Climate Change

AT350

Massachusetts vs. EPA. Nov. 29, 2006.

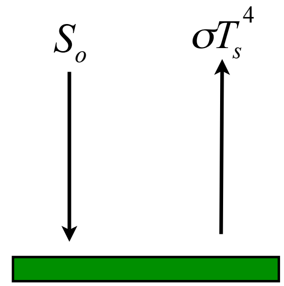
JUSTICE SCALIA: "...your assertion is that after the pollutant leaves the air and goes up into the stratosphere it is contributing to global warming."

MR. MILKEY: "Respectfully, Your Honor, it is not the stratosphere. It's the troposphere.

JUSTICE SCALIA: "Troposphere, whatever. I told you before I'm not a scientist. That's why I don't want to have to deal with global warming, to tell you the truth."

- Some basic physics/the theoretical basis
- Observations
- Attribution
- Outlook for the future

Radiative balance: no atmosphere



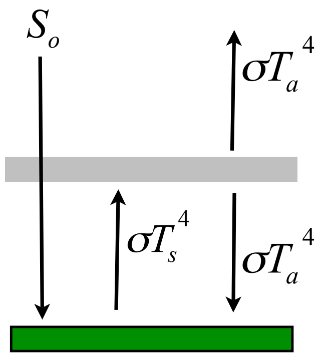
outgoing = incoming

$$\sigma T_s^4 = S_o$$

so :

$$T_s^4 = \frac{S_o}{\sigma}$$

One layer atmosphere



Balance for atmosphere

$$\sigma T_s^4 = 2\sigma T_a^4$$

Balance for earth system

$$\sigma T_a^4 = S_o$$

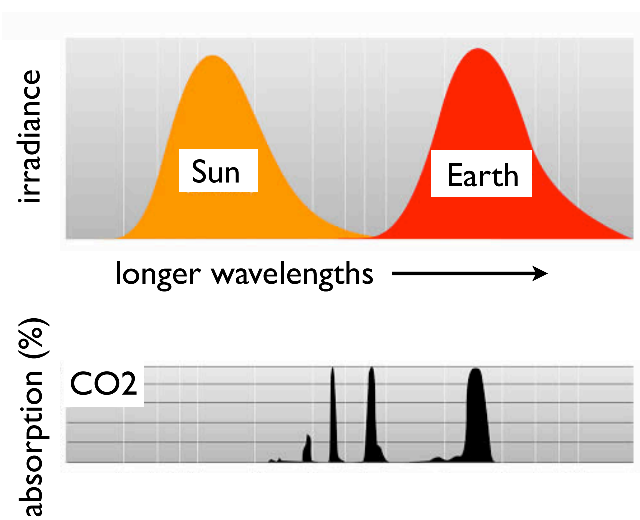
so :

$$T_s^4 = 2\frac{S_o}{\sigma}$$

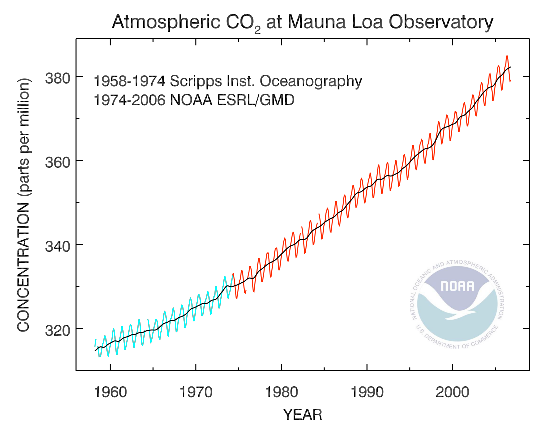
Earth's radiative equilibrium temperature: -18 C

Global mean surface temperature: + 15 C

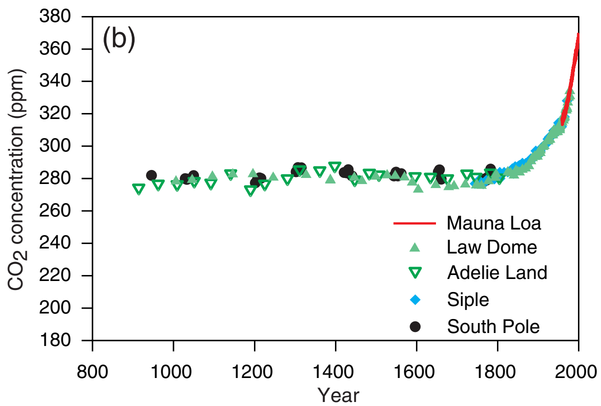
Absorption spectra



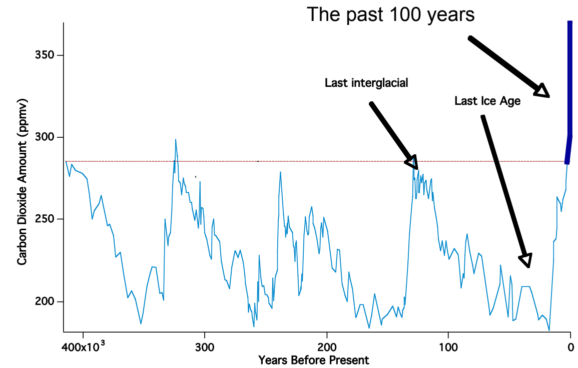
Some observations: CO2



CO2 from Antarctic ice cores



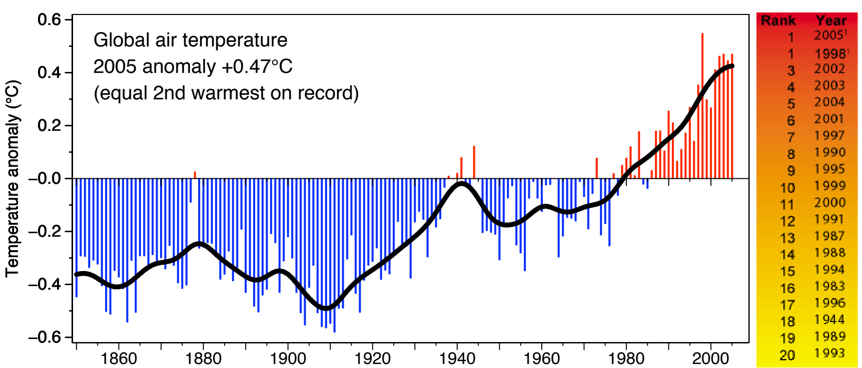
CO2 from Vostok



Ice ages are 'forced' by earth's orbital clock….

