Fundamentals of Climate Change (PCC 587): The Ocean

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DAY 12: 11-4-13

The Ocean

- Ocean acidification
  - "The other CO_2 problem"
- Sea level rise
- Thermohaline circulation
- El Nino

Ocean Acidification

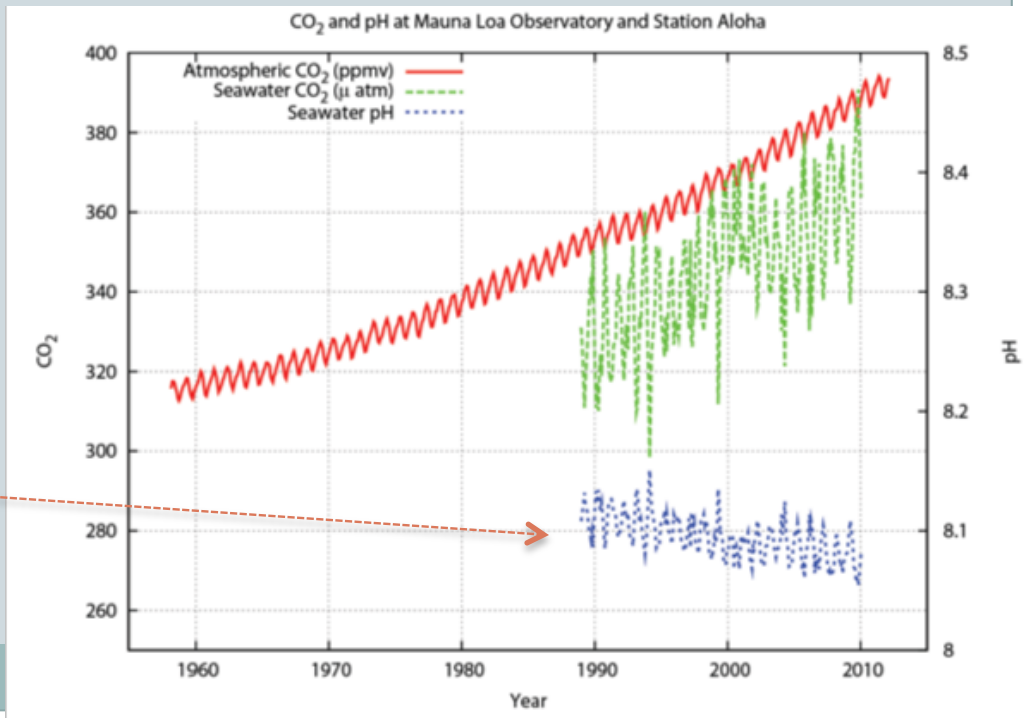
- Carbon dioxide can dissolve in water
  - *Carbonated* drinks: pressurized CO_2 is dissolved in water
    - When opened at normal pressure, it releases CO_2 bubbles

- Higher atmospheric CO_2 means more CO_2 dissolves in seawater

Chemistry of Ocean Acidification

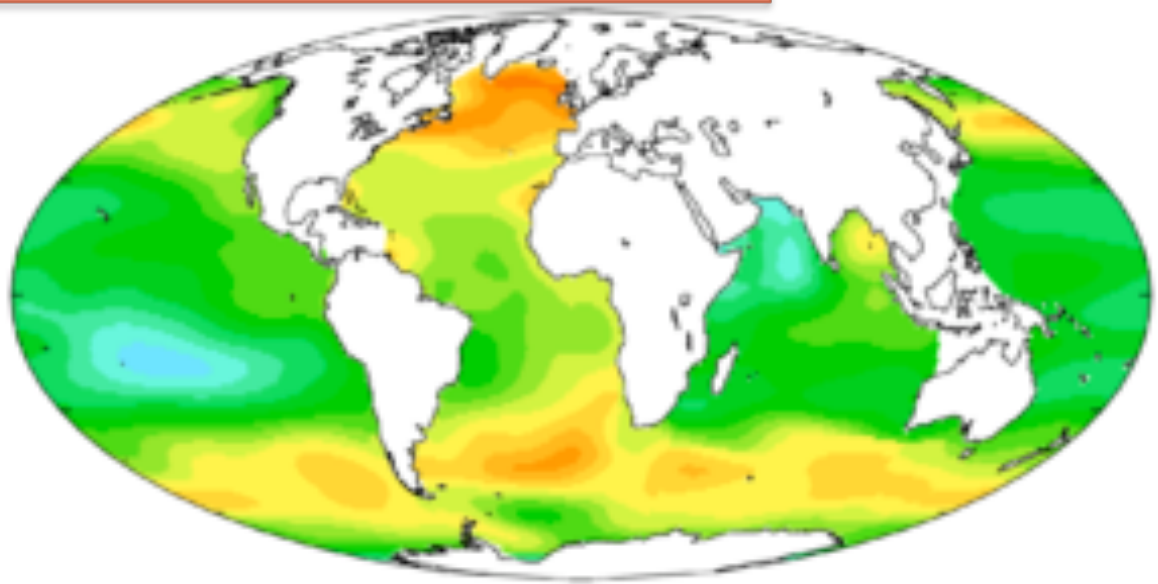
- When carbon dioxide is dissolved in water, some **carbonic acid** is formed (**H_2CO_3**)
- Water becomes **more acidic**
  - And the pH of the ocean has been decreasing as CO_2 levels have risen

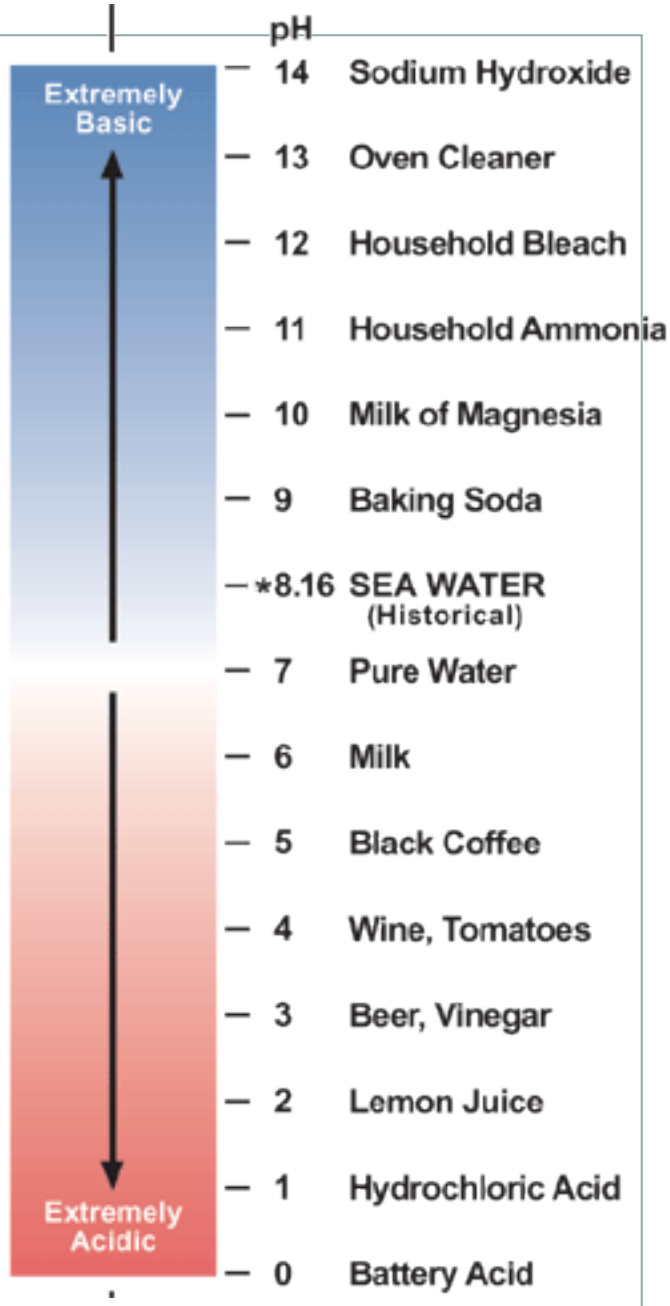
pH has been dropping at this Hawaii station (and globally as well)



Ocean Acidification

	pH
Pre-industrial (1700s)	8.18
Recent past (1990s)	8.10
2050 ($2\times CO_2$ = 560 ppm)	7.95
2100 (IS92a)	7.82





How much more acidic?

- pH is a logarithmic scale, so the observed drop in pH corresponds to **30% more** hydrogen ions
- Who cares about a more acidic ocean?

Acids

- What kinds of things react with acids?
  - Well, TUMS, for instance…

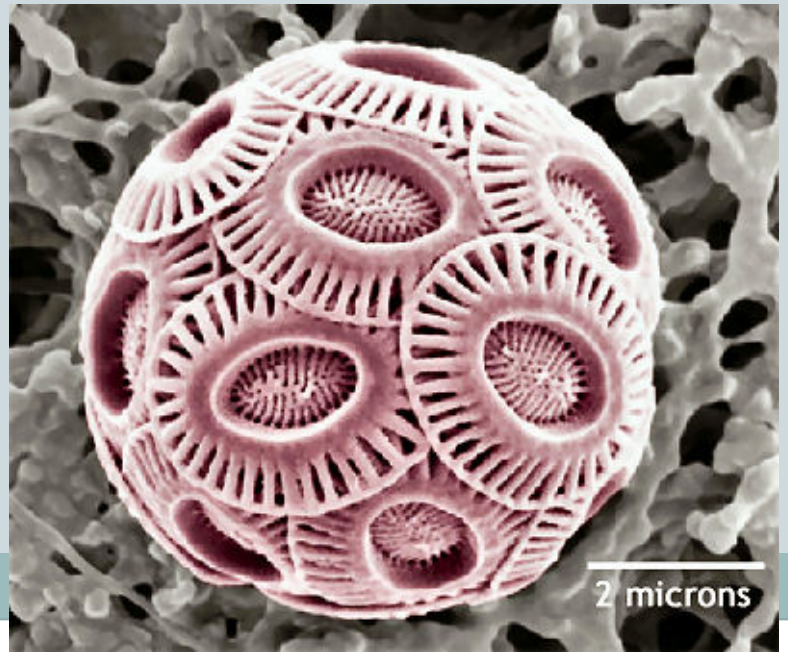
  - Tums has calcium: **calcium carbonate** ($CaCO_3$) that is…
  - This is actually relevant to the ocean: calcium carbonate is what marine organisms of all types use to build shells, skeletons, etc

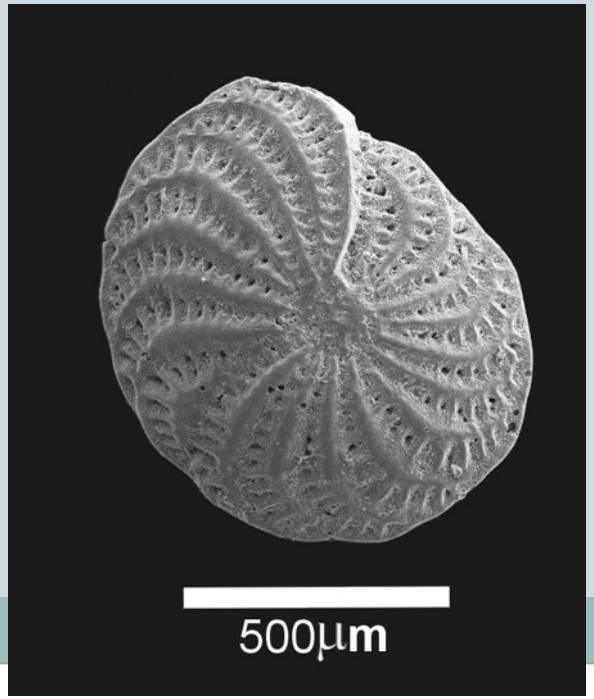
In your stomach or in the ocean, the chemistry is the same

Just as the Tums react with acid, creatures with shells also react…

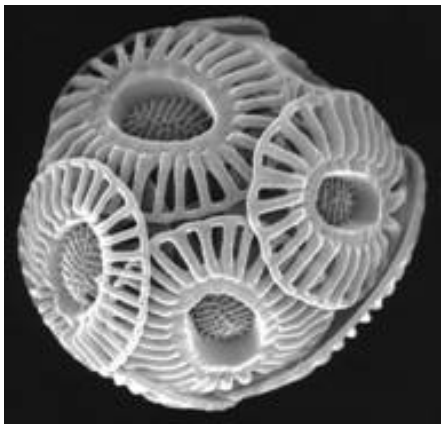
Not just clams & lobsters though!

Even low on the food chain organisms like **phytoplankton** are affected. Phytoplankton are responsible for 1/3 of all photosynthesis on the planet and feed the marine food web.



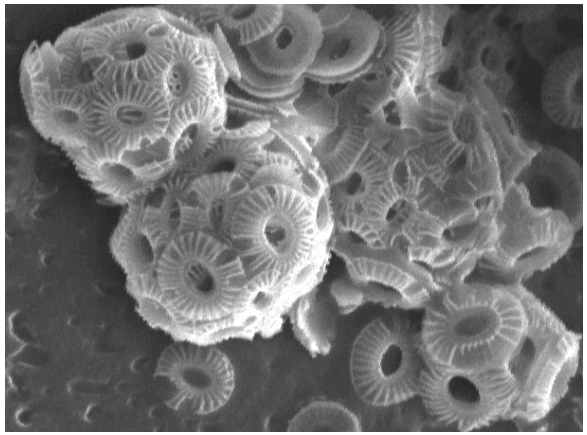


normal coccolithophorid



10-30 microns

coccolithophorids in acidified conditions

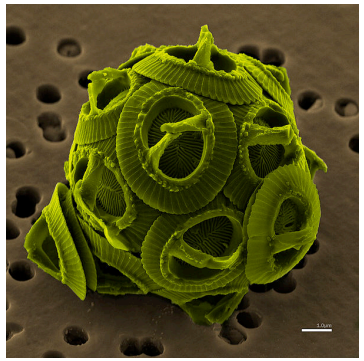


Ocean acidification is likely to **impair shell formation** in plankton and corals

Acidification of the Ocean

Increasing the acidity of the ocean has a negative impact on many types of biology

Pteropods (small molusks)

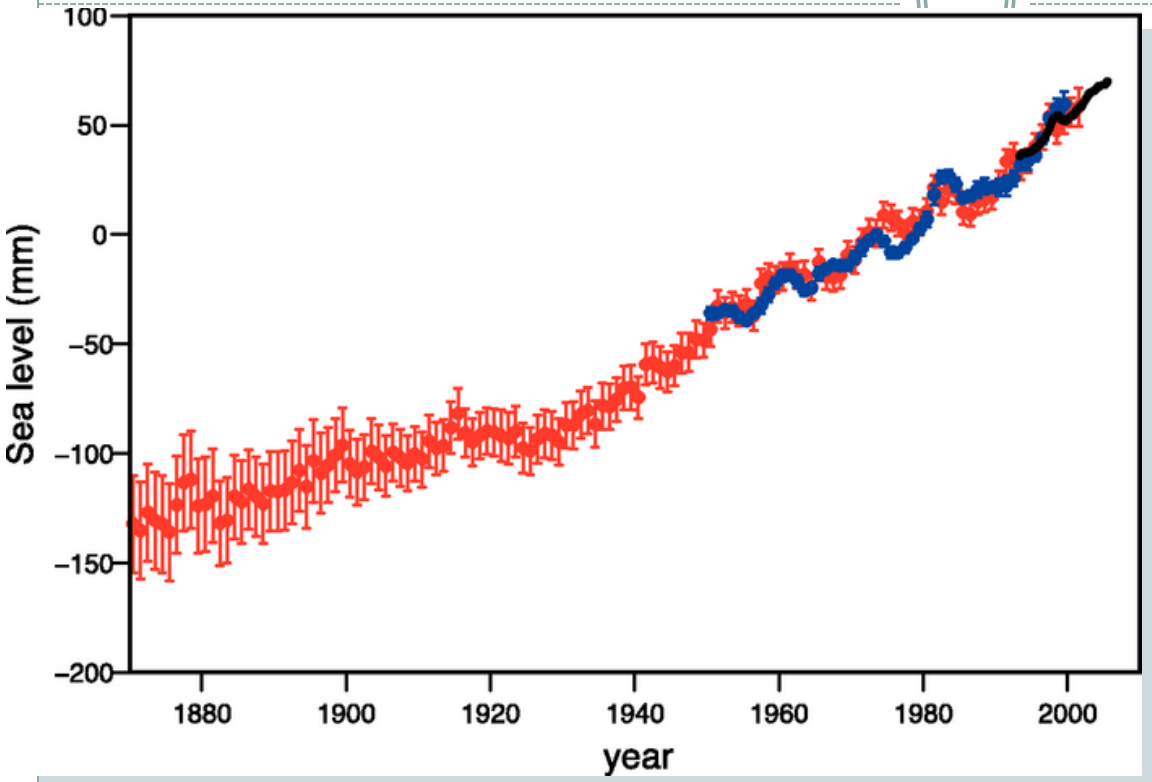


Coccolithophore
(single-celled algae, protists and phytoplankton)

Shellfish

Coralline (red) algae

20th Century Sea Level Rise



red = "reconstructed" from tide gauges and other sources
blue = tide gauges
black = satellite altimetry

- Sea level rise since 1870 has been around **12-22 cm** (5-9")

What affects sea level rise?

