

Modern Climate Change

Debunking Common Misconceptions

Climate predictability

Climate forcing

Climate models

Emission "scenarios" & climate of the 21st century

Responding to "Climate Skeptics"

Media Myths about Climate

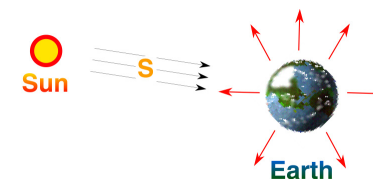
Be skeptical ... be very skeptical !

- 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
- CO₂ is "air pollution" ... cutting emissions will lead to falling CO₂ 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

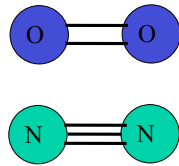
$$S(1-\alpha)\pi R^2 = 4\pi R^2\sigma T^4$$

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

But the observed T_s is about 15°C

Dancing Molecules and Heat Rays!

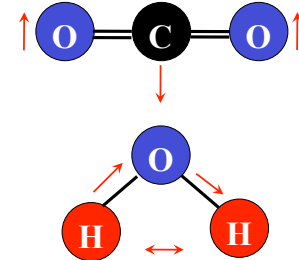
- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which **two atoms of the same element** share electrons
- Infrared (heat) **energy radiated up from the surface can be absorbed** by these molecules, but not very well



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

Dancing Molecules and Heat Rays!

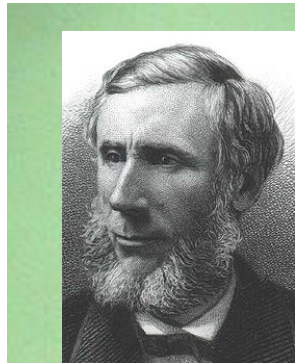
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have **many more ways to vibrate** and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



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

Absorption spectrum of CO₂ was measured by John Tyndall in 1863

Common Sense

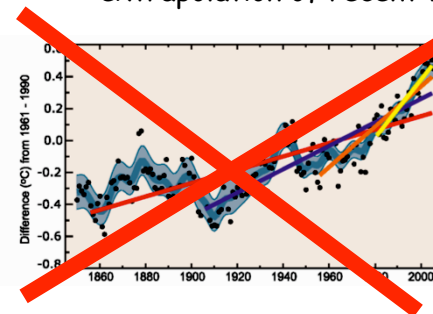


John Tyndall, January 1863

- 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)

$S_0(1 - \alpha)\pi r^2 = \epsilon\sigma T_s^4(4\pi r^2)$
 $S_0(1 - \alpha) = 4\epsilon\sigma T_s^4$

Differentiate, apply chain rule
 $0 = 4\Delta\epsilon\sigma T_s^4 + 4\epsilon(4\sigma T_s^3)\Delta T_s$

$$\Delta T_s = -\frac{T_s}{4} \frac{\Delta\epsilon}{\epsilon}$$

Arrhenius worked out a simple formula for the change in surface temperature given a change in effective atmospheric emissivity due to CO₂

19th Century Climate Physics (cont'd)

$$\Delta T_s = -\frac{T_s}{4} \frac{\Delta\epsilon}{\epsilon}$$

Plug in measured values

$\epsilon\sigma T_s^4 = 240 \text{ W m}^{-2}$
(from satellite data)

$(\Delta\epsilon)(\sigma T_s^4) = -4 \text{ W m}^{-2}$
(for 2 x CO₂ from radiative transfer)

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

$$T_s = 288 \text{ K}$$

→

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

For CO₂ alone (no feedback), expect about 2 °F warming for 2 x CO₂

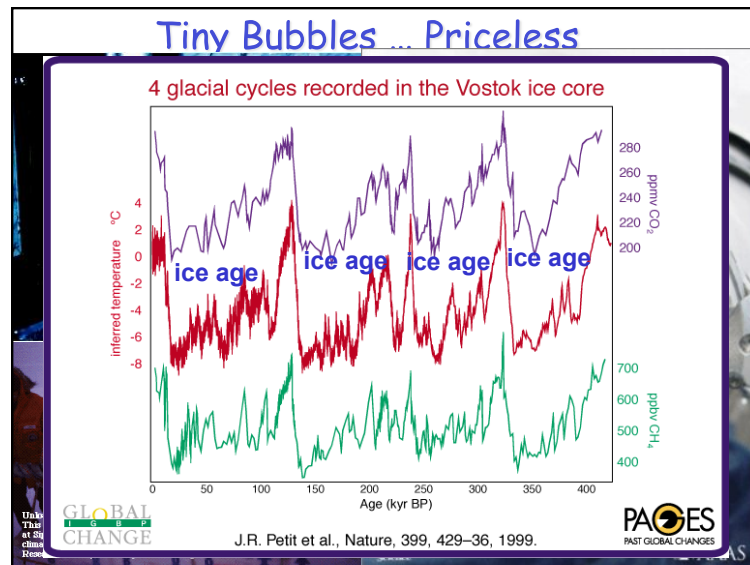
Climate Feedback Processes

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

Learning from the Past

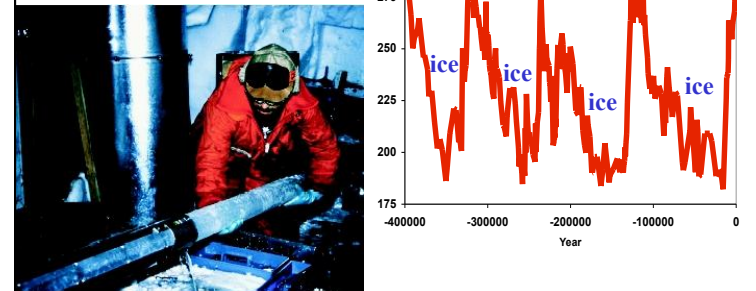
Last Glacial Maximum 18,000 years ago

Past climate changes reveal climate sensitivity



CO₂ and the Ice Ages

- Over the past 420,000 years atmospheric CO₂ 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
- CO₂ 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 ↑

