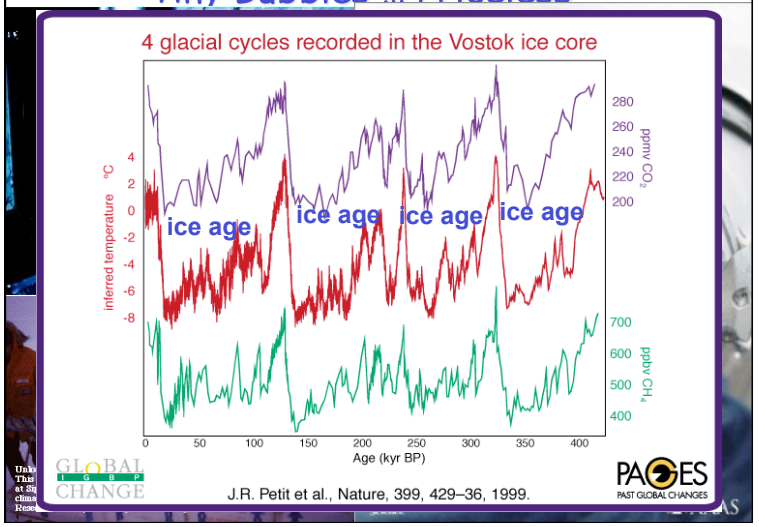
Modern Climate Change

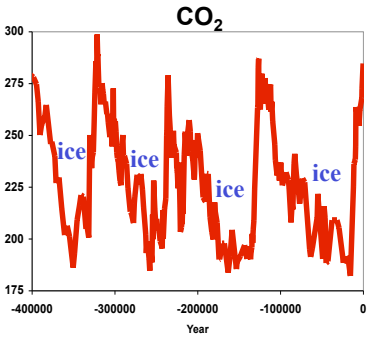
Climate change in the past
Climate predictability
Climate forcing
Climate models
Emission "scenarios" & climate of the 21st century
Responding to "Climate Skeptics"

Tiny Bubbles … Priceless



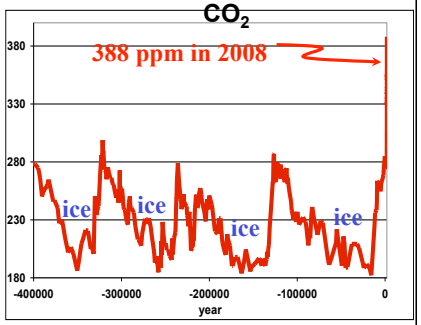
Paleo CO_2 and the Ice Ages

- Over the past 420,000 years atmospheric CO_2 has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles



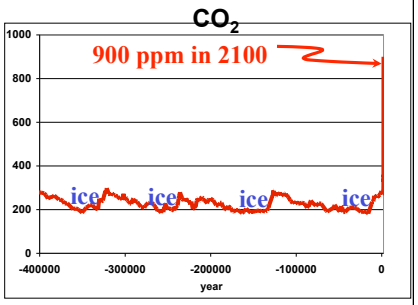
Paleo CO_2 and the Modern Age

- Over the past 420,000 years atmospheric CO_2 has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles
- Since the Industrial Revolution, CO_2 has risen very rapidly



Paleo CO_2 and the Future

- Over the past 420,000 years atmospheric CO_2 has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles
- Since the Industrial Revolution, CO_2 has risen very rapidly
- Atmospheric CO_2 is projected to rise to between 700 and 900 ppm in this Century



Climate vs. Weather

"Weather tells you what to wear today … climate tells you what clothes to buy!"