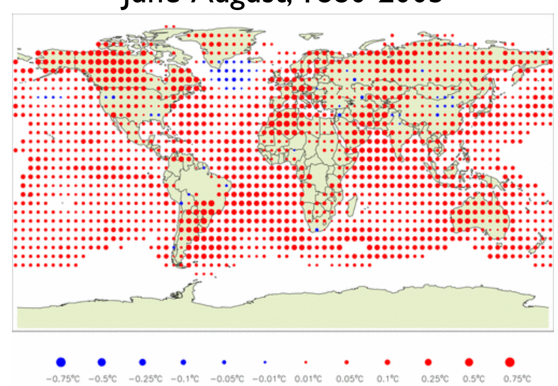
It is well established that there is more carbon dioxide in the atmosphere today than there was in more than the past half million years.

Observed temperatures

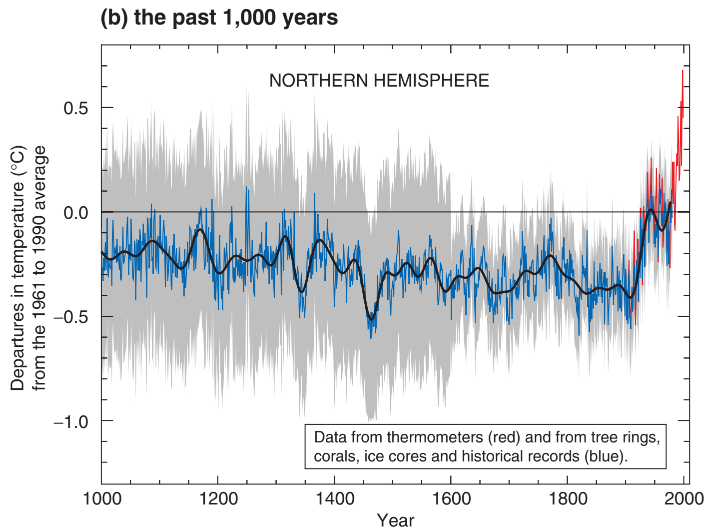


Observed temperature trends

June-August, 1880-2005

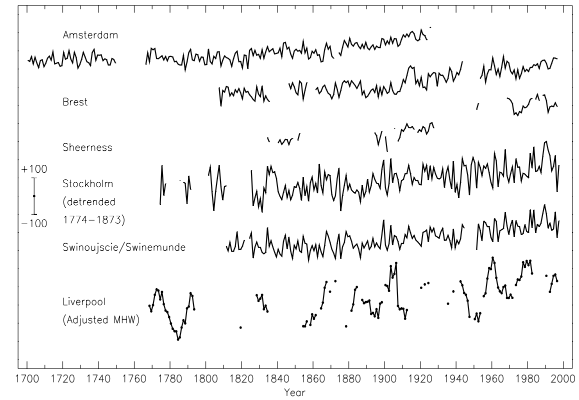


Observed + reconstructed temperatures



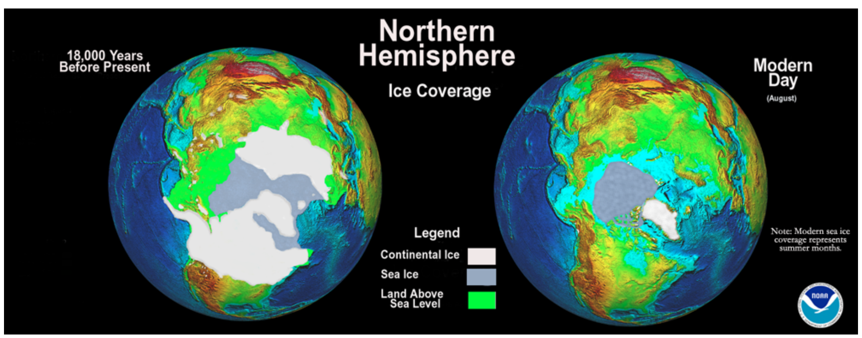
Sea level

Observations



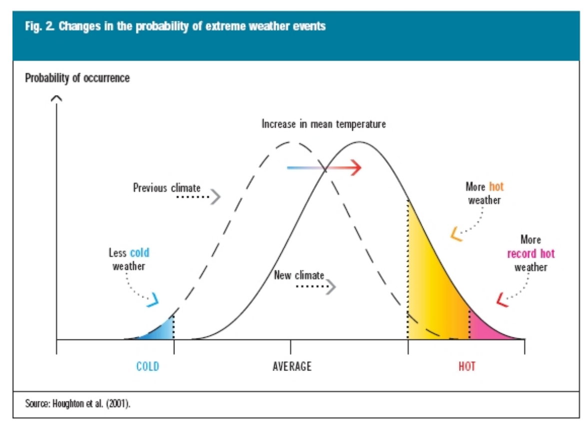
Context

Global mean temperatures were ~3C lower during the last glacial maximum



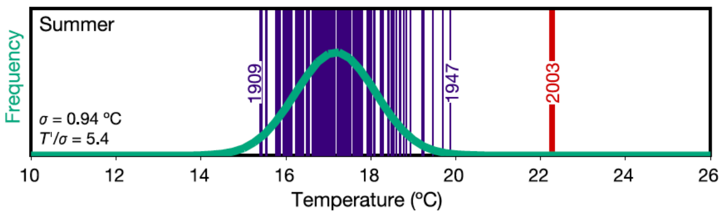
Context

Small changes in temperature are associated with large changes in the incidence of extremes.



