Climate Change and Global Warming

Debunking Common Misconceptions
Climate predictability
Climate forcing
Climate models
Emission "scenarios" & climate of the 21st century
Responding to "Climate Skeptics"

Media Myths about Climate

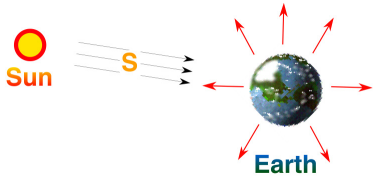
Be skeptical … be very skeptical !

- Concern about global warming is based on recent temperature trends
  - "9 of the 10 hottest years on record …"
  - If somebody could find some other cause for recent warming, we could quit worrying
- Global warming is a theory based on complicated computer models
- CO_2 is "air pollution" … cutting emissions will lead to falling CO_2 and therefore cooling
- If we stop burning coal, we'll freeze in the dark!

Global Warming is Based on Common Sense

not computer models …
not recent temperatures …
not complicated!

Planetary Energy Balance



Energy In = Energy Out

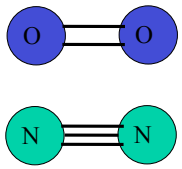
$$S(1-\alpha)\pi R^2 = 4\pi R^2 \sigma T^4$$

$$T \approx -18^{\circ}\mathrm{C}$$

But the observed T_s is about 15° C

Dancing Molecules and Heat Rays!

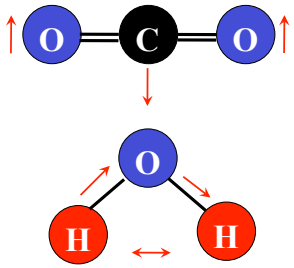
- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which two atoms of the same element share electrons
- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well



Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

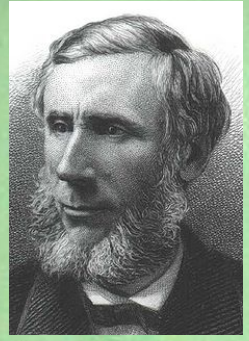
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



Molecules that have many ways to wiggle are called "Greenhouse" molecules

Absorption spectrum of CO2 was measured by John Tyndall in 1863

Common Sense

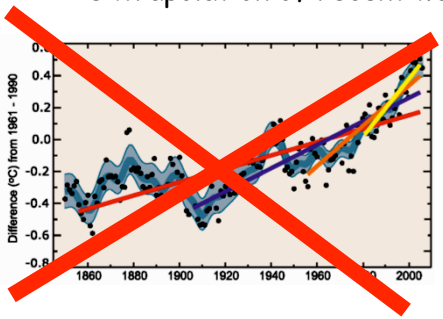


John Tyndall, January 1863

- Doubling CO_2 would add 4 watts to every square meter of the surface of the Earth, 24/7
- Doing that would make the surface warmer
- This was known before light bulbs were invented!

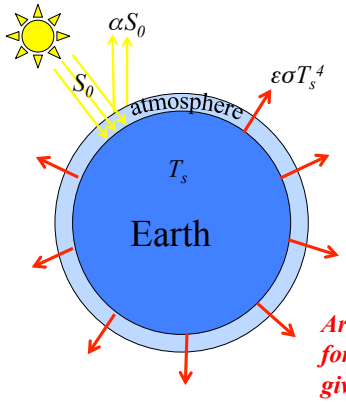
Common Misconception #1

"Expectations of future warming are based on extrapolation of recent warming trends"



WRONG! They are based on the idea that when we add energy to the surface, it will warm up

19th Century Climate Physics (Svante Arrhenius, 1897)



$$S_0(1-\alpha)\pi r^2 = \varepsilon\sigma T_S^4 (4\pi r^2)$$

$$S_0(1-\alpha) = 4\varepsilon\sigma T_S^4$$

Differentiate, apply chain rule

$$0 = 4\Delta\varepsilon\sigma T_S^4 + 4\varepsilon(4\sigma T_S^4)$$

$$\Delta T_S = -\frac{T_S}{4}\frac{\Delta\varepsilon}{\varepsilon}$$

Arrhenius worked out a simple formula for the change in surface temperature given a change in effective atmospheric emissivity due to CO_2

19th Century Climate Physics (cont'd)

$$\Delta T_S = -\frac{T_S}{4}\frac{\Delta\varepsilon}{\varepsilon}$$

Plug in measured values

$\varepsilon\sigma T_S^4 = 240$ W m^{-2} (from satellite data)

$(\Delta\varepsilon)(\sigma T_S^4) = -4$ W m^{-2} (for 2 x CO_2 from radiative transfer)