- Climate is an "envelope of possibilities" within which the weather bounces around
- Weather depends very sensitively on the evolution of the system from one moment to the next ("initial conditions")
- Climate is determined by the properties of the Earth system itself (the "boundary conditions")

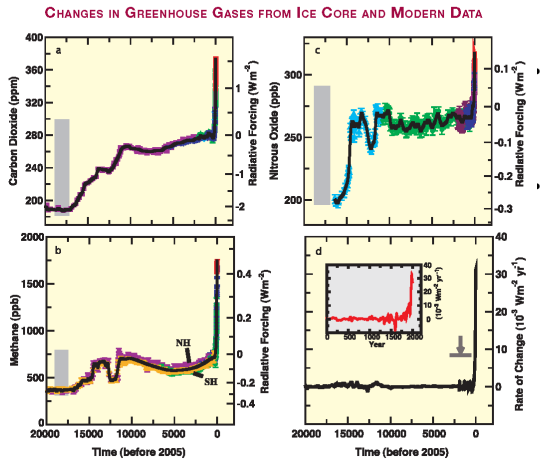
Climate Predictability

- Predicting the response of the climate to a change in the radiative forcing is *not* analogous to weather prediction
- If the change in forcing is large and predictable, the response can also be predictable
- I can't predict the weather in Fort Collins on December 18, 2008 (nobody can!)
- I can predict with 100% confidence that the average temperature in Fort Collins for December, 2008 will be warmer than the average for July!

Climate Forcing

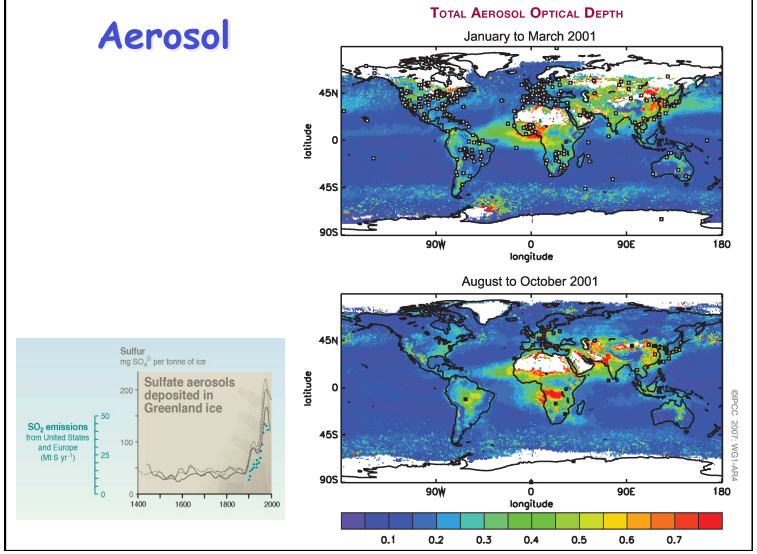
- Changes in climate often reflect changes in forcing, as amplified or damped by climate feedbacks
  - Diurnal cycle
  - Seasonal cycle
  - Ice ages
  - Response to volcanic aerosol
  - Solar variability
  - Greenhouse forcing
- If forcing is sufficiently strong, and the forcing itself is predictable, then the response of the climate can be predictable too!

Greehouse Radiative Forcing

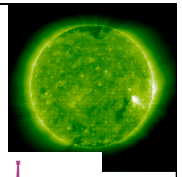


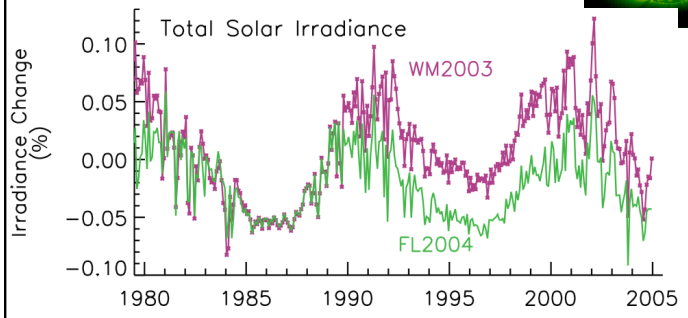
- Note different scales
- Modern changes
- comparable to
- postglacial, but much faster!

Aerosol



Our Variable Star





- Changes of ~ 0.2% (= 2.7 W m-2) reflect 11-year sunspot cycle

BOOM!