Context

Central European temperatures



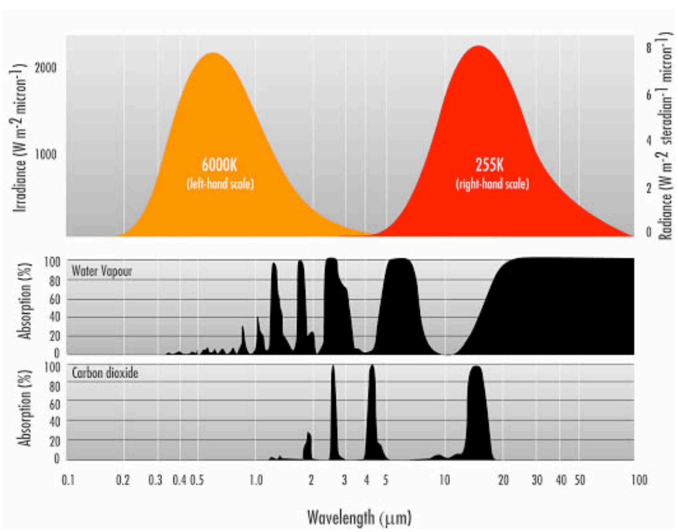
Feedbacks: water vapor

1) relative humidity = $\frac{\text{vapor pressure}}{\text{saturation vapor pressure}}$

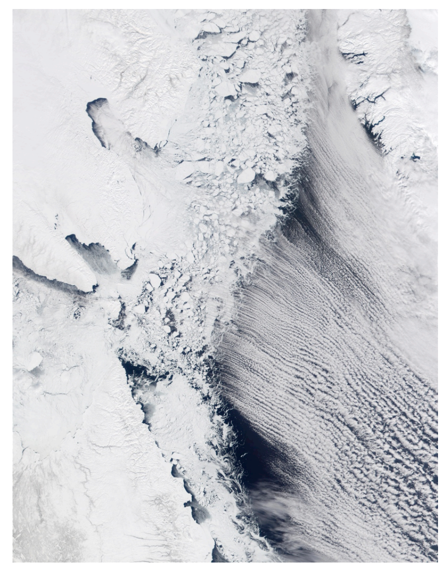
2) saturation vapor pressure is a function of temperature

