ATM S 111: Global Warming
Oceans

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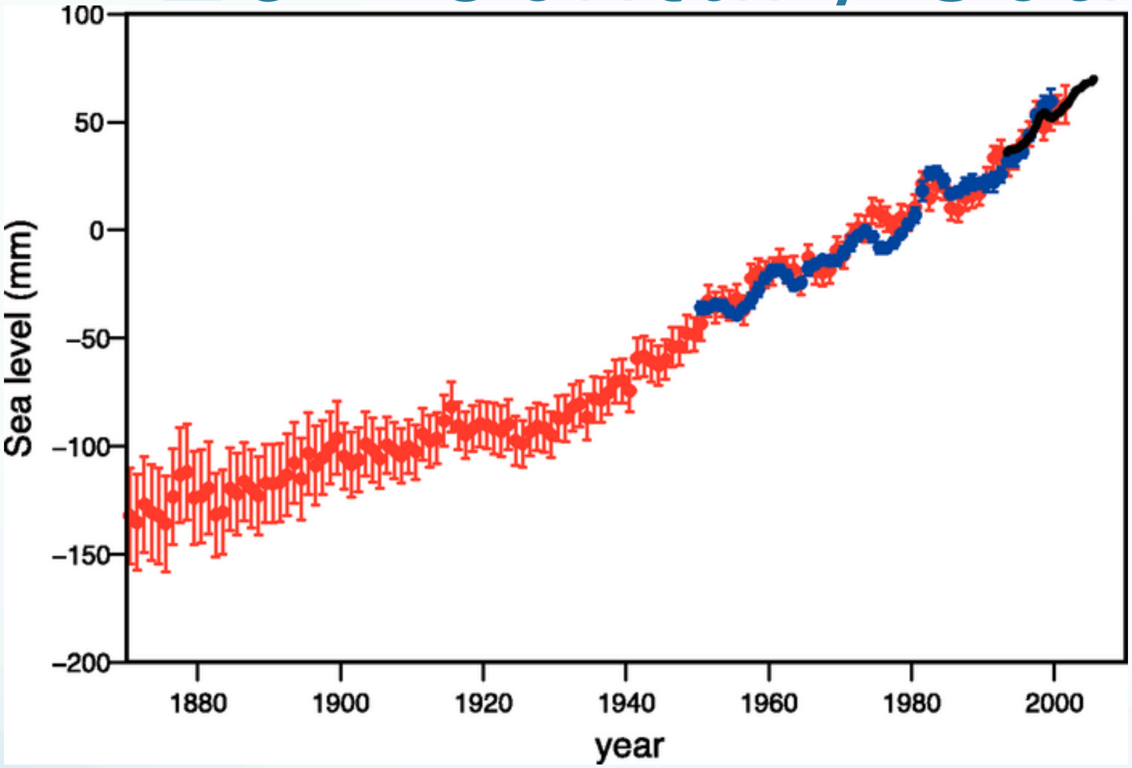
Day 17: July 14 2010

Outline

(Read *Rough Guide* pp. 106-127)

- Sea Level rise
- Will the Atlantic turn cold on Britain? The thermohaline circulation
- Living in a changing sea
- Ocean acidification

20th Century Sea Level Rise



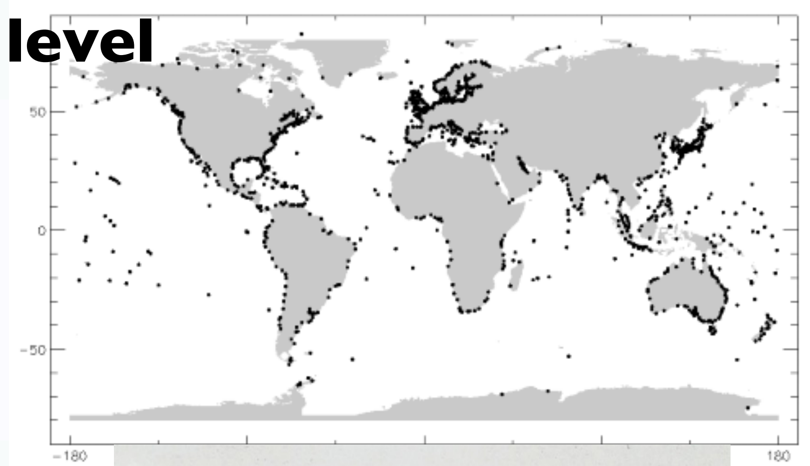
red = "reconstructed" from tide gauges and other sources
blue = tide gauges
black = satellite altimetry

- 20th century sea level rise was 12-22 mm/decade on average

Sea Level Rise

- These **contribute** to sea level rise:
  - **Thermal expansion** of sea water
  - **Mountain glaciers**
  - **Ice sheets** (Greenland and Antarctica)
- 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**
- How is sea level changing? How can we tell?

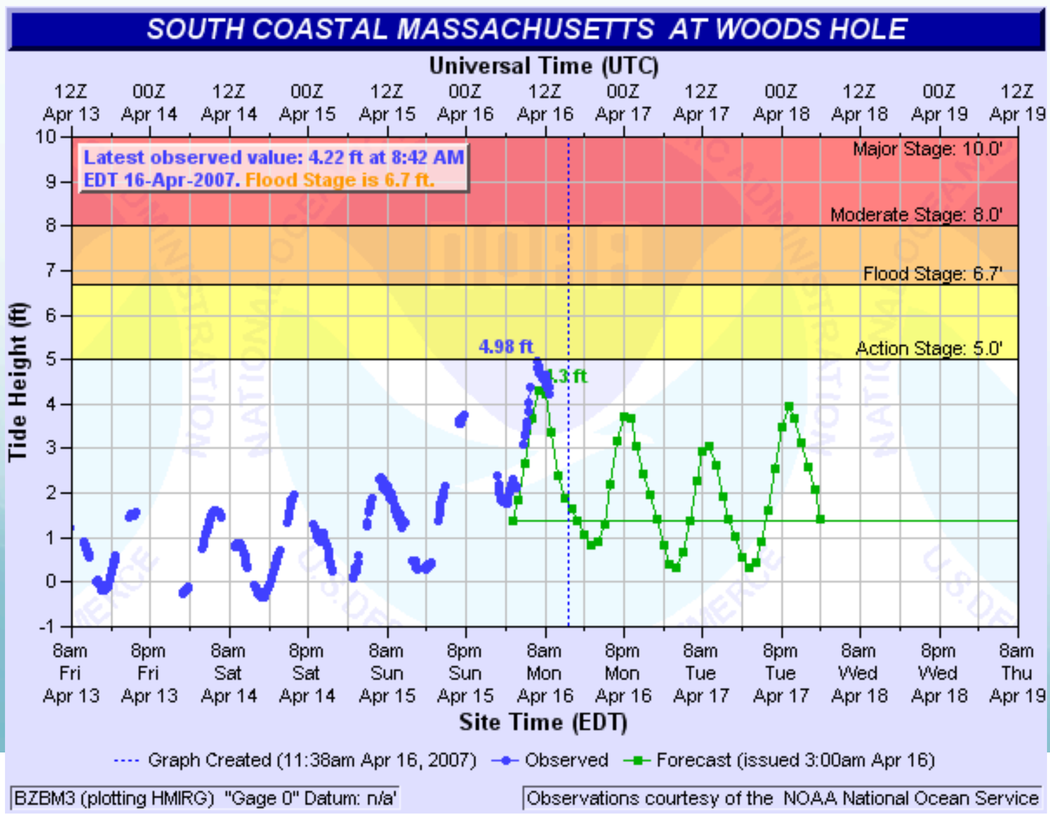
From sticks to satellites: measuring **sea level**



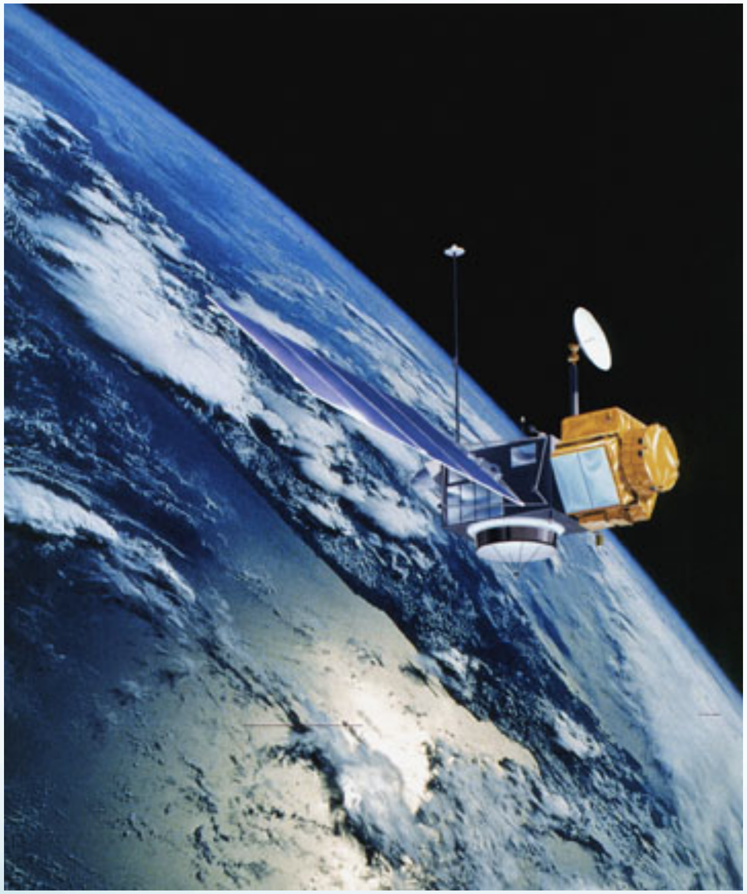
Tide gauges are measuring sticks or sometimes floats in wells