- These **don't contribute** to sea level rise:
  - **Sea ice**
  - **Ice shelves** (these are connected to ice sheets but floating on ocean)
- Contribute only a **tiny amount**:
  - **Permafrost**
  - **Snow cover**

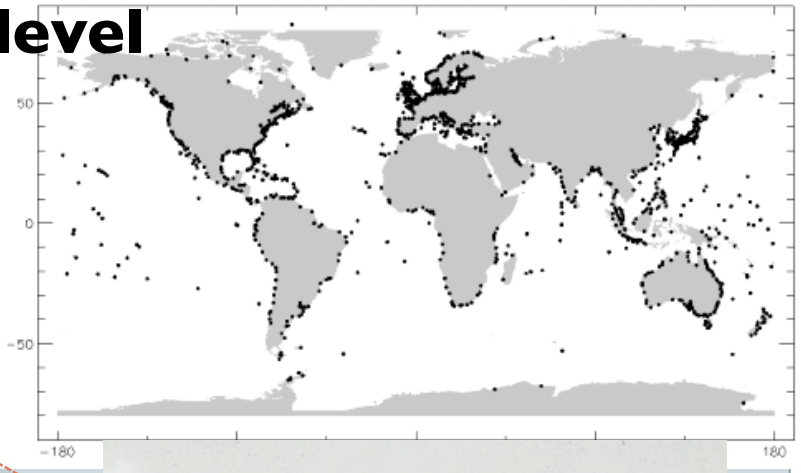
What affects sea level rise?

- These **do contribute** to sea level rise:
  - **Thermal expansion** of sea water
    - Water expands when it warms
    - This is the **main contributor** to sea level rise so far
  - **Mountain glaciers**
  - **Ice sheets** (Greenland and Antarctica)

Natural Influences on Sea Level

- Tides
- Ocean currents
- Winds
- Tectonic activity
  - Some locations are rising/falling
  - Northern part of the Olympic Peninsula is rising
    - Means it will experience less sea level rise than other locations
- These influences + spotty data means it's been hard to track global sea level accurately!

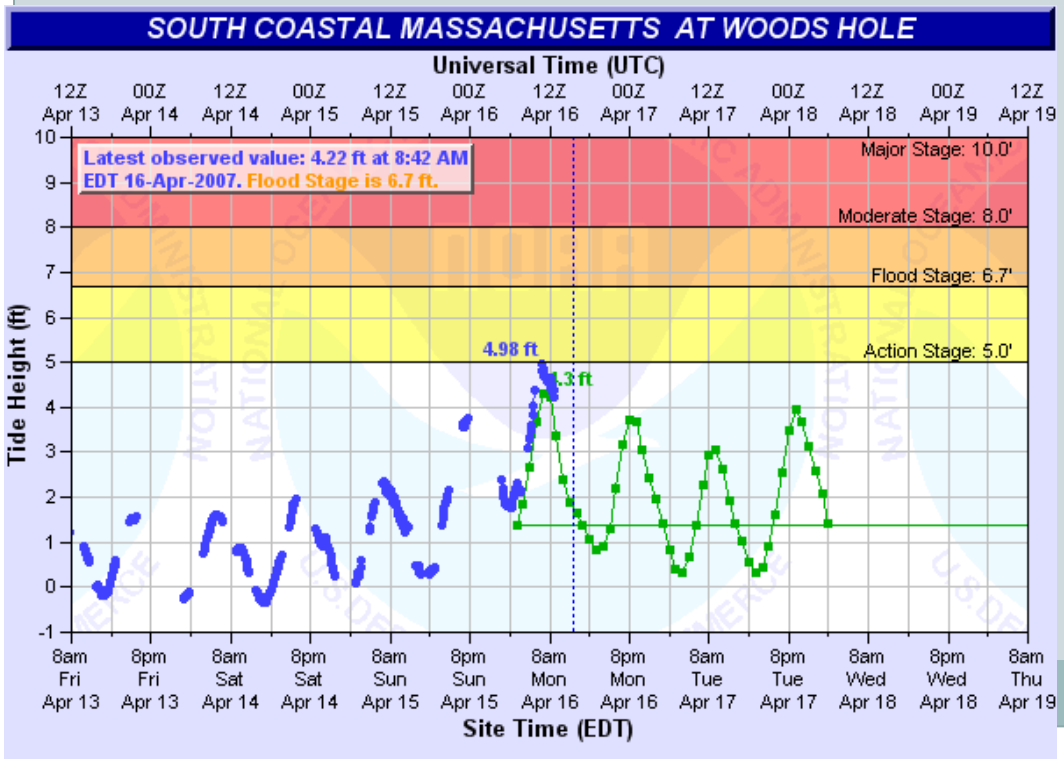
From sticks to satellites: measuring **sea level**



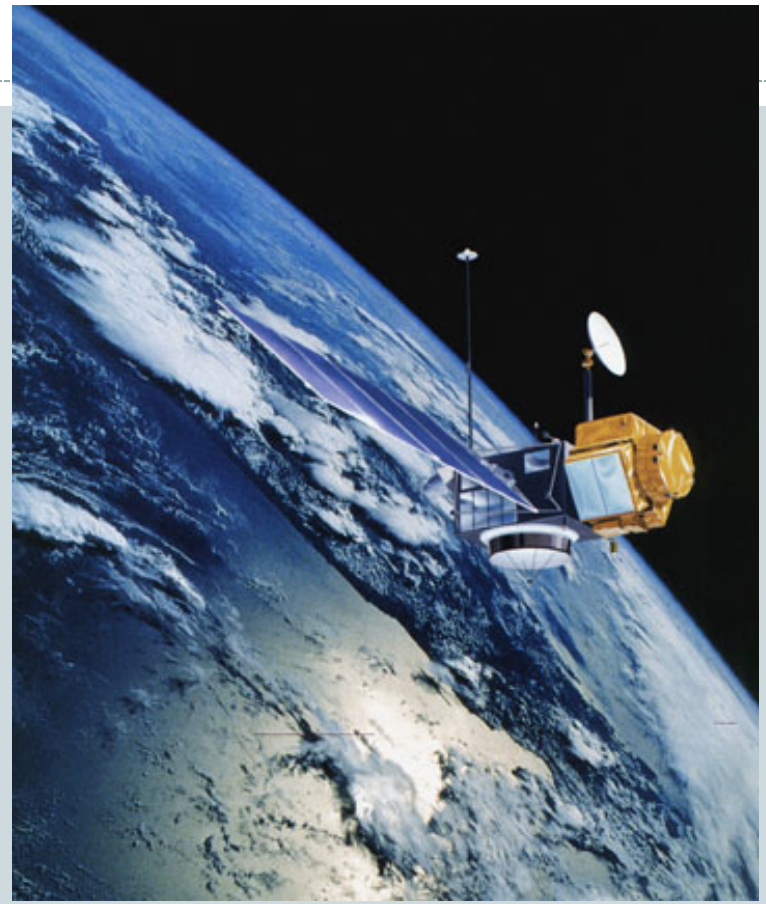
Tide gauges are measuring sticks or floats in wells

Always coastal

Few long records



From sticks to satellites: measuring **sea level**

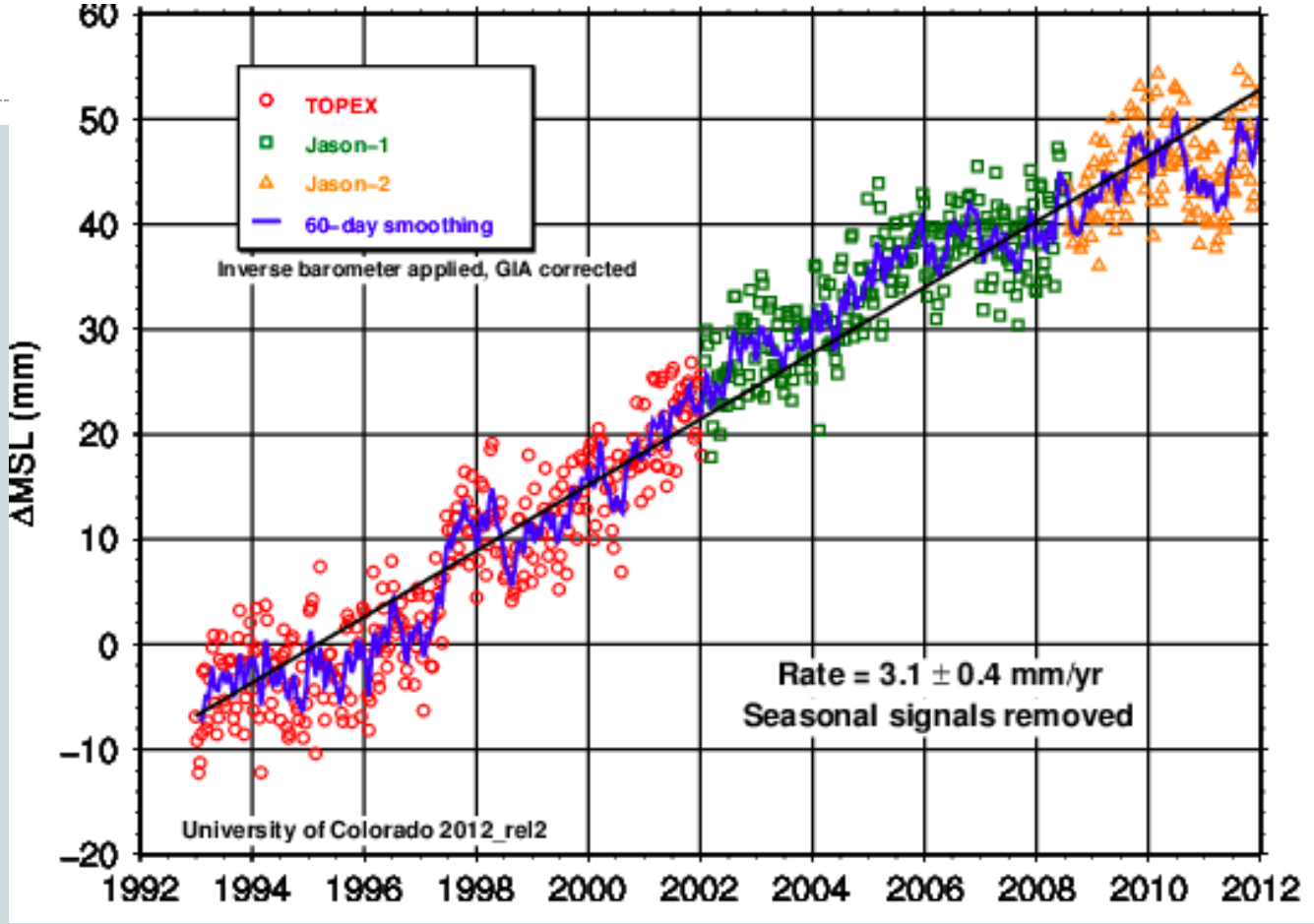


TOPEX-Poseidon Radar Altimetry

Instrument emits a short radar flash and measures the time-of-flight of its reflection from earth. 1,000 times per second.

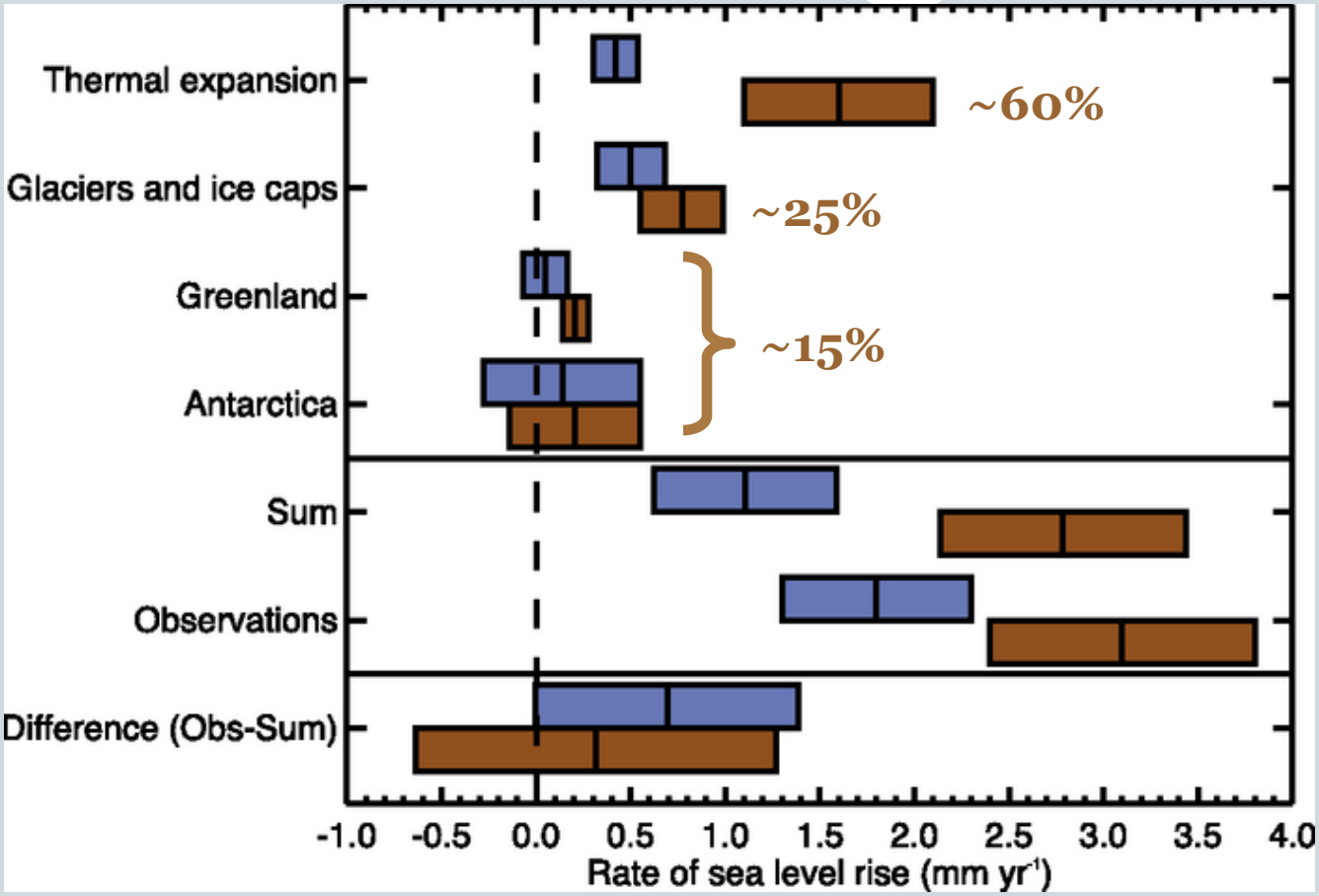
Measures **sea level** and ice sheet height

Sea level rise from TOPEX-Poseidon Radar Altimetry



Most accurate satellite measurements: just under **6 cm** (2.4”) rise in last **19 years**

Contributions to sea level rise



1961 to 2003 (blue)
1993 to 2003 (brown)

Older data (blue) didn't add up properly

Recent rise (brown) can be almost entirely explained

Mostly **thermal expansion** so far.