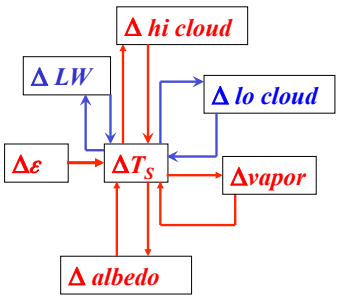
$$\frac{\Delta\varepsilon}{\varepsilon} = -\frac{4}{240}$$

$T_s = 288$ K

$$\Delta T_S = -\frac{288K}{4}\left(-\frac{4}{240}\right) = 1.2K$$

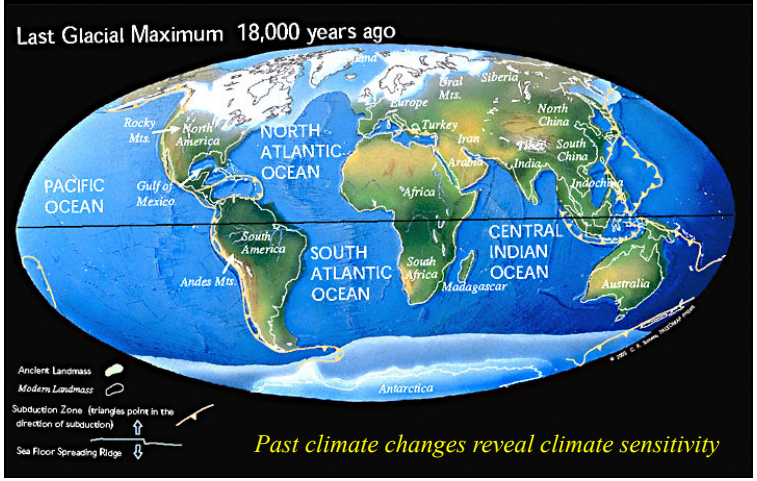
For CO_2 alone (no feedback), expect about 2 °F warming for 2 x CO_2

Climate Feedback Processes



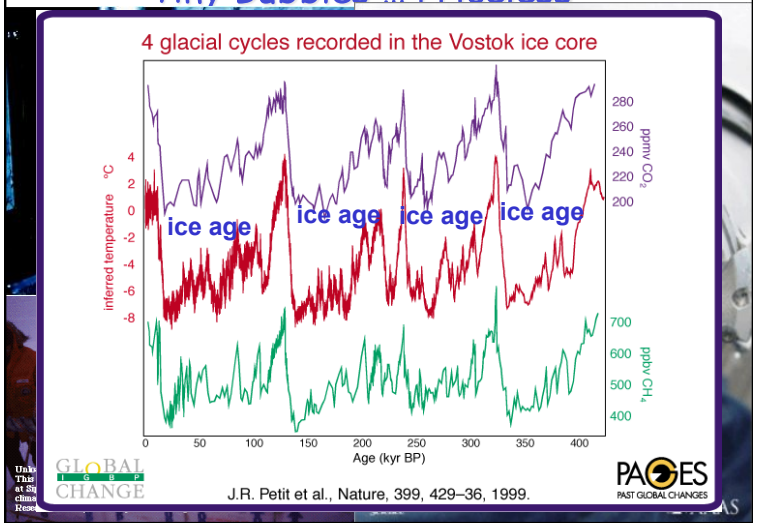
- Positive Feedbacks (amplify changes)
  - Water vapor
  - Ice-albedo
  - High clouds
- Negative feedbacks (damp changes)
  - Longwave cooling
  - Low clouds

Learning from the Past



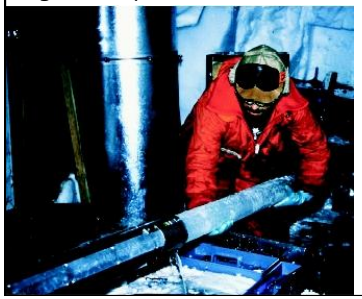
Past climate changes reveal climate sensitivity