Always coastal

Few long records



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

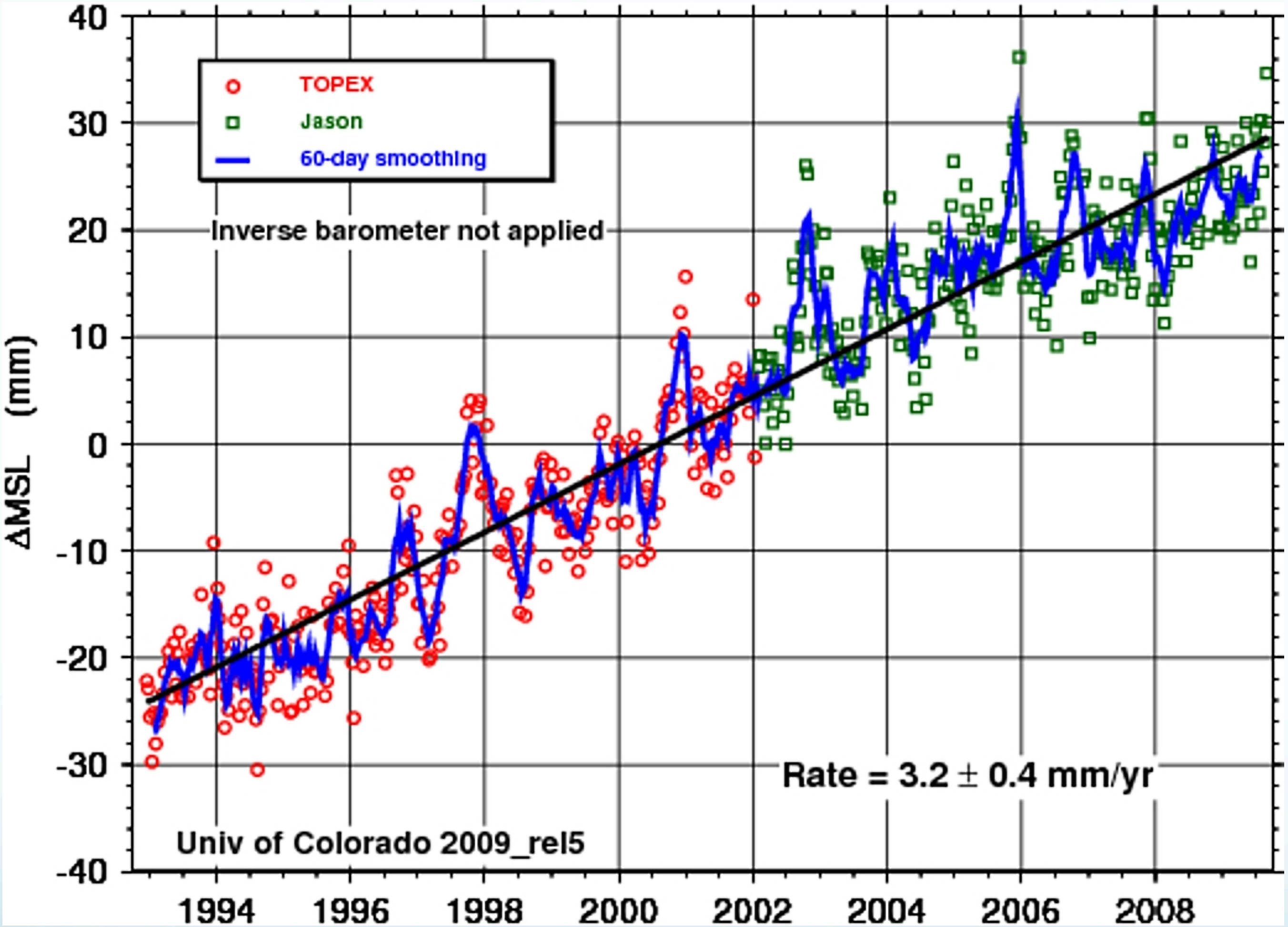


TOPEX-Poseidon Radar Altimetry

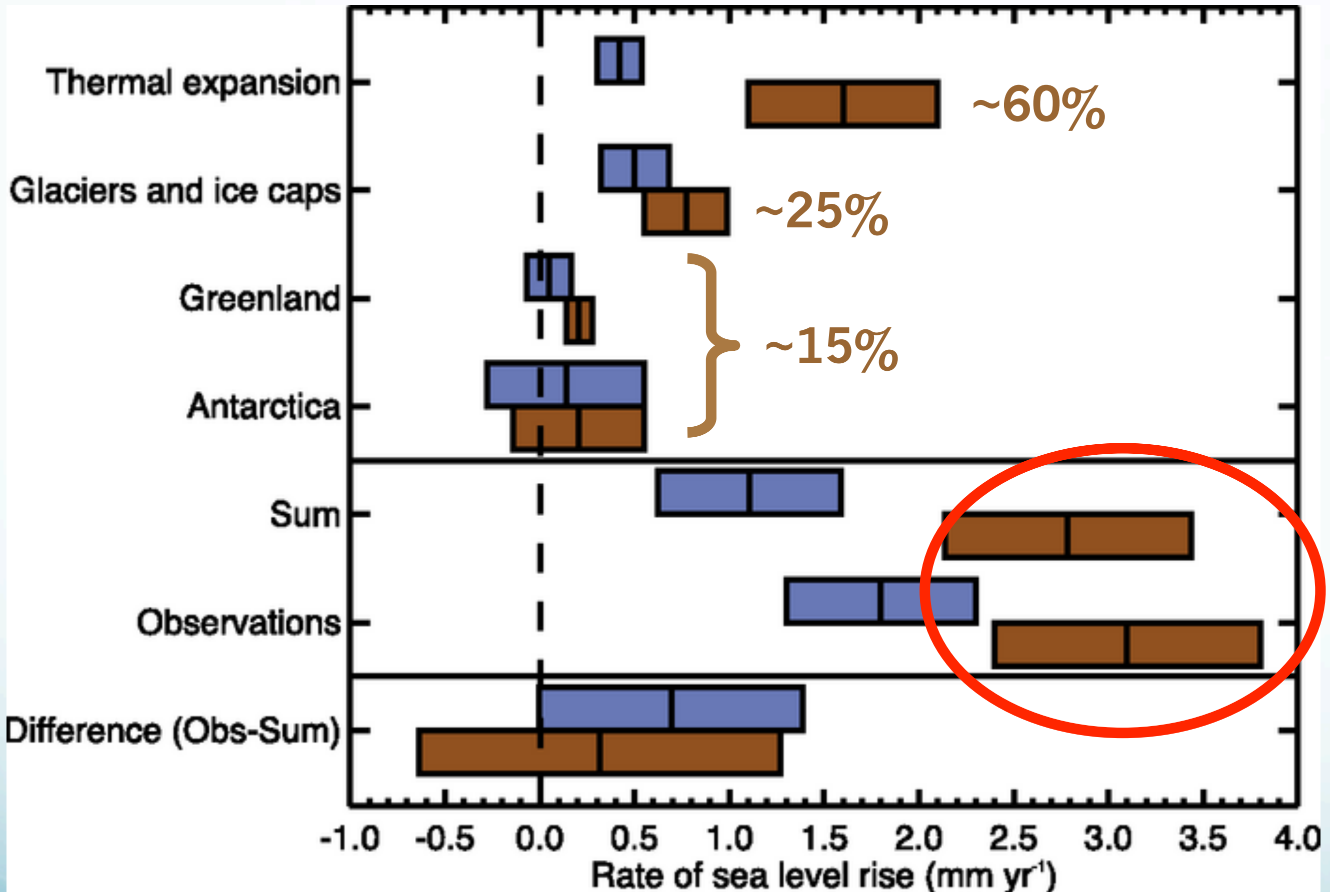
Instruments emits a short radar flash and measures the time-of-flight of its reflection from earth. 1,000 times per second.

Measures **sea level** and ice sheet height

Sea level rise from TOPEX-Poseidon Radar Altimetry



Balancing the Sea Level Rise Budget

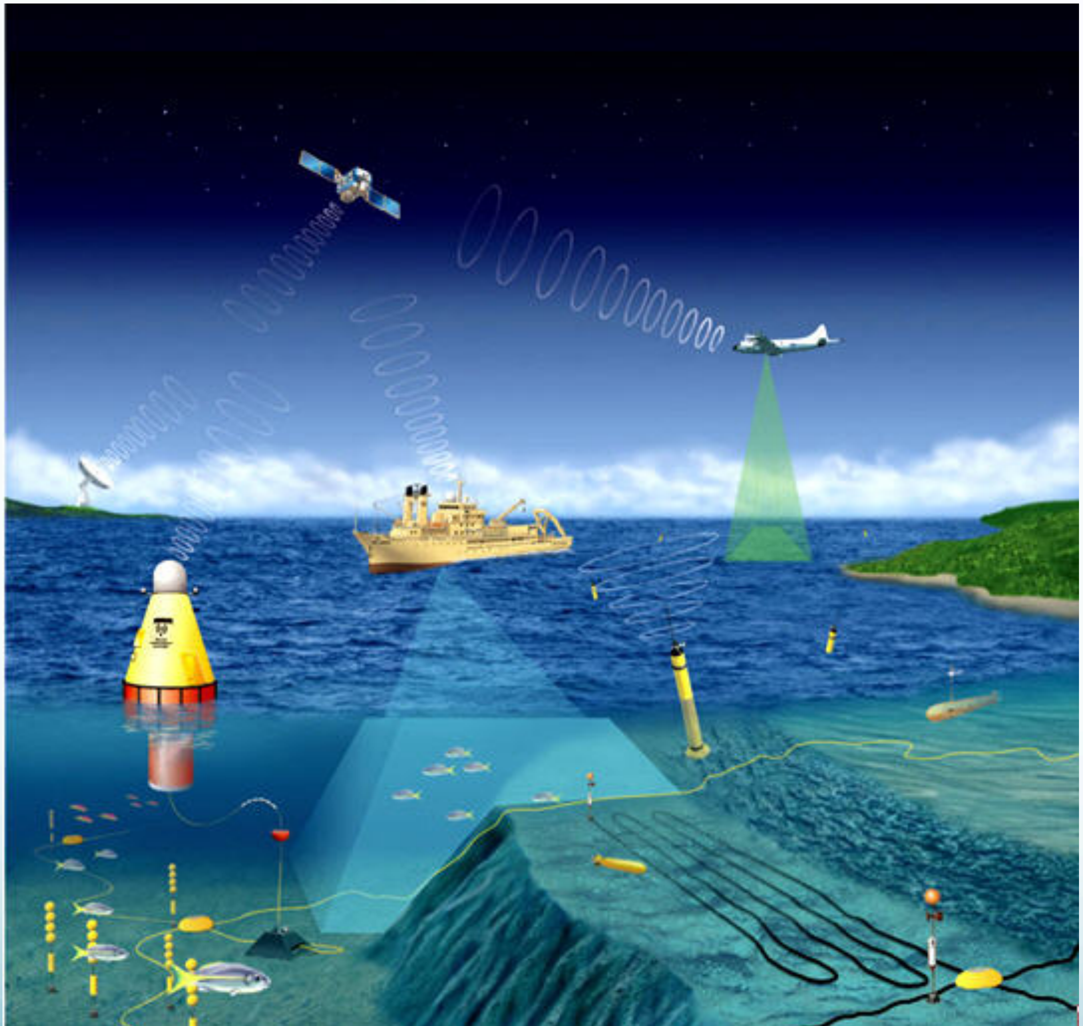


1961 to 2003 (blue)
1993 to 2003 (brown)

No more enigma

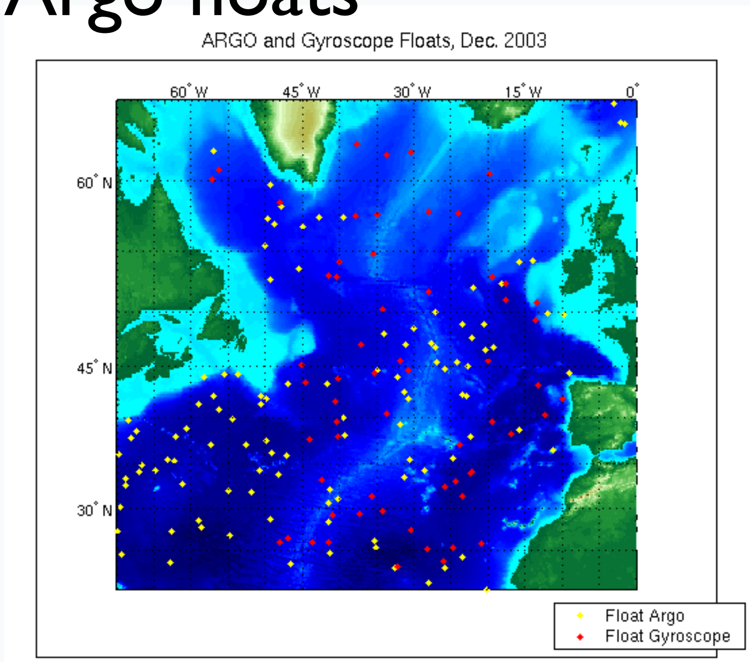
- *IPCC 2007 Figure 5.21.*

Monitoring the ocean

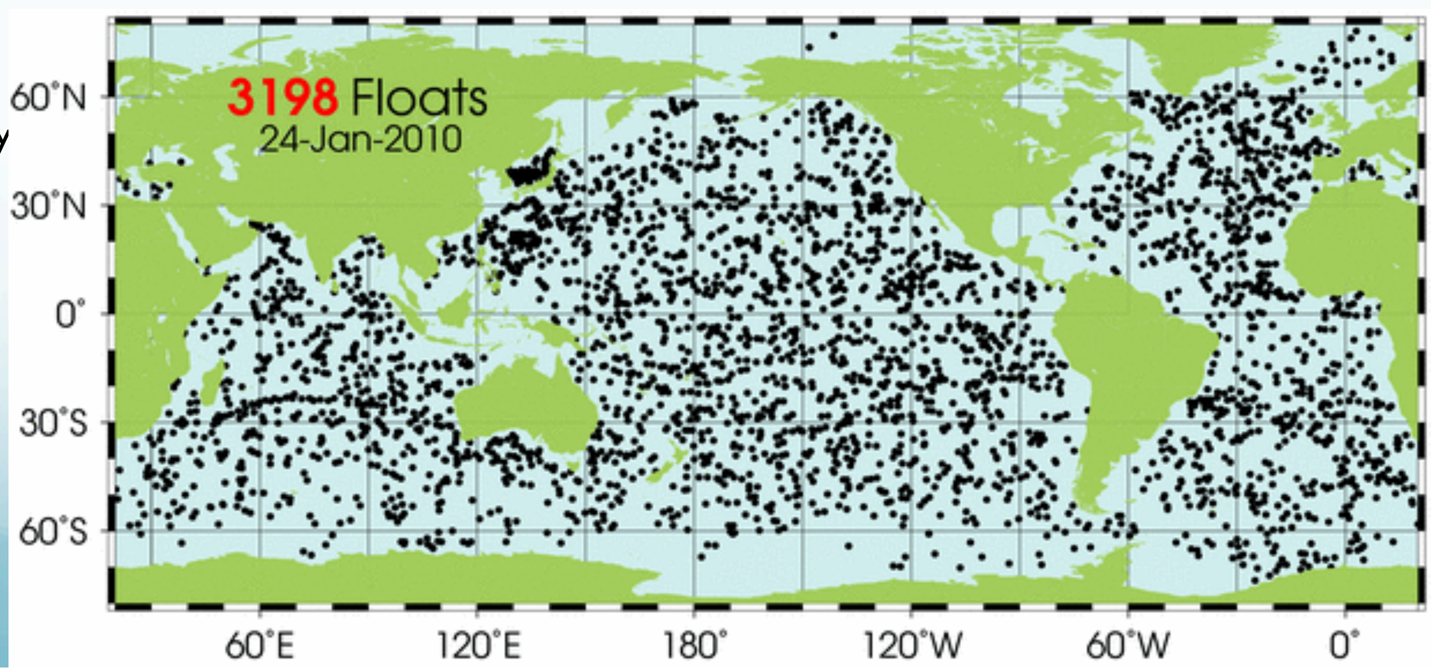


Many instruments are used to measure **ocean heat content** (how ocean temperatures are changing, especially at depth)