- Volcanos release huge amounts of SO2 gas and heat
- SO2 oxidizes to SO4 aerosol and penetrates to stratosphere
- SO4 aerosol interacts with solar radiation

Mt. Pinatubo, 1991

Stratospheric Aerosol Forcing

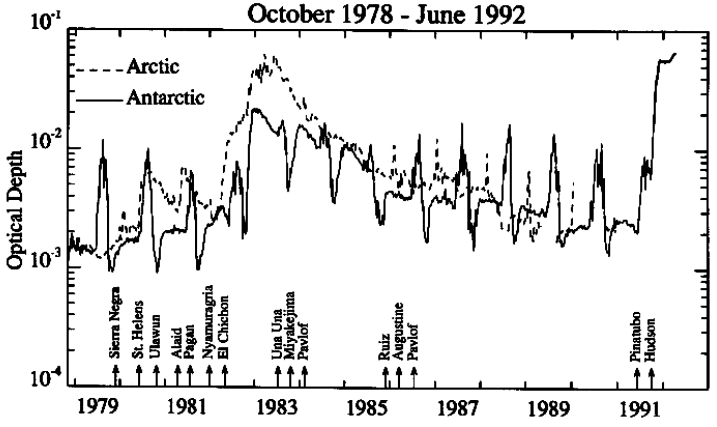
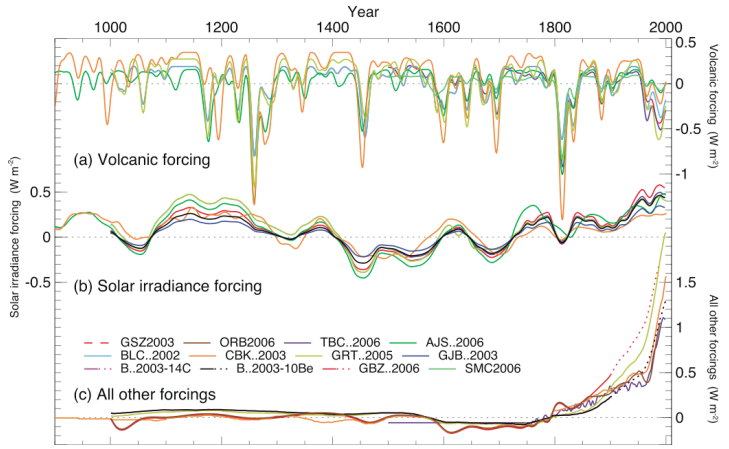
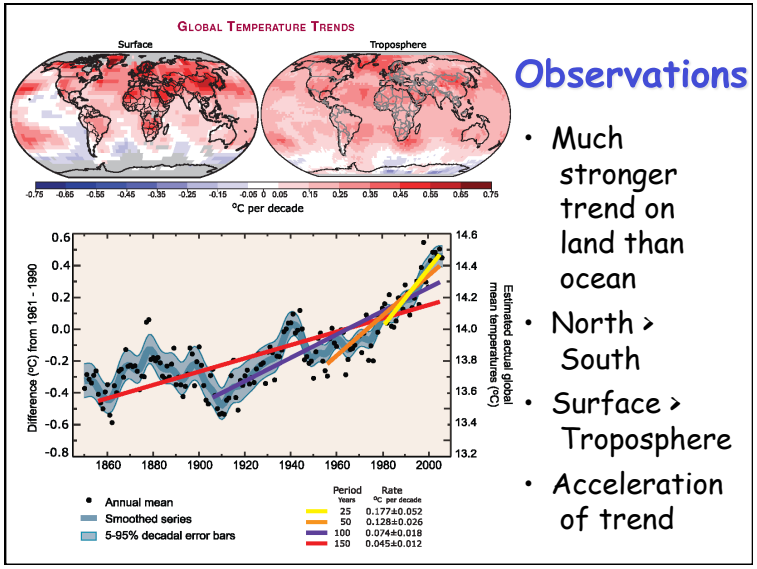


Fig. 11.5 Polar stratospheric optical depth versus time derived from SAM II and SAGE solar extinction measurements. Superimposed on the normal seasonal variations are major injections of aerosols associated with the El Chichón and Mt. Pinatubo eruptions. [From McCormick, *et al.* (1993).]