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

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

Or, for doubling of CO₂: expect 4 x 0.8 = 3.2 °C of warming

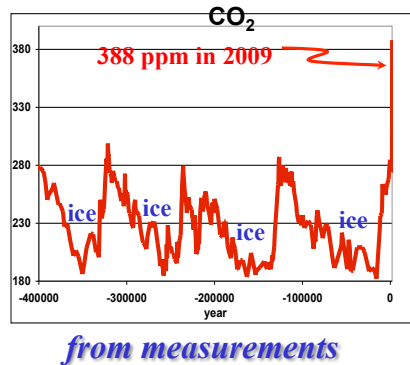
Review: 19th Century Physics (updated using paleo-data)

- Forcing:** changes in properties of atmosphere as measured by spectroscopy (4 W m⁻² per doubling of CO₂)
- 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 CO₂

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

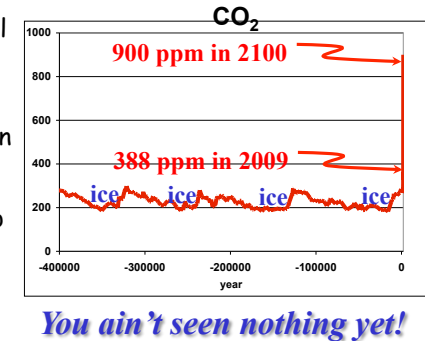
CO₂ and the Modern Age

- Over the past 420,000 years atmospheric CO₂ has varied **between 180 and 280** parts per million, beating in time with the last four glacial cycles
- Since the **Industrial Revolution**, CO₂ has risen very rapidly



CO₂ and the Future

- Over the past 420,000 years atmospheric CO₂ has varied **between 180 and 280** parts per million, beating in time with the last four glacial cycles
- Since the **Industrial Revolution**, CO₂ has risen very rapidly
- If China & India develop using 19th Century technology, CO₂ will reach **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

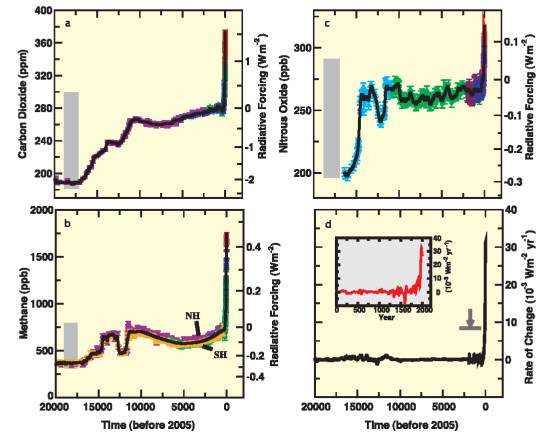
- Predicting the response of the climate to a change in the radiative forcing is **not analogous to weather prediction**
- If the **change in forcing** is large and predictable, the **response** can also be predictable
- I **can't predict the weather** in Fort Collins on December 18, 2009 (nobody can!)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

