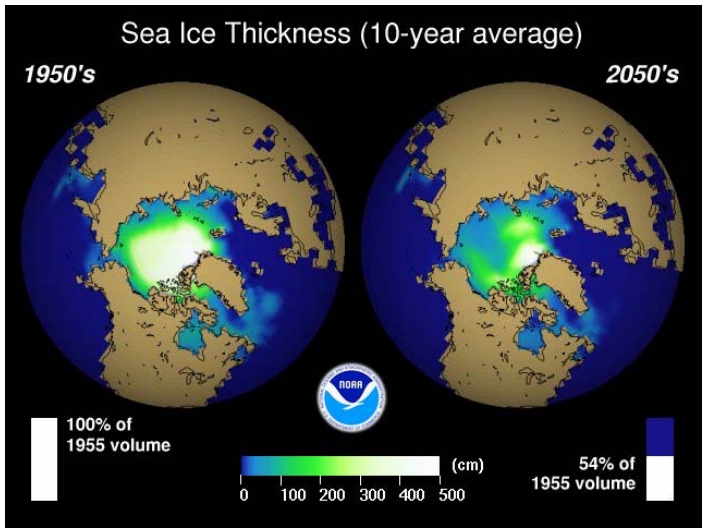
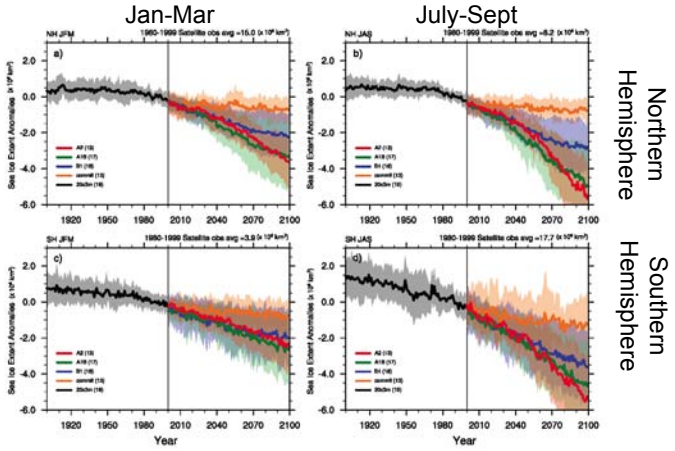


Projected Sea Ice Extent

"2080-2100" minus "1980-2000"



Largest decreases in northern hemisphere

Sea Ice Covered: when 15% of your neighborhood is covered by sea ice

IPCC AR4, Fig 10.13

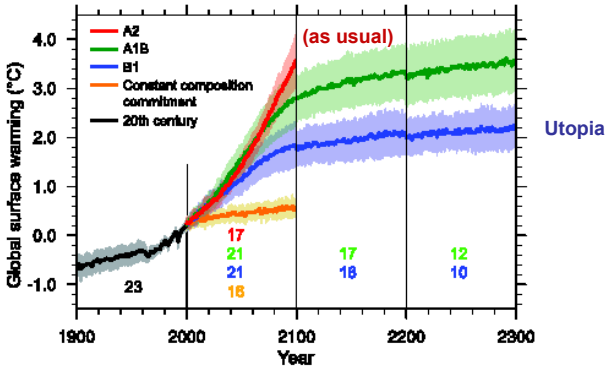
Climate changes due to human activity

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

IPCC 2007

Virtually certain > 99% Very likely >90% Likely >66% More likely than not > 50%

Global Annual Average Surface Temperature

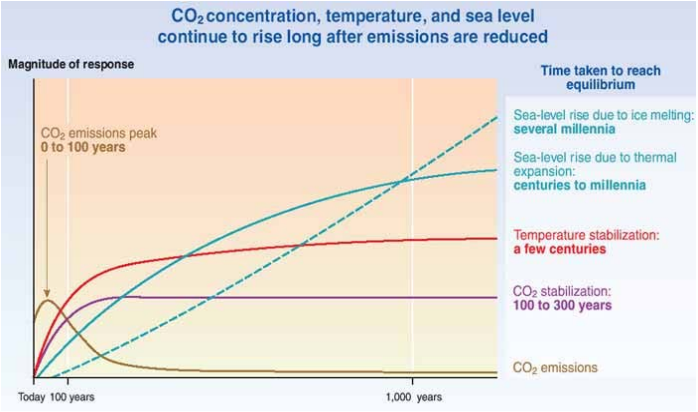


Referenced to the 1980-1999 Average Temperature

Solid lines: average of all models used. The number of models used varies; shaded area is the standard deviation of the models. No emission is assumed beyond 2100 (gold: beyond 2000)

