MFE Lecture 4b: Modeling Climate Change

Previous Lecture Global Warming

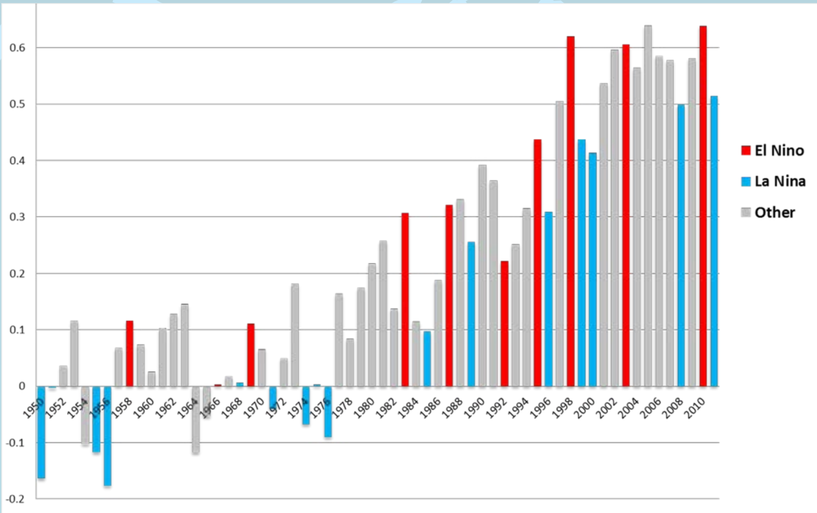
The strongest evidence for the sensitivity of the climate system is the empirical fact that the warmth of the current interglacial period, with Earth 5°C warmer than during the ice age 20,000 years ago, is maintained by a forcing between 6 and 9 Watts/m^2. This observation supports the National Academy of Sciences 1979 estimate of about 3°C warming for doubling of CO_2, which causes a forcing of 4.3 Watts/m^2.

Twenty-four hours a day, the Tar Sands operation eats into the most carbon rich forest ecosystem on Earth. The vast mines, tailings ponds, fire- and pollution-belching refineries.

Summary: Evidence for Recent Warming

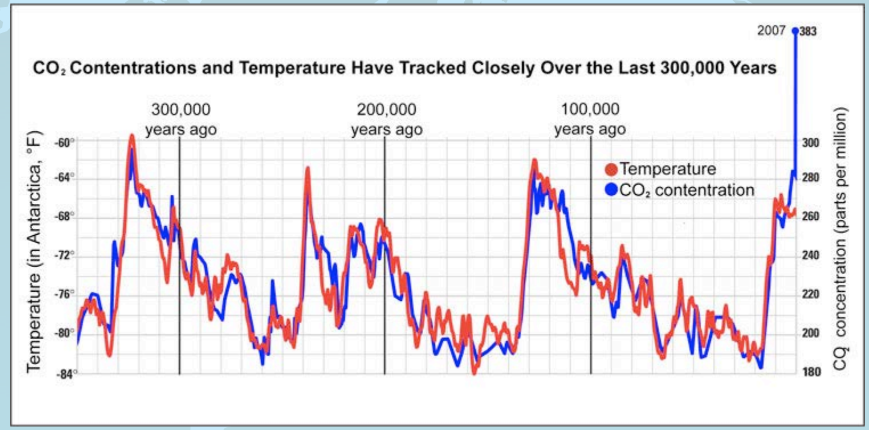
- The global average surface temperature has increased by 0.8 ˚C (1.4 ˚ F) with two thirds of the warming occurring since 1980.
  - the bulk of the warming has occurred at higher latitudes
- Hydrological cycle is more intense
  - Heavy rain events increasing
  - Droughts and heat waves more common
  - Increased in number and size of wild fires
- Decrease in sea ice thickness and extent in last 40 years
- Widespread melting of permafrost.
- Widespread retreat of mountain glaciers seen in non-polar regions.
  - Snow cover extent decreased ~20% in last 40 years
- Sea-surface temperature (SST) rise
  - widespread coral bleaching
- A gradual rise in sea level shows recent signs of acceleration

Annual Global Temperature Anomalies



This chart illustrates the important influence that SST has on the global mean temperature.

Carbon Dioxide Record



Current CO_2 concentration in the atmosphere from Mauna Loa is around 390 ppm

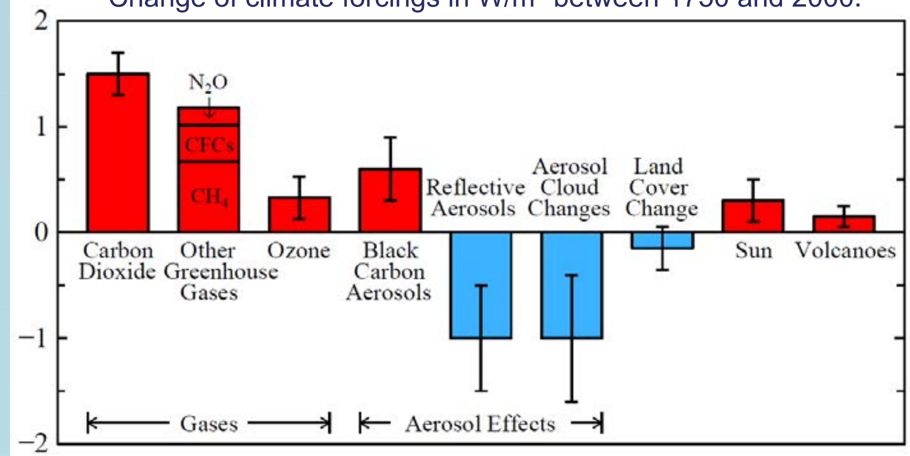
Anthropogenic Climate Change will Persist for a Long Time

Gas	CO_2	CH_4	N_2O	CFC's
Atmospheric lifetime	50-200 yr	12	120	50-300

- Water vapor has a residence time in the atmosphere of only a few weeks. Therefore, it is a slave (positive feedback) to the other long lived greenhouse gases.

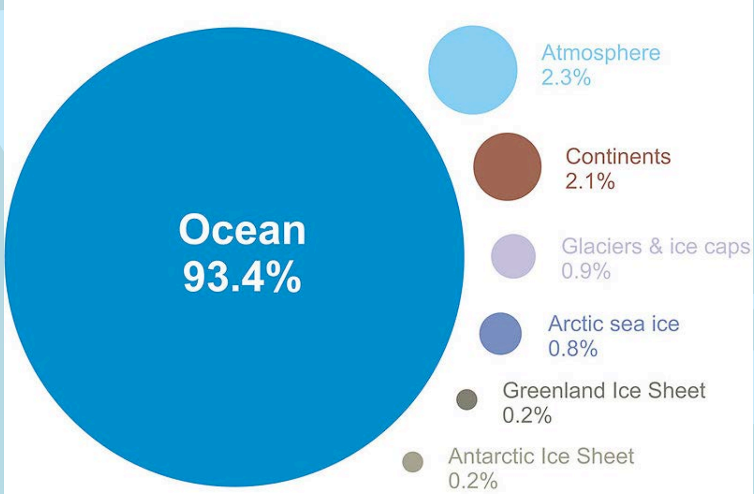
Climate Forcing

Change of climate forcings in W/m² between 1750 and 2000.