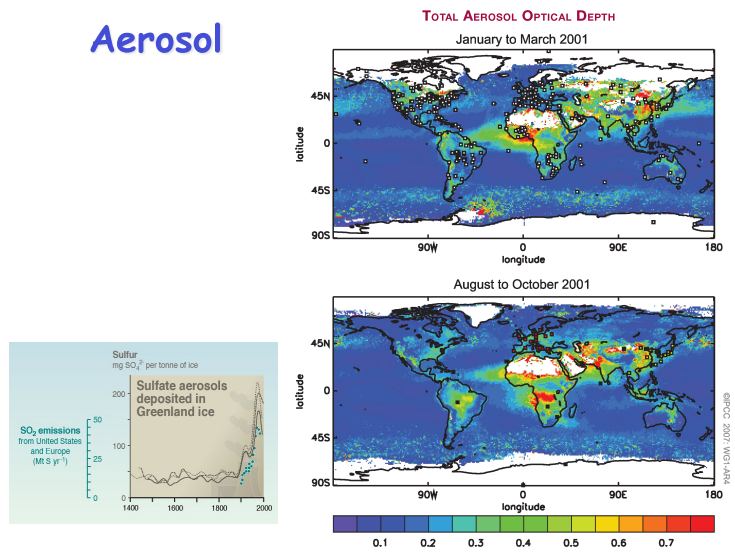
Greenhouse Radiative Forcing

CHANGES IN GREENHOUSE GASES FROM ICE CORE AND MODERN DATA

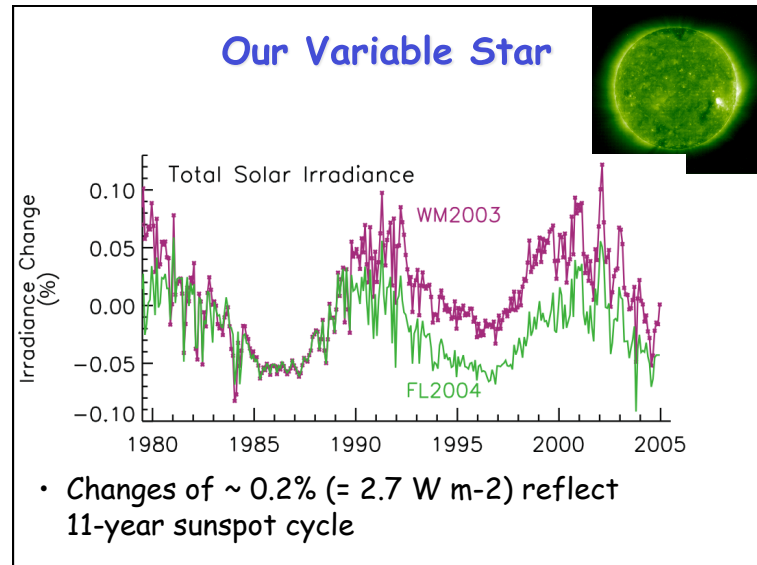


Note different scales
 Modern changes comparable to postglacial, but much faster!

Aerosol



Our Variable Star

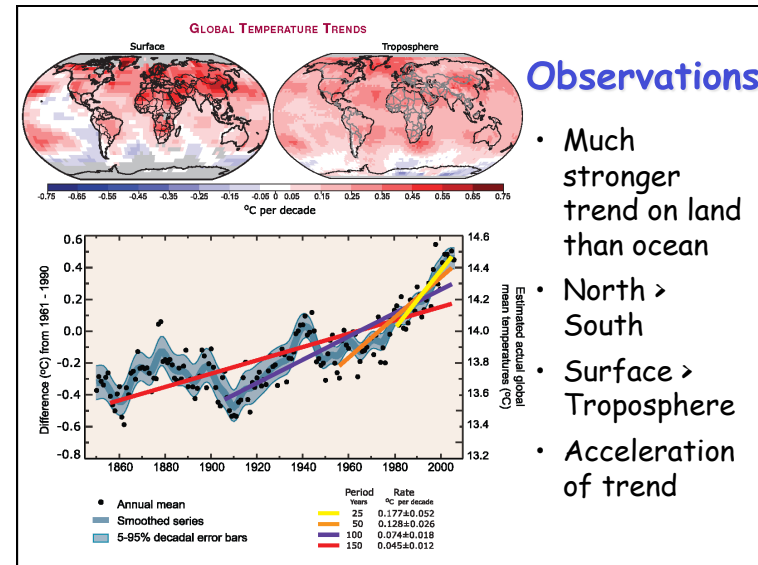
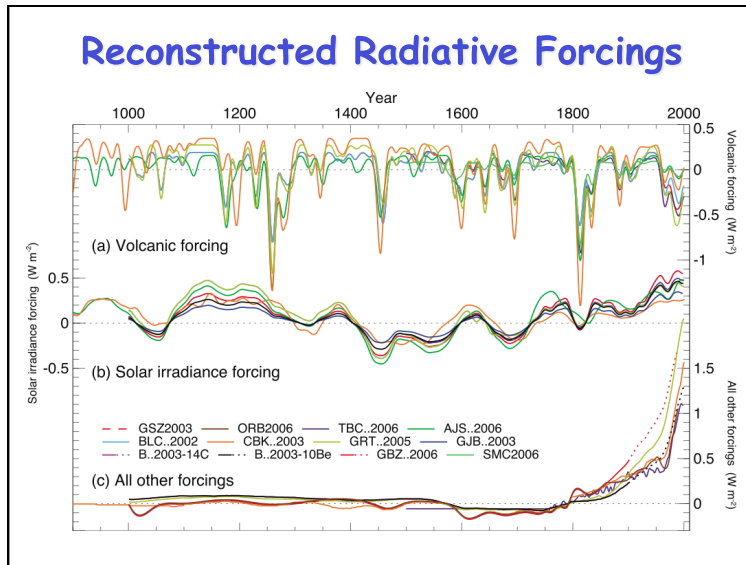
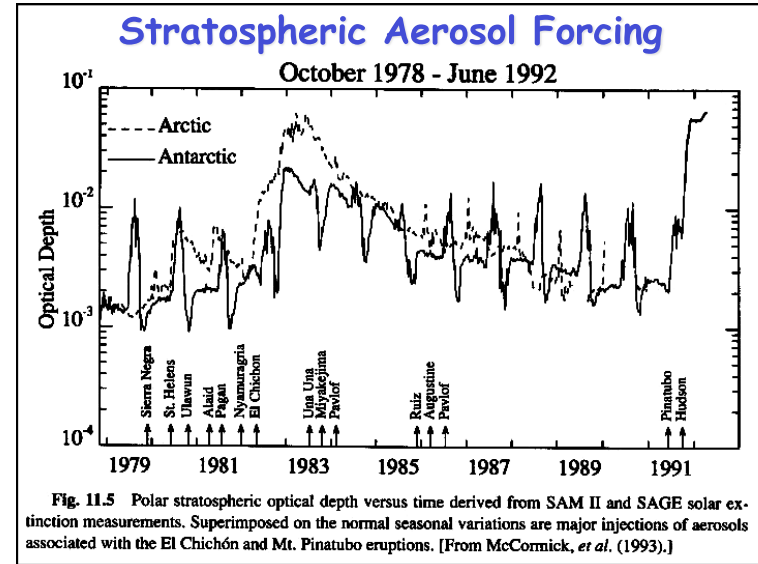