Reconstructed Radiative Forcings

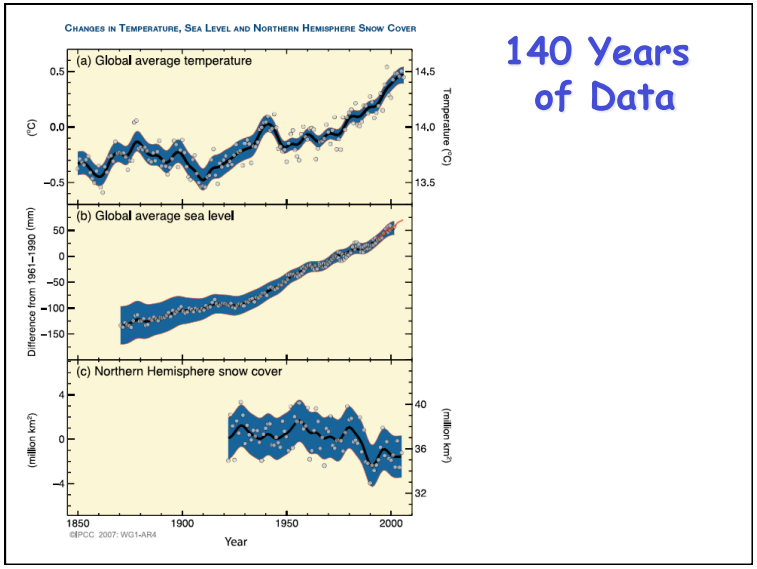


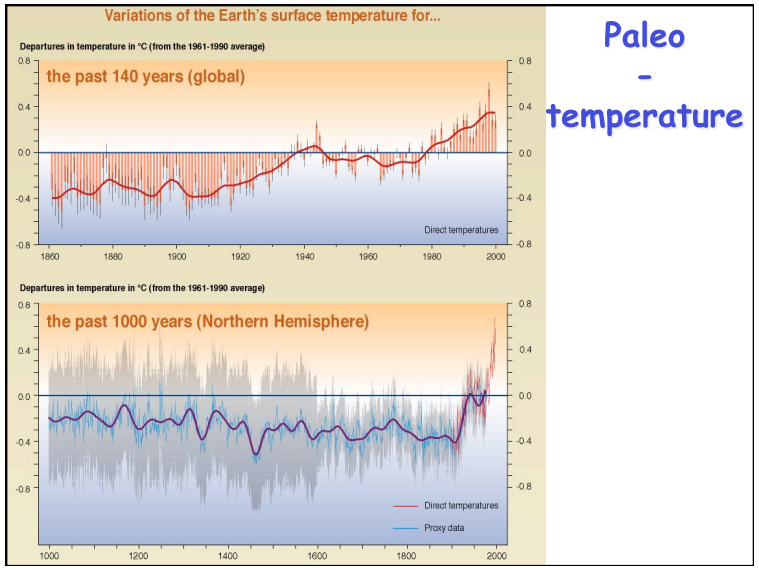
Observations



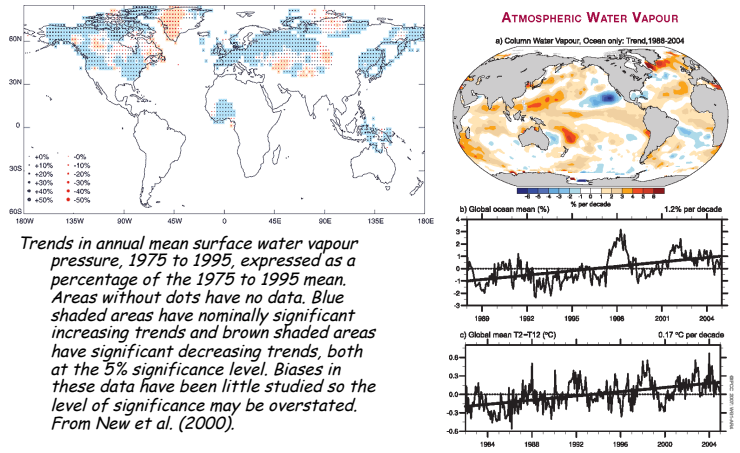
- Much stronger trend on land than ocean
- North > South
- Surface > Troposphere
- Acceleration of trend