- *IPCC AR4 Figure 5.21.*

Thermal Expansion

- Thermal expansion is primary contribution so far to sea level rise (60%)
- Due to ocean heat content increases
  - Water **expands** as it **warms**

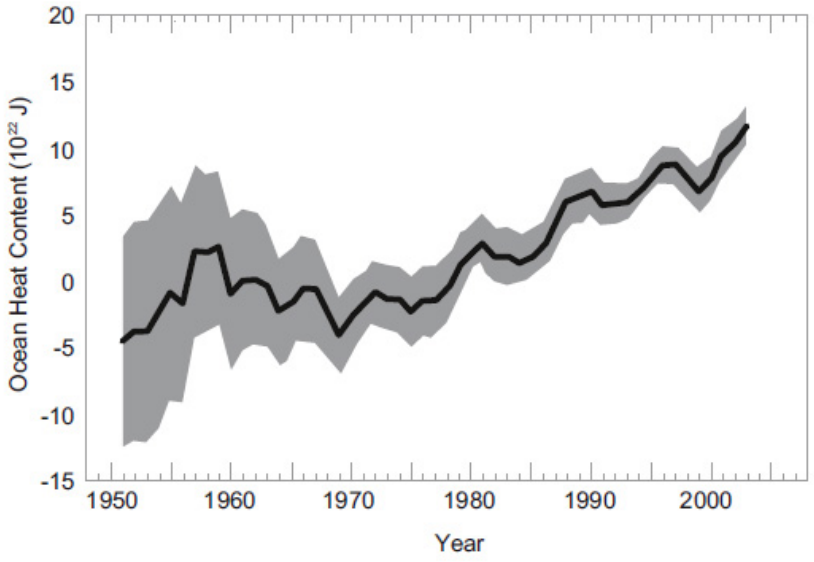
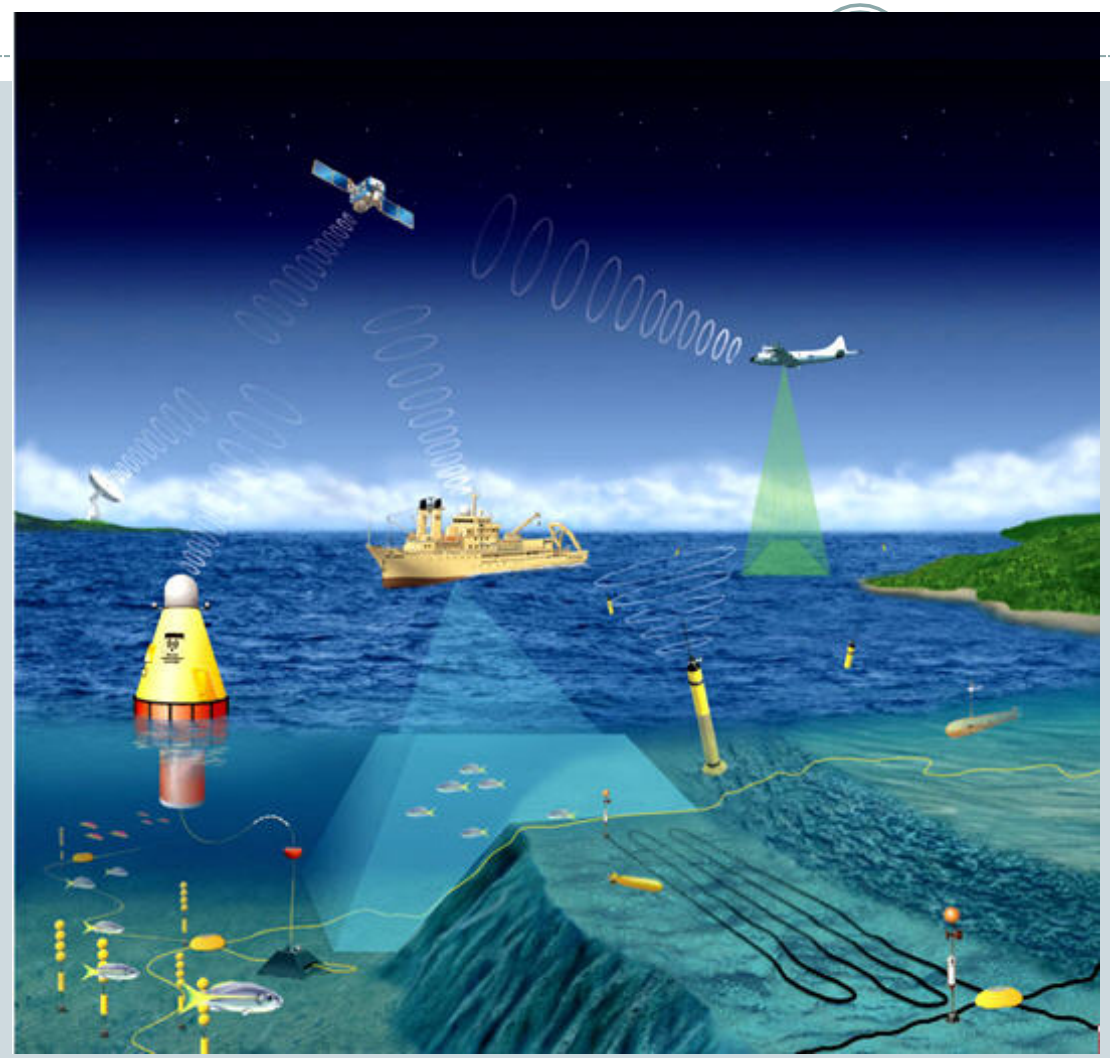


Figure 4
Change in ocean heat content since 1951 (observations - black line) with uncertainties (in grey shading), relative to the ocean heat content in 1961[4].

Ocean heat content has been steadily increasing in recent decades

How do we know this?

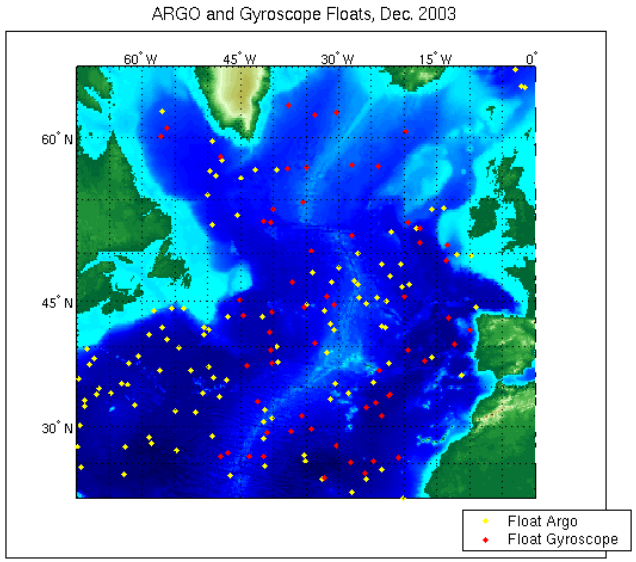
Monitoring the ocean

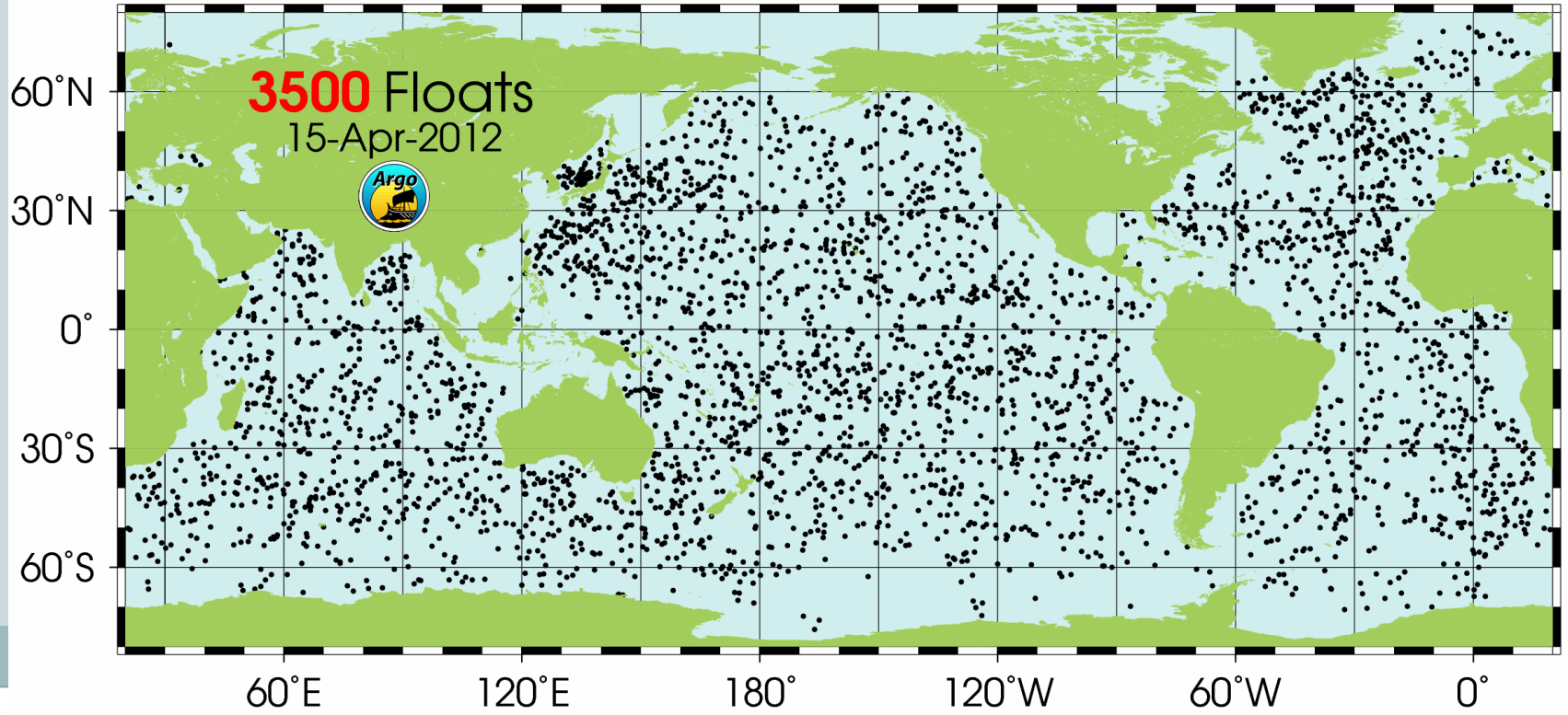


Many instruments are used to measure **ocean heat content**

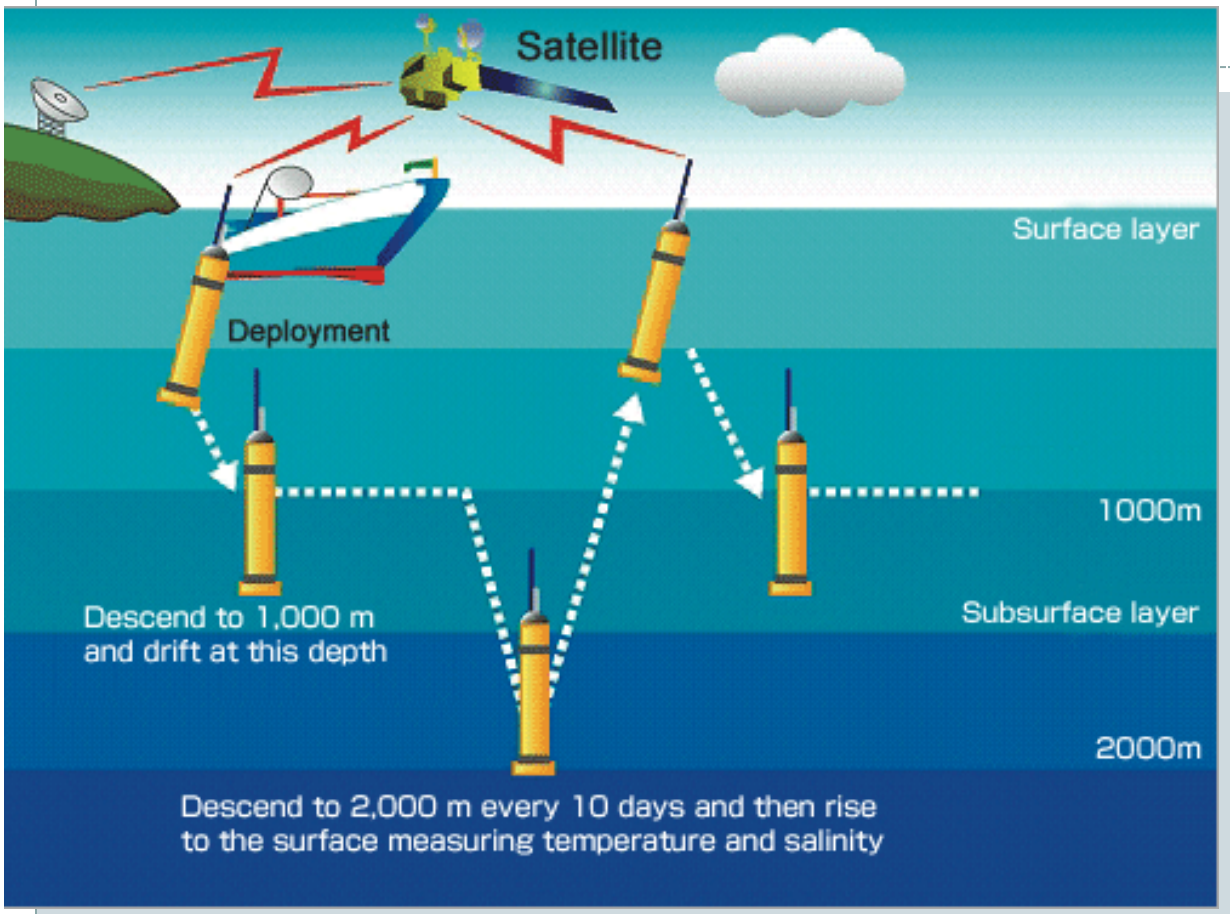
Argo floats

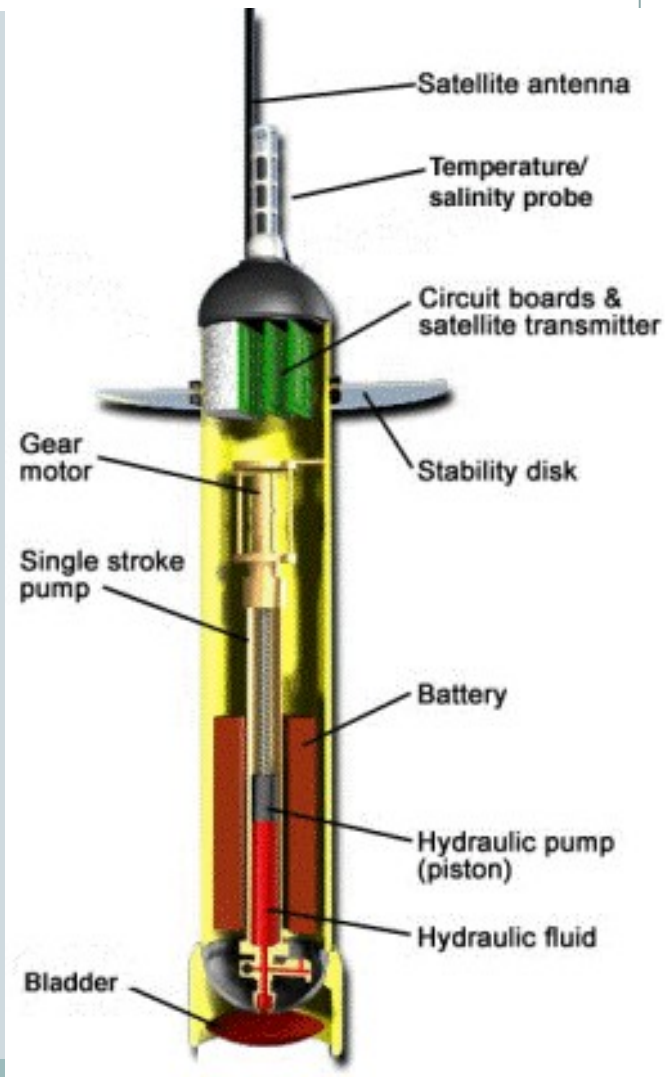
Stephen Riser,
UW Oceanography





Monitoring the **ocean heat content**





Argo floats, since ~2000 measure to 2000m depth

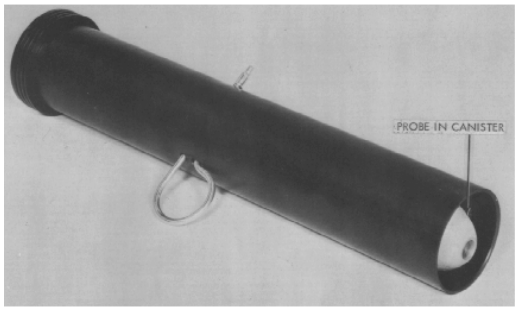
Monitoring the **ocean heat content**

Expendable Bathythermographs (XBT)