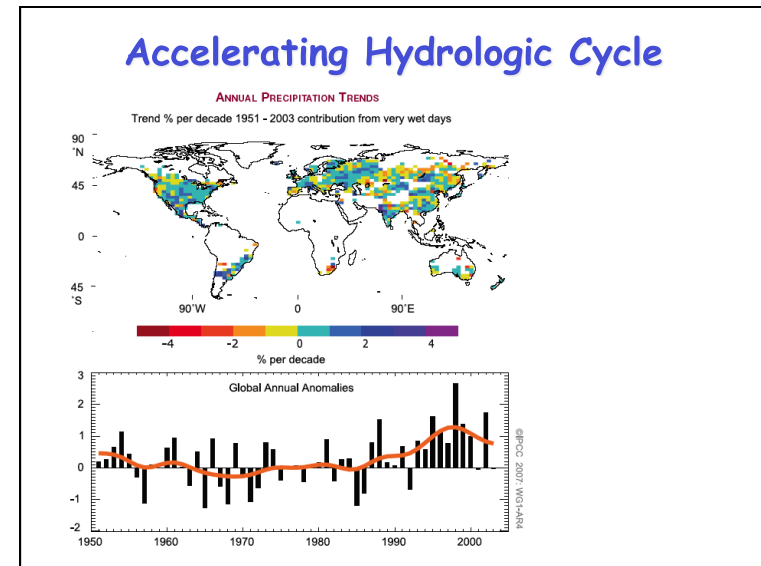
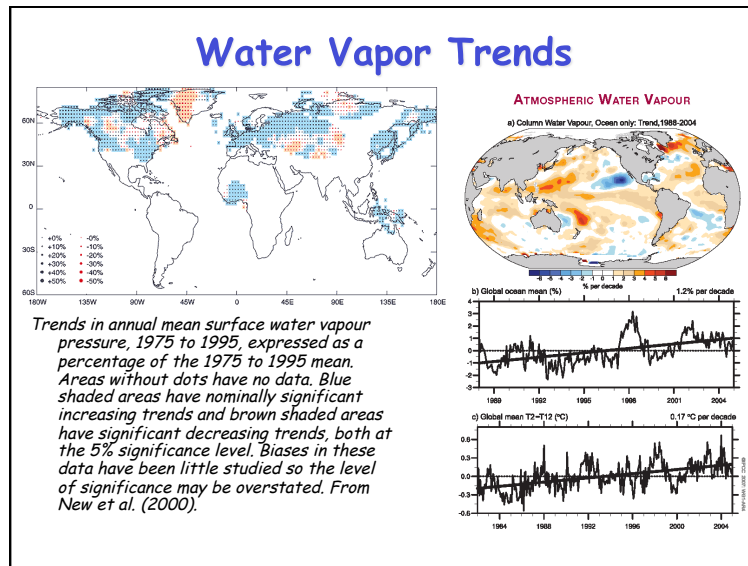
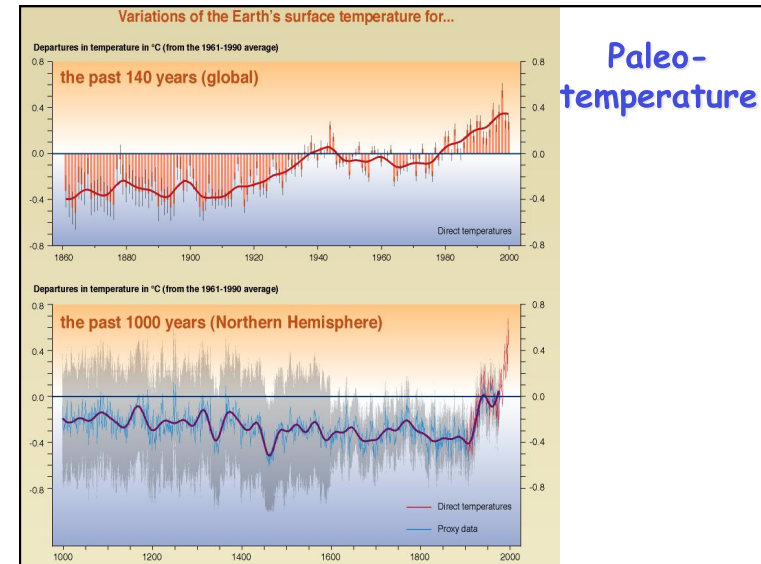
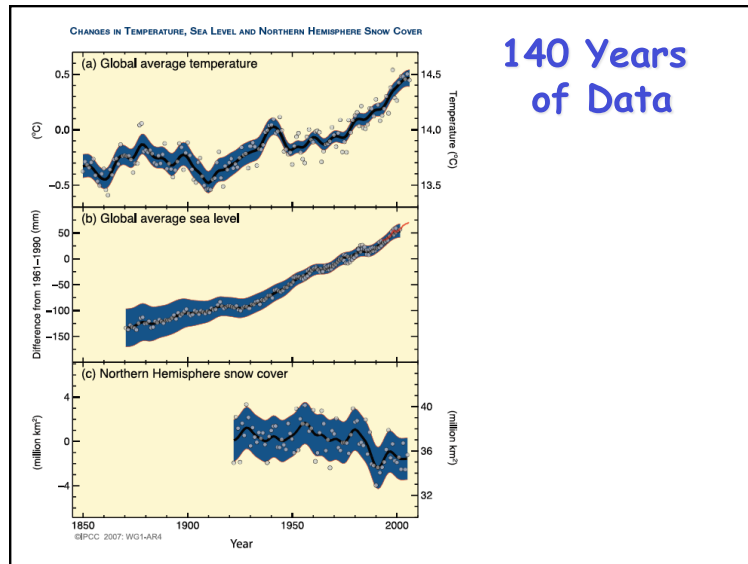