- examples : dry indoor air/cloud formation/climate

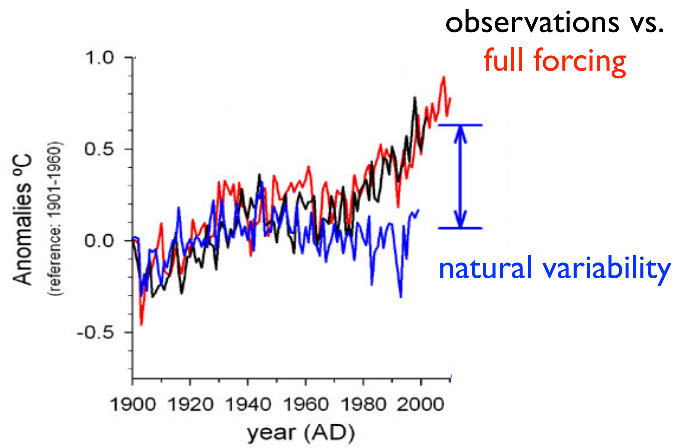
Absorption spectra



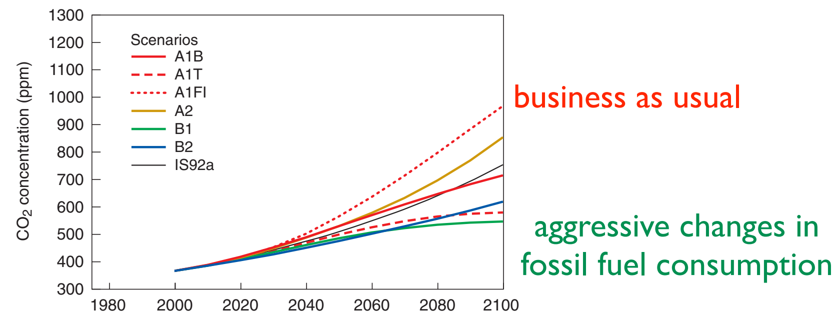
Feedbacks: ice/snow albedo



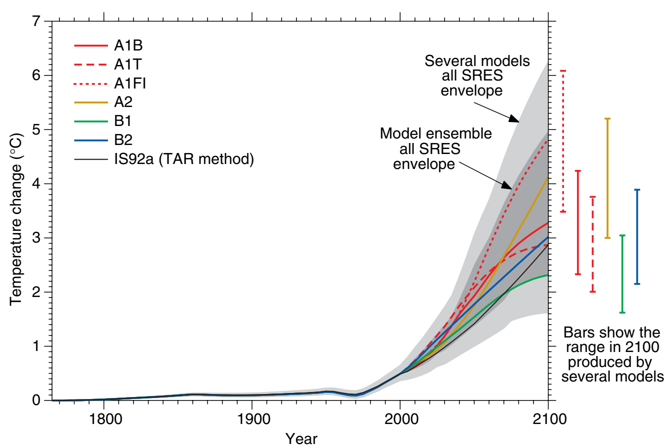
Attribution



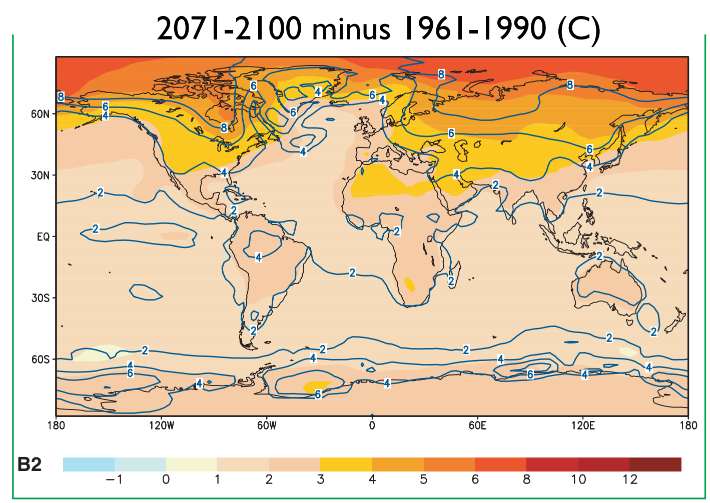
Projections



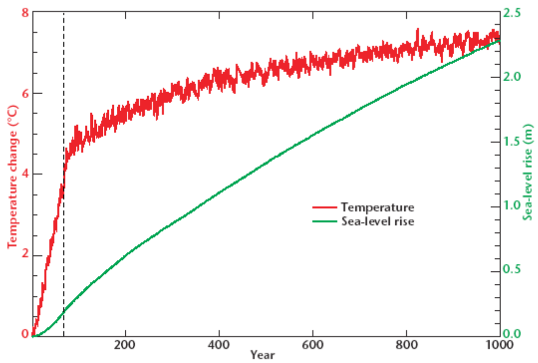
Projections



Projections

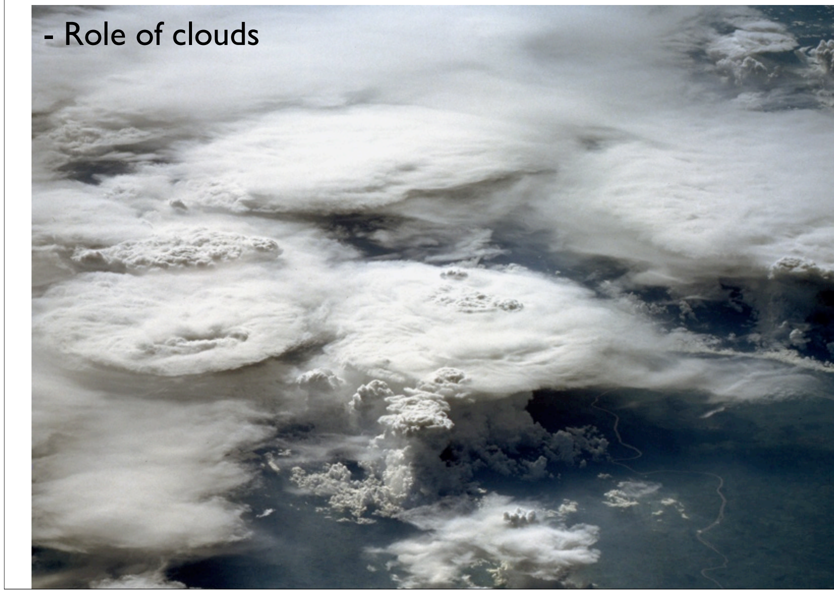


We're in it for the long haul

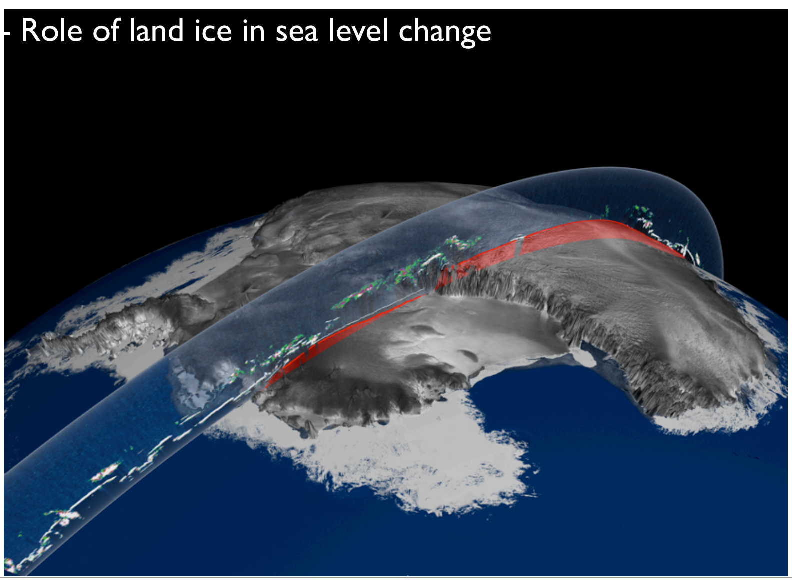


Simulated temperature change and the thermal-expansion component of sea-level rise for the four times pre-industrial CO_2 concentration ($4xCO_2$) experiment. Global temperatures stabilise quicker than sea level, which is still rising after 1,000 years. We estimate that it would take more than 2,500 years before the sea level reaches 90% of its final value. The dashed line shows the year when CO_2 concentrations were stabilised.