About 70 Voluntary ships toss them overboard

14,000 each year (they are cheap, even these figures are ugly)

measure down to 1500 m, in use since 1962



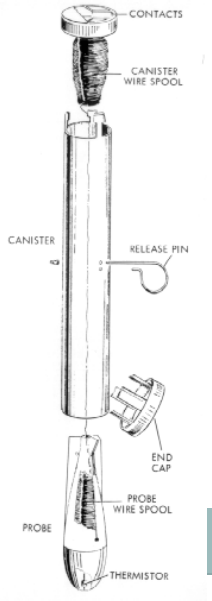


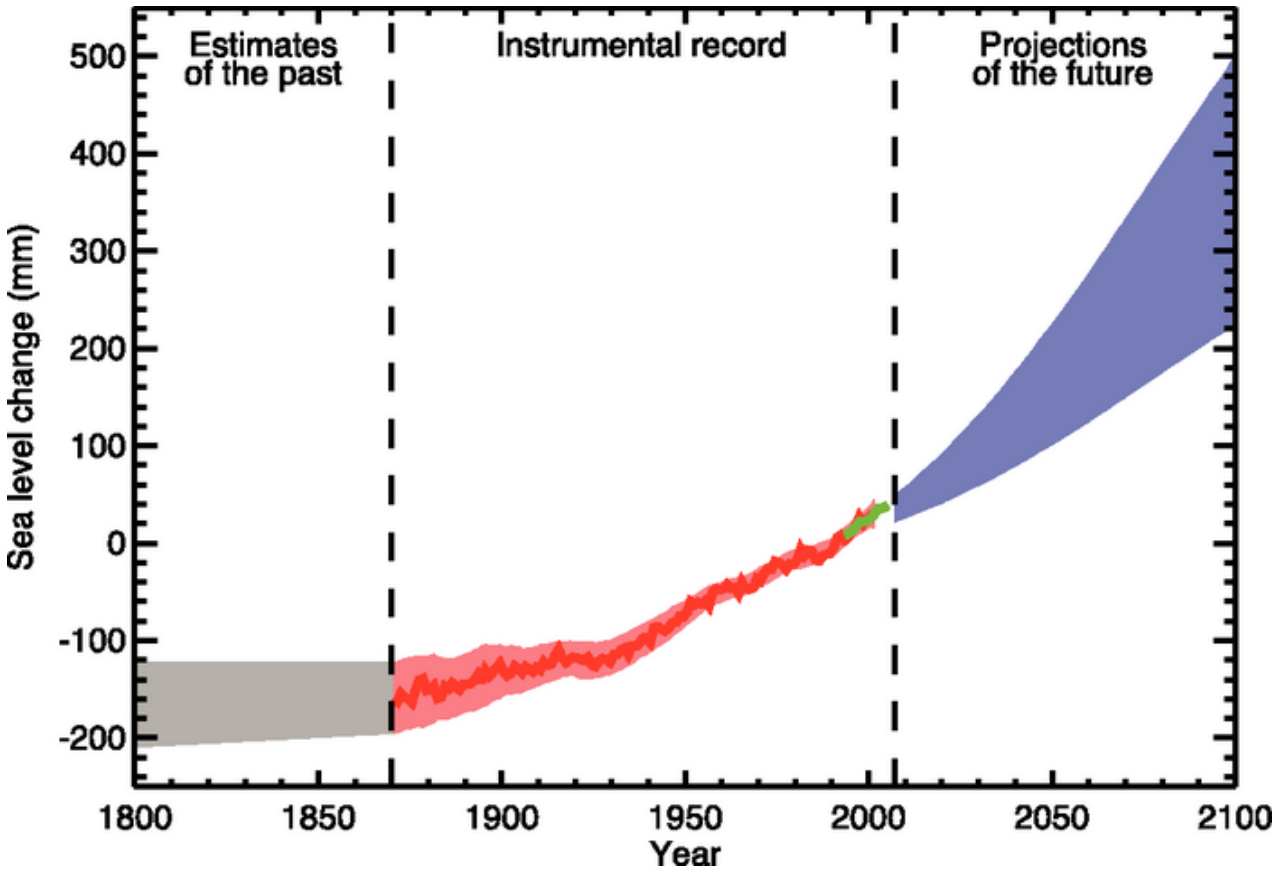
Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.

Ice Contributions to Sea Level Rise

Mountain glaciers currently contribute 25% to rising sea levels

Greenland + Antarctica currently contribute 15%

What will sea level be by the end of the 21st century? Estimate from **IPCC Report**



20-50 cm (8-20”) for 3 intermediate scenarios

But had no increase in **calving** from Greenland and Antarctica!

Criticized by James Hansen

IPCC AR4

More Recent Estimates of Sea Level Rise

- Some recent estimates **including** increases in **calving**:
  - **0.5 to 1.4 m** by considering past SLR to warming dependence with IPCC estimates of future warming (Rahmstorf 2007)
  - Accelerated but plausible dynamic thinning could give **0.8-2 m** (Pfeffer et al 2008)

Speed of Sea Level Rise

- Sea level rise is a **very slow** process
  - Takes an **extremely** long time to melt Greenland/Antarctica
    - In the long term, ice sheets will be the main problem, but this will take **centuries to happen**
    - We're closely monitoring for any surprises due to calving (extra ice breaking off)
- What places are most vulnerable to sea level rise?

Population Distribution

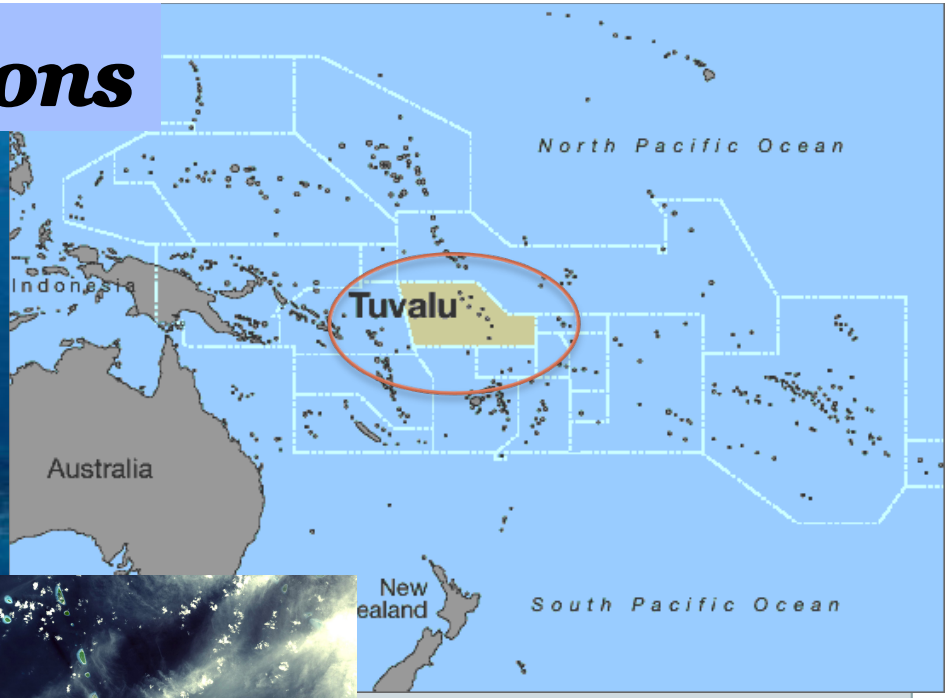
11 of the 15 largest cities in the **world** are along coasts or estuaries

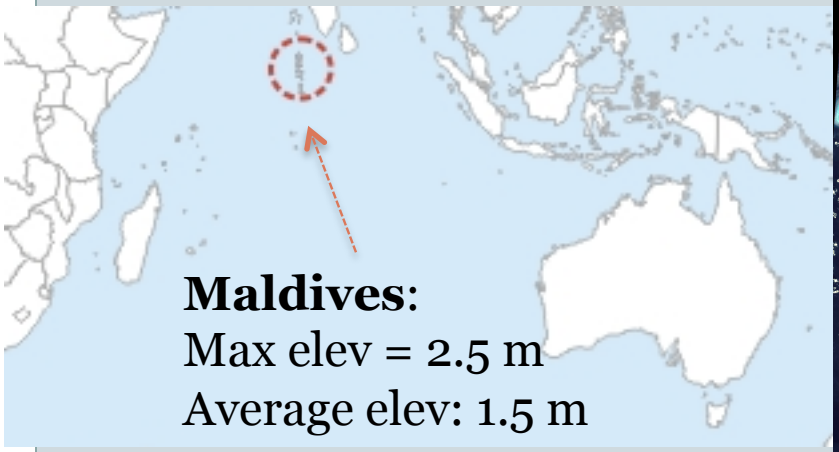
"It was estimated that in 2003, approximately 153 million people (**53 percent** of the nation's population) lived in the 673 **U.S.** coastal counties, an increase of 33 million people since 1980."