If we stop putting CO_2 in the atmosphere **today**, the climate would continue to warm for a few hundred years, then slowly return to pre-industrial carbon dioxide concentrations (and temperatures) in about 1000 years.

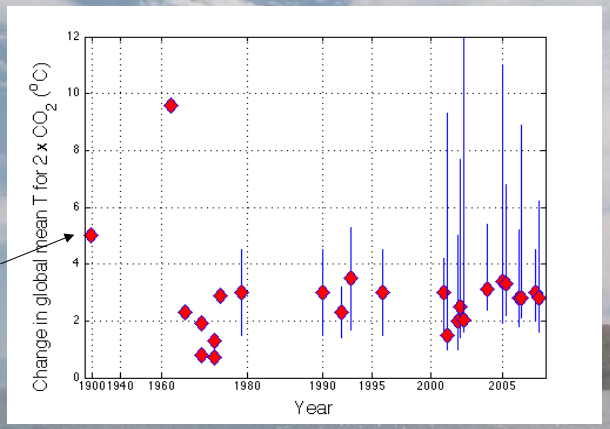
If we stabilize CO_2 emissions at a fixed level, the climate will eventually equilibrate. How long will it take to reach the new equilibrium?



4. What's new in Climate Science?

A better understanding of the reasons for uncertainty in the models

Estimates of the *climate sensitivity*: the change in global temperature for a doubling of carbon dioxide



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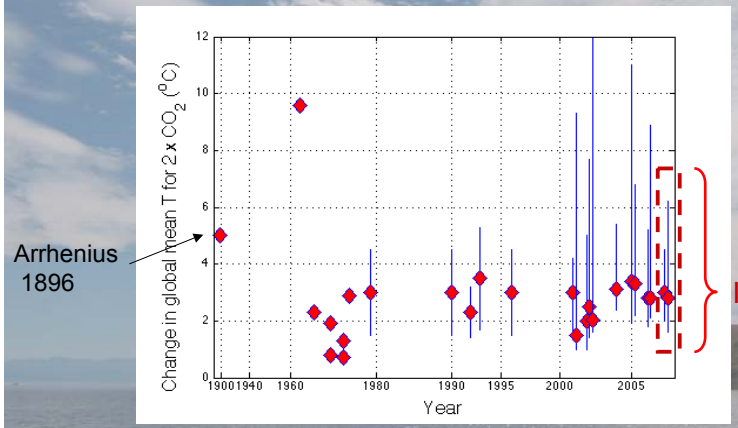
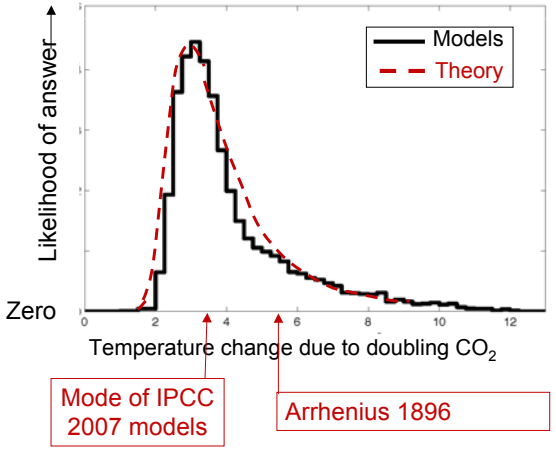
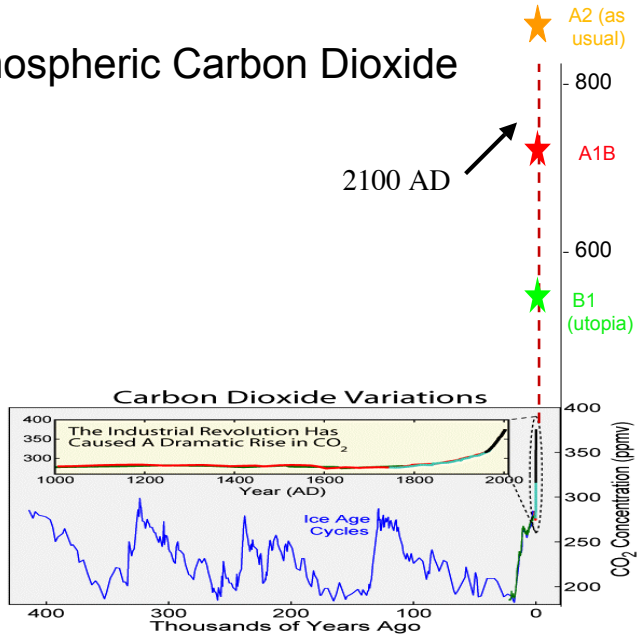