140 Years of Data



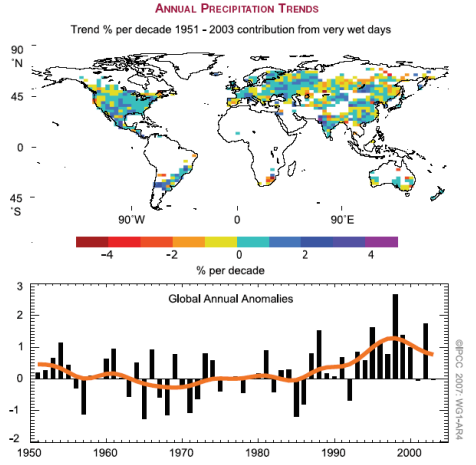


Water Vapor Trends

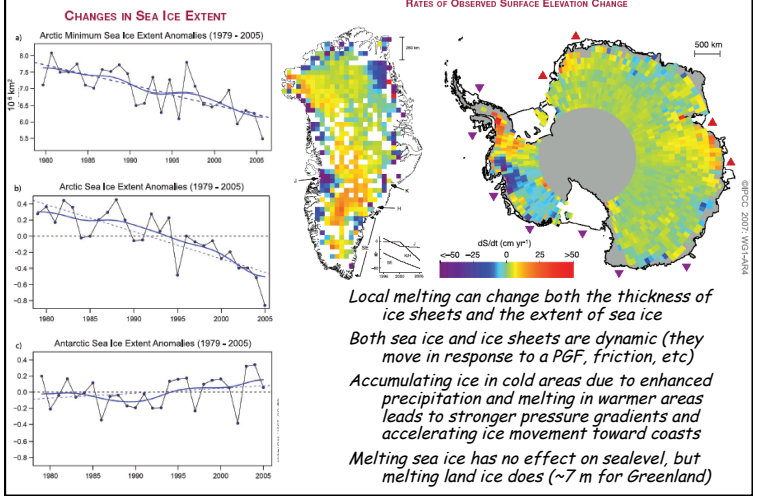


Trends in annual mean surface water vapour pressure, 1975 to 1995, expressed as a percentage of the 1975 to 1995 mean. Areas without dots have no data. Blue shaded areas have nominally significant increasing trends and brown shaded areas have significant decreasing trends, both at the 5% significance level. Biases in these data have been little studied so the level of significance may be overstated. From New et al. (2000).

Accelerating Hydrologic Cycle



Cryospheric Change



Local melting can change both the thickness of ice sheets and the extent of sea ice

Both sea ice and ice sheets are dynamic (they move in response to a PGF, friction, etc)

Accumulating ice in cold areas due to enhanced precipitation and melting in warmer areas leads to stronger pressure gradients and accelerating ice movement toward coasts

Melting sea ice has no effect on sealevel, but melting land ice does (~7 m for Greenland)

Historical Sealevel Changes

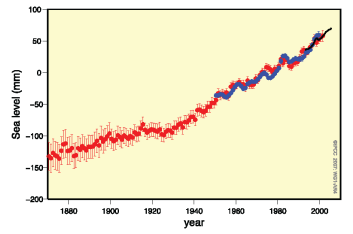


Figure TS.18. *Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals. (Figure 5.13)*

Sources of Sea Level Rise	Sea Level Rise (mm yr⁻¹) 1961–2003 Observed	1961–2003 Modelled	1993–2003 Observed	1993–2003 Modelled
Thermal expansion	0.42 ± 0.12	0.5 ± 0.2	1.6 ± 0.5	1.5 ± 0.7
Glaciers and ice caps	0.50 ± 0.18	0.5 ± 0.2	0.77 ± 0.22	0.7 ± 0.3
Greenland Ice Sheet	0.05 ± 0.12[a]		0.21 ± 0.07[a]	
Antarctic Ice Sheet	0.14 ± 0.41[a]		0.21 ± 0.35[a]	
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	1.2 ± 0.5	2.8 ± 0.7	2.6 ± 0.8
Observed total sea level rise	1.8 ± 0.5 (tide gauges)		3.1 ± 0.7 (satellite altimeter)	
Difference (Observed total minus the sum of observed climate contributions)	0.7 ± 0.7		0.3 ± 1.0	