The population living within 1 m of sea level is unknown

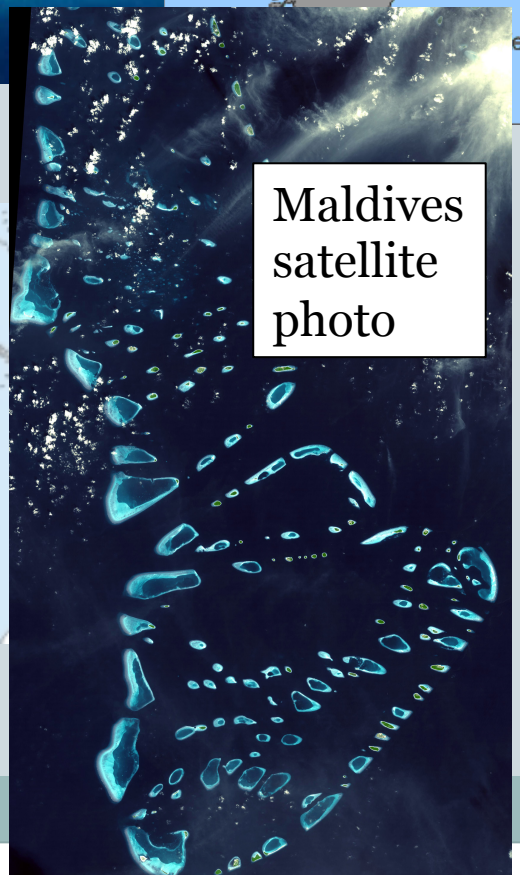
Low Lying Island Nations

Tuvalu: highest point is **4.5 m** above sea level





Maldives:
Max elev = 2.5 m
Average elev: 1.5 m

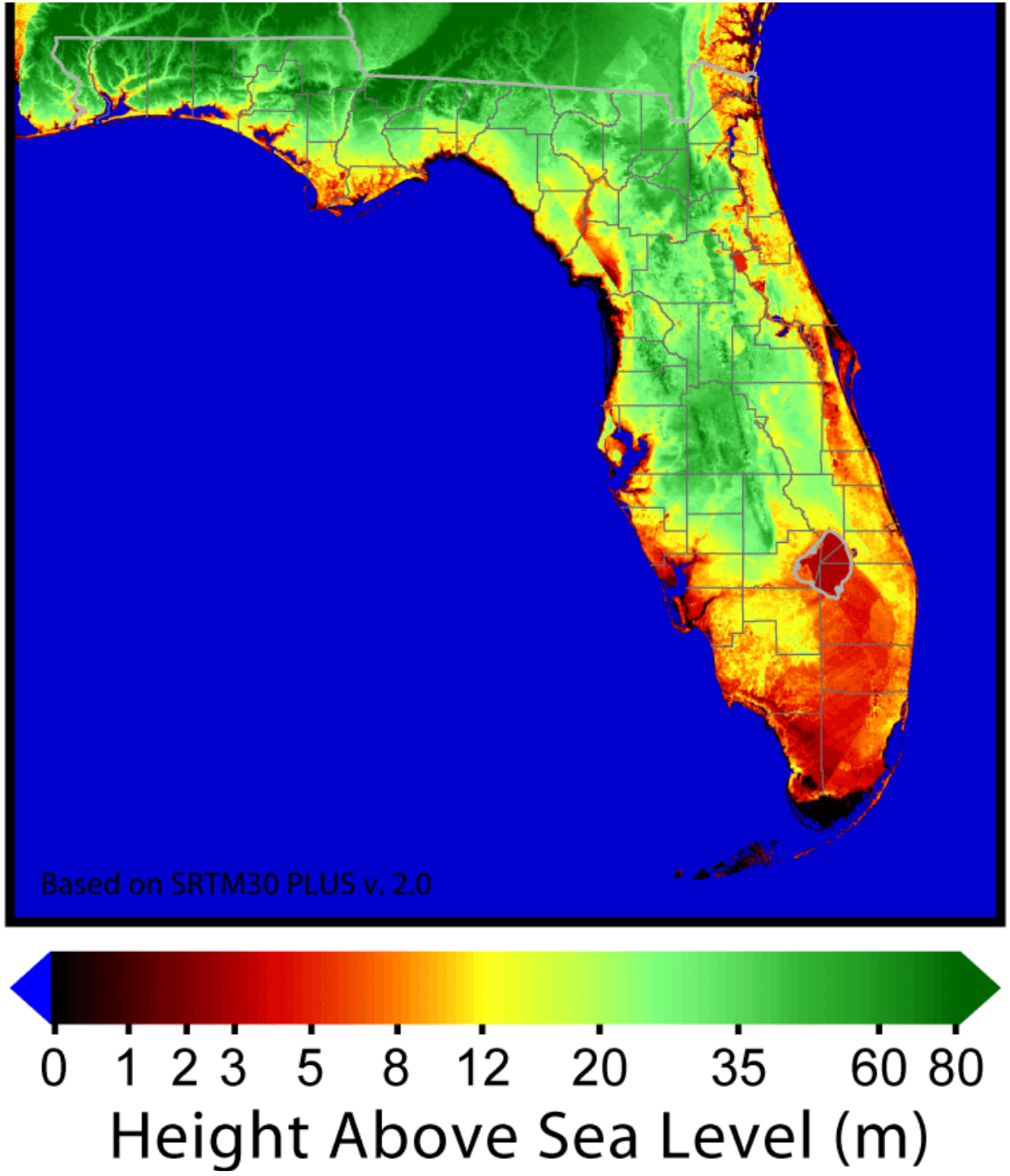


Maldives satellite photo

Some **Caribbean** nations are also quite vulnerable

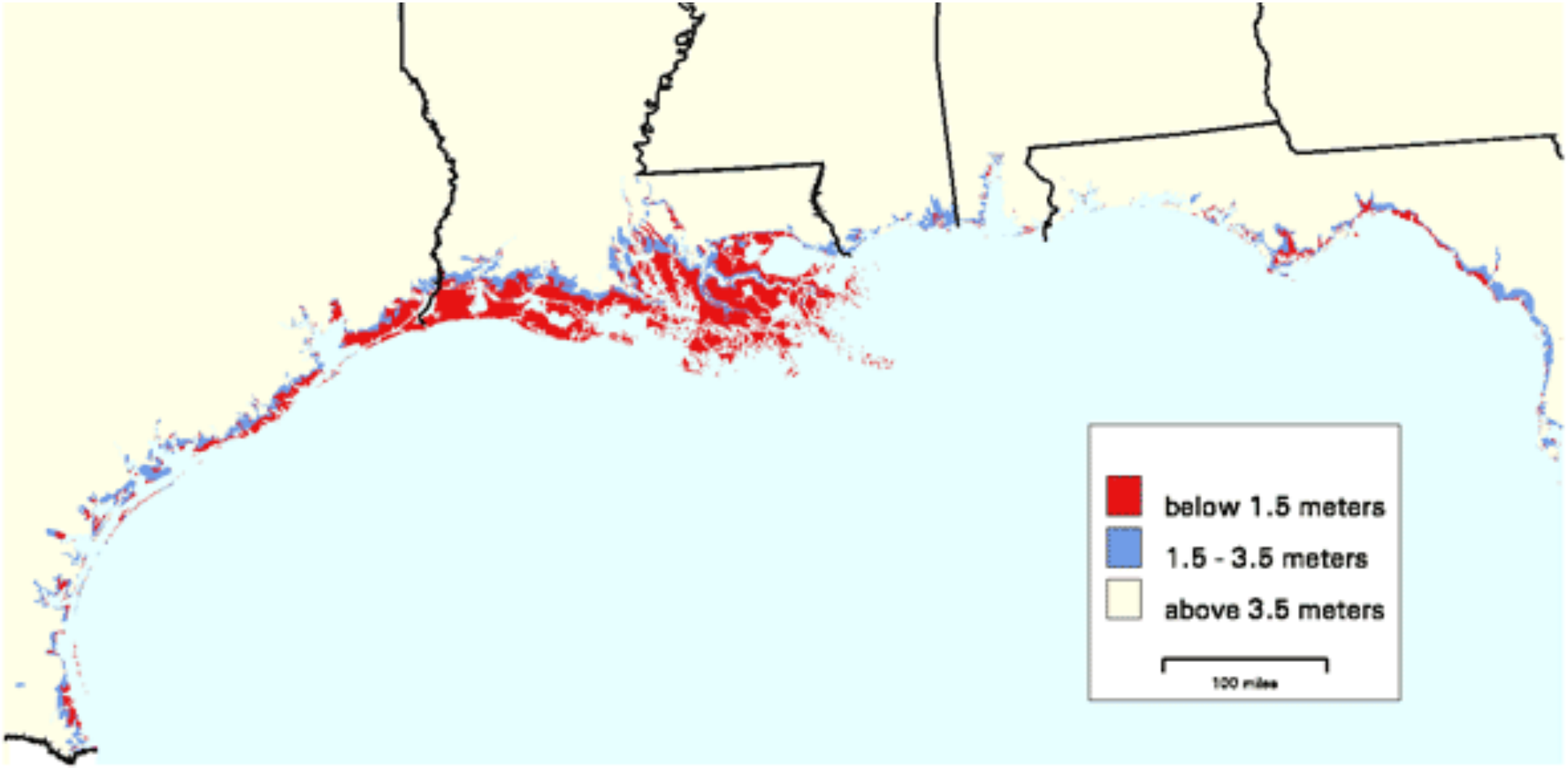
Bahamas: 80% within 1.5 m of sea level

These nations could [disappear](#)!



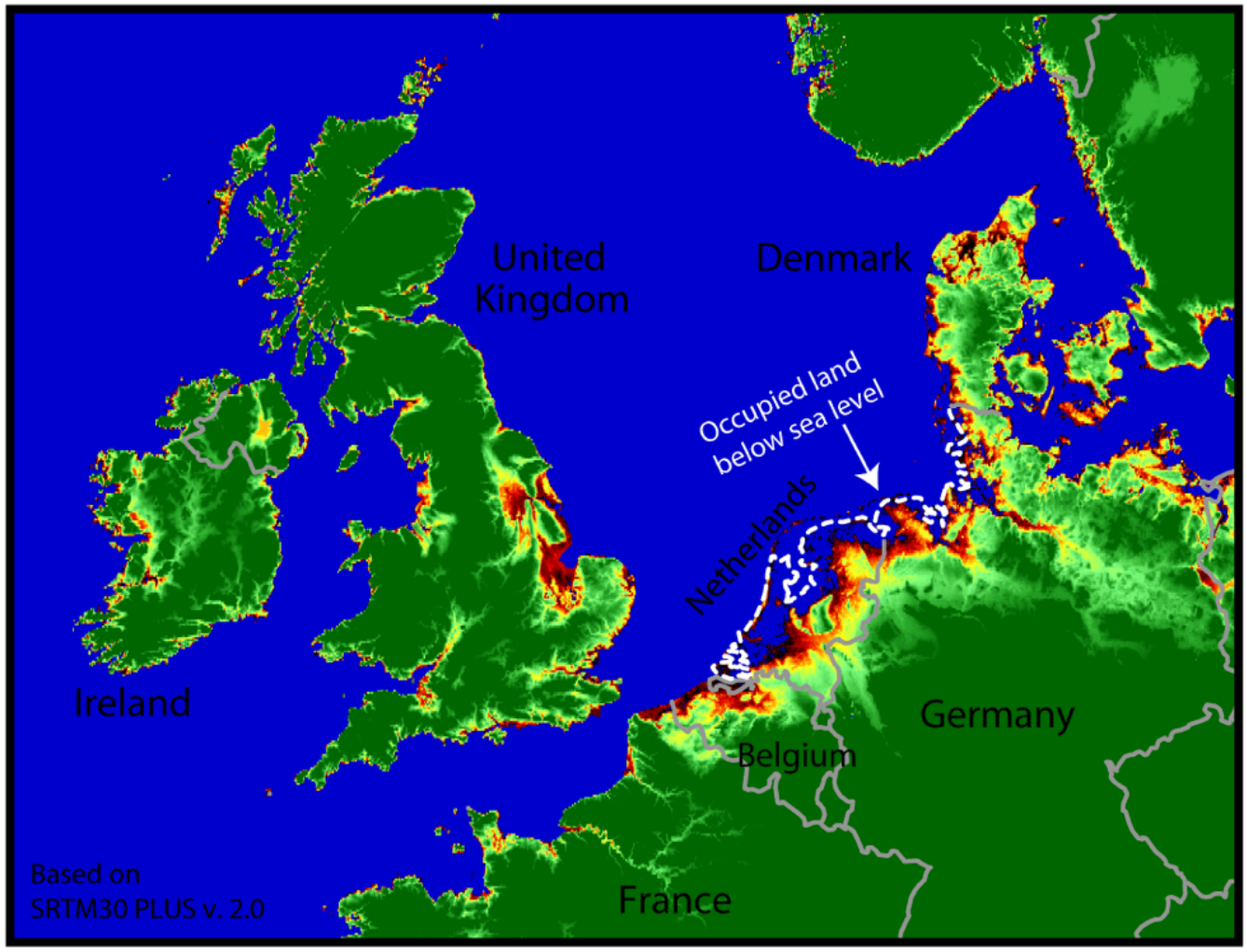
$30 billion of taxable property within 3 feet of high tide level in FL (not including Miami-Dade County)

Source:
Surging Seas Report



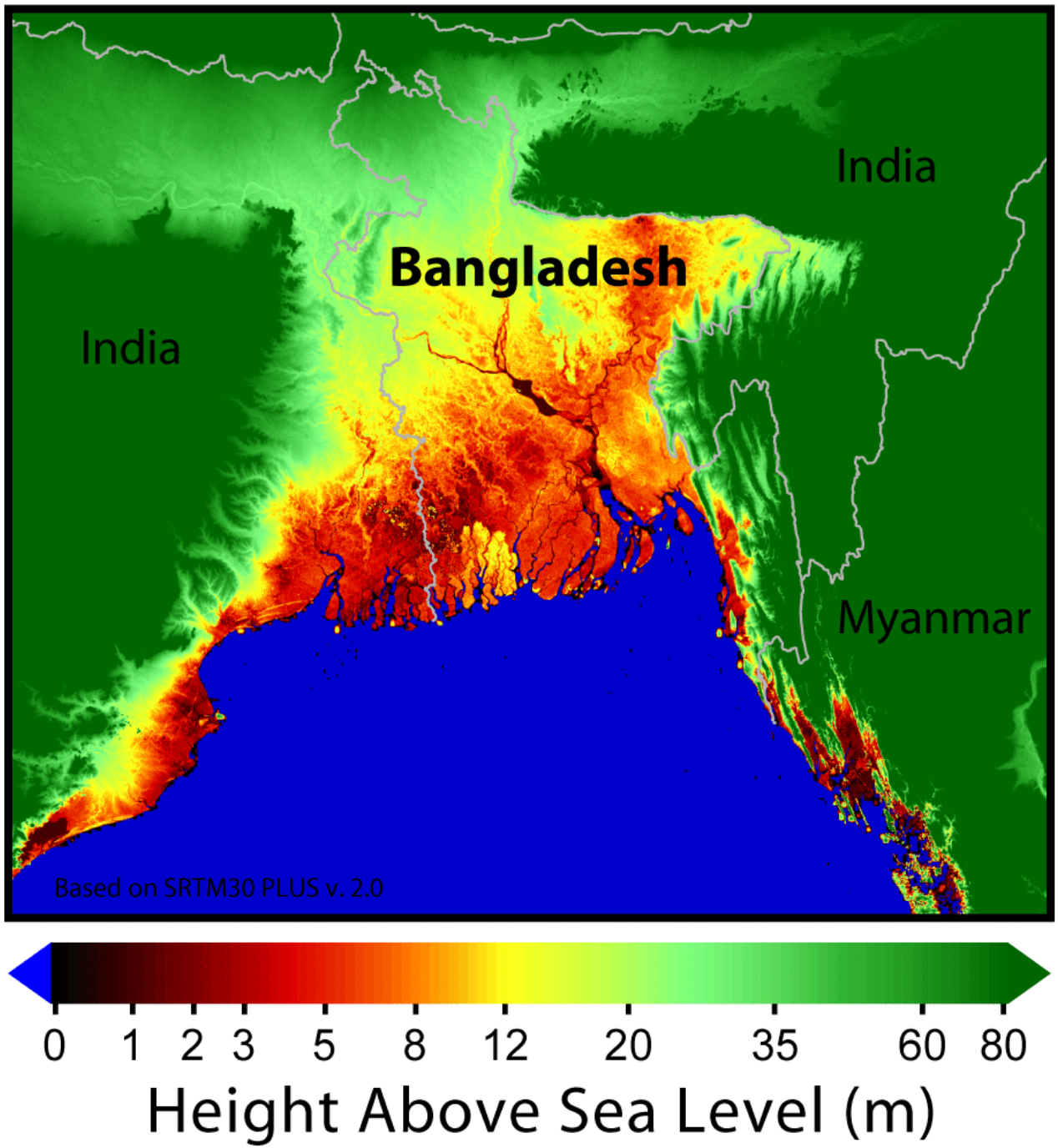
[Climate Central analysis]

Sea Level Risks - North Sea



Height Above Sea Level (m)

Sea Level Rise - Bangladesh



Costs of Sea Level Rise

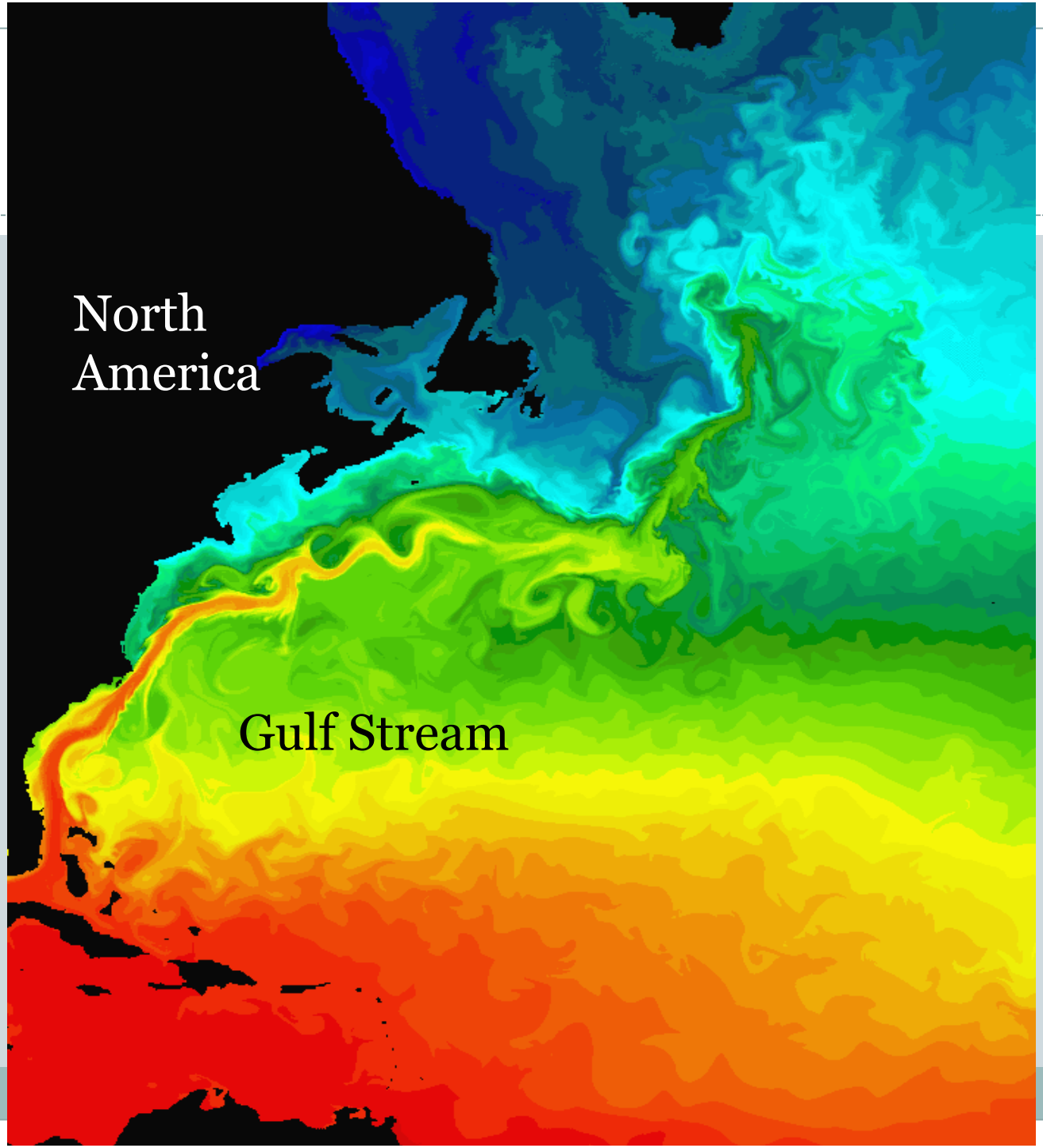
- Main problems will likely be from large storm surges on top of the sea level rise

- Costs:
  - Wetland loss
  - Salinization of aquifers/crops
  - Constructing barriers
  - Relocation

How Might Ocean **Circulation** Change?