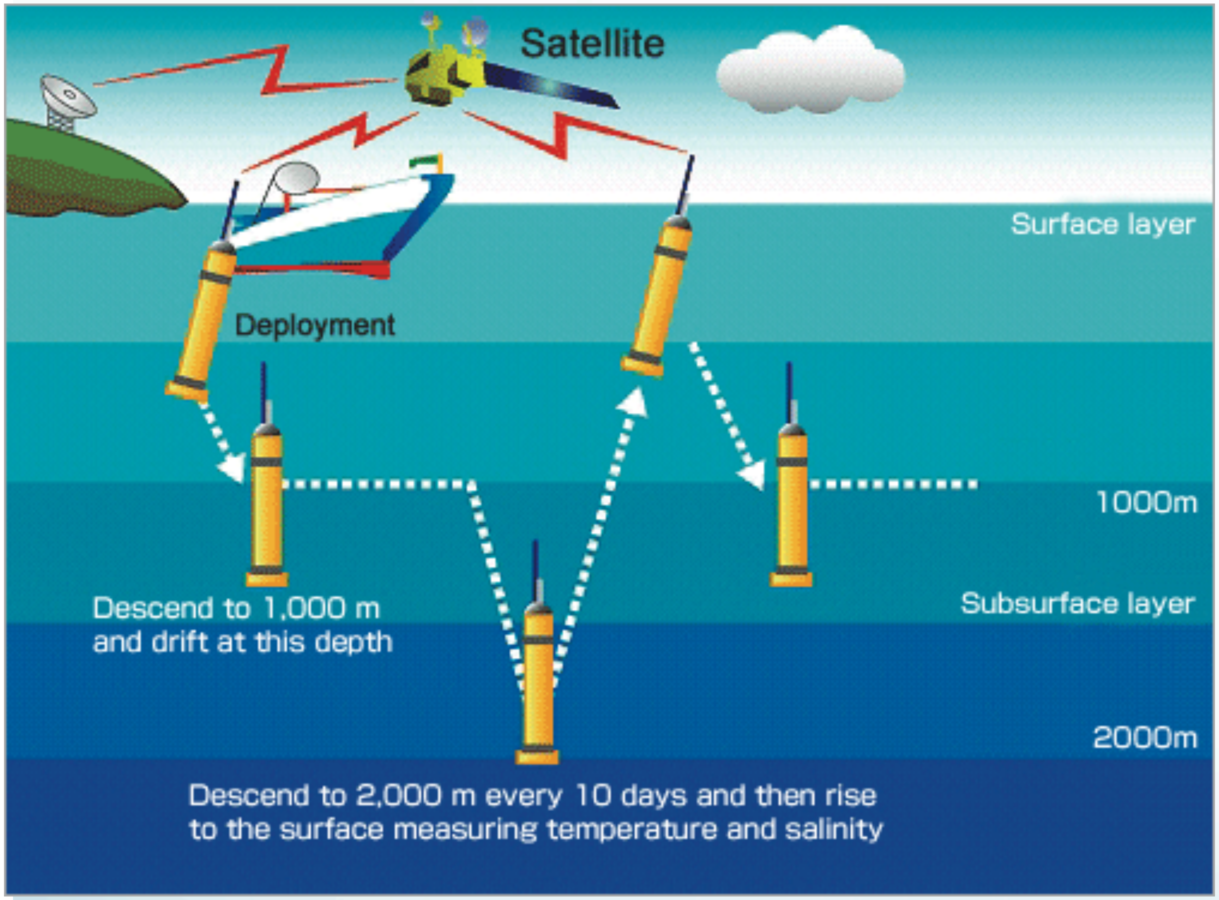
Argo floats

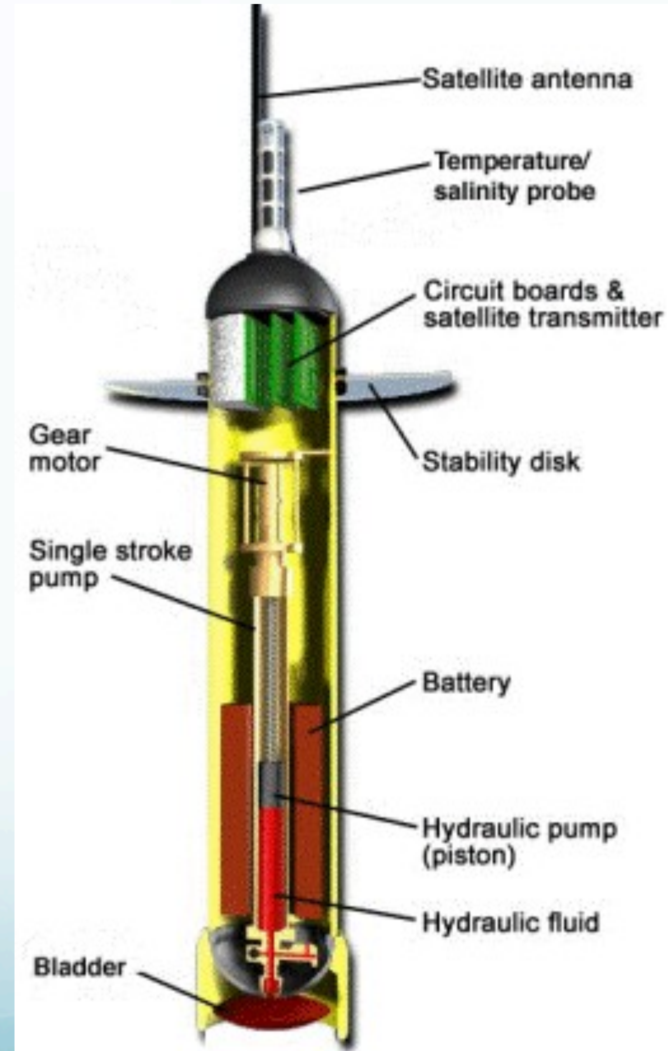


Stephen Riser,
UW Oceanography



Monitoring the **ocean heat content**





Argo floats, since ~2000 measure to 2000m depth

Monitoring the **ocean heat content**

Expendable Bathyermographs (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

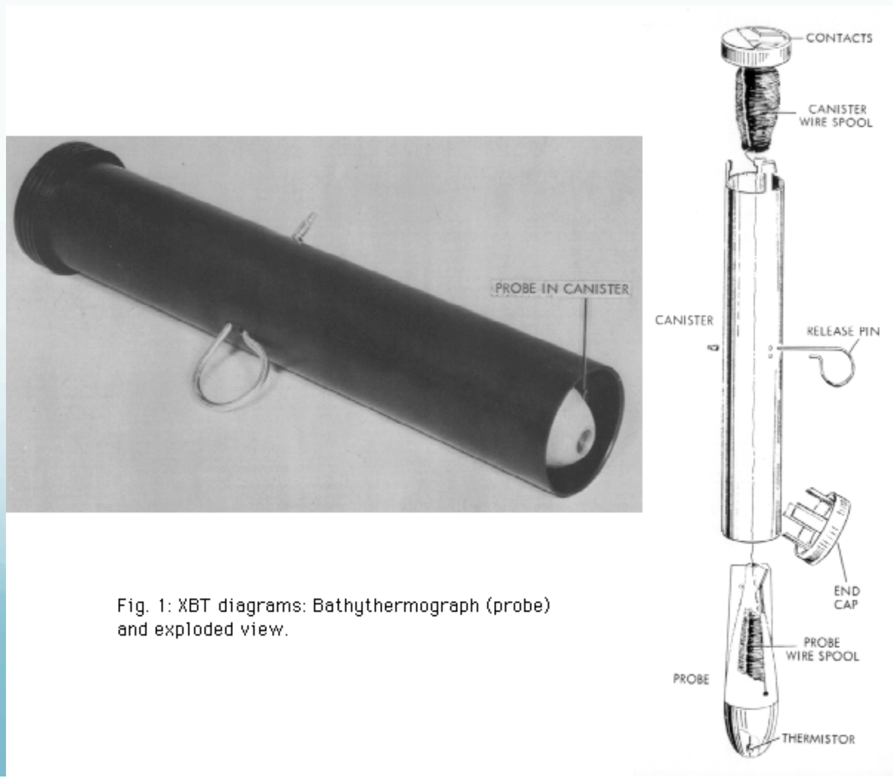
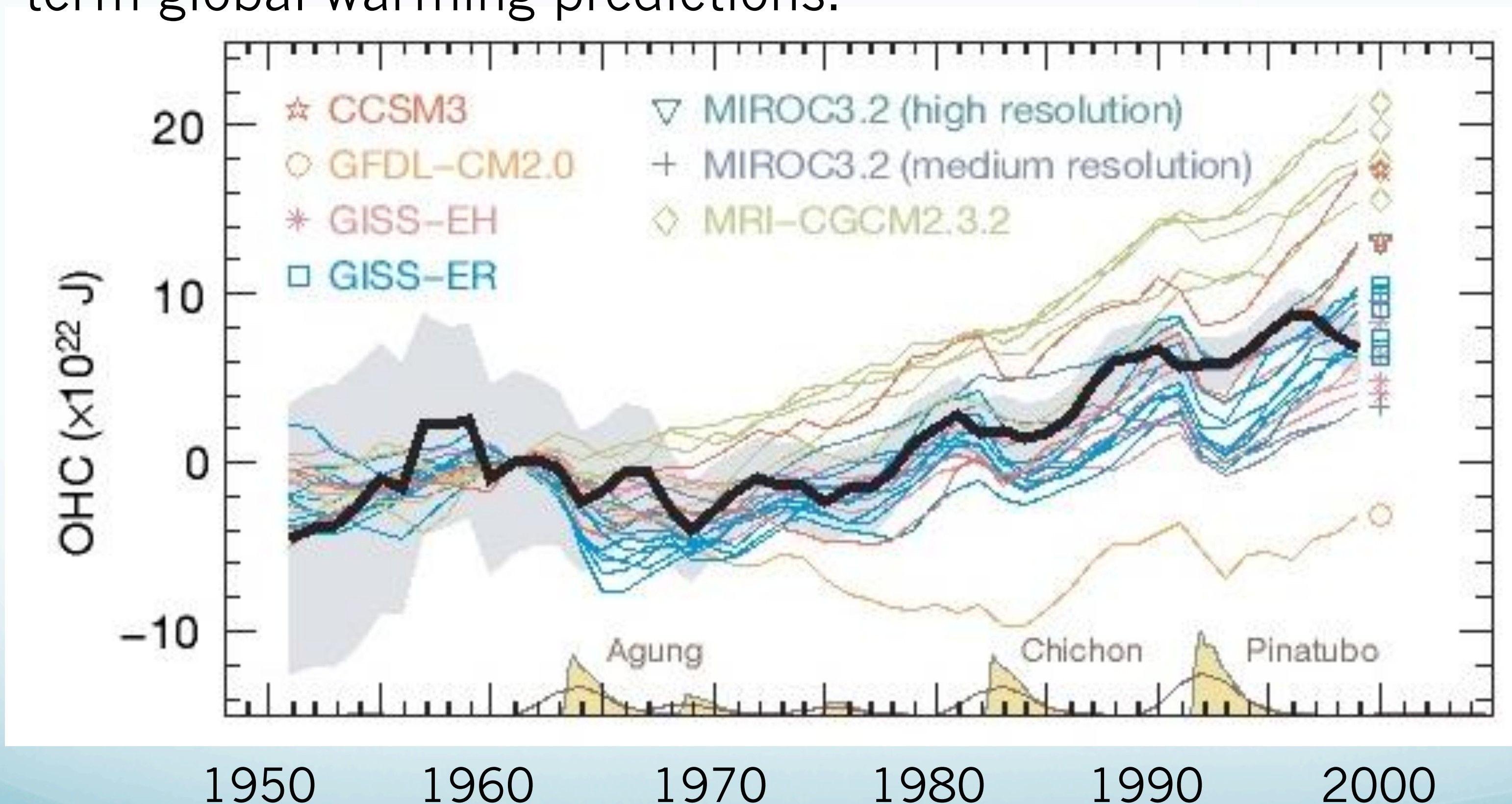


Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.

Like the atmosphere, we can simulate the ocean with models
Observations in black with uncertainty shaded grey
Models are colored lines – they successfully reproduce observed ocean heat uptake, which is important for medium-term global warming predictions.



Domingues et al 2008

How do we know how much Greenland and Antarctica's ice sheets are melting?

The very latest on Greenland from the GRACE satellite

GRACE - Gravity Recovery and Climate Experiments

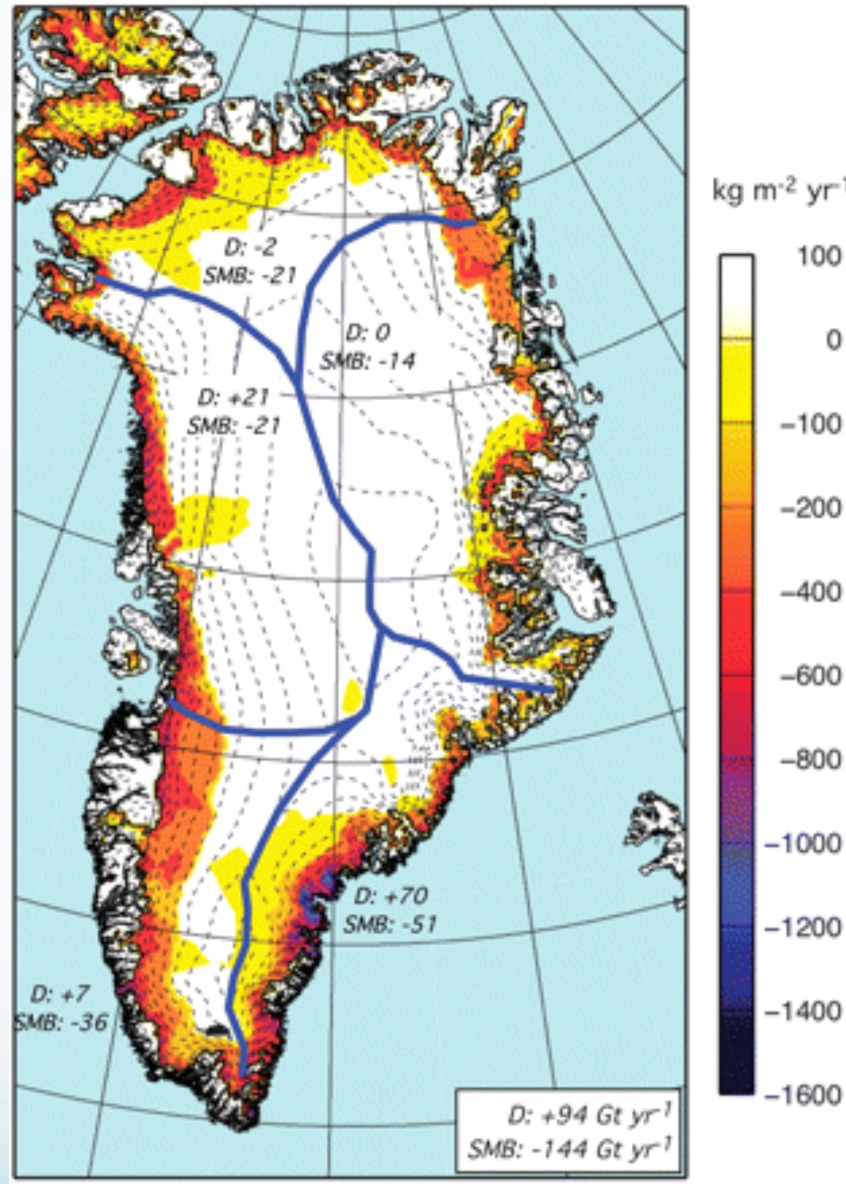
Fun fact: measures Earth's mass distribution by sensing acceleration and deceleration of two other satellites.