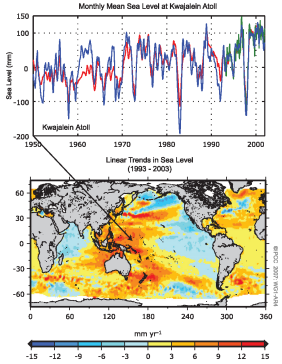
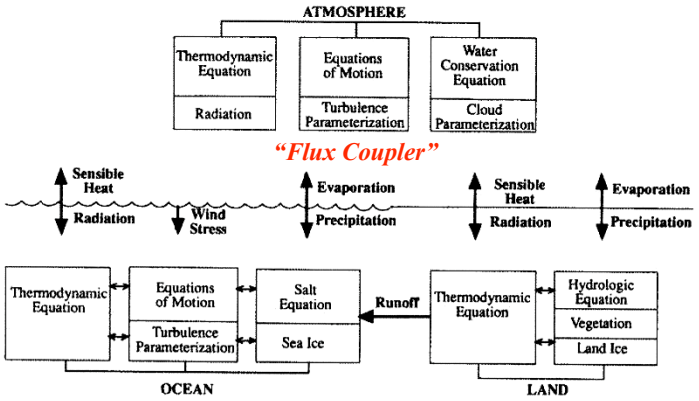
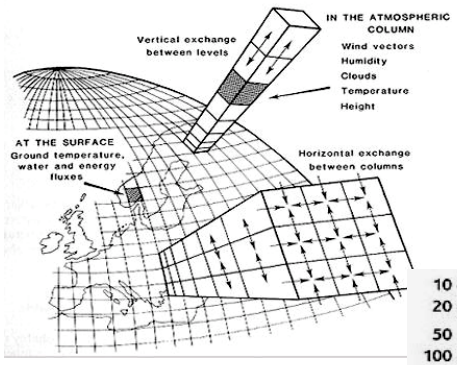


Figure TS.19. *(Top) Monthly mean sea level (mm) curve for 1950 to 2000 at Kwajalein (8°44'N, 167°44'E). The observed sea level (from tide gauge measurements) is in blue, the reconstructed sea level in red and the satellite altimetry record in green. Annual and semiannual signals have been removed from each time series and the tide gauge data have been smoothed. (Bottom) Geographic distribution of short-term linear trends in mean sea level for 1993 to 2003 (mm yr⁻¹) based on TOPEX/Poseidon satellite altimetry. (Figures 5.15 and 5.18)*

Climate Model Structure

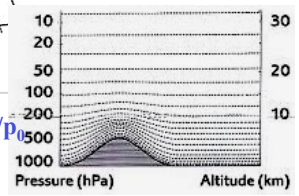


Climate Model Grids



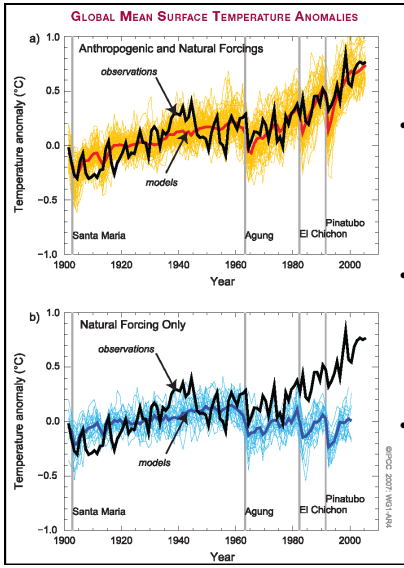
Typical climate model
$\Delta x \sim 200$ km