- Will currents change?
  - We'll discuss the **thermohaline circulation**
    - And why claims of **Europe freezing over** with global warming are **overblown**
  - And El Niño
    - El Niño cycles are the most important **natural** climate variation

The Gulf Stream transports heat



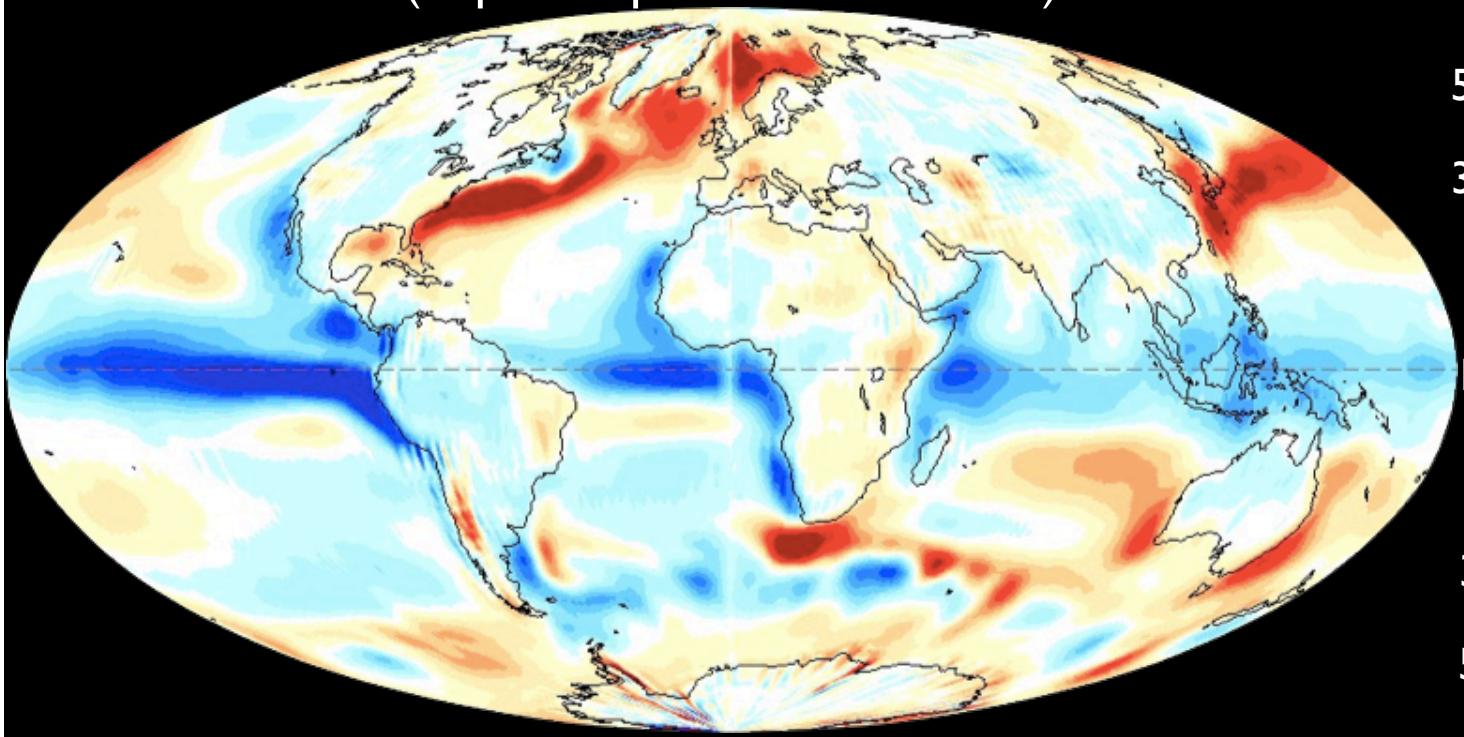
It's driven by winds and is **not subject to stopping**

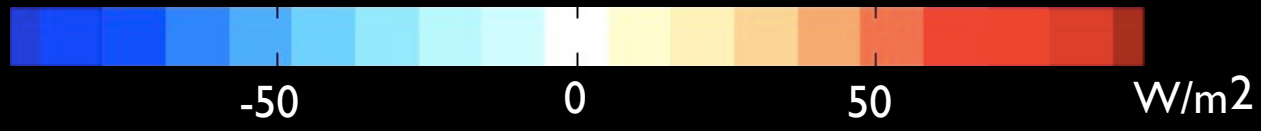
Colors show Temperature

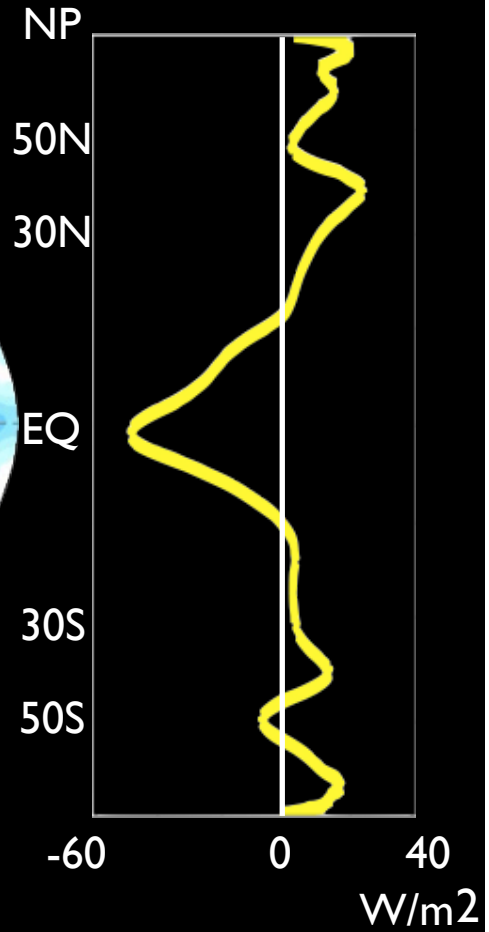
AVHRR satellite

Surface Flux (Ocean to Atmos)

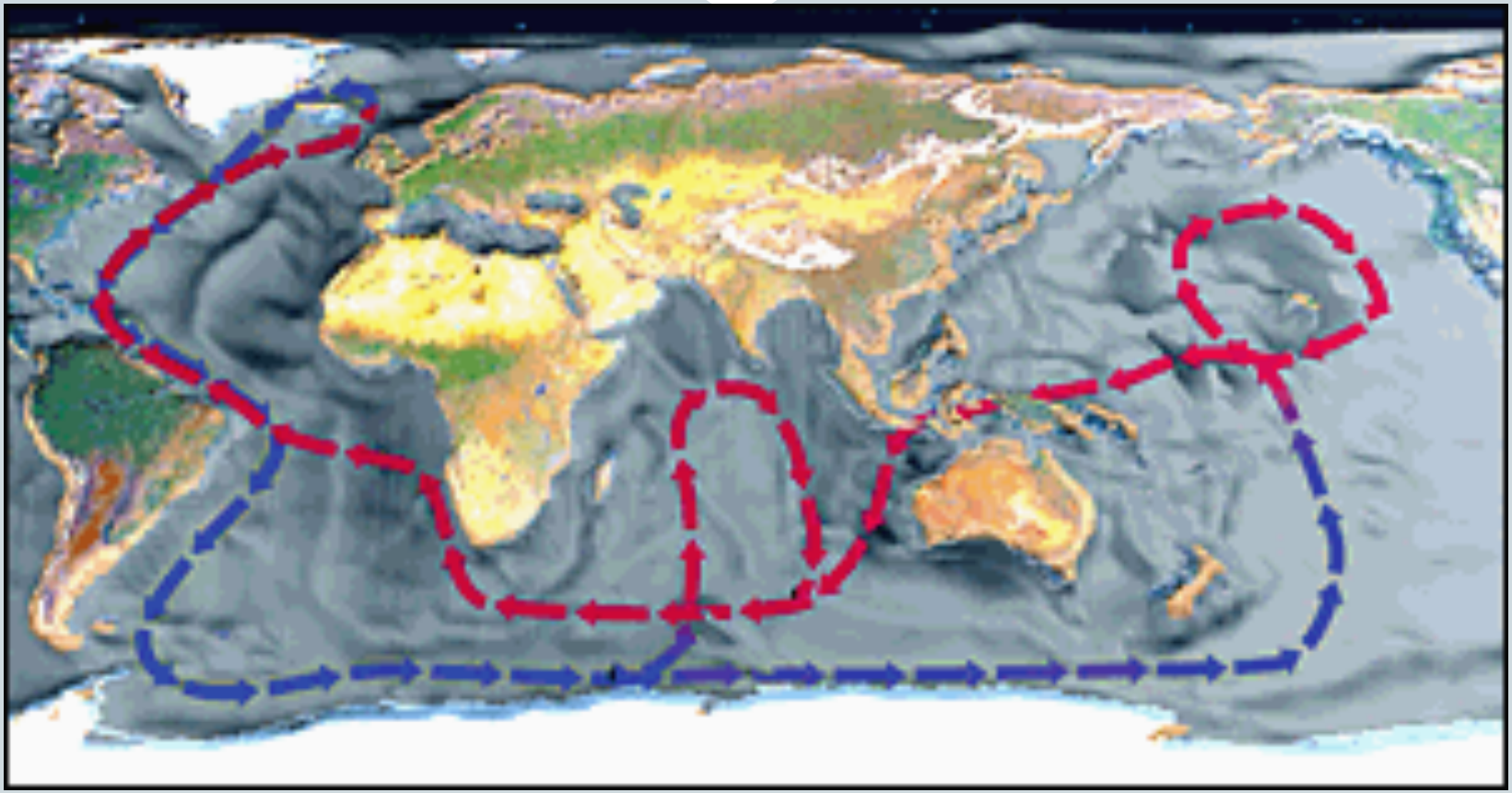
2001~2010 ERA-I MSE Divergence minus
CERES TOA Budget
(Implied Upward Surface Flux)





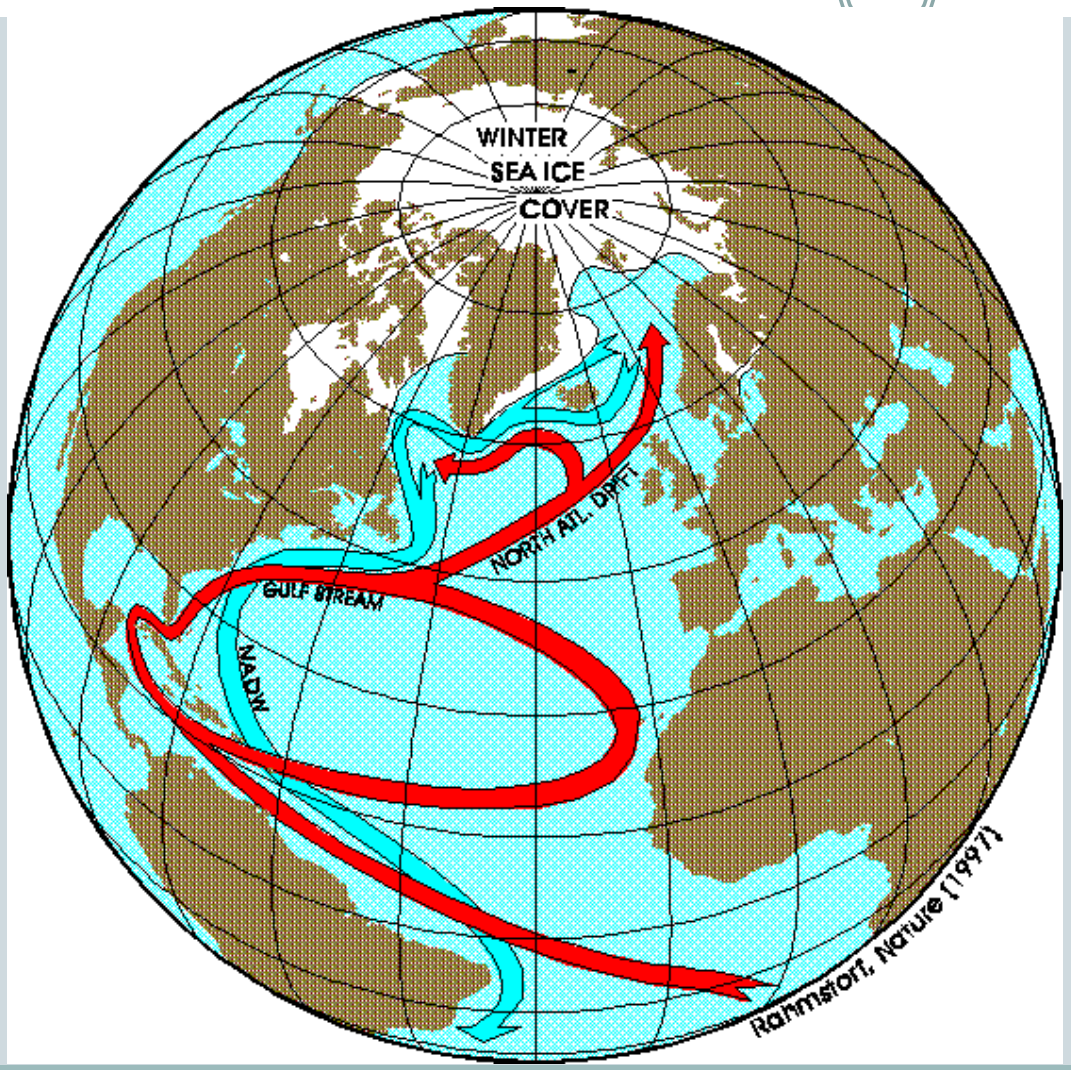


Thermohaline circulation, driven by heavy water sinking, also moves heat



This **could slow down** with global warming…

Atlantic circulation



North Atlantic Drift:
Part of thermohaline circulation driven by sinking of dense water near Greenland

Circulation could slow as surface water gets **warmer** & **fresher** at high latitudes (freshening from more rain & melting ice)

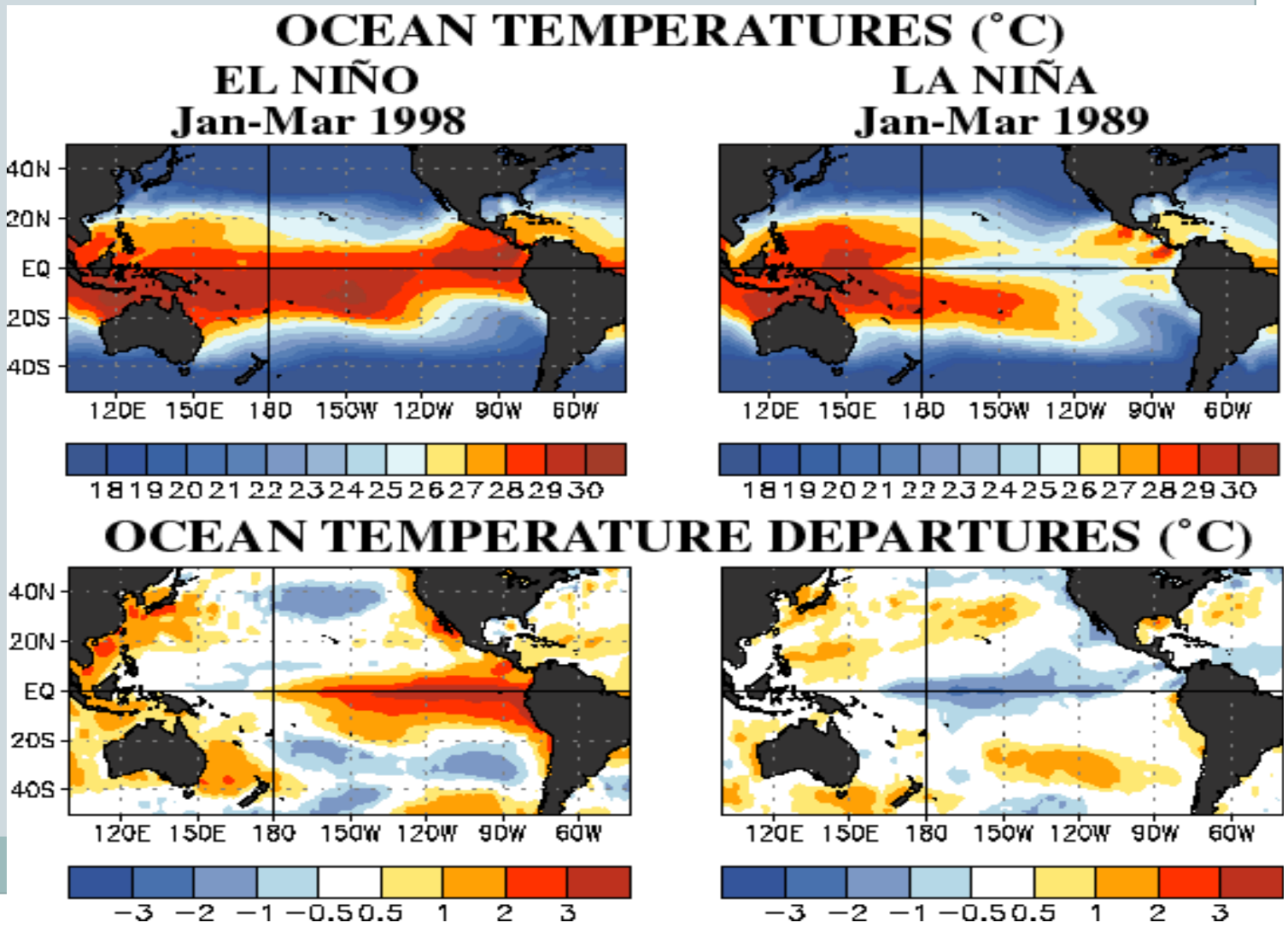
Less dense water → Less sinking → Slower circulation