[from Hansen *et al.* *"Efficacy of Climate Forcings" J. Geophys. Res.* (2005)]

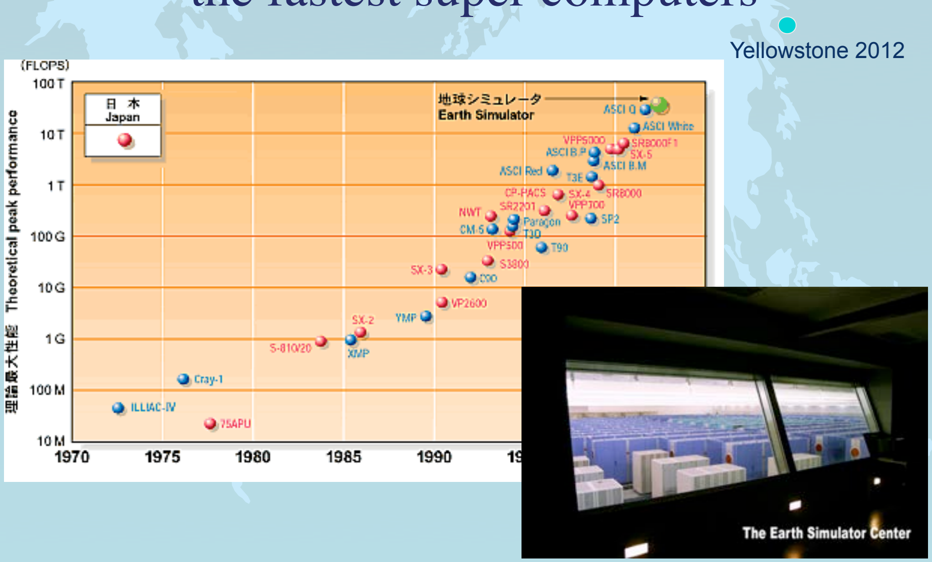
Where is global warming going?



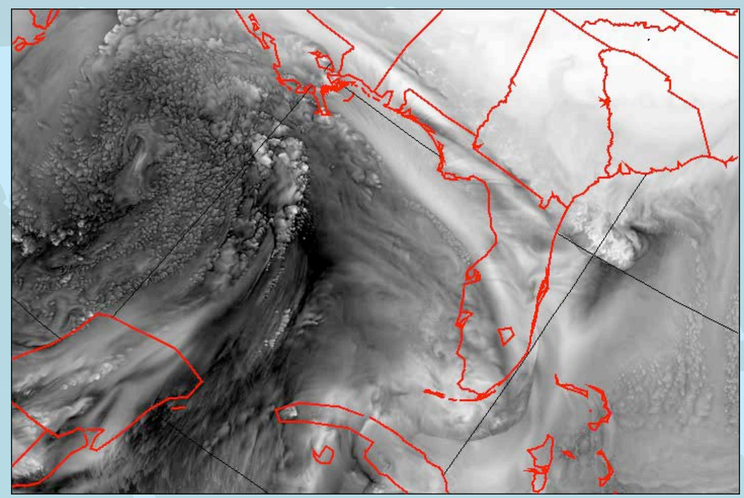
Lecture 28: Modeling Climate Change

Yellowstone is an IBM iDataPlex supercomputer system, consisting of 149.2 terabytes of memory, 74,592 processor cores, and a peak computational rate of 1.6 petaflops.

Modeling Climate Change requires the fastest super computers



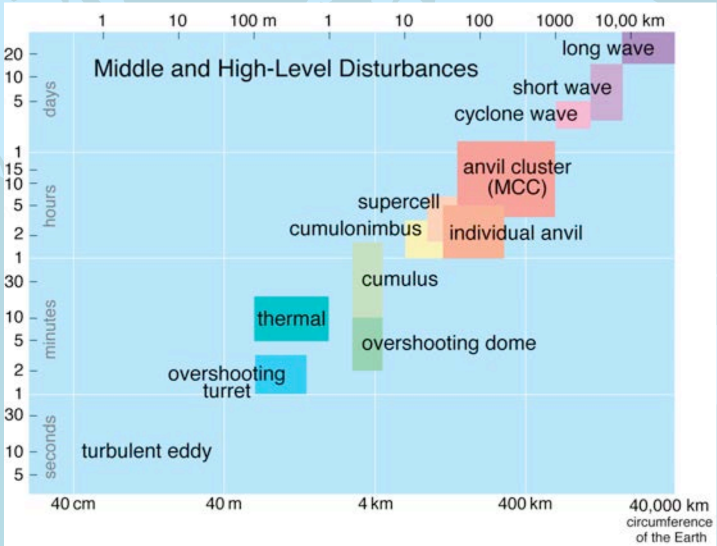
Modeling Climate Change



Resolution and sophistication of climate models is increasing.

Even so Yellowstone is not fast enough to do the job.

Forecasting Phenomena over Four Orders of Magnitude



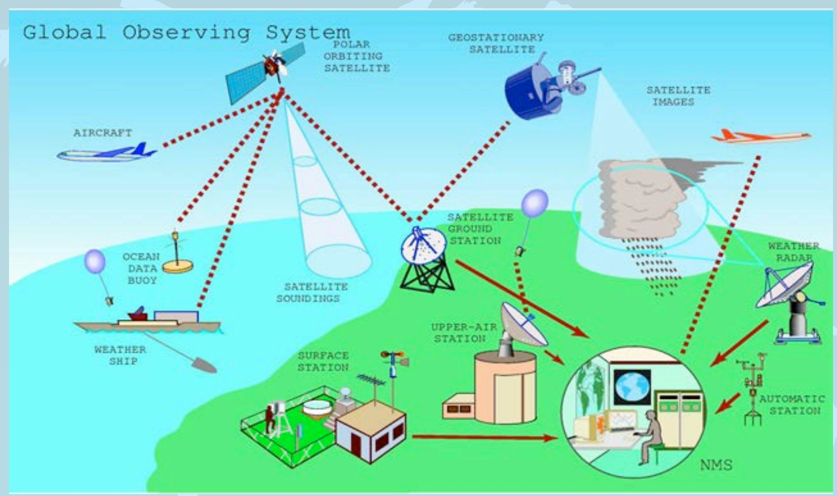
Atmosphere/Climate Simulation Models

- A coordinate system
- Variables to be solved for and governing equations
- A finite numerical discretization in space (e.g. a spatial grid, spectral Fourier series)
- Discretization in time (“timesteps”)
- Numerical approximations for the governing equations
- “Parameterization” of the effects of “subgrid scale” variability on the resolved scale circulation
- Numerical algorithms and a computer
- Initial conditions (assimilation of observations)

Summary of Weather Modeling: 4 Steps

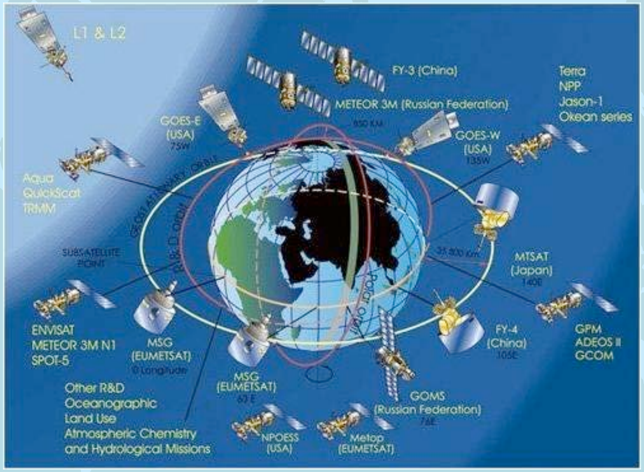
1. Input all available observations.
2. Numerical procedures (grid, boundary conditions, etc.).
3. Apply laws of physics, including parameterization of surface and cloud processes too small for the model to directly include - integrate equations forward in time.
4. Output resulting forecast as contoured maps for easy interpretation.