Greenland contributed 0.5 mm/yr to SLR between 2000-2008 (about 15% sea level rise measured by satellite altimeter)

or 237 Gt/yr loss

more than 2X the IPCC 2007 estimate for 1993-2003

van den Broeke et al 2009

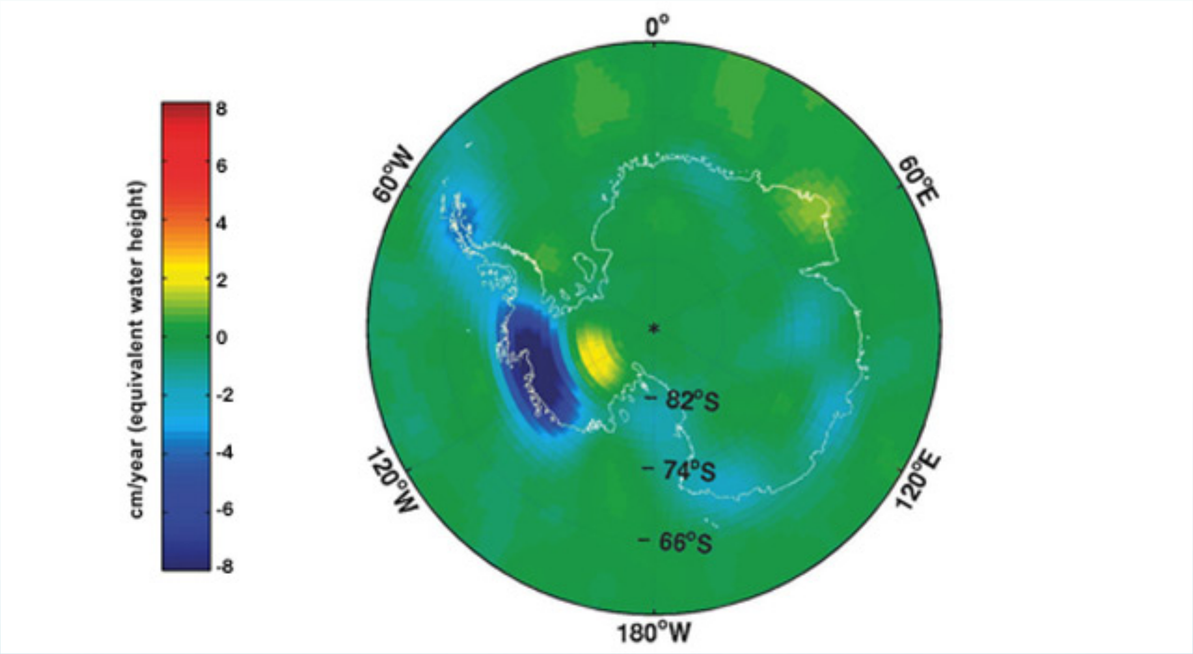


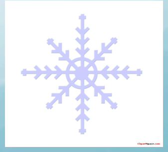
D=dynamic loss (+ = loss),
SMB = accumulation - ablation

The very latest on Antarctica from GRACE

2002-2009 Antarctica losing ice - despite increased snowfall

cause - dynamic thinning





http://grace.jpl.nasa.gov/news/index.cfm?FuseAction=ShowNews&NewsID=33

192 Gt/yr from 1996-2006 according to Rignot et al 2008

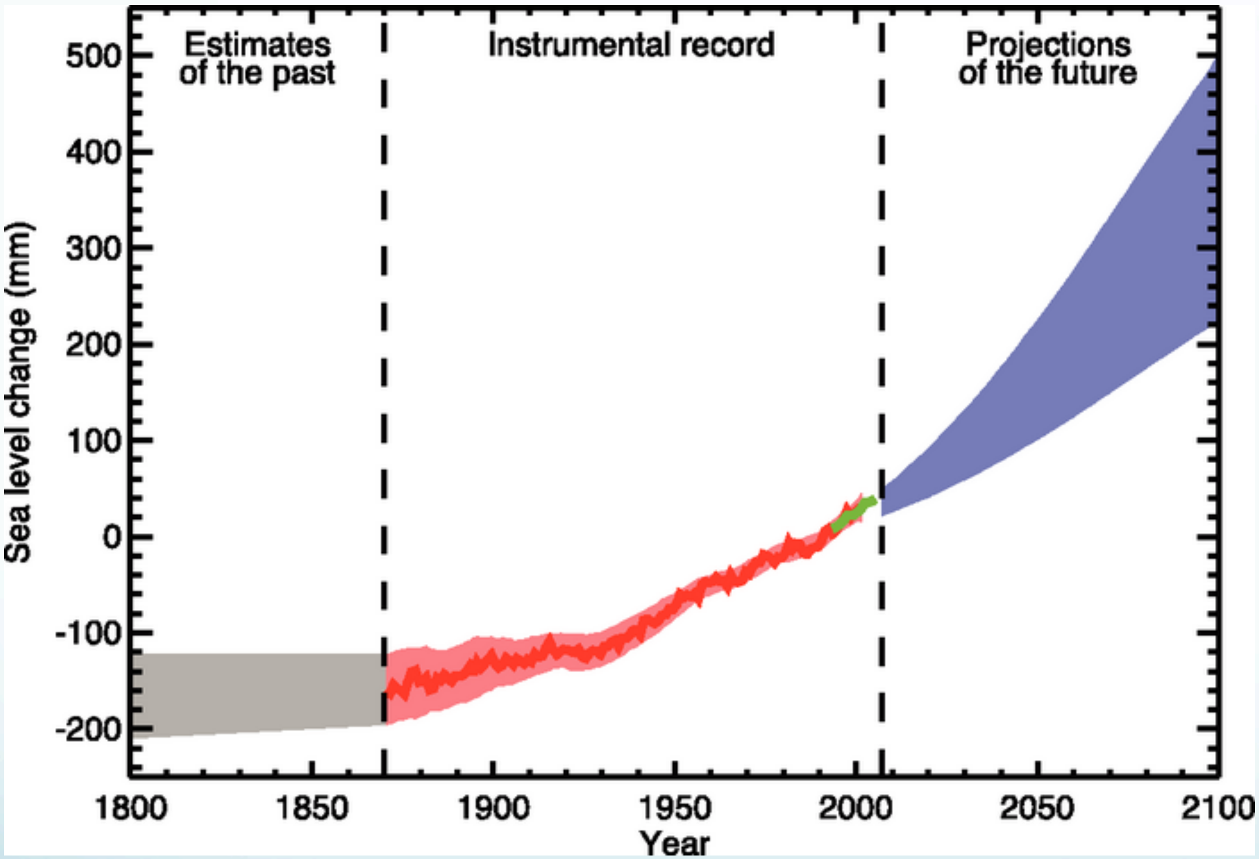
Mass loss each year from:

Greenland 237 Gigatons
Antarctic 192 Gigatons

Compare sum to weight of all humans on the planet 1/3 Gt

Note these values are revised upwards from James Hansen 2007 paper mentioned in *Rough Guide* p 117

What will sea level be by the end of the 21st century?



FAQ 5.1, Figure 1

200-500 mm
(8-20 inches)
for 3 intermediate scenarios

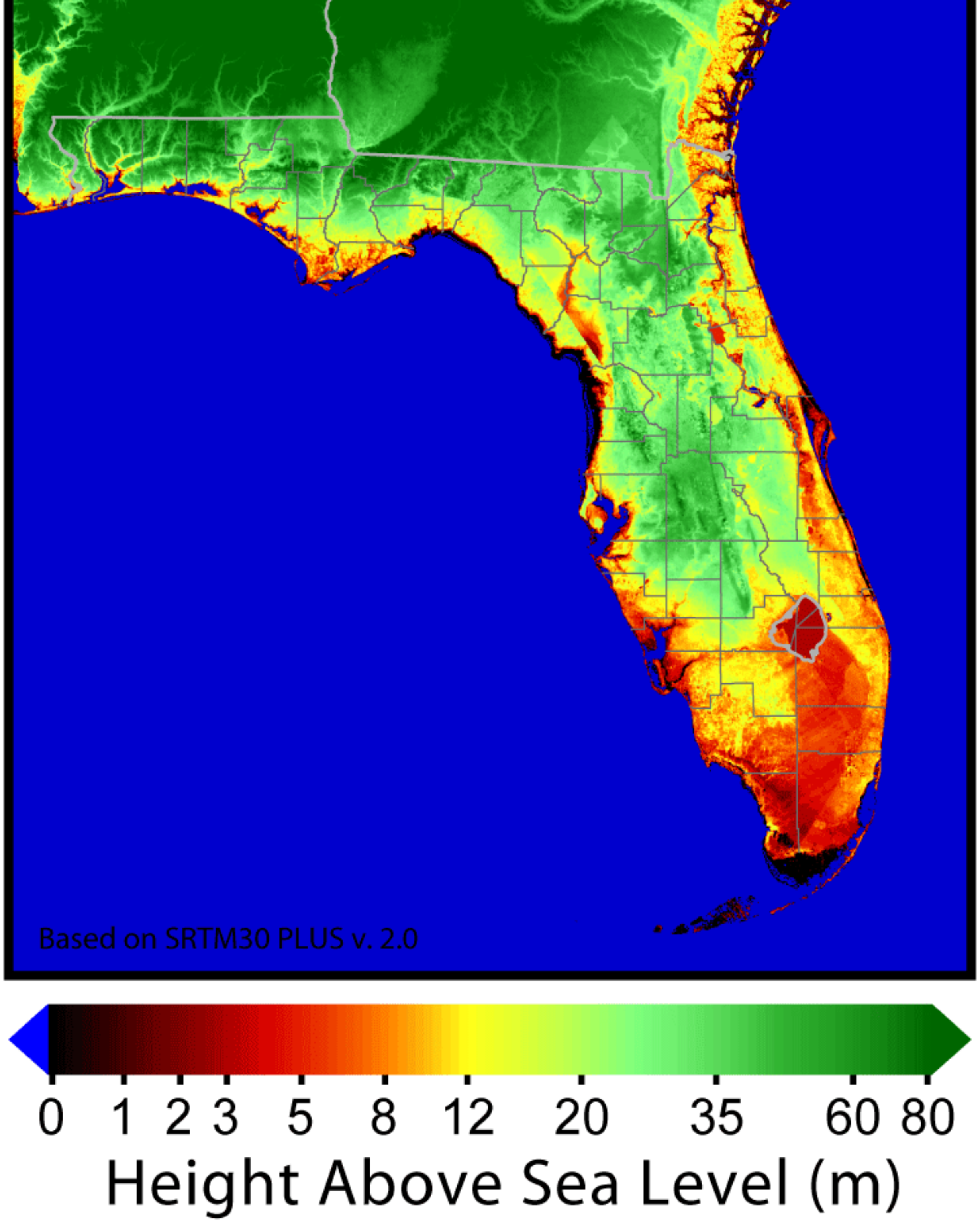
But had no increase in dynamical thinning from Greenland and Antarctica!