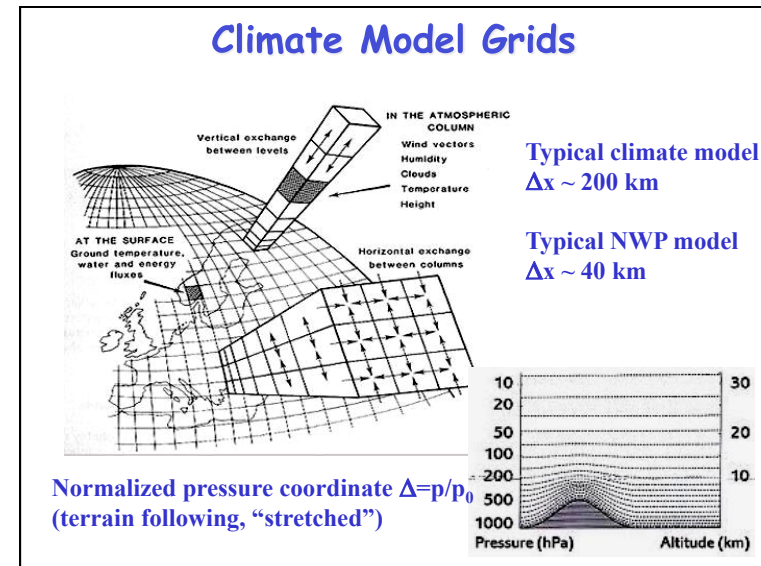
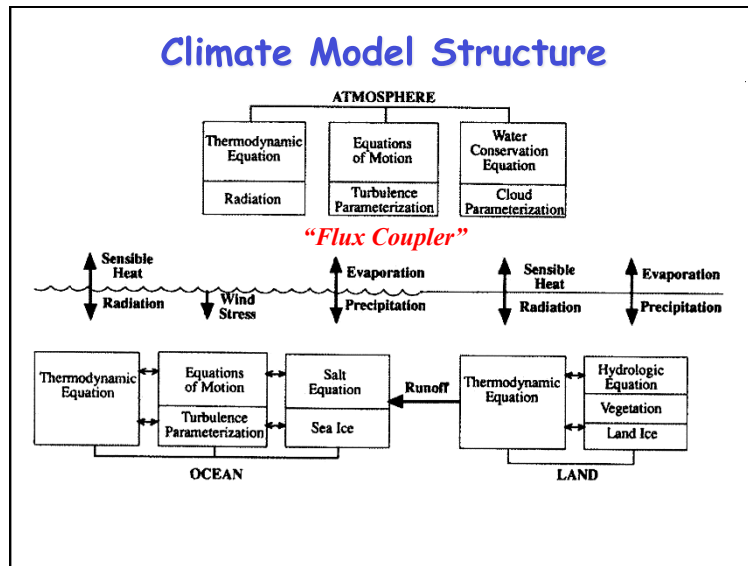
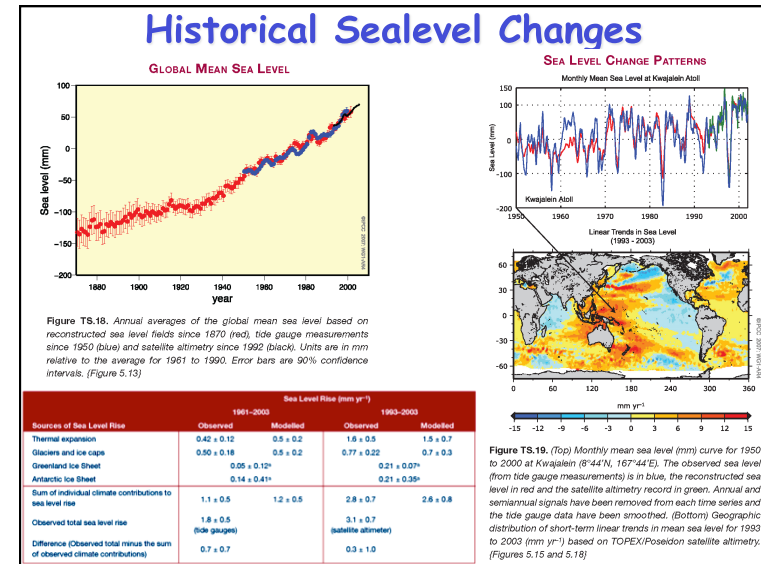
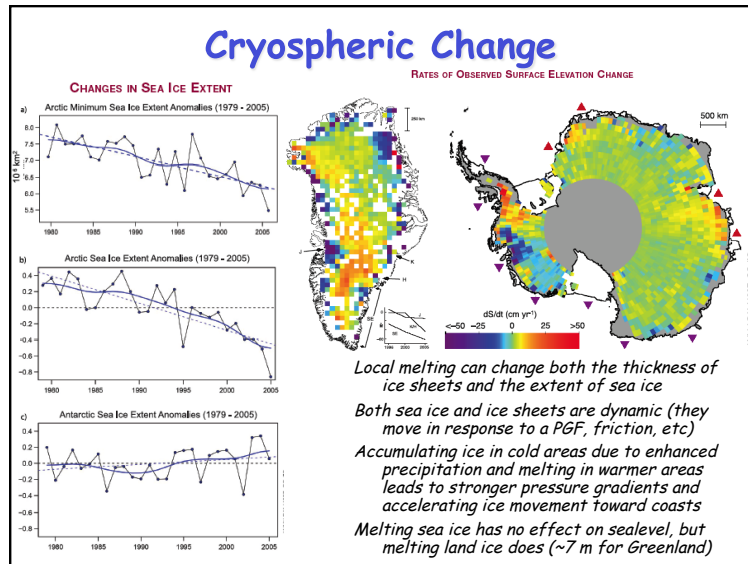
BOOM!