Global Observing System

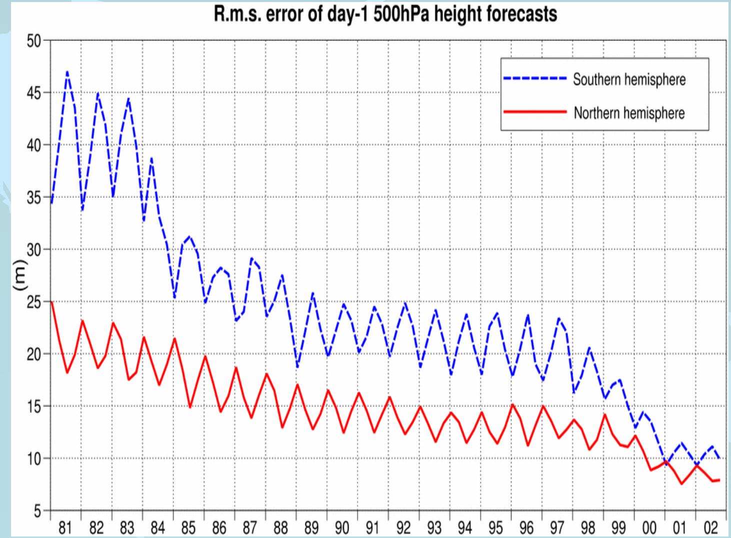


Input all available observations: surface, ship, buoy, radiosonde, aircraft, radar, satellite, etc...

Weather Satellites

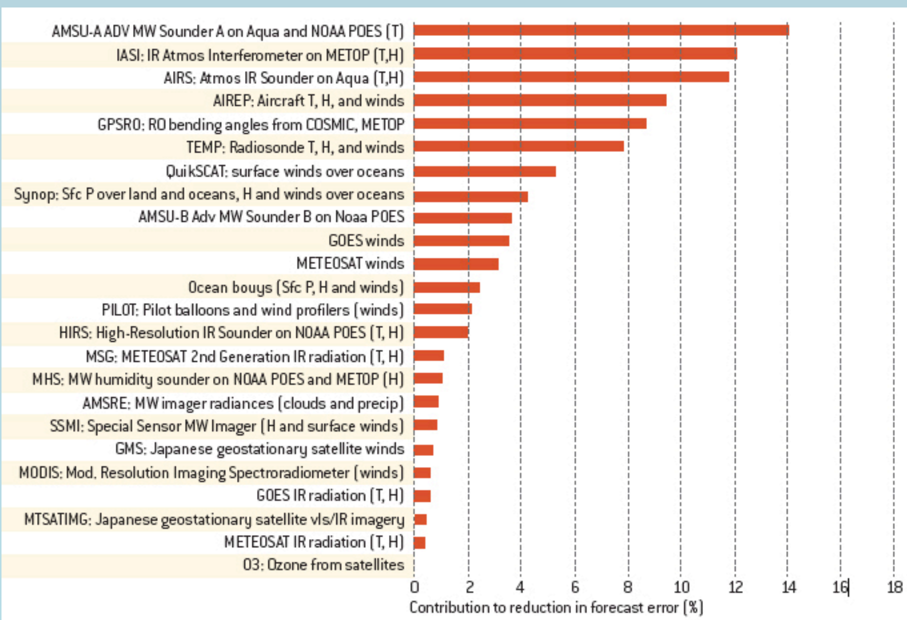


ECMWF 500 hPa Error Evolution 1981 – 2002



- A. Hollingsworth ECMWF - Sloan Conference on Weather Predictability 2003

Reducing Forecast Error with Satellite Data

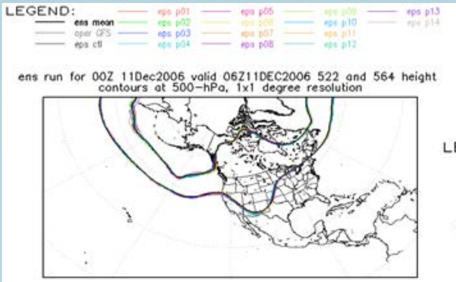


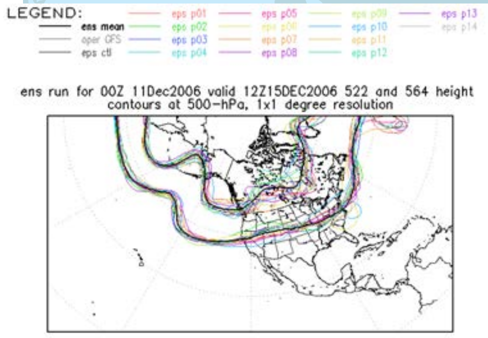
Wisdom from the ECWMF

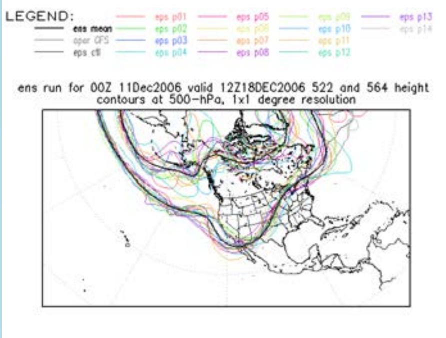
- Numerical Weather Prediction (NWP) .. is based on solving a complex set of hydrodynamic equations that describe the evolution of the atmosphere, subject to the initial atmospheric state and initial conditions at the Earth's surface .
- Since the initial state is not known perfectly, all forecasts begin with estimates. Unfortunately the system is very sensitive to small changes in the initial conditions (it is a chaotic system) and this limits the ability to forecast the weather beyond 10-14 days.