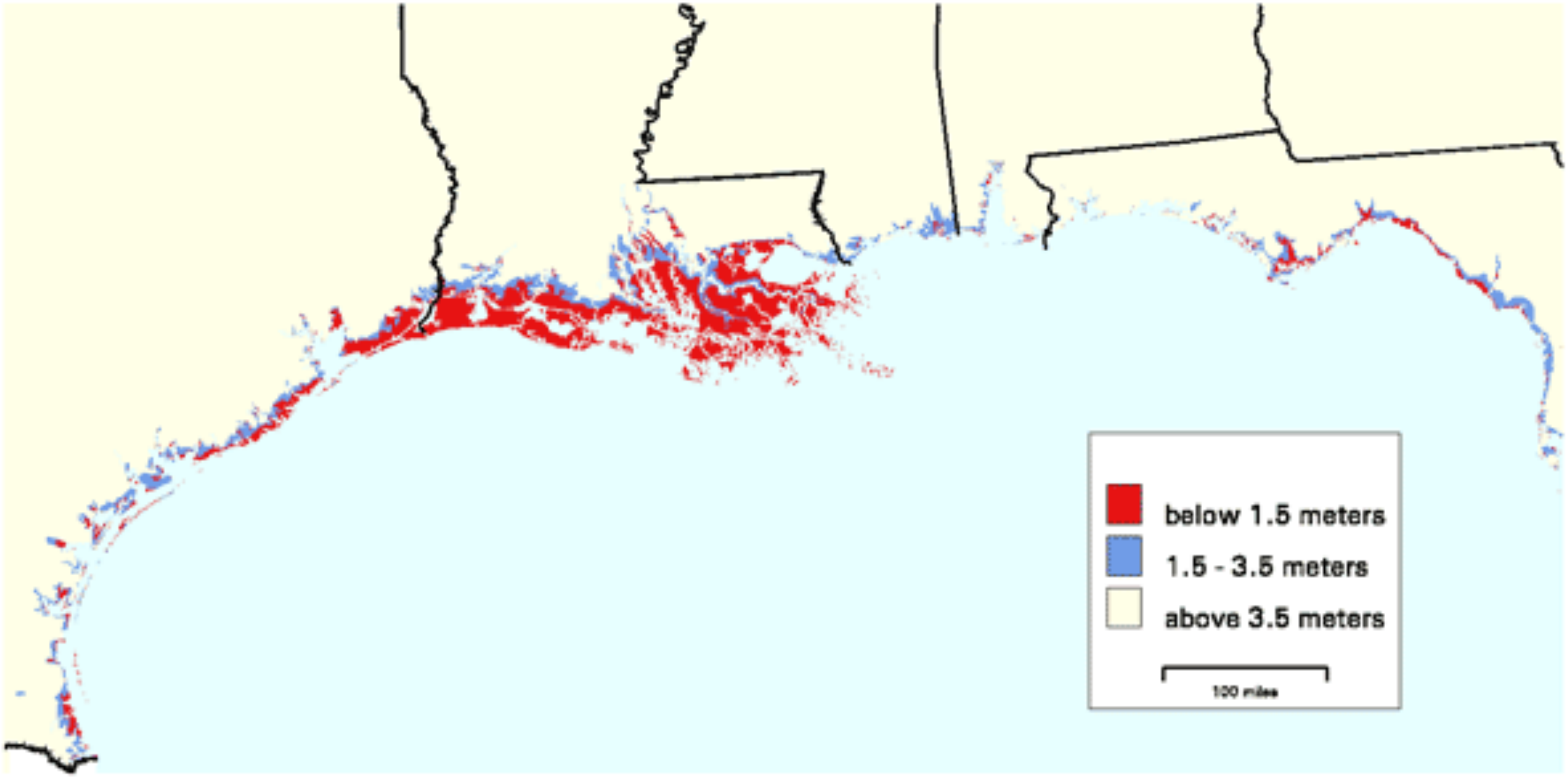
Criticized by James Hansen

More recent estimates of sea level rise:

0.5 to 1.4 m by considering past SLR to past warming dependence and used IPCC estimate of future warming, Rahmstorf 2007
http://www.sciencemag.org/cgi/content/abstract/315/5810/368

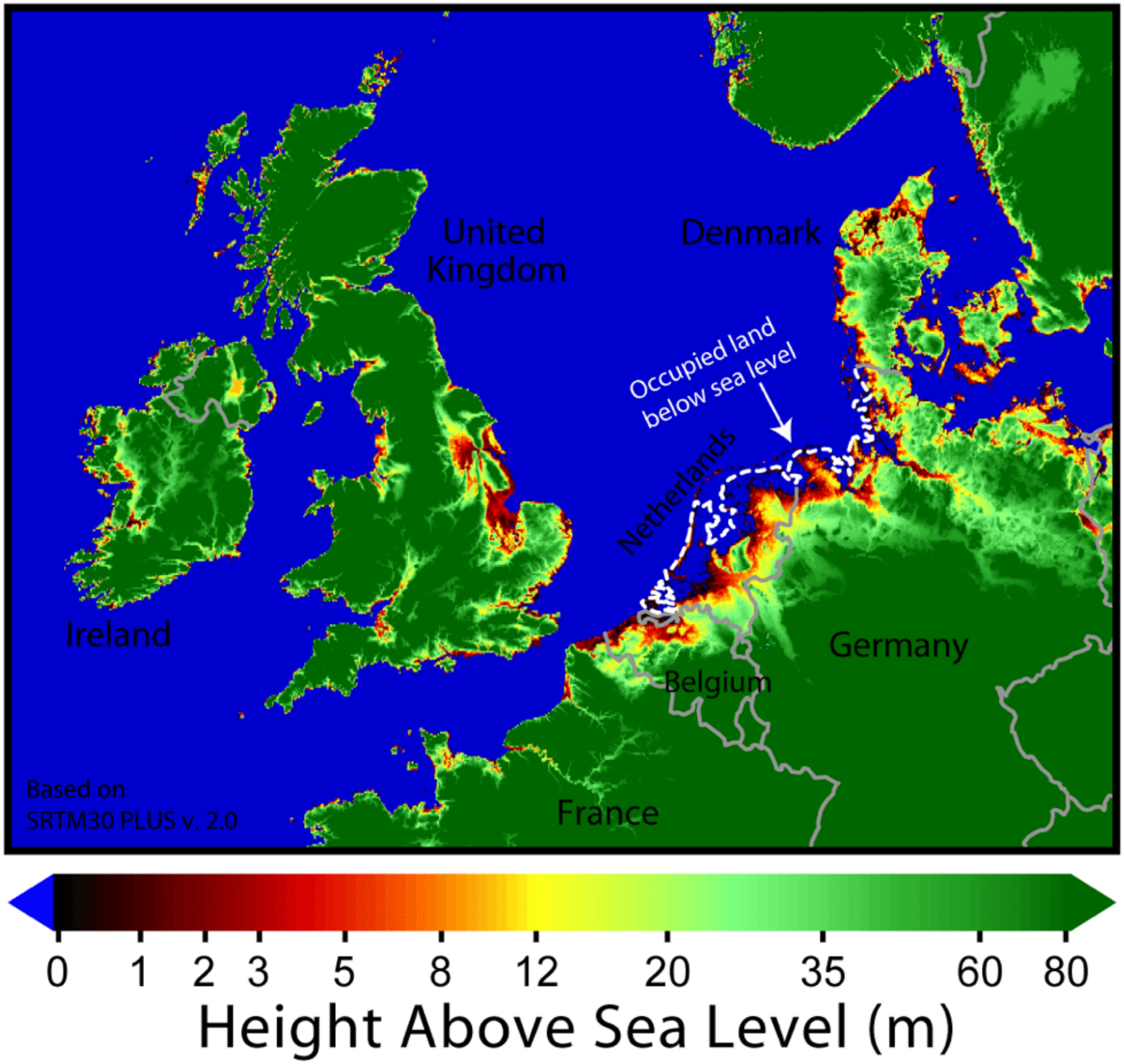
Accelerated but plausible dynamic thinning could give 0.8-2 m Pfeffer et al 2008
http://www.sciencemag.org/cgi/content/abstract/321/5894/1340


Based on SRTM30 PLUS v. 2.0
0 1 2 3 5 8 12 20 35 60 80
Height Above Sea Level (m)

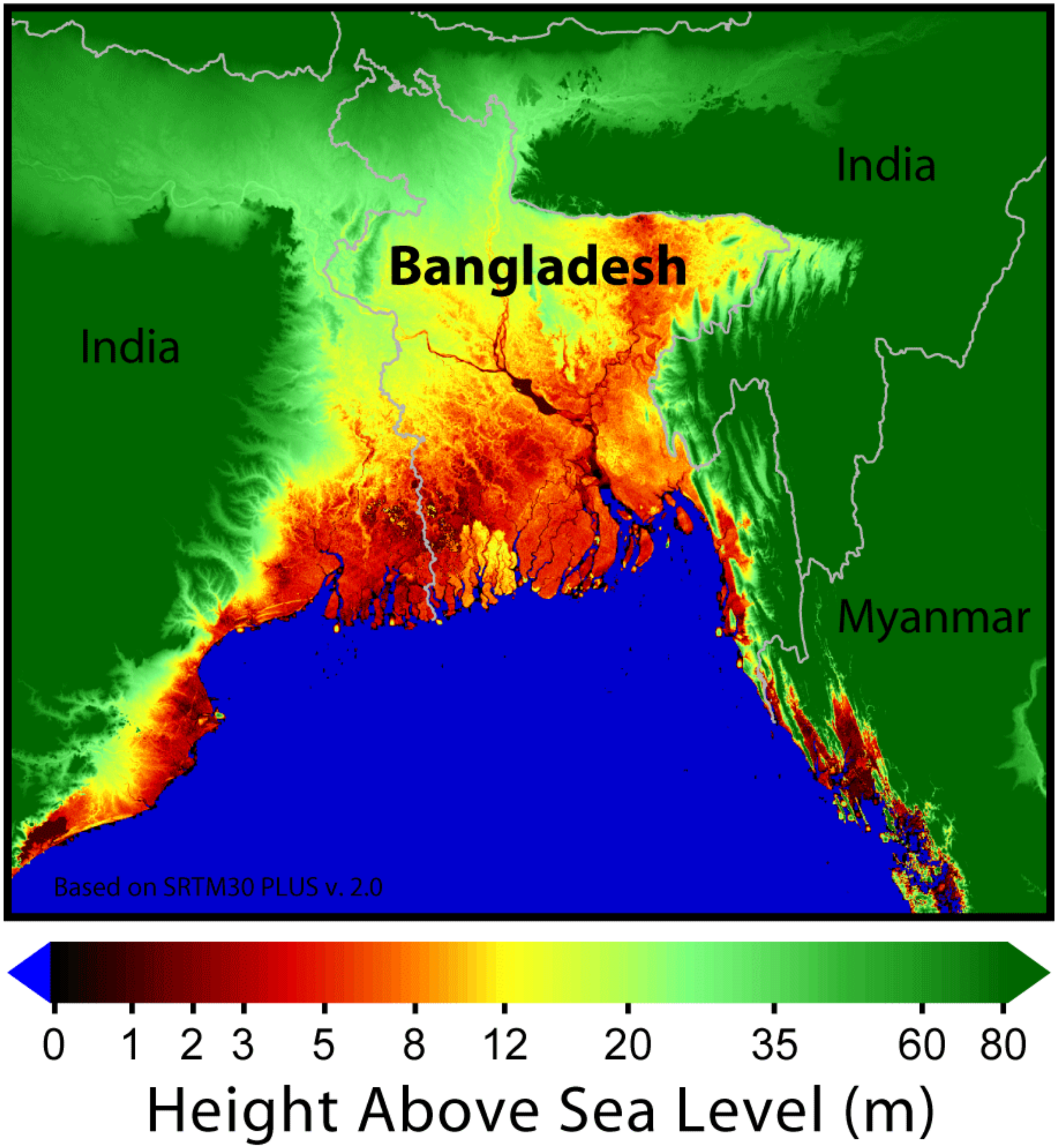


below 1.5 meters
1.5 - 3.5 meters
above 3.5 meters
100 miles

Sea Level Risks - North Sea



Sea Level Risks - Bangladesh



Seattle sea level rise science/art project in 2009

Rough Guess of 2100 Storm Surge height

Population Distribution

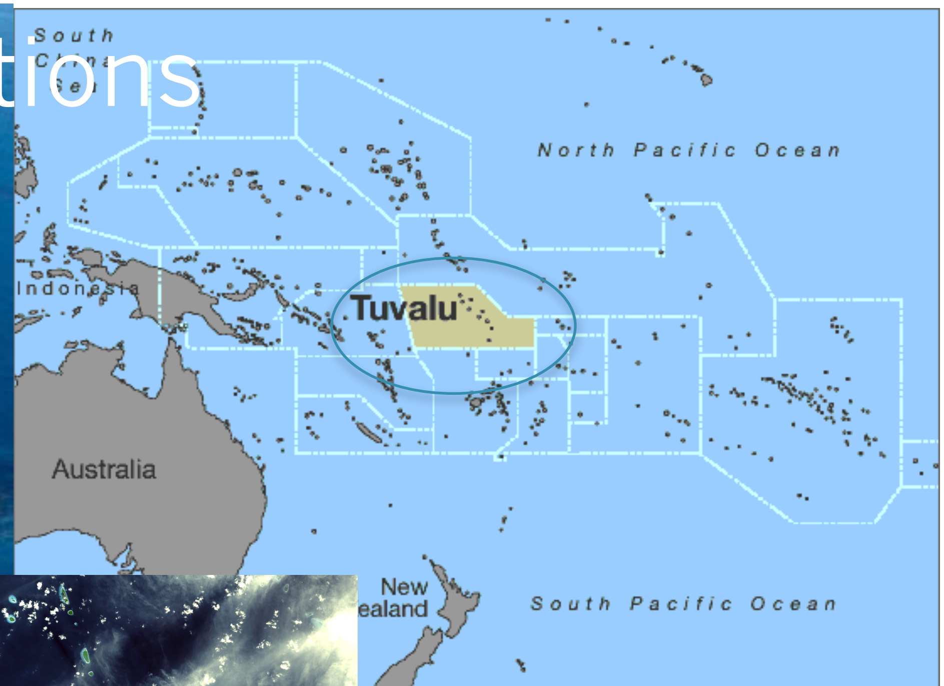
11 of the 15 largest cities in the world are along coasts or estuaries

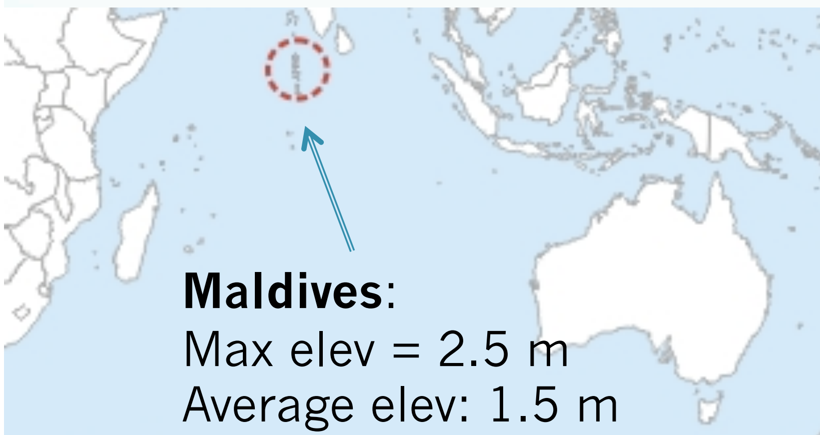
"It was estimated that in 2003, approximately 153 million people (53 percent of the nation's population) lived in the 673 U.S. coastal counties, an increase of 33 million people since 1980."