If this weakened it would cause Europe to warm less

Natural Climate Variability: El Niño

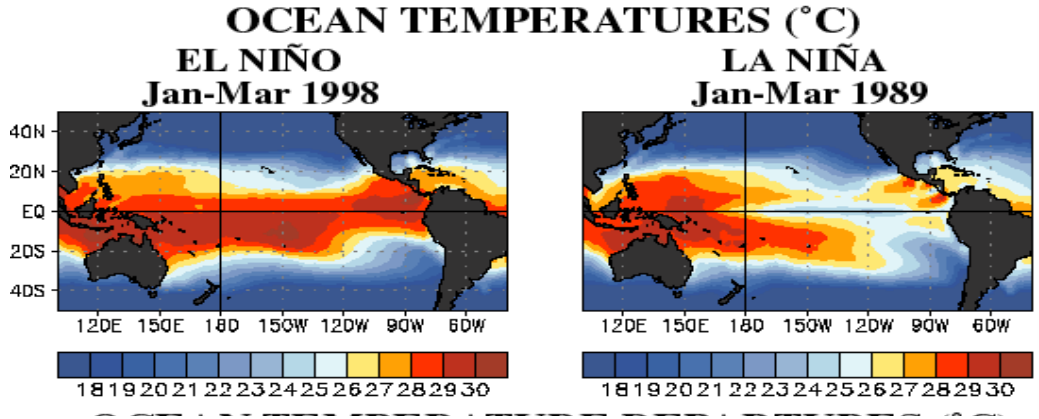
Big warming of **tropical Pacific** during El Niño

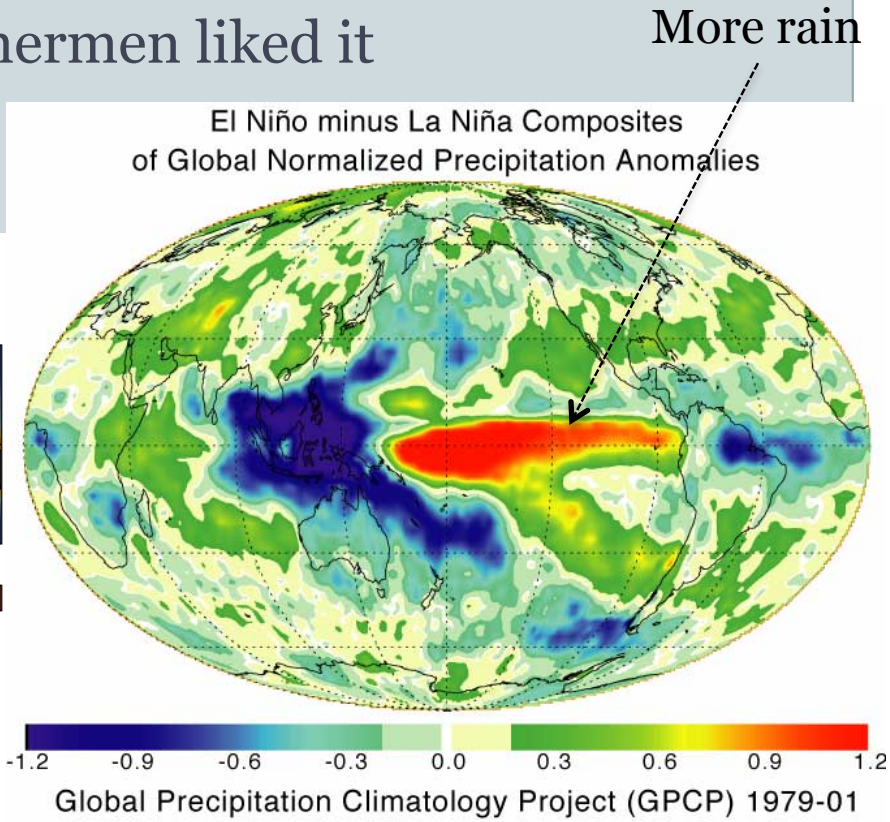
Where would the rising motion shift to?



El Niño Rain Changes

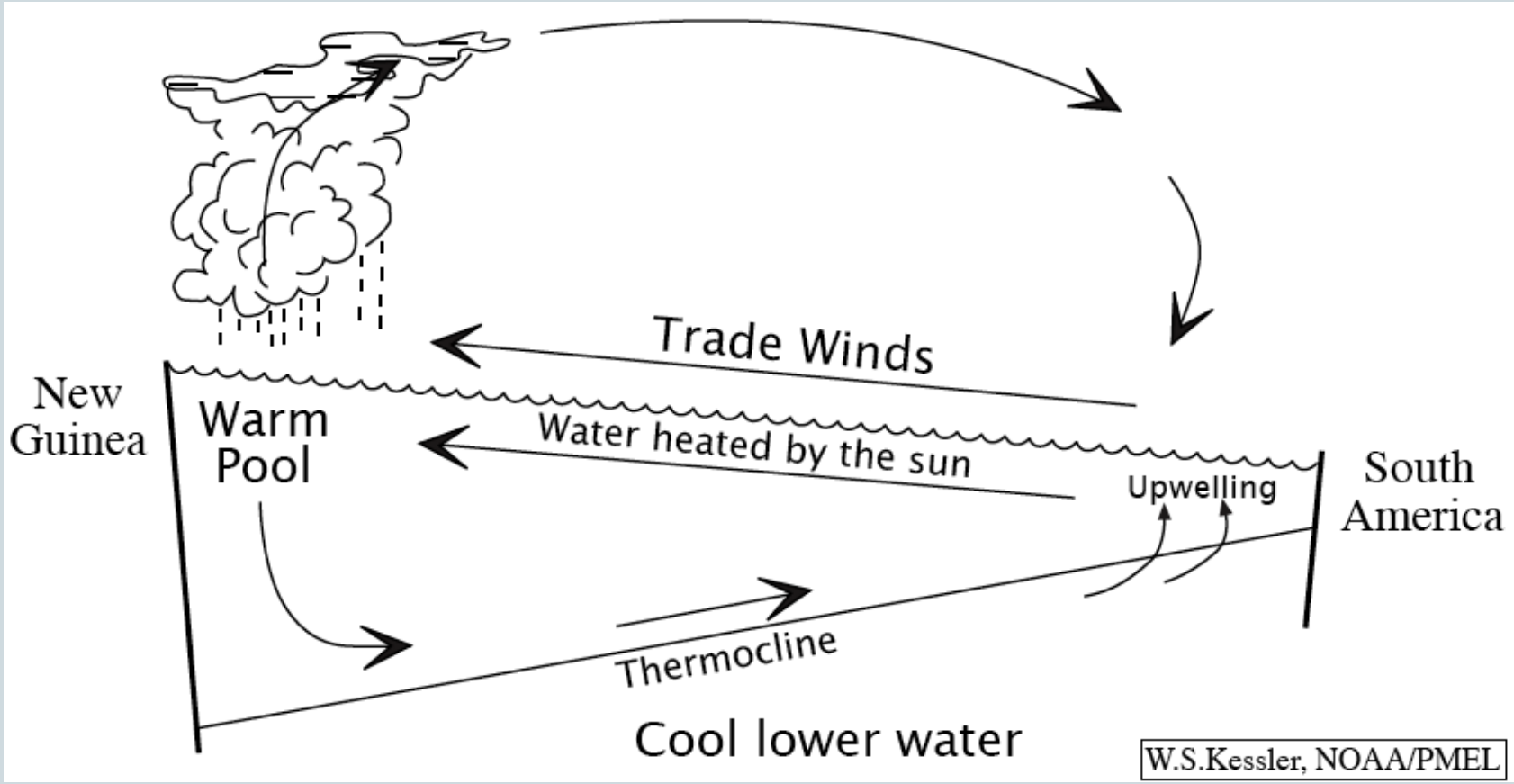
- Rain shifts along with the warmer waters
- Coast of Peru (normally desert-like) becomes very rainy & tropical plants grow
  - It peaks around Christmas & fishermen liked it
    - "El Niño" = the Christ child