http://www.ecmwf.int/products/forecasts/seasonal/documentation/system3/ch1.html

NCEP ensemble forecasts

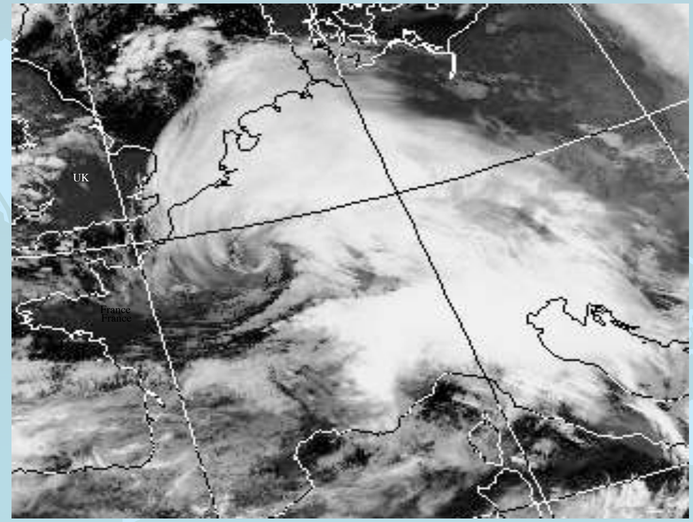






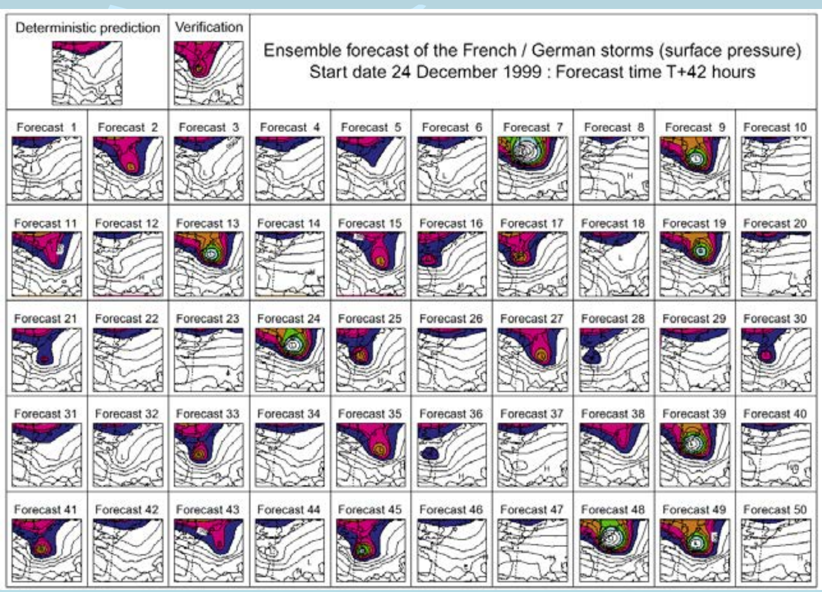
The quality of atmospheric forecasts decreases as a function of time

Lothar



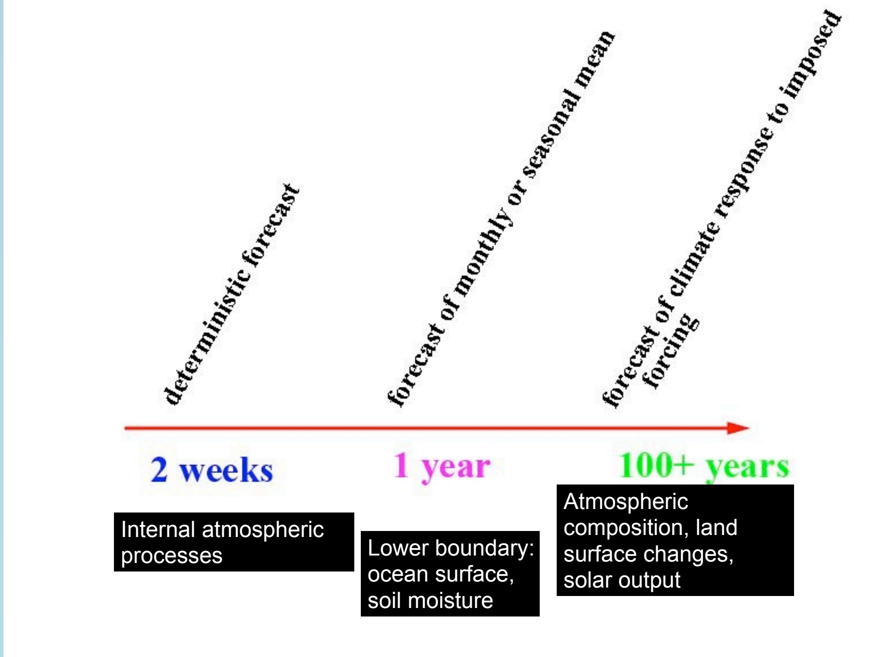
Dundee Satellite Station: 0754 UTC 26 December 1999

Lothar (T+42 hour TL255 rerun of operational EPS)



Is there any hope of extending this limit – to seasons, years, decades… ?

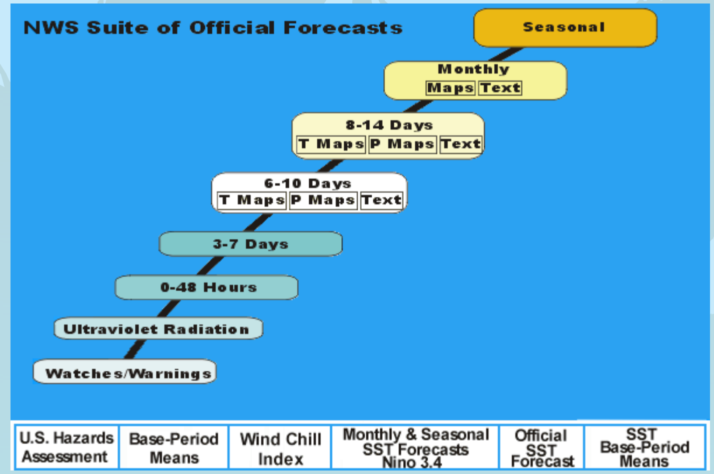
- Ensemble forecasting to try to reduce effects of uncertain initial conditions.
- Low frequency aspects of system depend on longer term “memory” in the ocean and land-surface conditions – may allow forecast of “time mean conditions” rather than deterministic forecasts.
- Including projected changes in atmospheric composition, solar output .. could allow a projection of changes in the long-term mean climate on very long time scales.



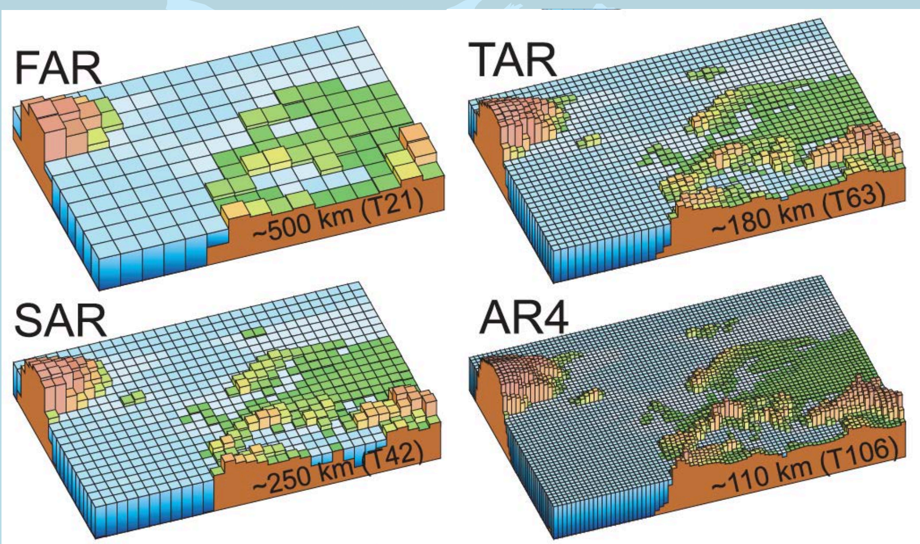
Extended-range Forecasting – weeks-months-seasons-years

- National Weather Service Climate Prediction Center (CPC)