Typical NWP model
$\Delta x \sim 40$ km



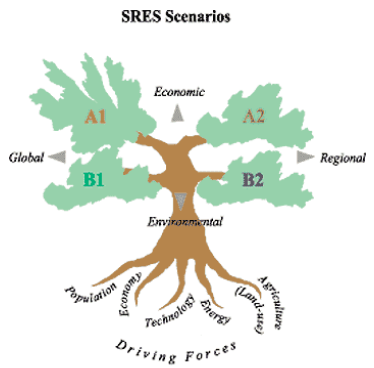
Normalized pressure coordinate $\sigma = p/p_0$
(terrain following, "stretched")

20th-Century Temperatures



- Black lines show obs, yellow lines show each model, red line shows model mean T_{sfc}
- With all forcings, models capture much of historical record
- Bottom panels: models do not include greenhouse emissions

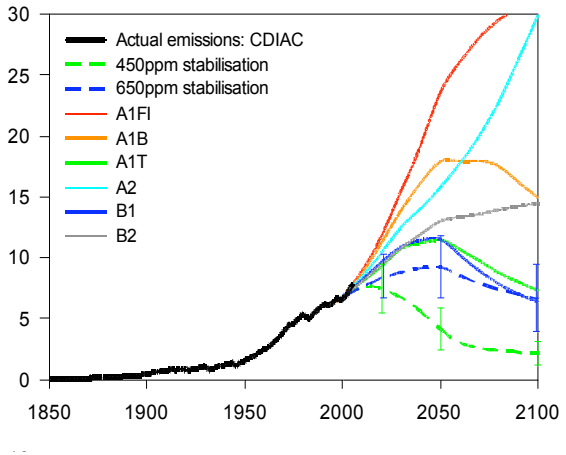
Emission Scenarios



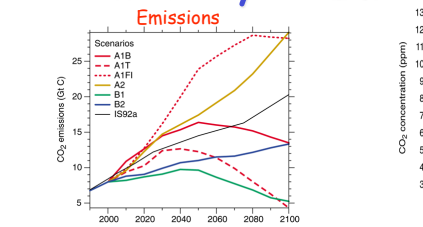
- **A1**: Globalized, with very rapid economic growth, low population growth, rapid introduction of more efficient technologies.
- **A2**: very heterogeneous world, with self -reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in high population growth. Economic development is regionally oriented and per capita economic growth & technology more fragmented, slower than other storylines.
- **B1**: convergent world with the same low population growth as in A1, but with rapid changes in economic structures toward a service and information economy, reductions in material intensity, introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, without additional climate initiatives.
- **B2**: local solutions to economic, social, and environmental sustainability. Moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1.

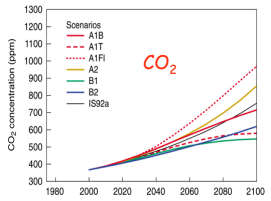
Each "storyline" used to generate 10 different scenarios of population, technological & economic development

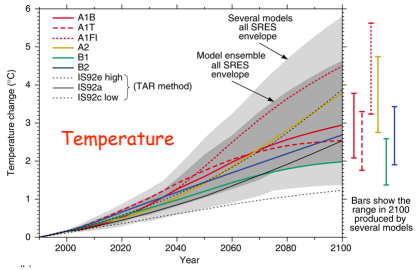
Emission Scenarios



Sensitivity to Emission Scenarios







- Uncertainty about human decisions is a major driver of uncertainty in climate change
- Model ensemble simulated warming ranges ~ 2.5° K in 2100