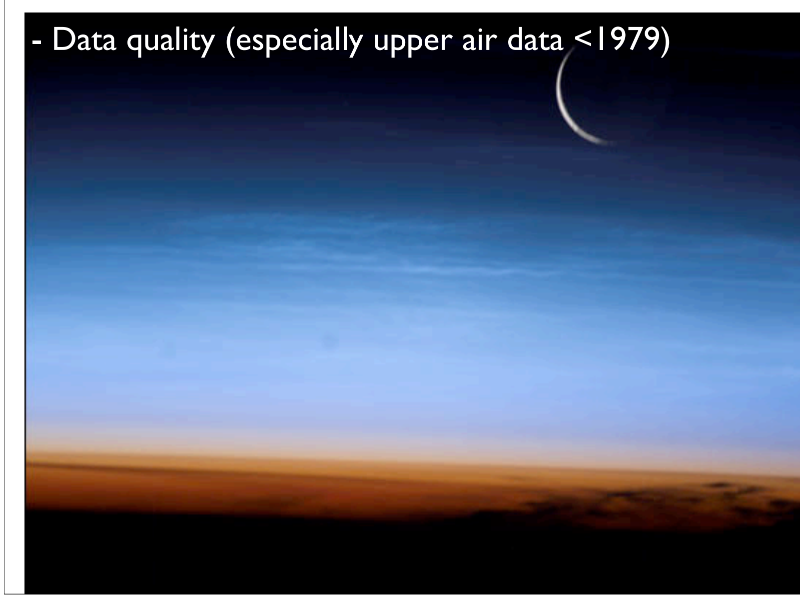
Uncertainties



Uncertainties

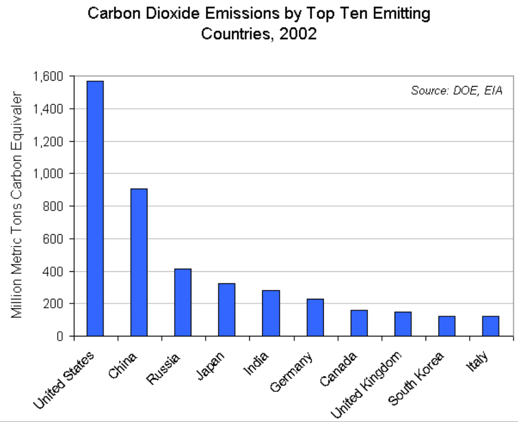


Uncertainties



Scientists provide information to policy makers and educate society.

But society - not the scientific community - needs to decide what level of risk is acceptable.



Common questions I might get on an airplane...

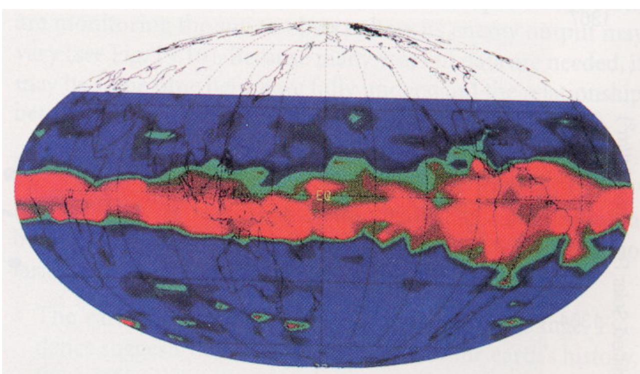
Doesn't climate vary naturally?

Doesn't the ocean change climate?

Doesn't the sun change climate?

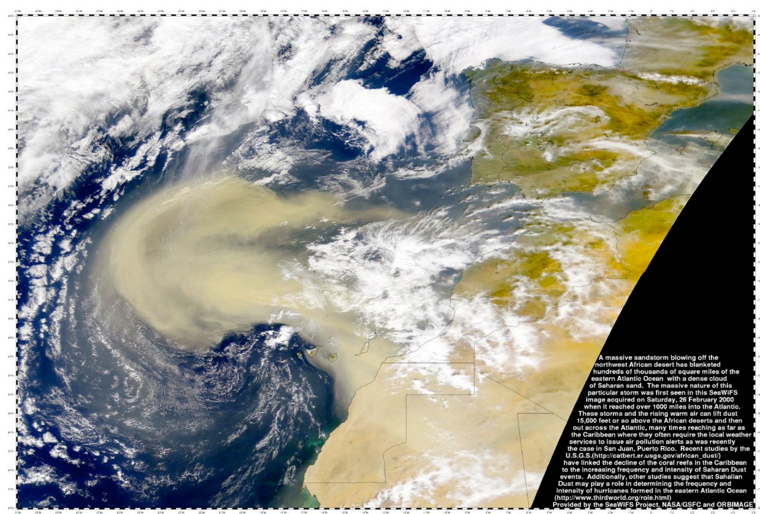
Aren't the data wrong?