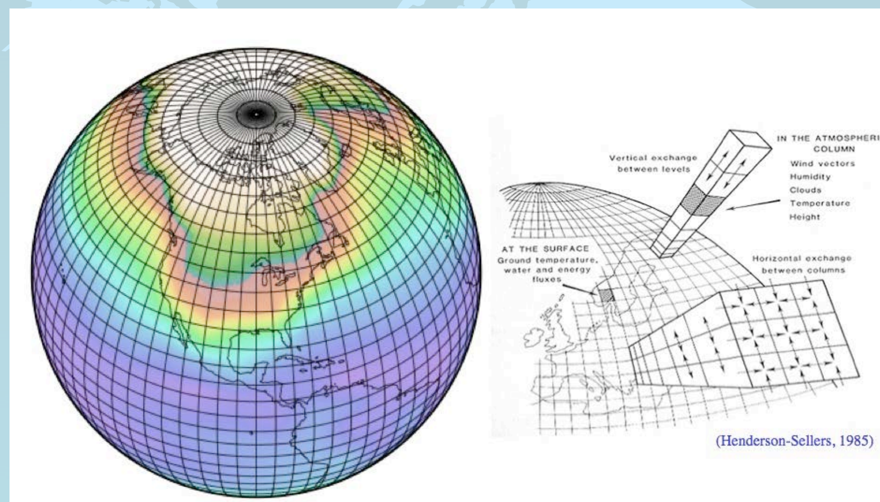
http://www.cpc.ncep.noaa.gov/



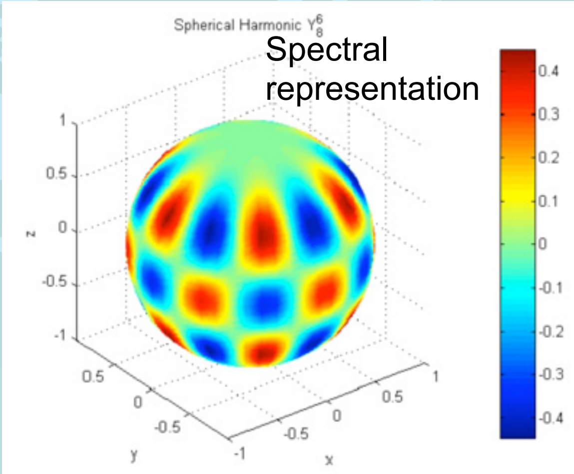
Improving Climate Change Model by Adding Resolution



Global Model Grid has 4 Dimensions

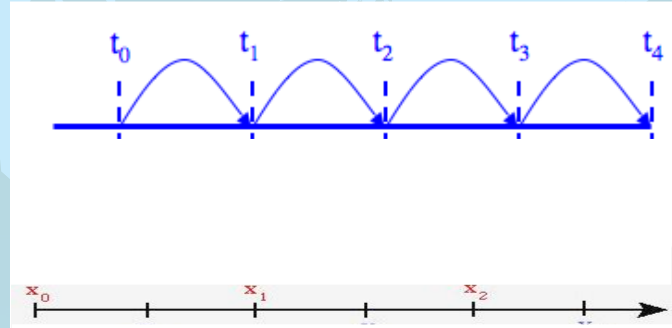


Atmosphere/Climate Simulation Models



A finite numerical discretization in space
(e.g. a spatial grid, spectral Fourier series)

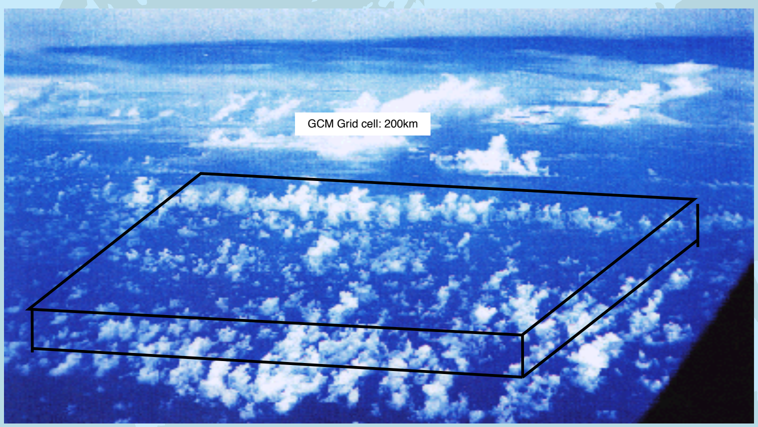
Atmosphere/Climate Simulation Models



Timesteps for moderate resolution models may be ~15 minutes, for high resolution models they could be considerably shorter

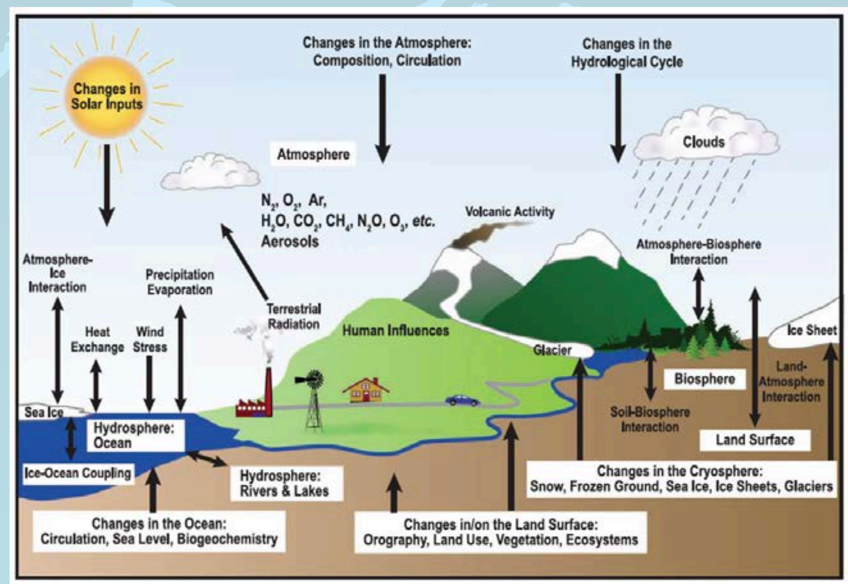
Discretization in time (“timesteps”)

Challenge of Modeling Clouds



Typical grid box in a GCM with inhomogeneous distribution of clouds within it. Distribution of clouds must be parameterized in the model.