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!

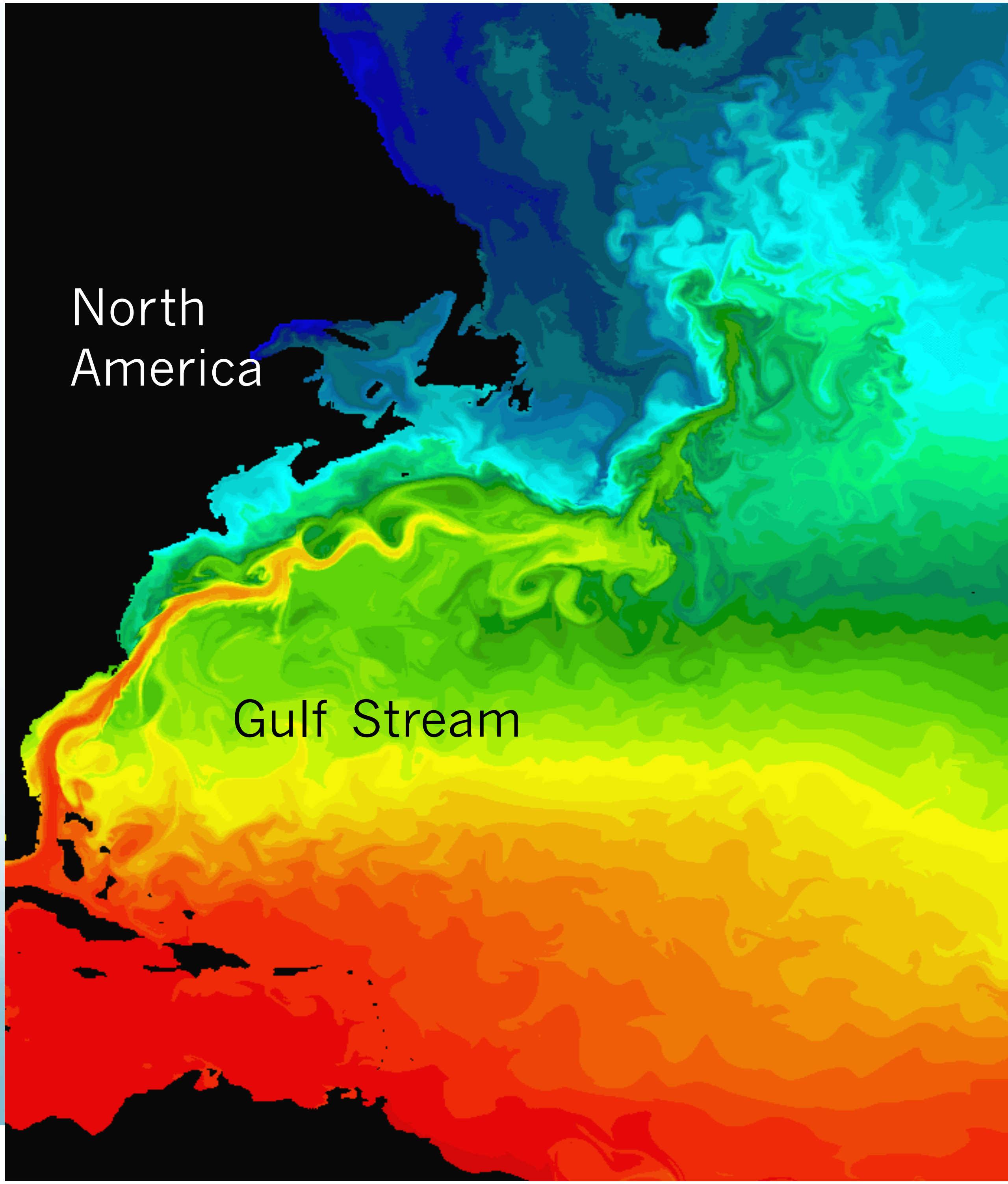
Costs of Sea Level Rise

- 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

Climate and Oceans

- What else might change besides sea level?
- Ocean currents!
- Most currents are wind-driven, and could change if atmospheric circulation changes.
- Some currents are driven by gradients in sea water density, due to gradients in temperature and/or salinity.



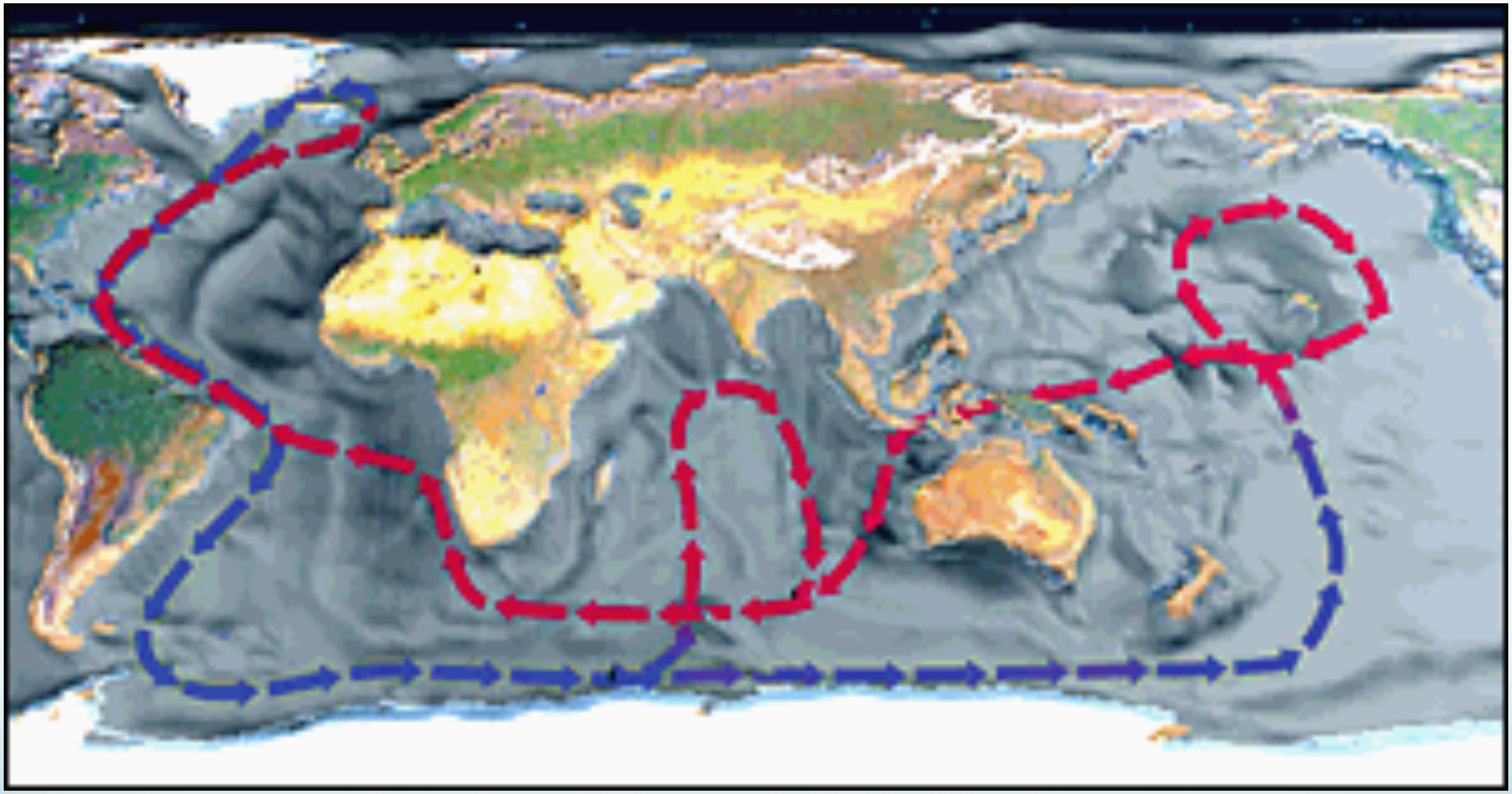
Gulf Stream
transports heat

it is mostly
wind driven
(not subject to
stopping)

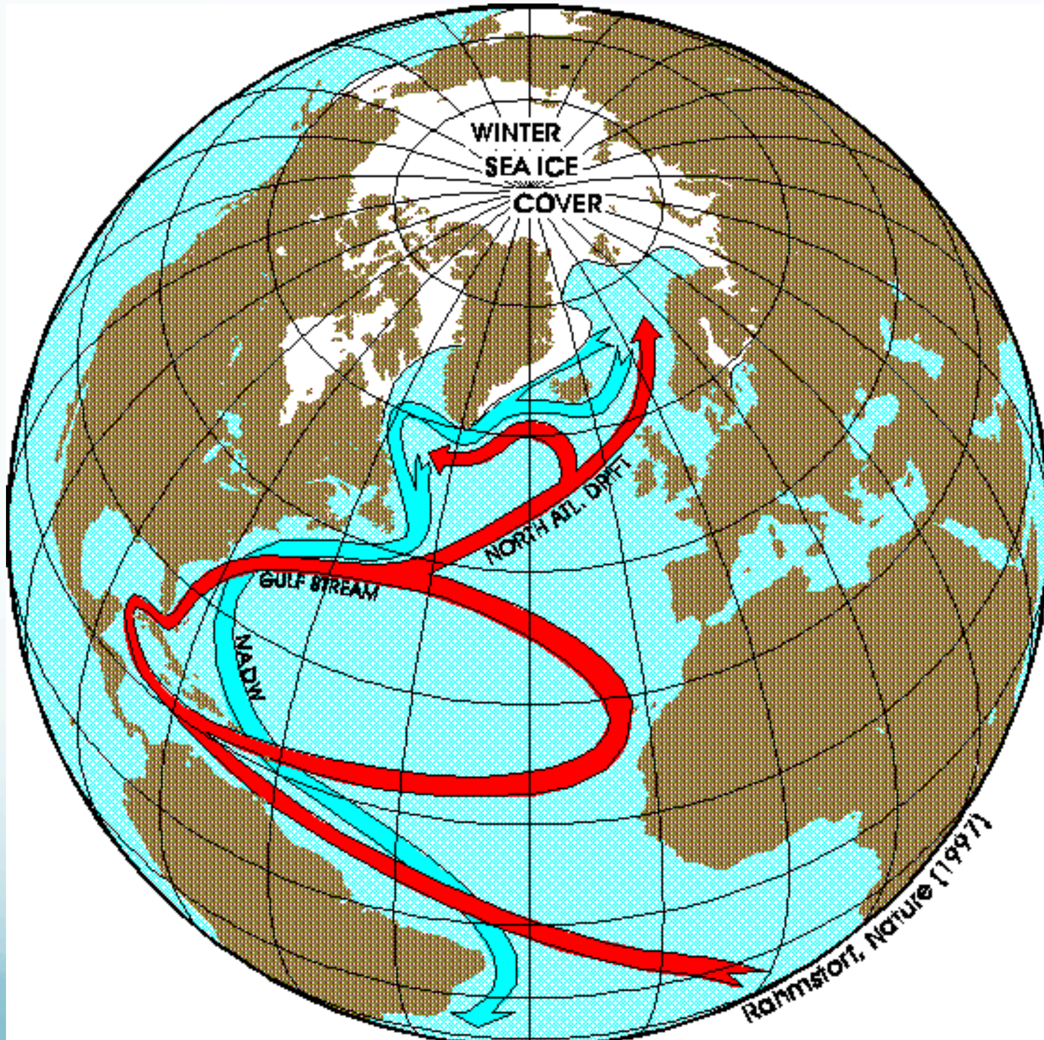
Colors show
Temperature

AVHRR satellite

Thermohaline circulation driven by buoyancy differences also moves heat



Atlantic circulation



Red branches carry heat northward

When water loses enough heat it tends to sink

Weaken this circulation would cool England and Norway

Global warming is expected to weaken the portion that is buoyancy driven as the water would not lose as much heat.