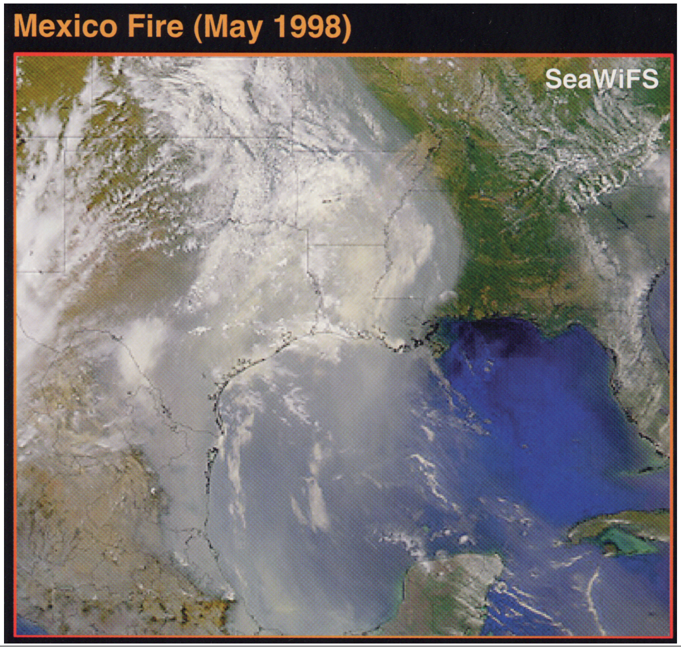
Volcanic Activity



Mt. Pinatubo Stratospheric Sulfur Plume - 1991

Saharan Dust Aerosol





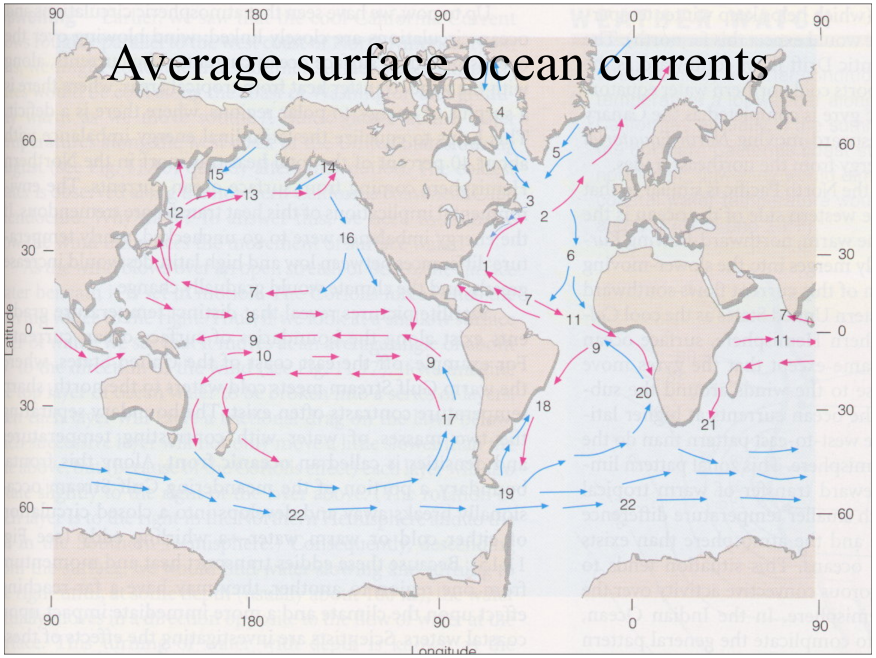
The ocean in climate

- Upwelling
- The Ekman layer
- Sverdrup balance
- Gyre circulations, western boundary currents
- The thermohaline circulation
- ENSO

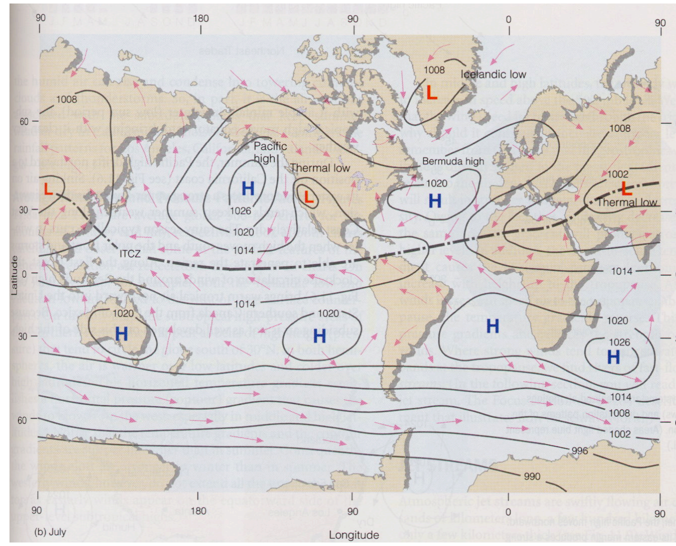
Ocean Currents

- Ocean currents play an important role in the global transport of energy
  - Help balance surplus input of energy near equator and excess loss of energy near poles
    - ~40% of total heat transport in NH is from surface ocean currents
  - In the NH, ocean currents carry warm water north along the western side of the Atlantic and Pacific
- What determines surface current patterns?

Average surface ocean currents

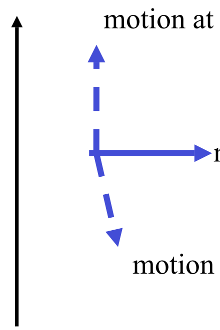


General Circulation - July



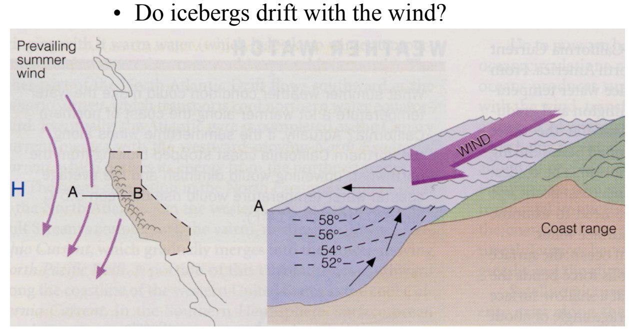
How the atmosphere drives the ocean

The layer where the ocean "feels" the atmosphere directly is called the Ekman layer.



Ekman layer and upwelling

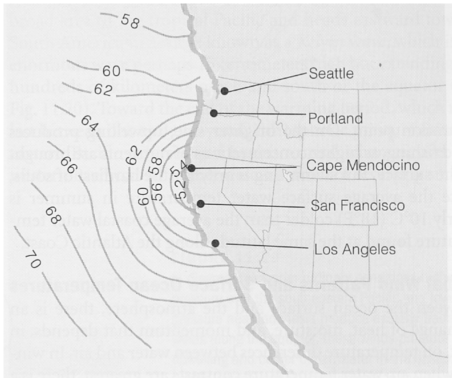
- Surface currents are driven largely by atmospheric wind patterns
  - Water is deflected from wind direction (typically 20-45 degrees at surface) by Coriolis force
    - Greater deflection occurs in deeper layers
    - 90 degrees is average deflection over 100 m surface layer
    - Do icebergs drift with the wind?



Coastal upwelling brings cold water to the surface

Upwelling

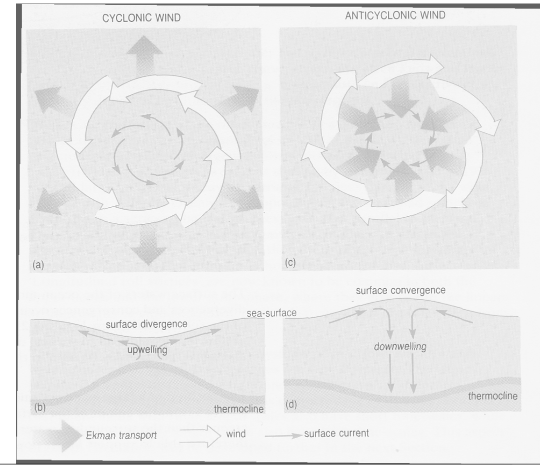
Mean sea surface temperatures during August



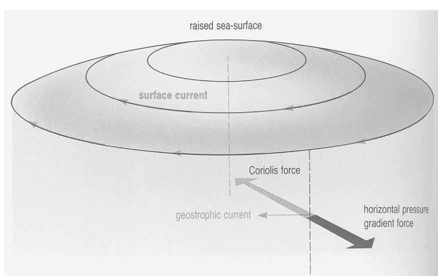
The Ekman layer and ocean gyres.