The Complexity of the Climate System

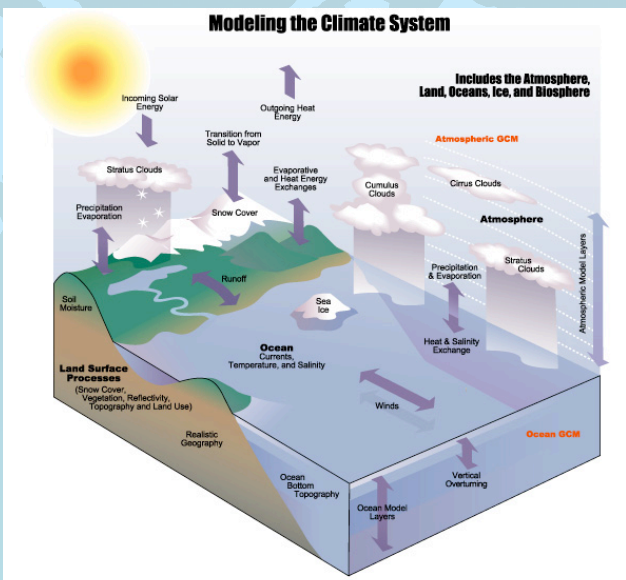


Adding Complexity

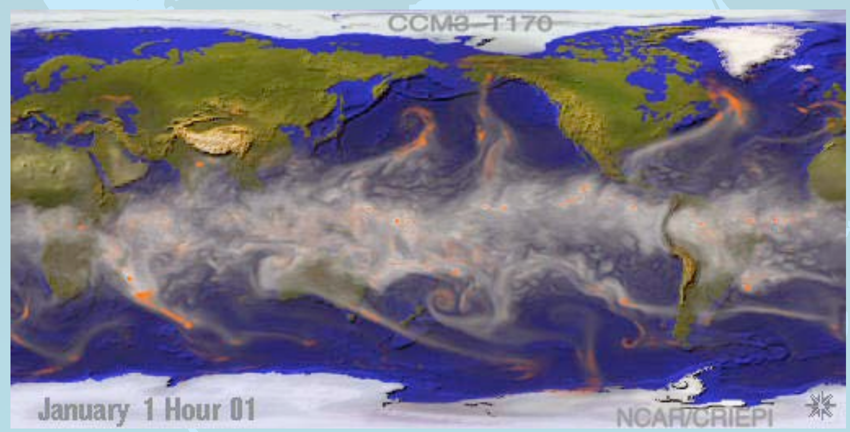
Mid 1960s	Mid 1970s–1980s	1990s	Present Day	2000–2010
Atmospheric/ Land Surface	Atmospheric/ Land Surface/ Vegetation	Atmospheric/ Land Surface/ Vegetation	Atmospheric/ Land Surface/ Vegetation	Atmospheric/ Land Surface/ Vegetation
Ocean	Ocean	Ocean	Ocean	Ocean
	Sea Ice	Sea Ice	Sea Ice	Sea Ice
	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model
		Sulfate Aerosol	Sulfate Aerosol	Sulfate Aerosol
			Carbon Cycle	Carbon Cycle
			Dust / Sea Spray / Carbon Aerosols	Dust / Sea Spray / Carbon Aerosols
			Interactive Vegetation	Interactive Vegetation
			Biogeochemical Cycles	Biogeochemical Cycles
				Ice Sheet

Models Need to Resolve Convective Clouds

Modeling the Water Cycle

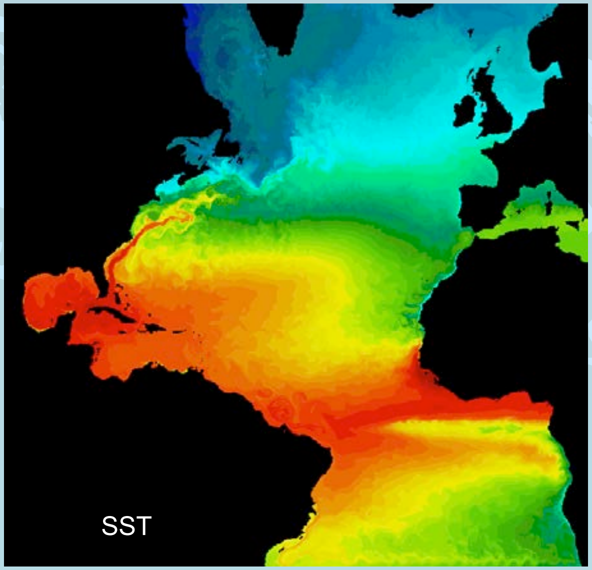


Global Simulation showing Tropical - Extratropical Interaction



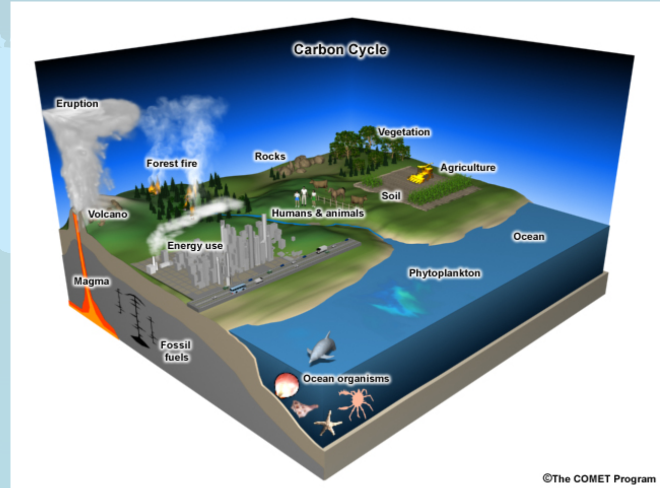
Water Vapor is shown in white and precipitation in orange.

Modeling Climate Change



Modeling climate change means modeling the ocean circulation.

Modeling the Carbon Cycle

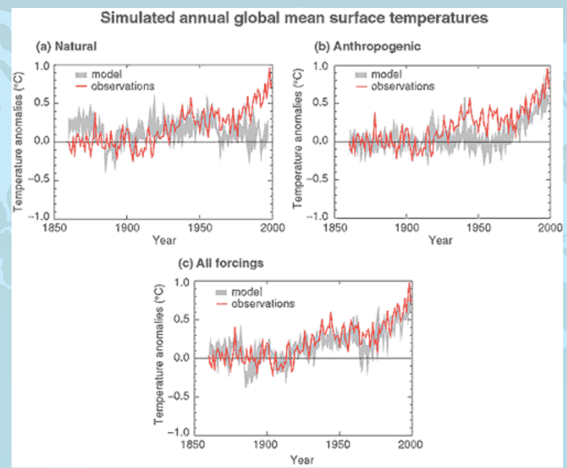


- Some man-made CO_2 goes (in the short-term) from the atmosphere to vegetation, ocean surface.
- Long term sink is deep ocean. It's very slow.

How Reliable are Climate Models?

- A common argument heard is "scientists can't even predict the weather next week - how can they predict the climate years from now". This betrays a misunderstanding of the difference between weather, which is chaotic and unpredictable, and climate which is weather averaged out over time.
- The major forcings that drive climate are well understood. In 1988, James Hansen projected future temperature trends (Hansen 1988). Those initial projections show good agreement with subsequent observations (Hansen 2006).

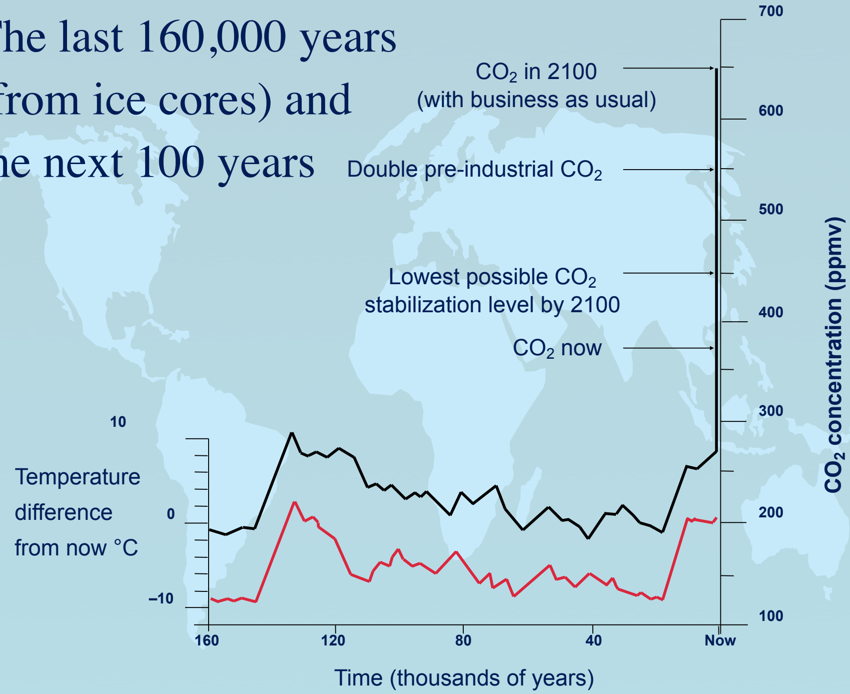
How Reliable are Climate Models?