Sealevels and Emission Scenarios

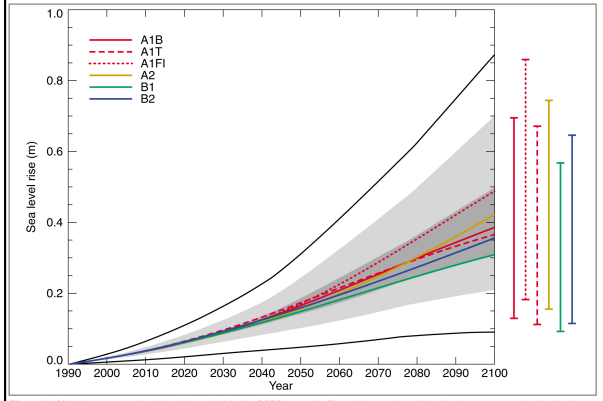
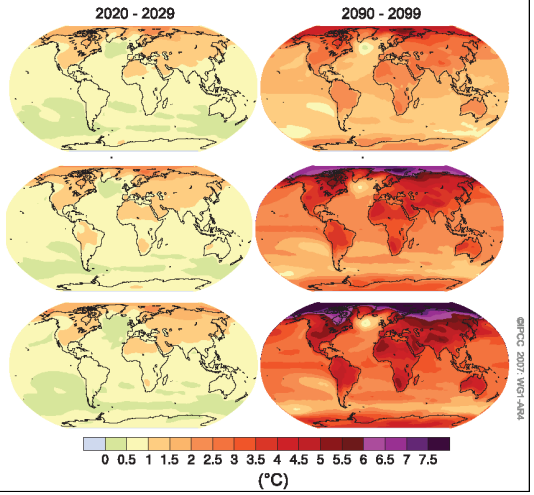
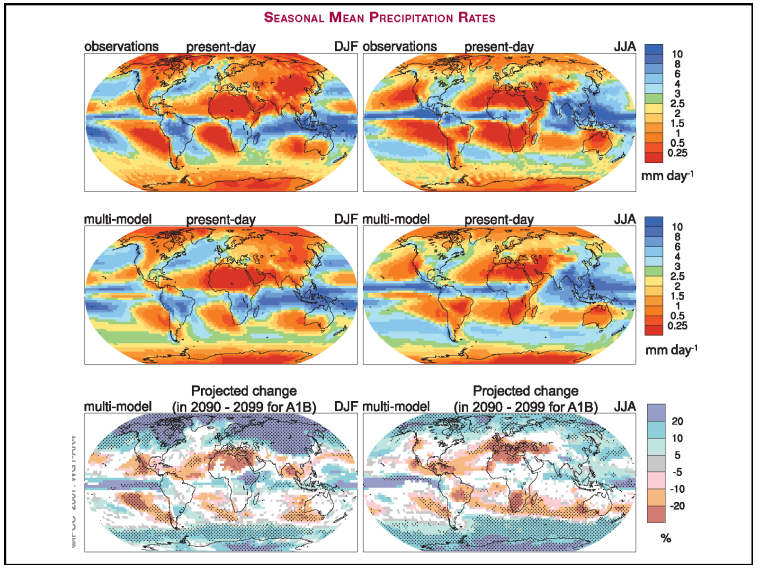


Figure 24: Global average sea level rise 1990 to 2100 for the SRES scenarios. Thermal expansion and land ice changes were calculated using a simple climate model calibrated separately for each of seven AOGCMs, and contributions from changes in permafrost, the effect of sediment deposition and the long-term adjustment of the ice sheets to past climate change were added. Each of the six lines appearing in the key is the average of AOGCMs for one of the six illustrative scenarios. The region in dark shading shows the range of the average of AOGCMs for all thirty five SRES scenarios. The region in light shading shows the range of all AOGCMs for all thirty five scenarios. The region delimited by the outermost lines shows the range of all AOGCMs and scenarios including uncertainty in land-ice changes, permafrost changes and sediment deposition. Note that this range does not allow for uncertainty relating to ice-dynamic changes in the West Antarctic ice sheet. [Based on Figure 11.12]

Global Projections of Sfc Temp

- Land vs ocean!
- North vs South





Climate Skeptics

- Observed warming in the past is caused by something else
  - Natural cycles (e.g., recovery from Little Ice Age)
  - Changes in the sun
  - Volcanos
  - Etc
- Climate system is too complicated to be predicted, and climate models are too simplistic to represent real physics

Responding to Skeptics

- Observed warming not caused by humans:
  - There hasn't been much warming yet, because CO_2 hasn't increased very much (about 30%)
  - Does that mean that there won't be warming when CO_2 increases by 300%?
- Models are insufficiently complicated:
  - Predictions of warming don't require complicated models, just simple physics
  - Predicting that climate will not change if we double or triple CO_2 requires some kind of huge offsetting forcing ("follow the energy")
  - Complicated models don't show any such thing
  - Observations seem to favor the simple solution