El Niño/Southern Oscillation

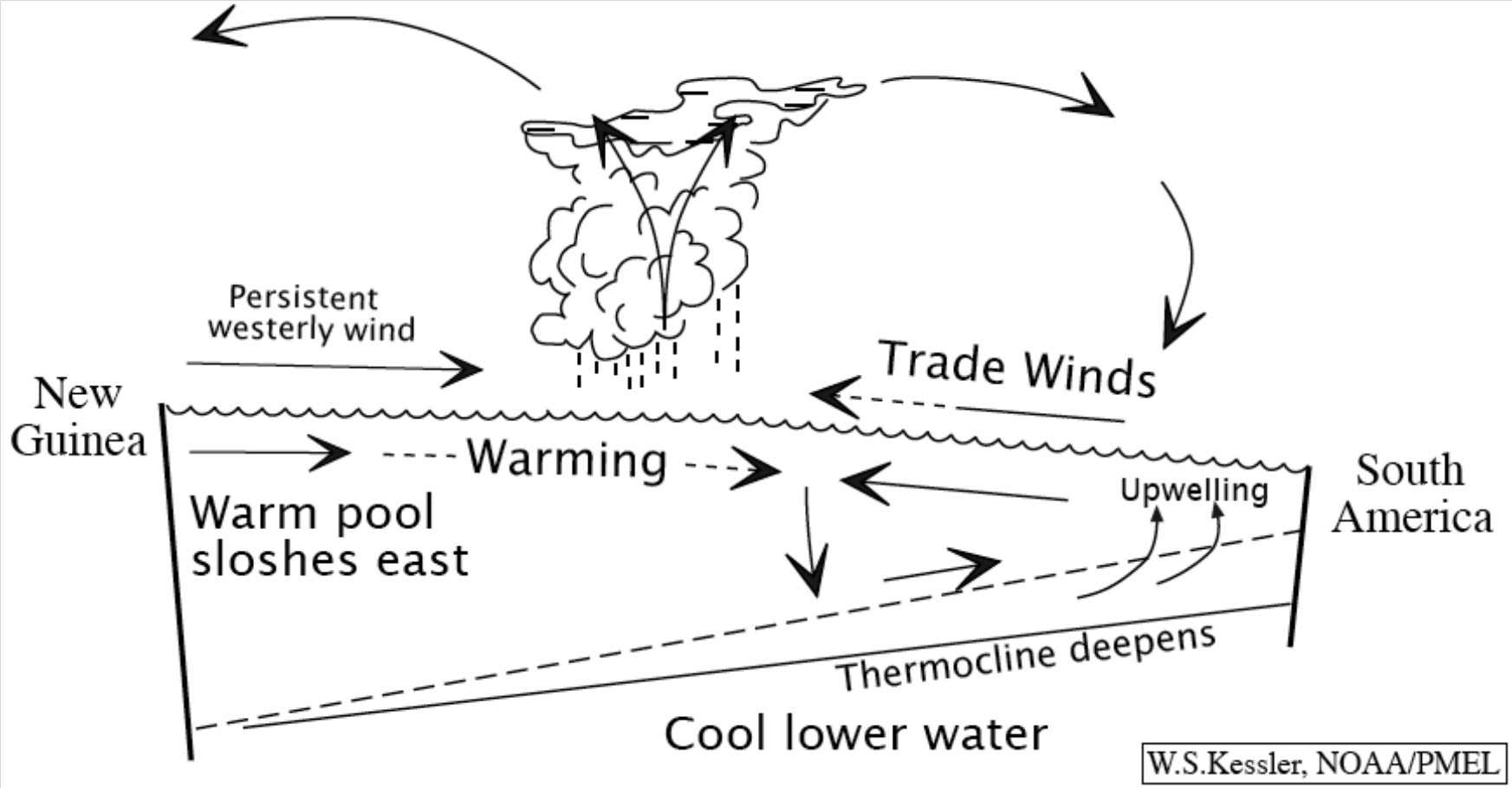
La Niña conditions



Winds keep warm water to the west during La Niña

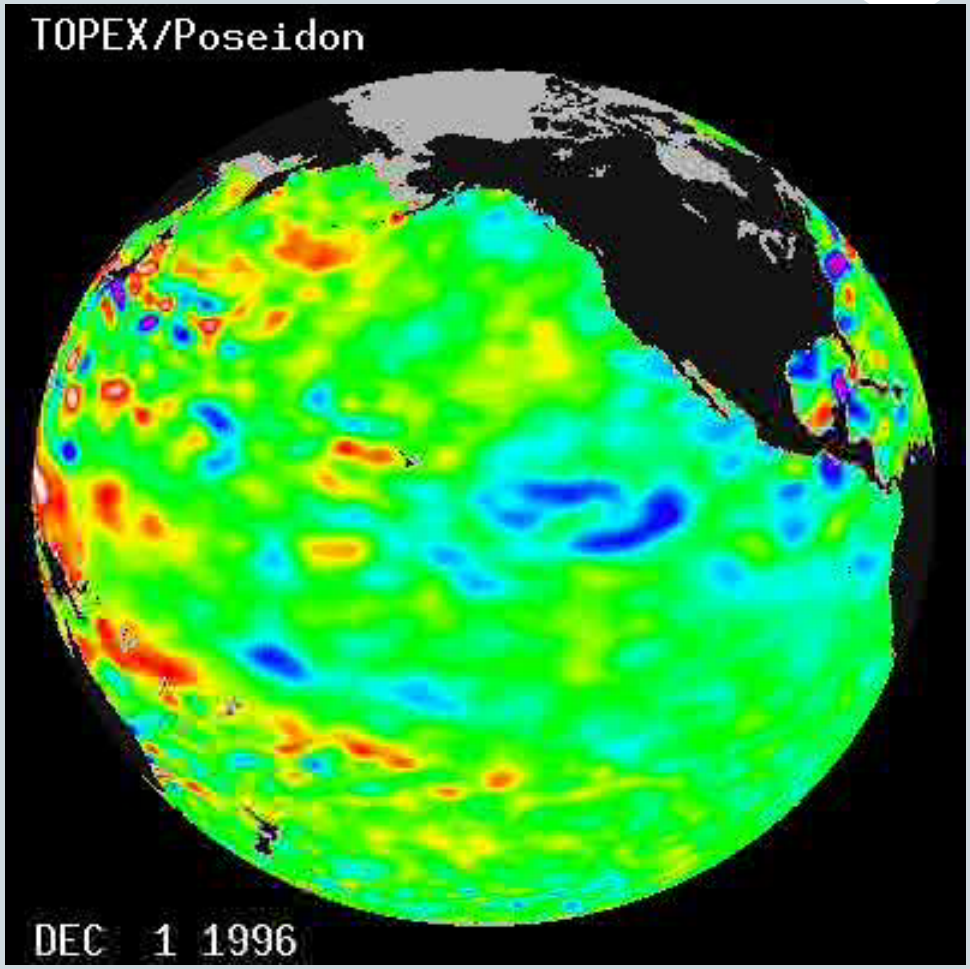
El Niño/Southern Oscillation

El Niño conditions



Winds slacken, and the warm water/rising motion shift into the central Pacific

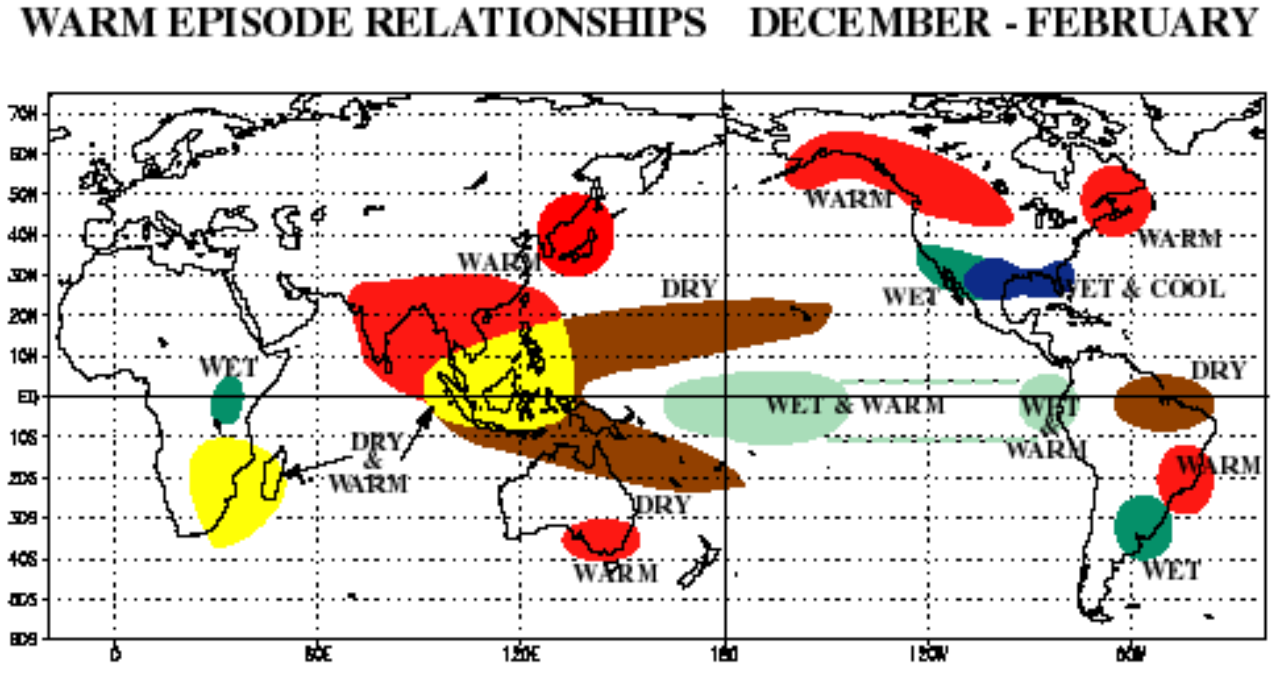
El Niño Onset



Giant scale waves that move exactly on the equator are key for setting El Niño in motion!

Much smaller height changes than typical ocean waves – but huge in scale!

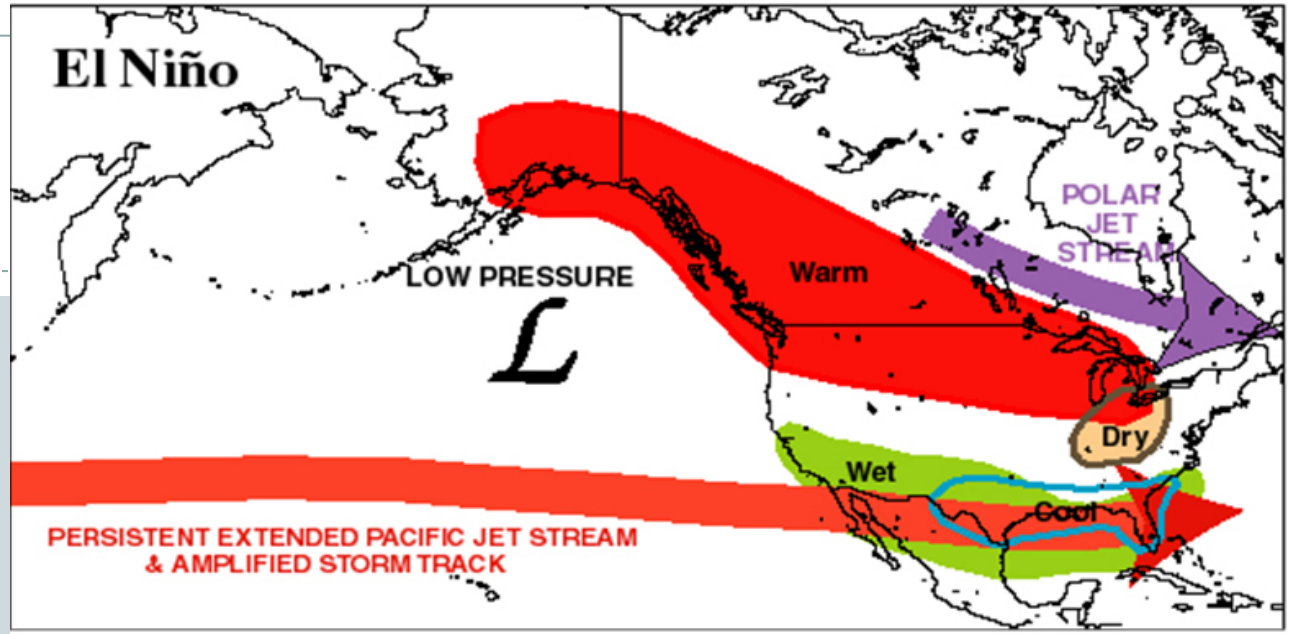
El Niño Impacts

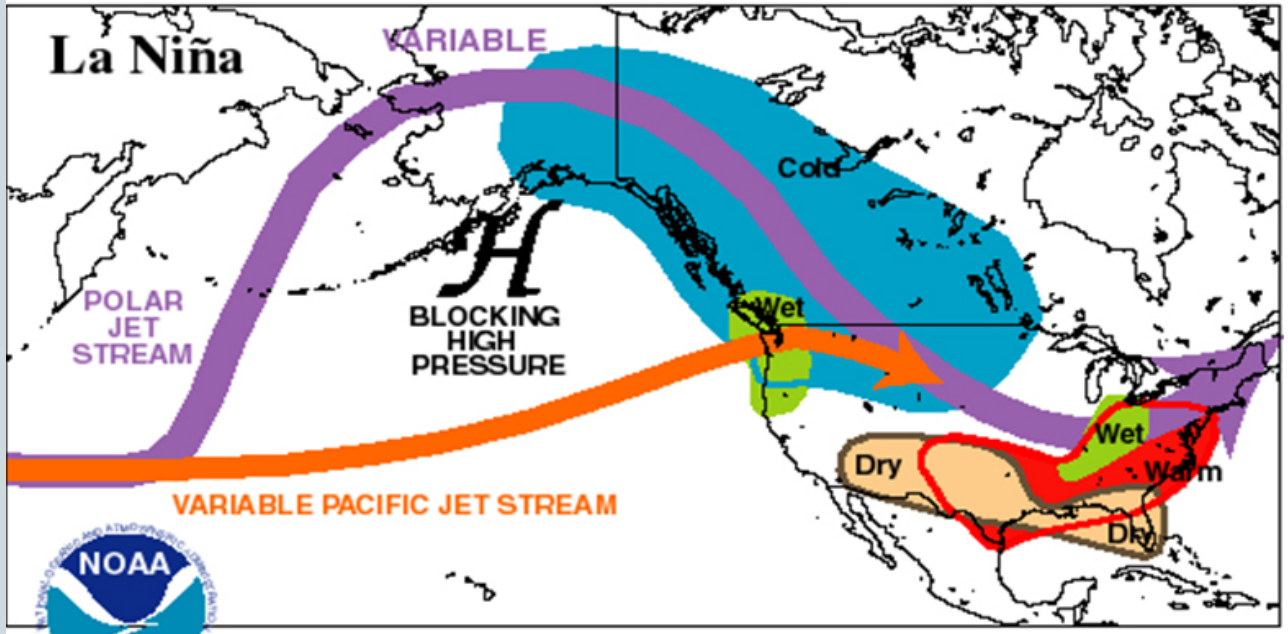


- Drought in India/Australia, floods in S. America
- Pacific NW weather is affected significantly

- La Niña impacts are opposite to this

Another view of ENSO impacts

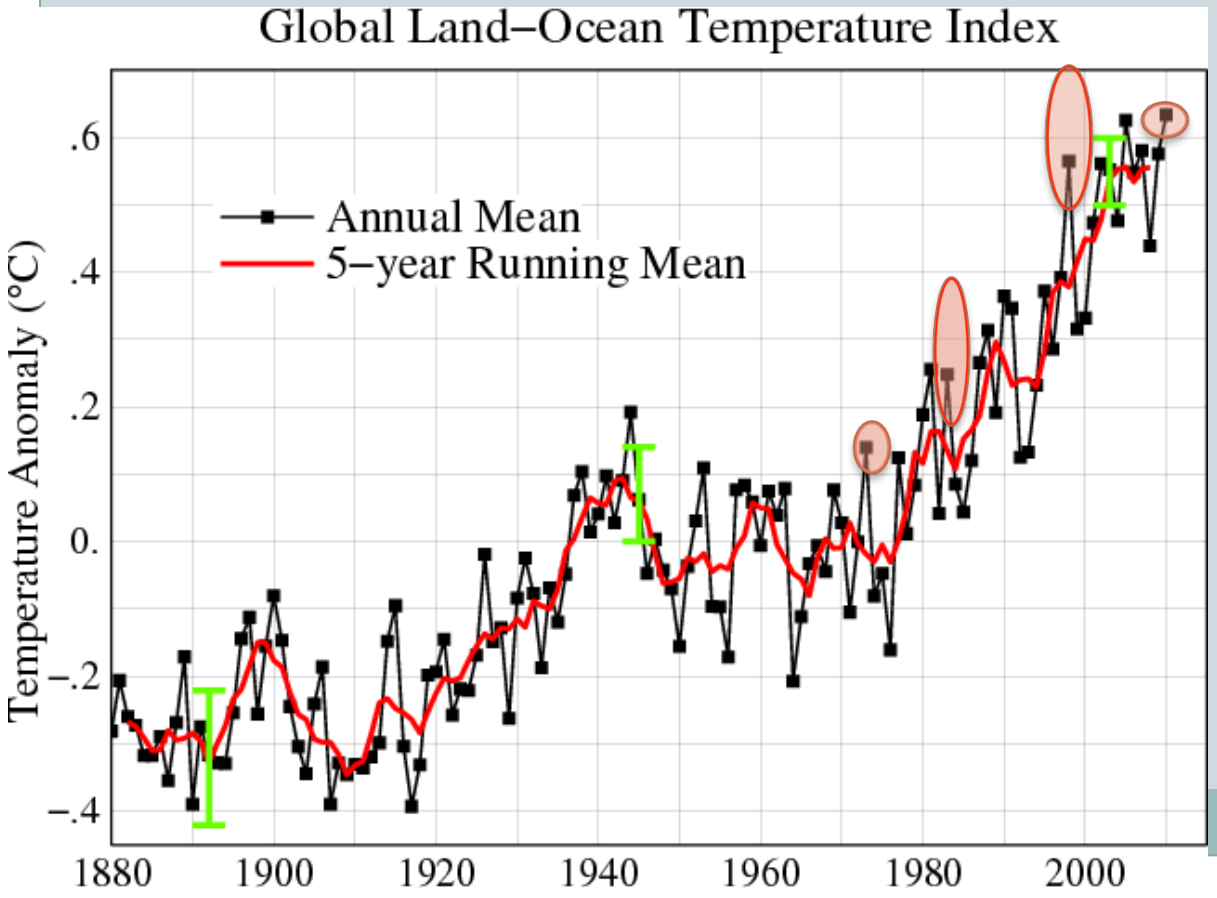




Climate Prediction Center/NCEP/NWS

El Niño Affects Global Temperature

- Much warmer water in the Pacific during El Niño
- Enough to raise global temperature by 0.1-0.2° C

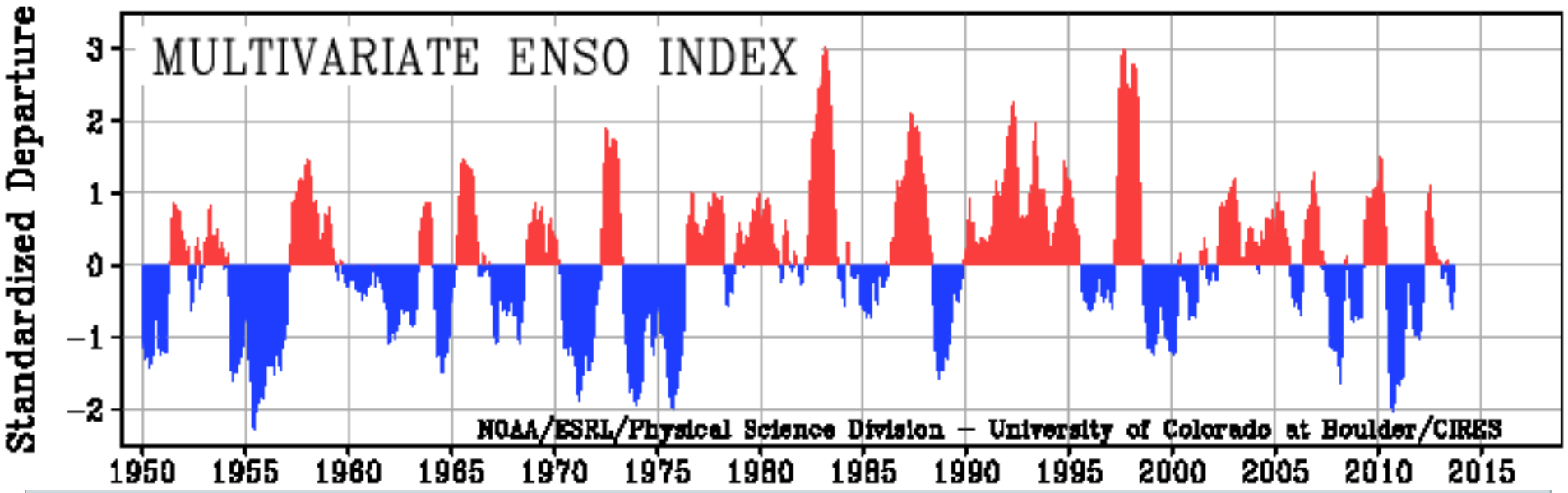


Highlighted years are some recent El Niño events

Big ovals are the **two biggest** events of the century (1982-83, 1997-98)

ENSO Since 1950

- ENSO over last 60 yrs



Future of El Niño

- Very uncertain how El Niño will change in the future
- Could change regional precipitation responses
  - Also strongly affects things like local warming and precipitation

Summary of Ocean Circulation

- Gulf Stream will not slow down
  - It's wind-driven
- North Atlantic Drift will likely slow some
  - This won't freeze Europe, but may cause less warming there
- El Nino/Southern Oscillation
  - Very important for regional precipitation patterns
  - Uncertain how this will change with global warming