•*The thermocline is at the bottom of the Ekman layer. Marked by large vertical temperature gradients.*

•*Piling up of water in the Ekman layer squishes the column below*



The force balance in an ocean gyre



What happens to the squished water below the gyre?

•Columns that are "squished" want to move to a lower latitude. Why?

Angular momentum ~
(rotation of column/column height)

•If we have high pressure sitting over much of the subtropical North Atlantic, what kind of motion must we have?

•Why do we have a gulf stream?

Big picture concepts:

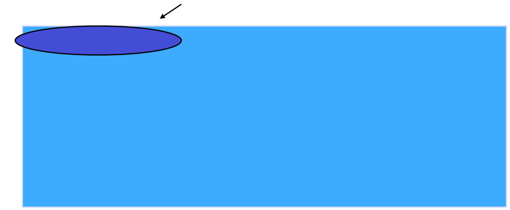
1. Only the top ~100 meters of the ocean ‘feel’ the wind directly.
2. At the surface, the flow is slightly to the right of the wind. As you descend through the surface “Ekman layer”, the flow rotates increasingly rightward.
3. The average flow through the ~100 meters is to the right of the wind (in the NH).
4. The deep ocean is driven by convergence/divergence in the Ekman layer. Squished columns move south and vice versa. The subsurface ocean is also driven by the “thermohaline” circulation.

The thermohaline circulation

•Gyre circulations are driven by the wind. The thermohaline circulation is driven by differences in density/convection.

Cold, salty blob of water

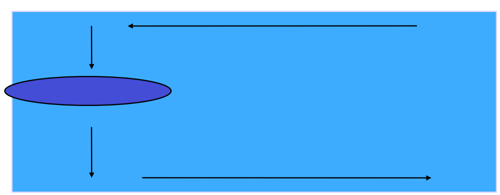
(looking eastward)



North Equator South

The thermohaline circulation

•Cold, salty water sinks. This drives an overturning circulation.



North Equator South

The Ocean Conveyor Belt

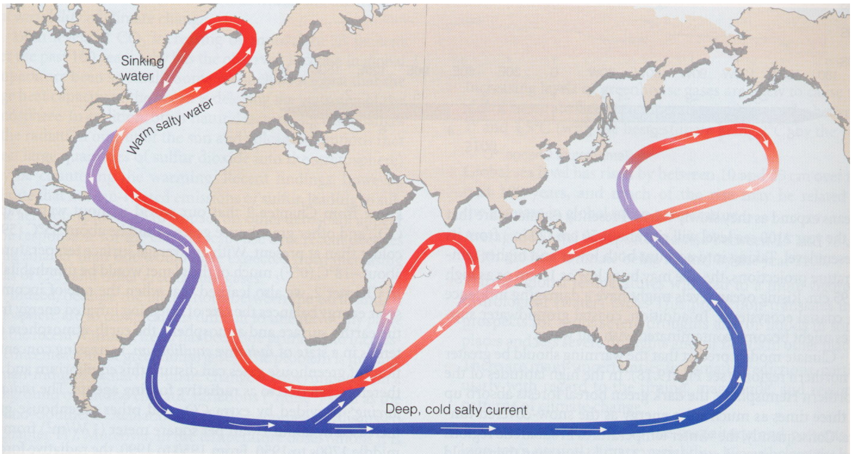


FIGURE 1
The ocean conveyor belt. In the North Atlantic cold, salty water sinks, drawing warm water northward from lower latitudes. The warm water provides warmth and moisture for the air above, which is then swept into northern Europe by westerly winds that keep the climate of that region milder than one would normally expect. When the conveyor belt stops, winters apparently turn much colder over northern Europe.

The ocean in climate:

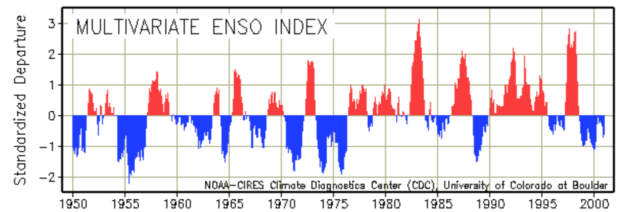
Concepts:
WIND DRIVEN CIRCULATION:

THERMOHALINE CIRULATION:
- driven by sinking of cold, salty water. Why is there no deep water formed in the North Pacific? Why is the Atlantic saltier?

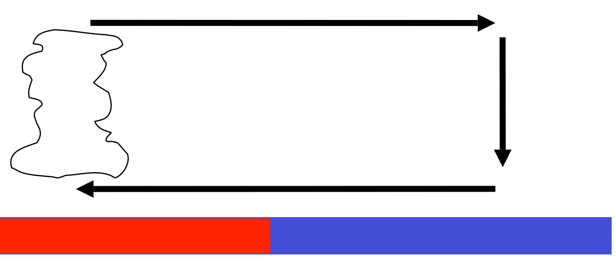
Note that the ocean is driven by atmosphere, but that the ocean impacts the atmosphere as well…next we'll look at coupled ocean/atmosphere interactions…

El Niño Southern Oscillation (ENSO)

- Trade winds promote cold water upwelling in eastern tropical Pacific
  - Cool, deep water is nutrient rich and supports rich ecosystem (plankton, fish, birds,…)
- Weaker trades lead to weaker upwelling. Warm nutrient-poor tropical water replaces the cold, nutrient-rich water .
  - called El Niño (*boy child*)
- Every few years this El Niño (surface warming) persists and is widespread
  - Huge ecosystem and economic losses
  - Alters weather pattern over a large region



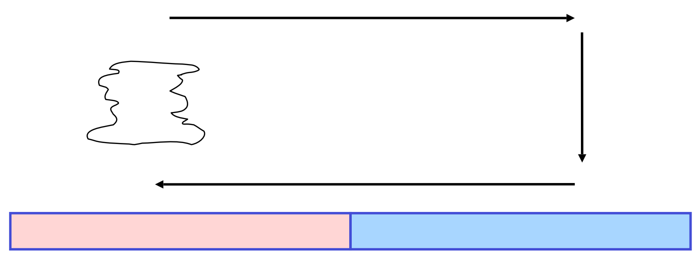
1 - trade winds "cause" the observed east-west gradient in SST
2 - gradient in SST drives a convection "loop" in the atmosphere that maintains the trades.