The *Expected* Distribution of Climate Sensitivity

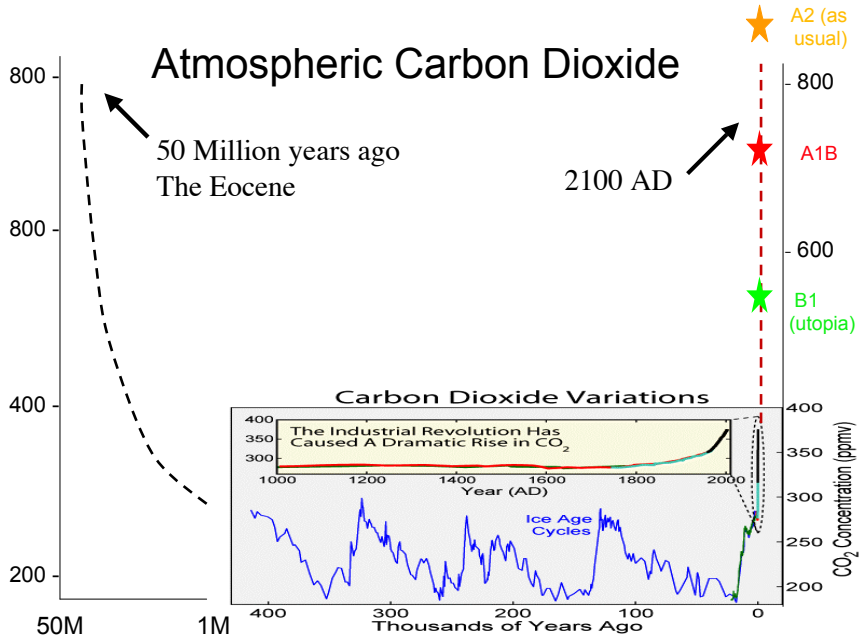


Roe and Baker (2007) provide a simple theory for estimating the the *expected* distribution of model responses due to model uncertainty.

Atmospheric Carbon Dioxide



Atmospheric Carbon Dioxide



In 100 years, the atmospheric CO_2 will reach 500-1000 ppm, which was last experienced during the EOCENE (55 to 36 million years ago)

The Eocene climate was warm, even at high latitudes:

-palm trees flourished in Wyoming and Antarctica was a pine forest
-crocodiles lived in the Arctic
-deep ocean temperature was 55°F (today it is ~35°F)
-sea level was at least 300 feet higher than today

* Climate models with mid-range climate sensitivity simulate an Eocene that is much too cold compared to the fossil records

Summary

•Greenhouse gases have increased over the past 150 years to do human activity, and this has caused the climate to change:

- Warming -- more over continents than oceans; more in high latitudes than in tropics; more at night than day
- fewer frost days per year
- decreased sea ice extent and volume
- higher sea levels; more acidic ocean

•Changes *very likely* over the next 100 years include:

- the planet will continue to warm, more so in middle and high latitudes than in the tropics
- The rate of warming will increase
- the hydrologic cycle will speed up
- the area covered by snow and sea ice will decrease
- the subtropics will be drier (less precip/more evaporation)
- the sea level will rise; the ocean will become more acidic.

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)