Climate models are unable to duplicate the recent warming without taking GHG into account.

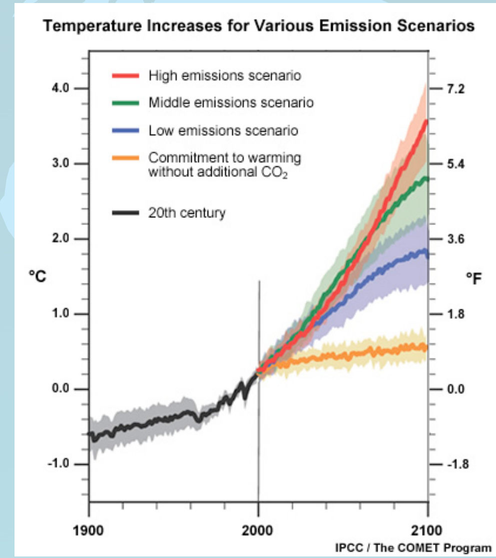
http://www.skepticalscience.com/climate-models-intermediate.htm

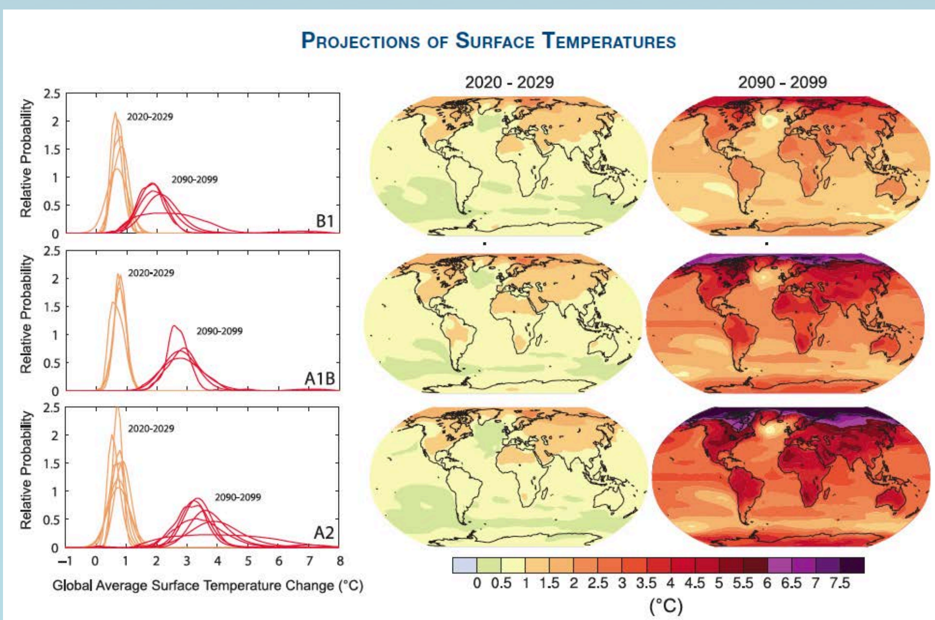
The last 160,000 years (from ice cores) and the next 100 years



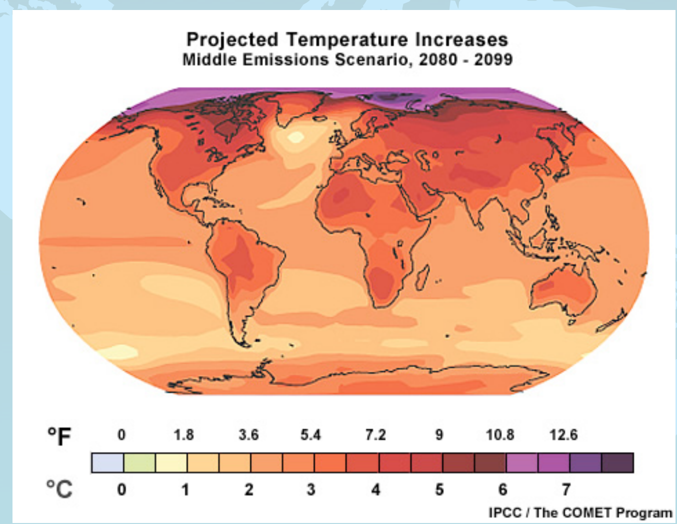
Future temperature trends for different responses to global warming

Variations of the Earth's surface temp., 1900 to 2100



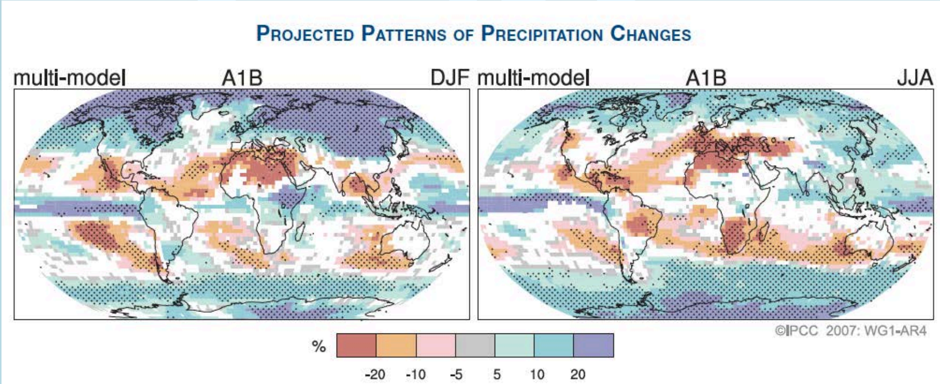


Future Temperature for Middle Emission Scenario



Surface Temperature – 2080 to 2099

More Rain for Some, Less for Others

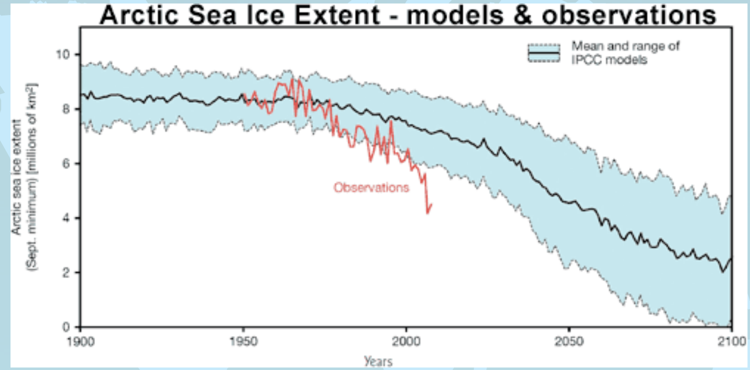


(2090s: medium emissions scenario; highest confidence in stippled areas)

Regional changes (+/-) of up to 20% in average rainfall.