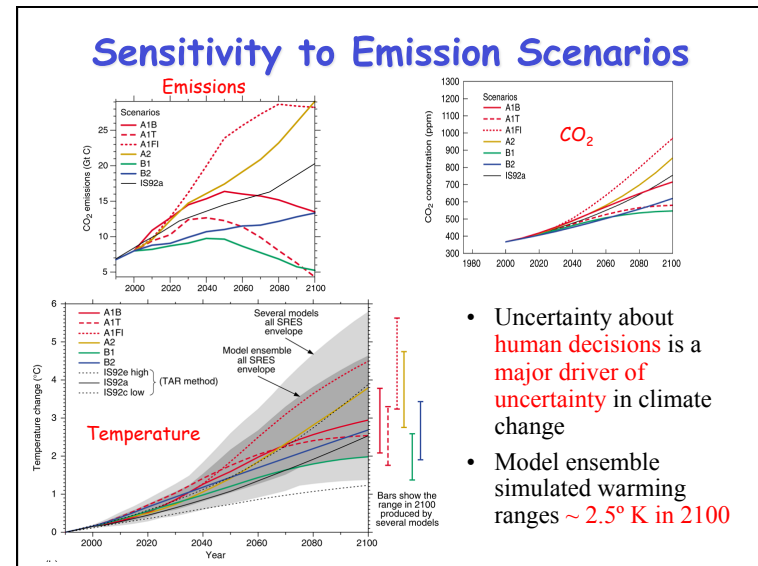
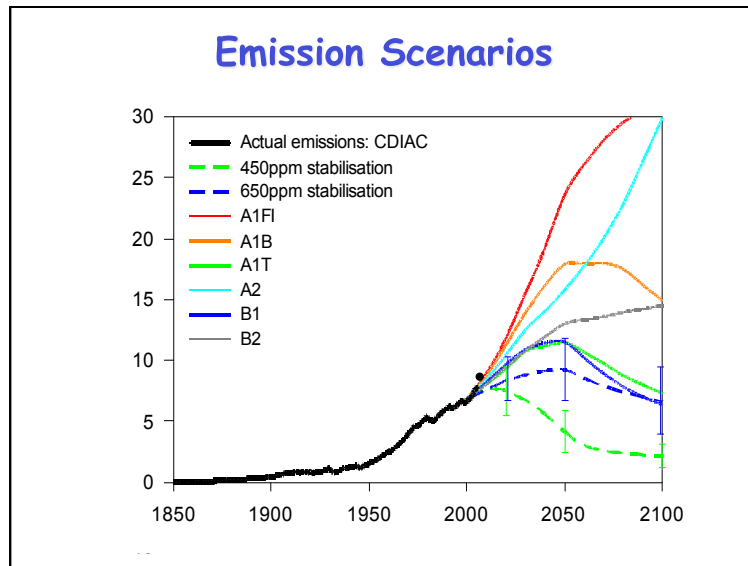
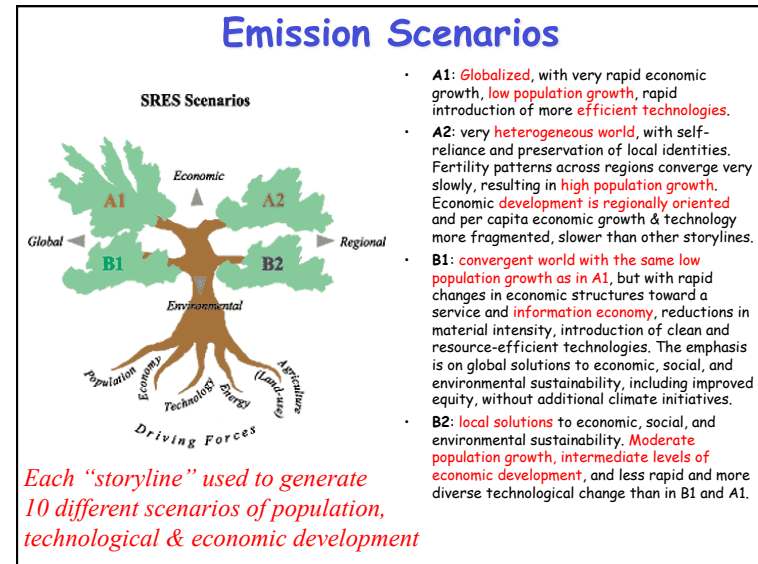
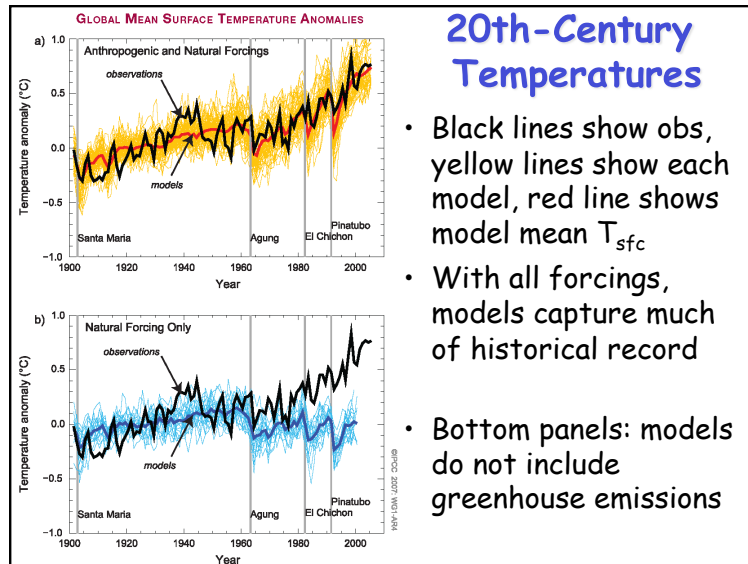
- Volcanos release huge amounts of SO₂ gas and heat
- SO₂ oxidizes to SO₄ aerosol and penetrates to stratosphere
- SO₄ aerosol interacts with solar radiation