Other Global Warming Impacts on the Ocean

- We'll next discuss:
  - Coral reef loss
  - Ocean acidification
  - "Dead zones"

Coral reefs at risk

Coral Bleaches in high temperature

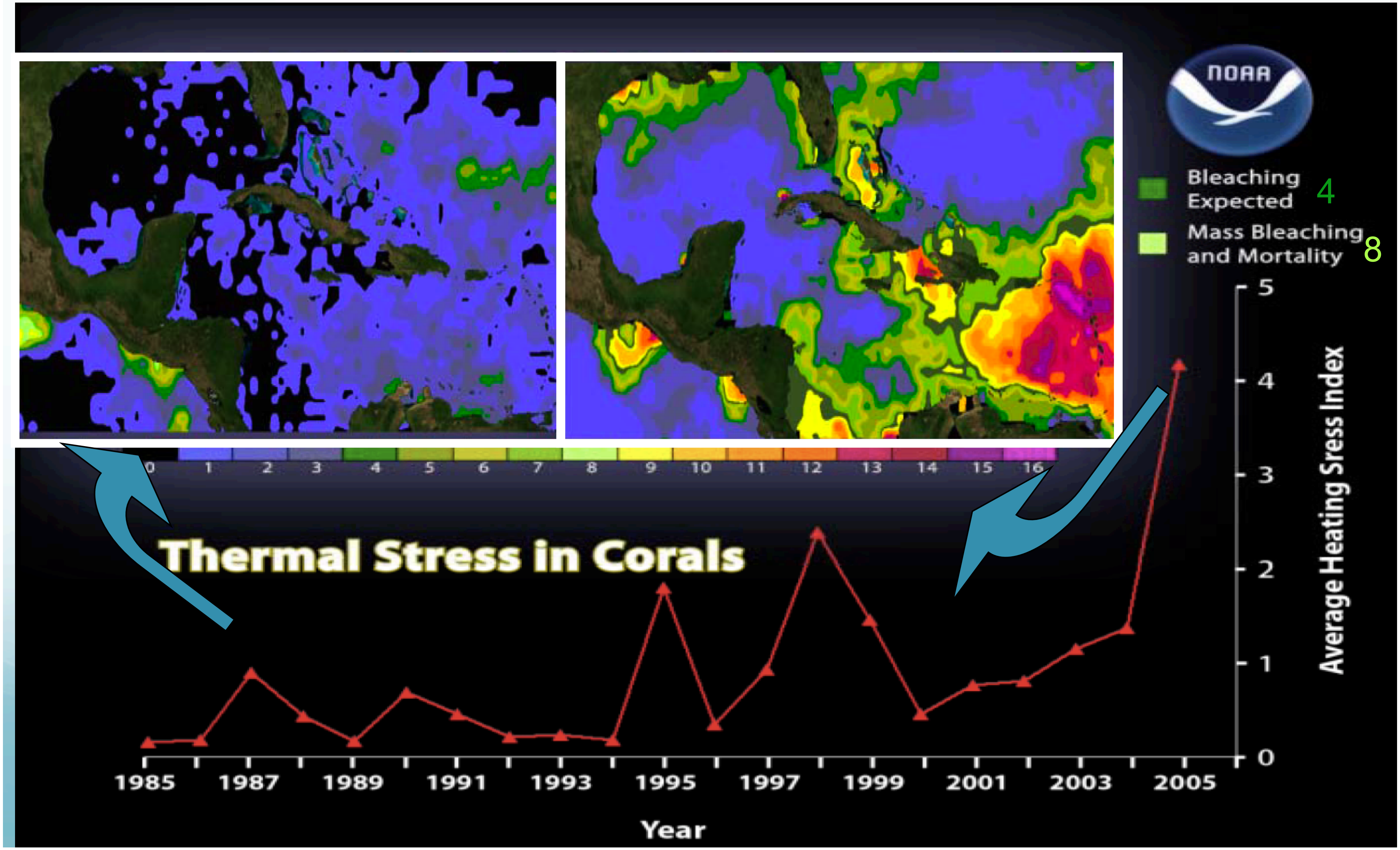
Coral health is highly dependent on phytoplankton algae that provides nutrients for slow growing coral.

Algae leaves when the temperature exceeds about ~24°C,

so color of reef reflects color of underlying coral (white).


Coral bleaching

Coral Bleaches in El Niño years and with global warming



Severe coral bleaching (1979-2008)

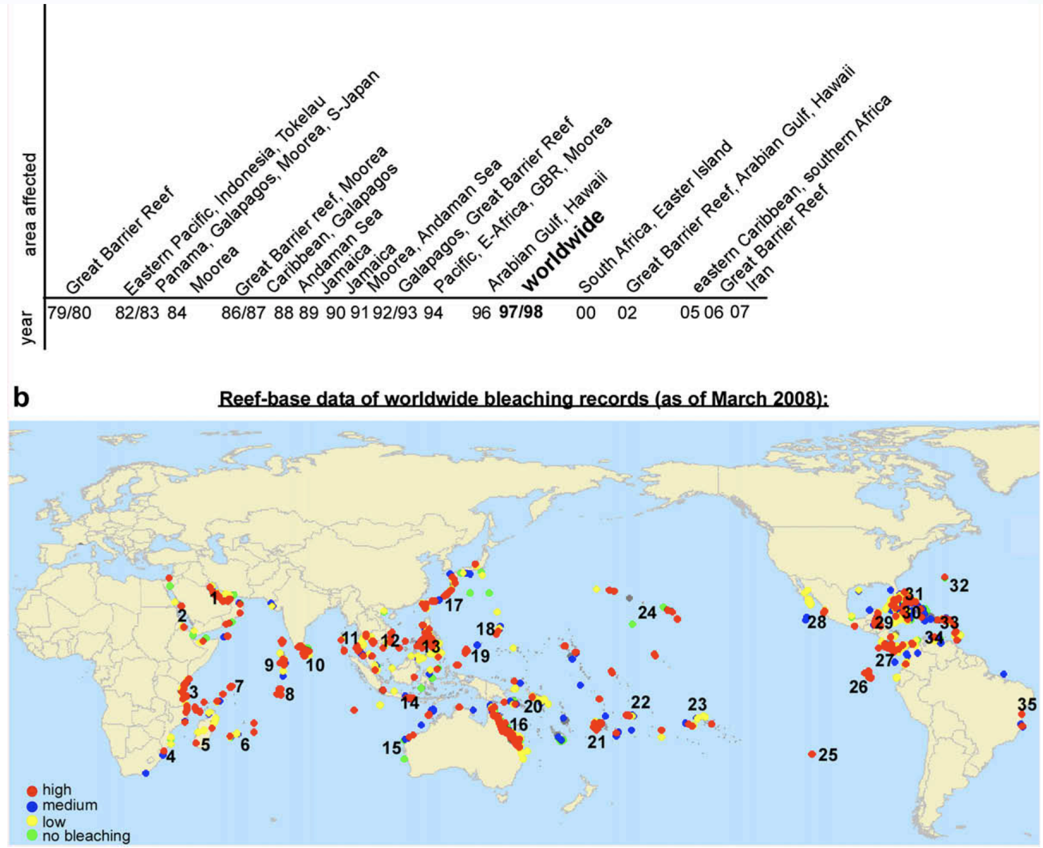


Fig. 3. Incidence of coral reef bleaching on a worldwide scale. (a) Selected bleaching years and locations (from various sources; Brown, 1987; Glynn, 1993, 1996; Coles and Brown,

"By 2030 or 2050, bleaching thresholds will be exceeded annually or bi-annually at the majority of reefs worldwide"

More possible ocean changes due to temperature

- Increased disease in fish
- Poleward movement of some species
  - Tuna, marlin, cod, ...
- Increased mortality of winter flounder eggs and larvae
- Marine mammals, birds, seals, sea lions and walruses:
  - Feed on mainly on plankton, fish and squid
  - Vulnerable to changes in prey in response to climatic factors
- Nesting of sea turtles is strongly affected by temperature

Source: IPCC 2007 WG2

Another risk to coral: ocean acidification

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

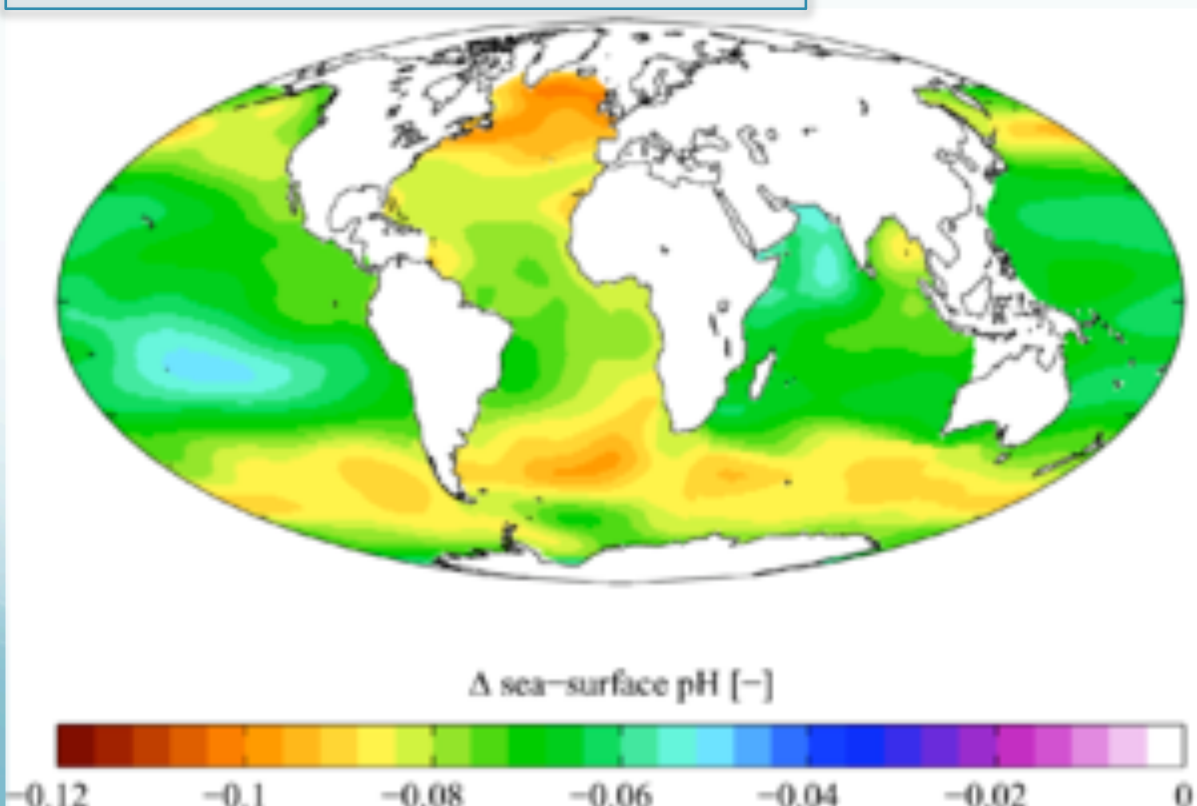
- Higher atmospheric CO_2 means more CO_2 dissolves in seawater

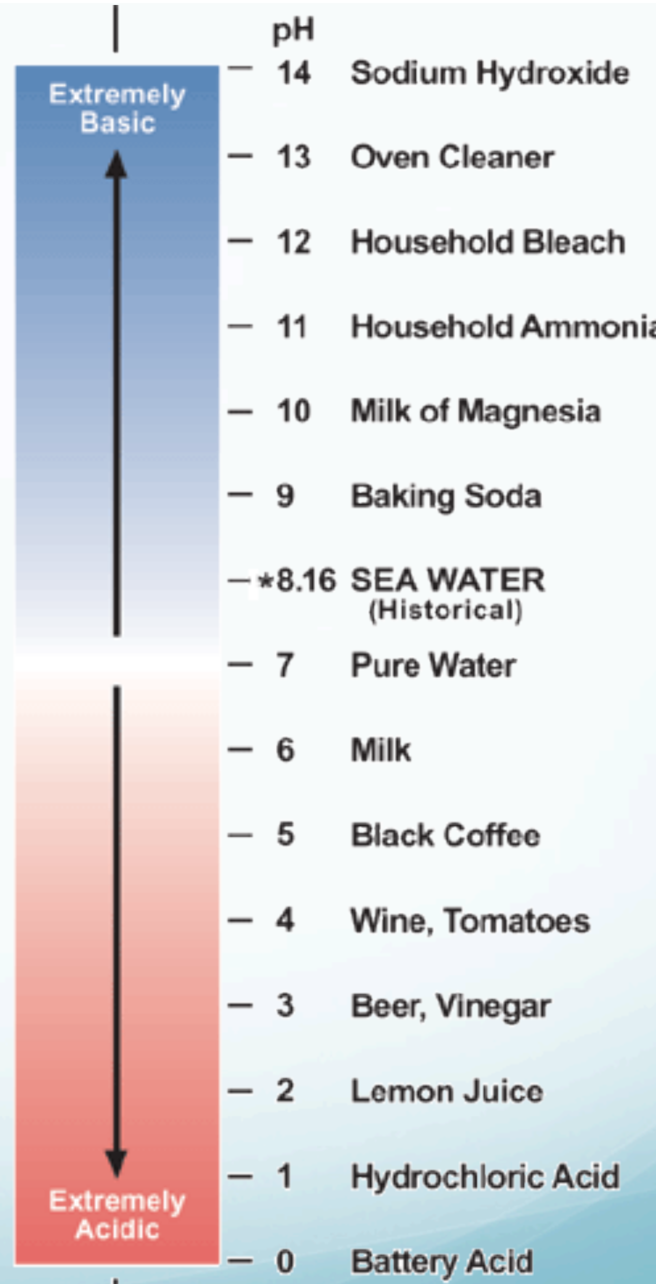
Chemistry of Ocean Acidification

- 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

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?
  - TUMS, of course…

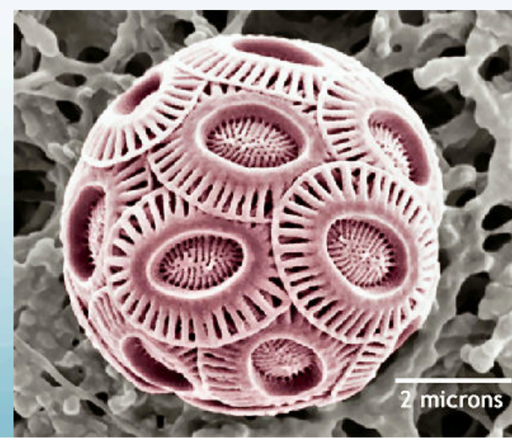
  - Tums has calcium: **calcium carbonate** ($CaCO_3$) that is…
  - This is actually relevant to the ocean: calcium carbonate is what marine organisms of all types use to build shells, skeletons, etc

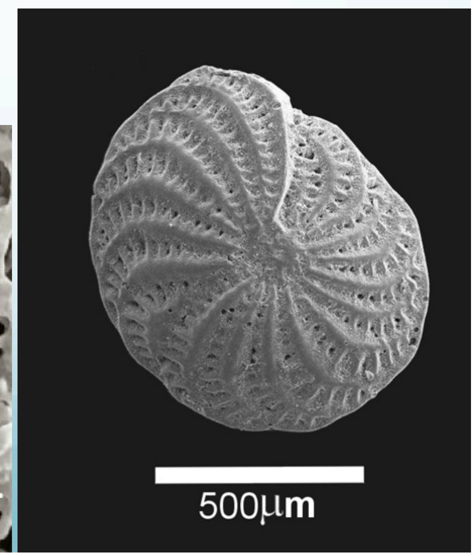
In your stomach or in the ocean, the chemistry is the same

The source of the carbonate ions CO_3^{2-} is calcium carbonate $CaCO_3$

Just as the Tums dissolve, creatures with shells dissolve…

such as phytoplankton, which are responsible for 1/3 of all photosynthesis on the planet and feed the marine food web.