Indonesia

South America

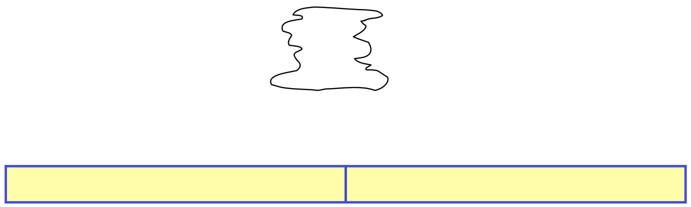
1 - if trade winds weaken, so does east-west gradient in SST
2 - if gradient in SST weakens, convection "loop" weakens. This reinforces the original weakening of the trades.



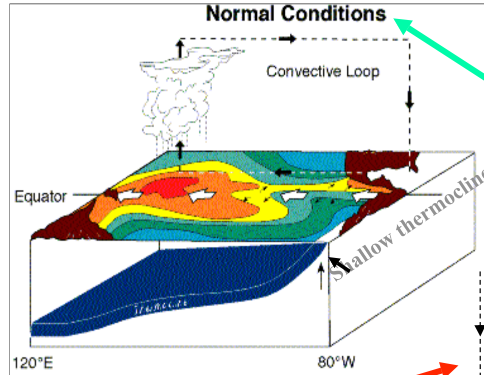
Indonesia

South America

1 - no trade winds = no east-west gradient in SST = no east-west “convective loop” = no trades, etc.

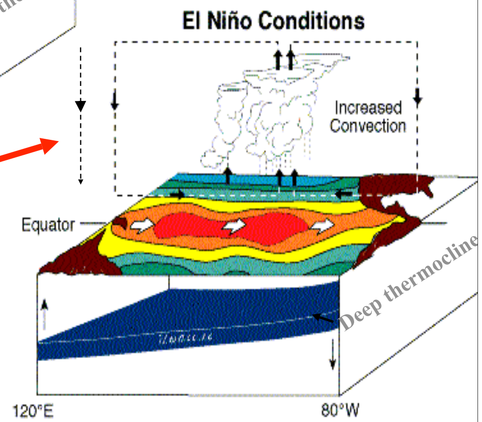


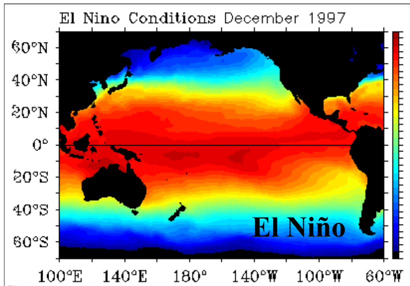
Indonesia South America



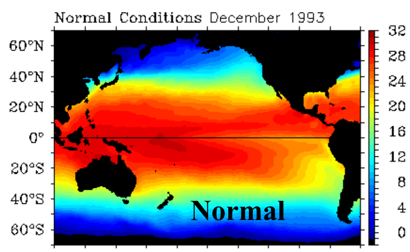
Strong Trade Winds
Surface water flows toward west
Convection over western Pacific
Warm Pool over western Pacific
Cool SST’s over Northern South America and Southern US Coasts

Weak Trade Winds
Surface water flows toward east
Convection shifts to central Pacific
Warm Pool shifts to central Pacific
Warm SST’s over Northern South America and Southern US Coasts

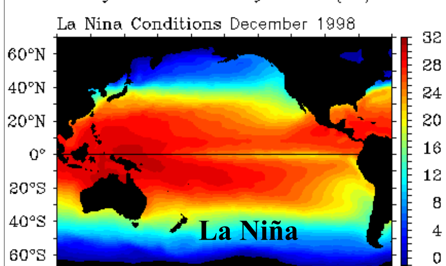




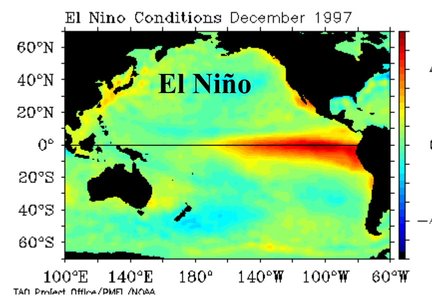
Sea Surface Temperatures °C



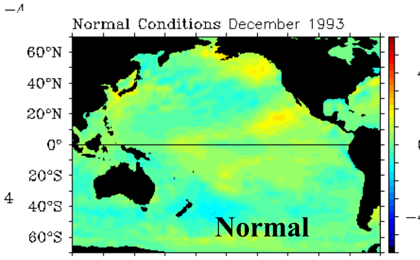
Reynolds Monthly SST (°C)



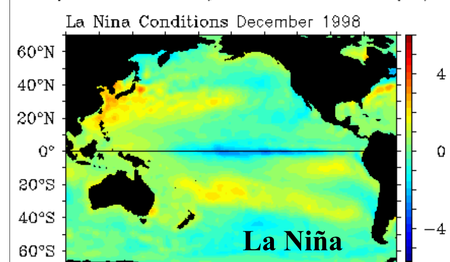
La Niña: cold surface water moves over central and eastern Pacific.



Sea Surface Temperature Anomalies °C



Reynolds Monthly SST Anomalies (°C)



N. American Winter Weather Impacts of El Niño