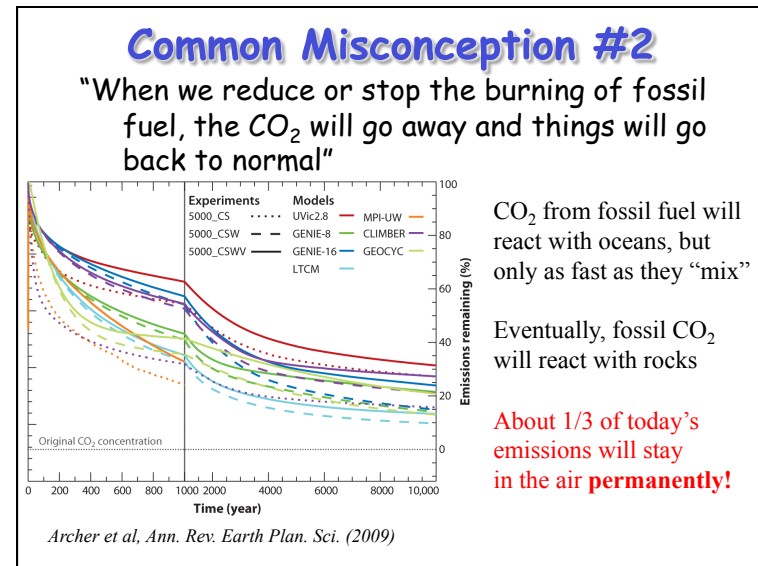
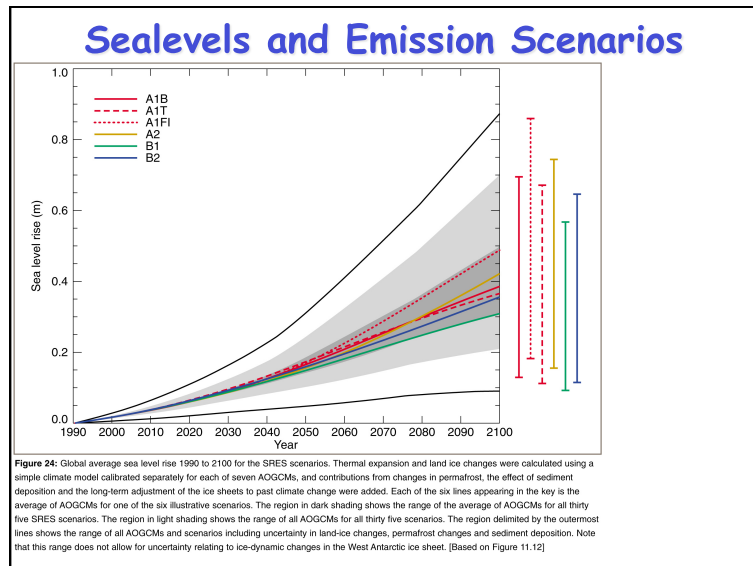
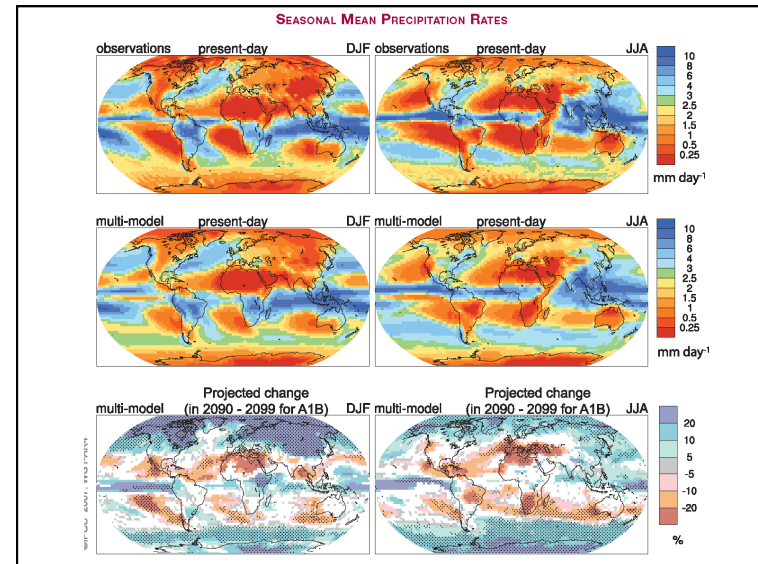
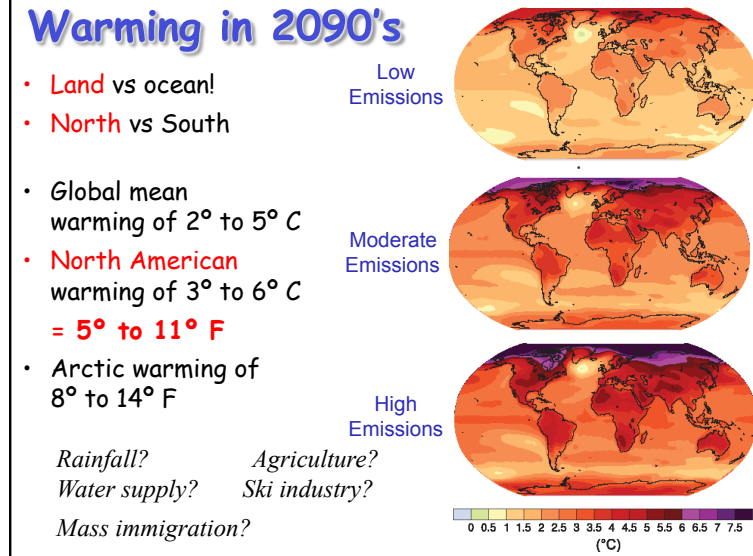
Mt. Pinatubo, 1991