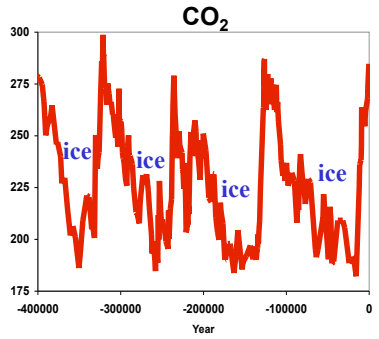
Tiny Bubbles … Priceless



CO_2 and the Ice Ages

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





Estimating Total Climate Sensitivity

- At the Last Glacial Maximum (~ 18k years ago) surface temp ~ 6 °C colder
- CO_2 was ~ 180 ppm (weaker greenhouse, 4.1 W m^{-2} more LW↑)
- Brighter surface due to snow and ice, estimate 3.4 W m^{-2} more reflected solar ↑

$$\lambda = \frac{\Delta T_S}{\Delta F} = \frac{T_S(now) - T_S(then)}{F(now) - F(then)}$$

$$= \frac{6K}{(4.1 + 3.4) Wm^{-2}} = 0.8 \frac{K}{Wm^{-2}}$$

Or, for doubling of CO_2: expect 4 x 0.8 = 3.2 °C of warming

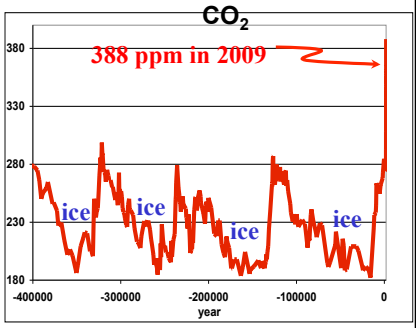
Review: 19th Century Physics (updated using paleo-data)

- **Forcing:** changes in properties of atmosphere as measured by spectroscopy (4 W m^{-2} per doubling of CO_2)
- **Feedback:** both positive and negative, total response to forcing estimated from Ice Age climate data (about 0.8 °C per W m^{-2})
- **Response:** about 3.2 °C warming for 2 x CO_2

No climate models required … just based on observations (modern calculations agree … coincidence?)

CO_2 and the Modern Age

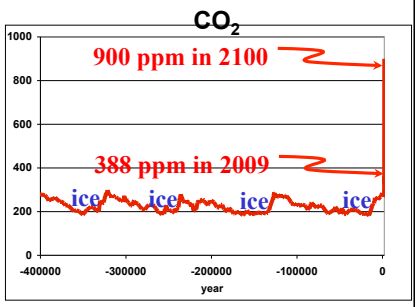
- Over the past 420,000 years atmospheric CO_2 has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles
- Since the Industrial Revolution, CO_2 has risen very rapidly



from measurements

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
- If China & India develop using 19th Century technology, CO_2 will reach 900 ppm in this century



You ain't seen nothing yet!

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")

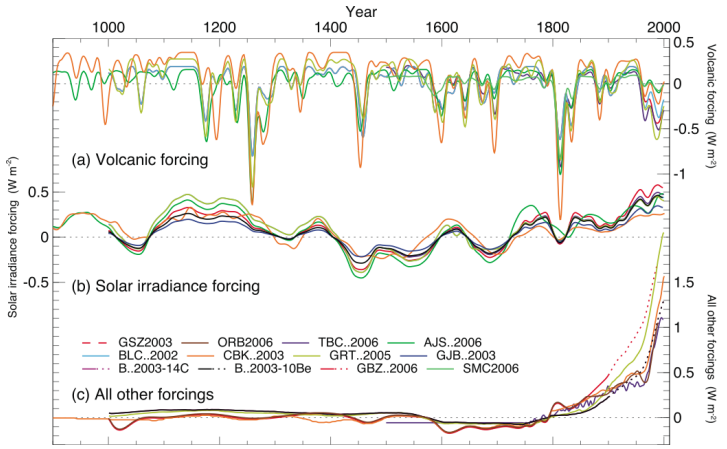
Climate Predictability

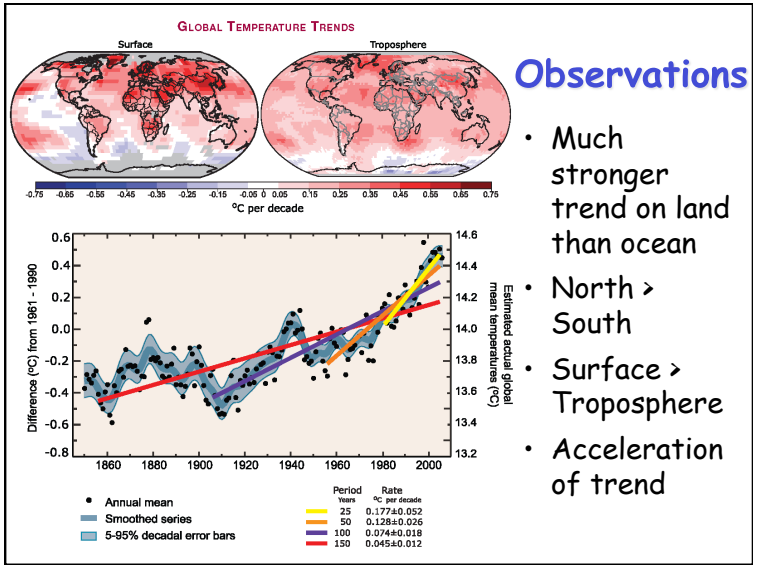
- Predicting the response of the climate to a change in the radiative forcing is *not* analogous to weather prediction
- If the change in forcing is large and predictable, the response can also be predictable
- I can't predict the weather in Fort Collins on December 18, 2009 (nobody can!)
- I can predict with 100% confidence that the average temperature in Fort Collins for December, 2009 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!