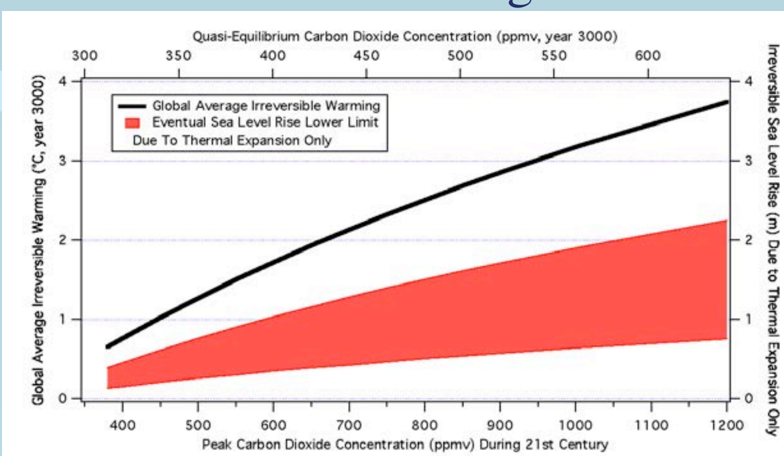
At mid to low latitudes, dry get drier, higher latitudes get wetter.

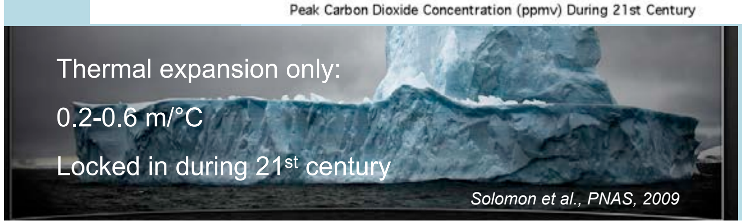
Sea-Ice Modeling



Most land areas and high latitudes will warm faster than the global average, resulting in melting and thinning of arctic ice sheets. Models have underestimated the pace of sea-ice loss.

Sea Level Rise: How High Will it Go?



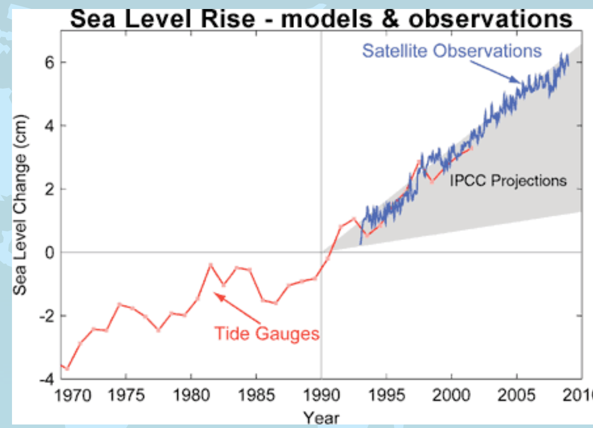


add glaciers

(0.3 - 1 m)

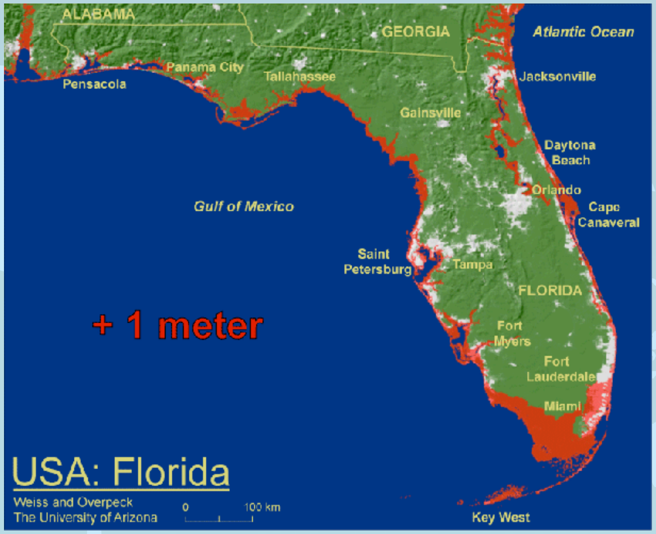
add ice sheets?

Modeling Sea Level Rise

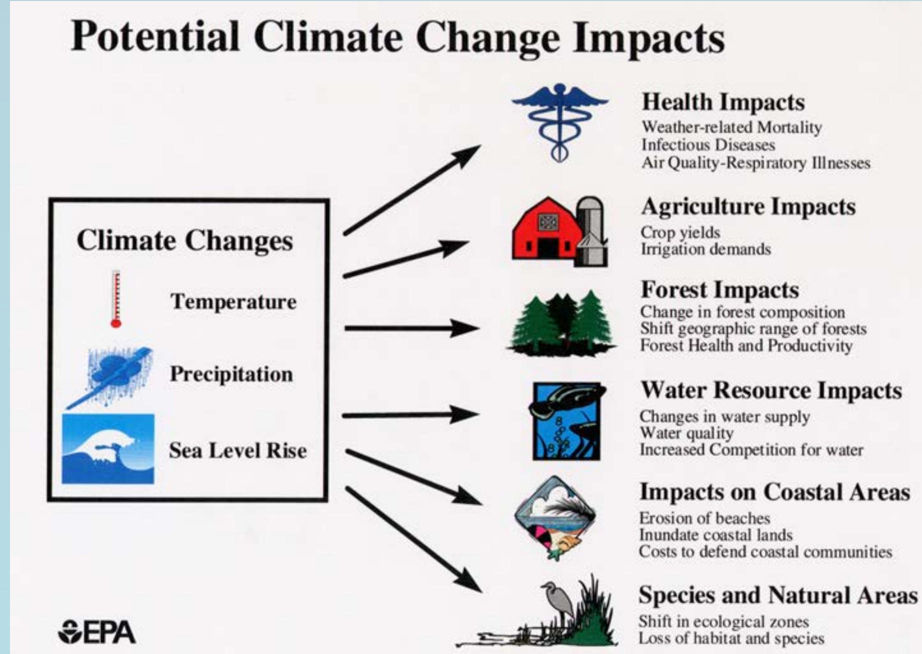


Thermal expansion of seas and melting of land ice expected to cause sea level rise of 0.3 to 1 m by 2100 depending on societies response to global warming. Current sea-level rise is at the upper range of earlier IPCC projections.

Sea-Level Rise



Should Greenland's Glaciers melt, it would result in a ~6 m or 20-ft rise in sea level.



Some Things I Hope You'll Remember About Climate Change

- Caused mainly by different long-lived gases produced by people via a well understood physical mechanism. CO_2 from fossil fuel burning is (by far) the main climate change agent.
- Abundant data for at least a century, carefully calibrated, show the changes in the industrial era.
- Temperatures are rising globally. There is local variability.
- Young people today will live in a world some 5-10°F warmer by the time they are old men and women, if emissions continue ramping.
- Rainfall changes with climate change would affect many people and ecosystems. Droughts like the dust bowl would be widespread.
- Climate changes from CO_2 emissions should be expected to last more than 1000 years (unless we find a 'miracle cure' to remove CO_2)
- Climate change challenges us to think beyond our own backyards.

Questions?