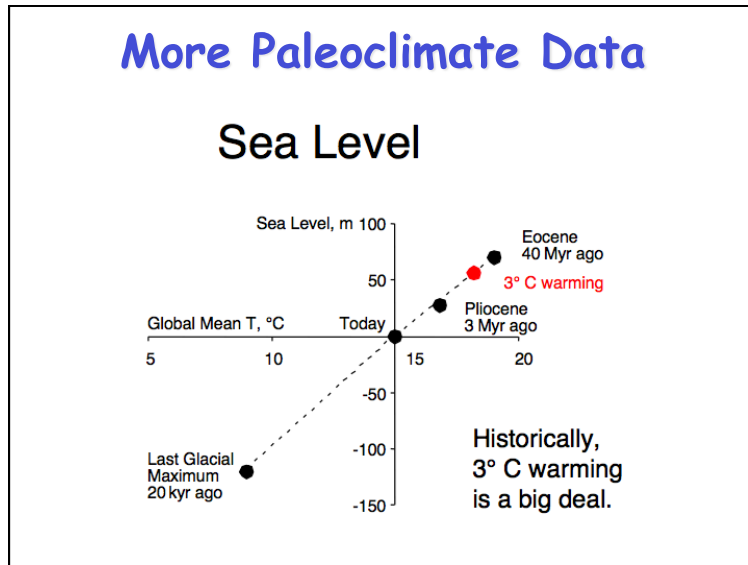
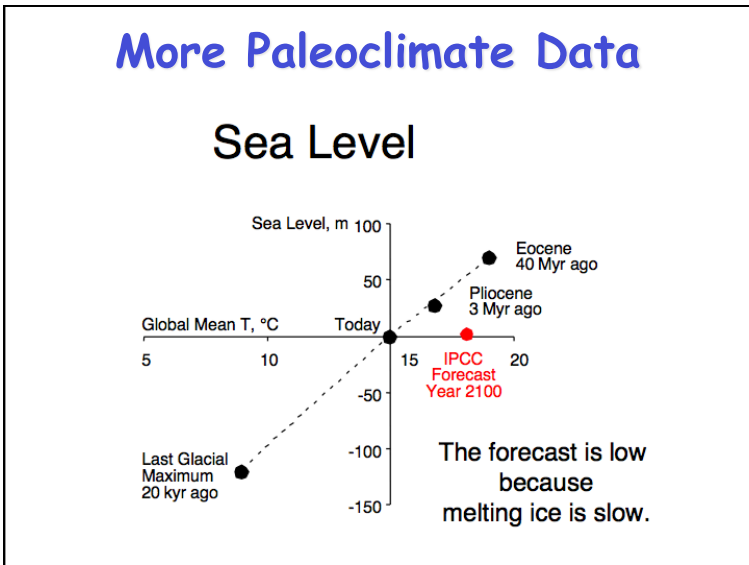
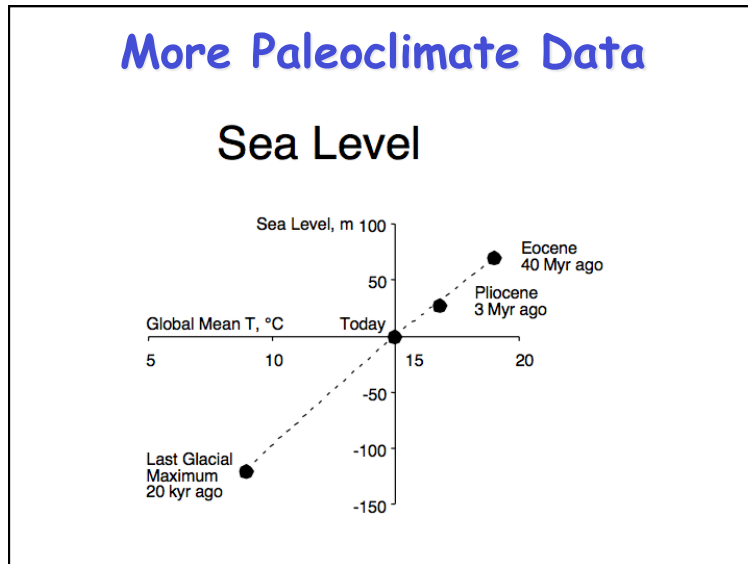








So What?



Historical Perspective



Climate change, CO₂, and energy will likely be dominant themes in human history for centuries, much as religious wars, feudalism, colonialism, and industrialization in the previous millenium

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
- "Conspiracy theories"

Responding to Skeptics

- **Observed warming not caused by humans:**
 - There hasn't been much warming yet, because CO₂ hasn't increased very much (about 30%)
 - Does that mean that there won't be warming when CO₂ 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 CO₂ requires some kind of huge offsetting forcing ("follow the energy")
 - Complicated models don't show any such thing
 - Observations favor the simple solution