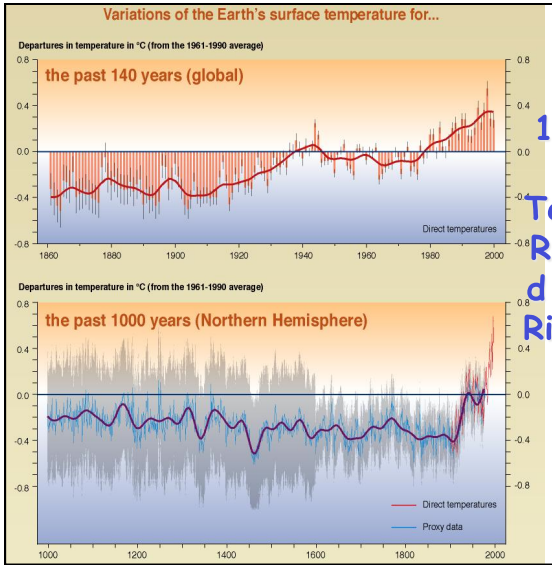
Reconstructed Radiative Forcings





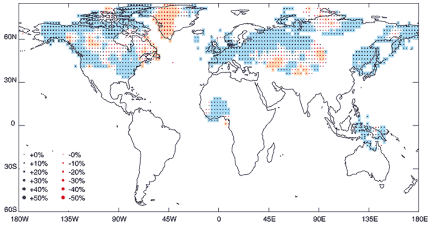
Observations

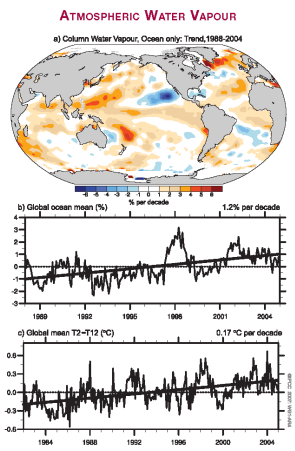
- Much stronger trend on land than ocean
- North > South
- Surface > Troposphere
- Acceleration of trend



1000 Years of Temperature Reconstructed from Tree Rings, Pollen, etc

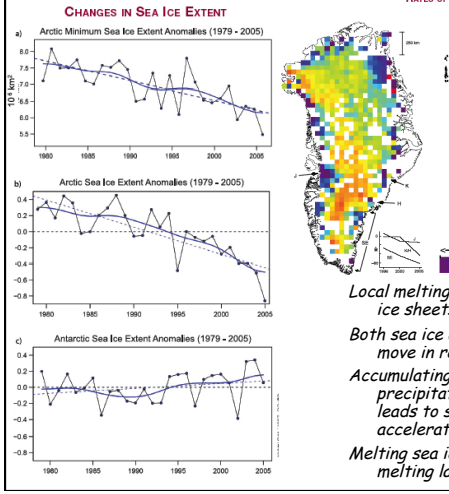
Water Vapor Trends

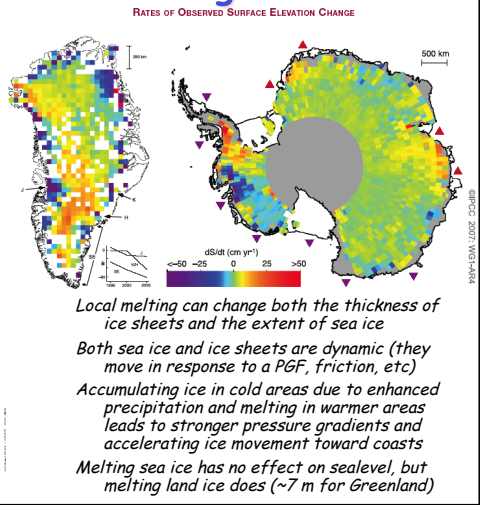




Trends in annual mean surface water vapour pressure, 1975 to 1995, expressed as a percentage of the 1975 to 1995 mean. Areas without dots have no data. Blue shaded areas have nominally significant increasing trends and brown shaded areas have significant decreasing trends, both at the 5% significance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

Ice Sheet Changes





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)