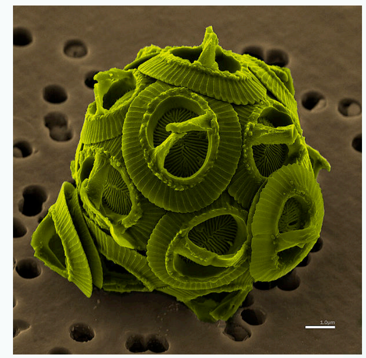




Acidification of the Ocean

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)

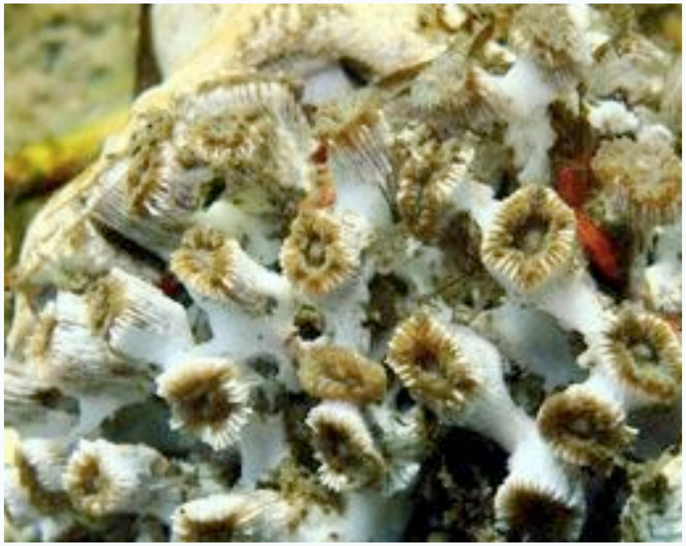
Shellfish

Coralline (red) algae

The Record 1997-8 El Nino

Coral in normal conditions

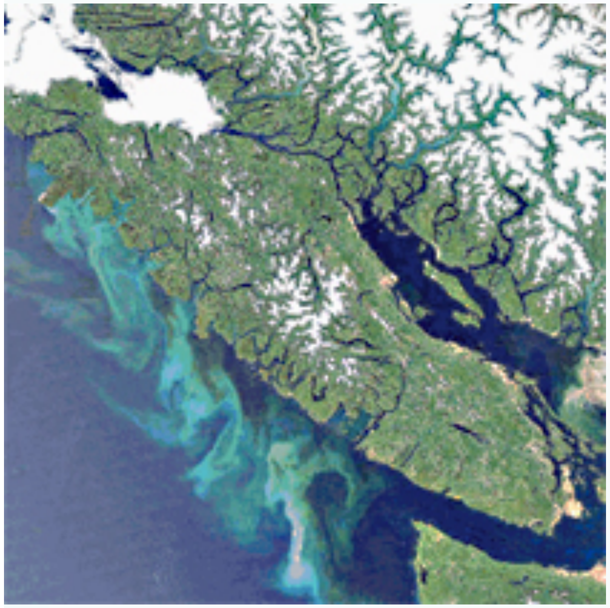
Coral in acidified conditions

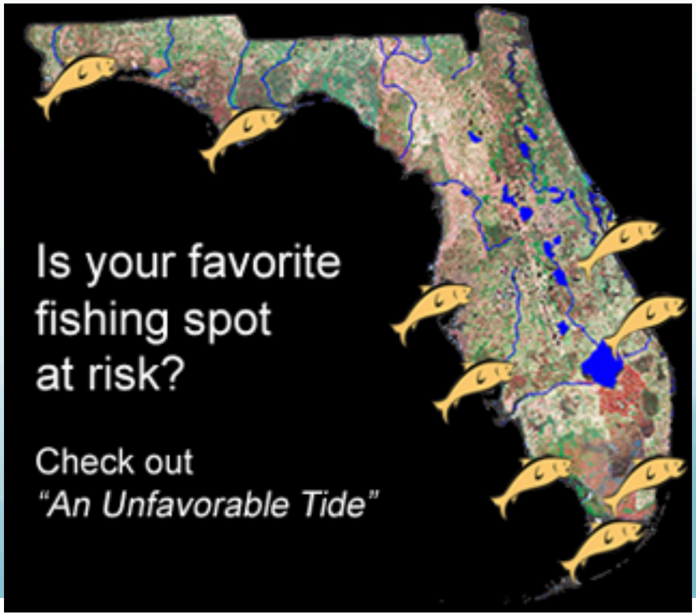


- 16% of all coral were damaged in 1997-8 El Nino alone. Some bounced back.
- "Corals could become rare on tropical and subtropical reefs by 2050 due to the combined effects of increasing CO_2 and increasing frequency of bleaching events"

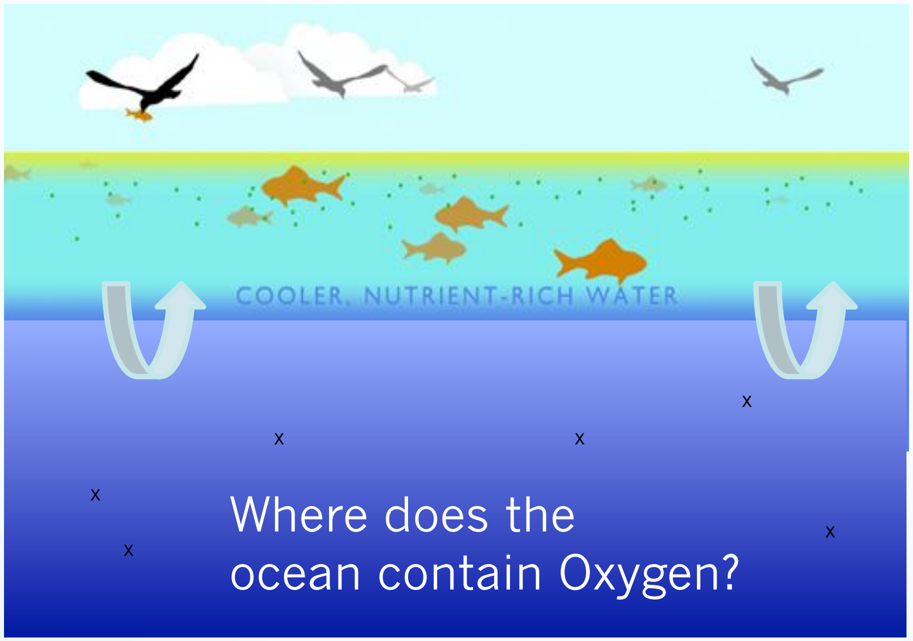
Source: IPCC 2007 WG2

Harmful algal blooms (HABs)





Phytoplankton and Ocean Oxygen cycle

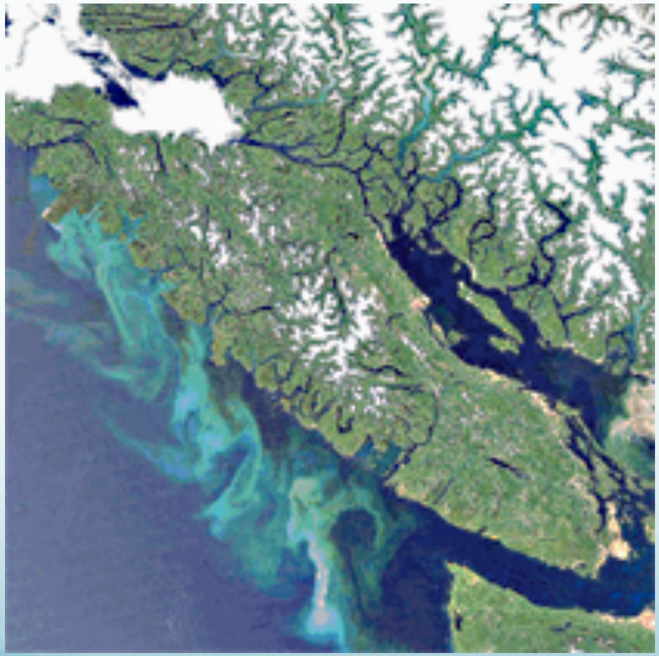


- **Water contains O_2 from contact with the atmosphere**
- **Rotting dead organic material uses O_2**
- **Hence O_2 is low underlying surface ocean that is very productive.**

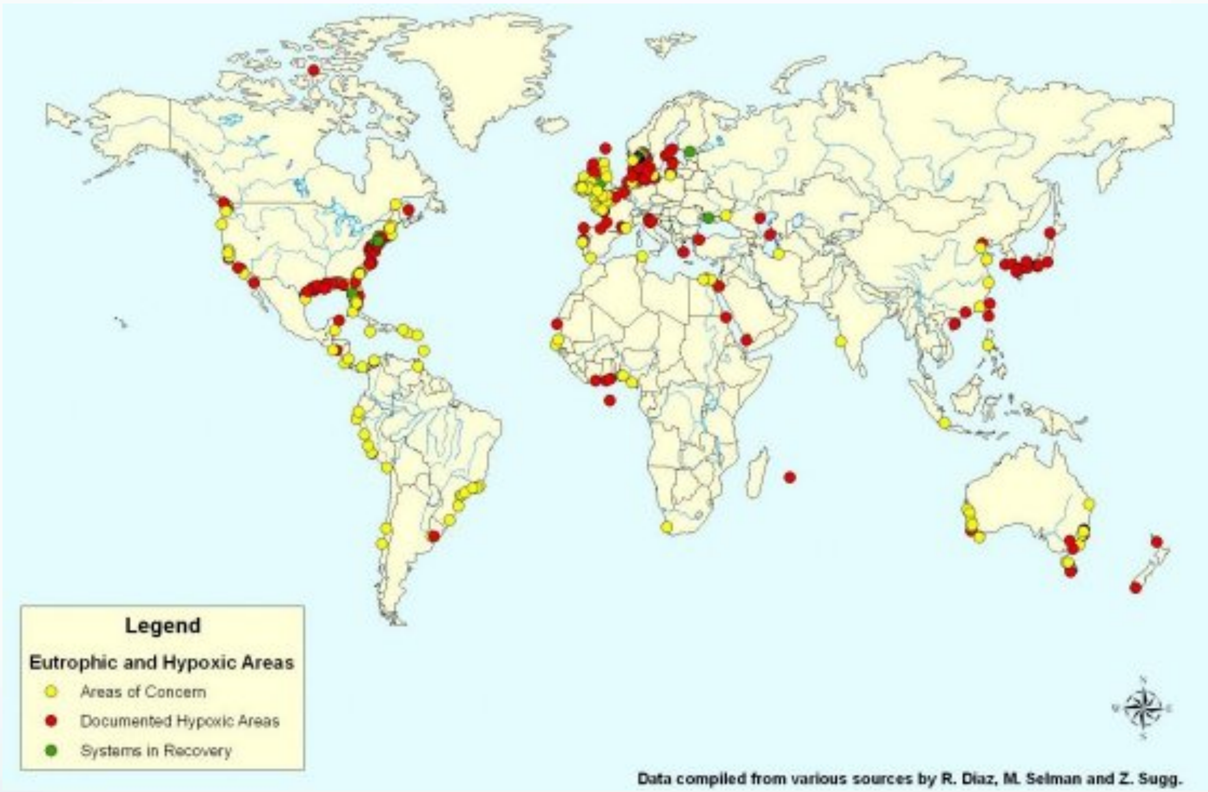
Dead Zone: regions of the ocean where the dissolved oxygen is too low to support marine life

Example: off the coast of Chile where there's strong upwelling. Nothing lives at depth. If this water comes to the surface, it can kill all organisms quickly.

- In regions where there is river runoff that brings a lot of nutrients (N) with it (**fertilizer** from agriculture). This causes large phytoplankton blooms that eventually die, fall below the surface, decay, and may create a dead zone



Regions of the world with Dead Zones today



- Most are due to human activity (fertilizers, etc)

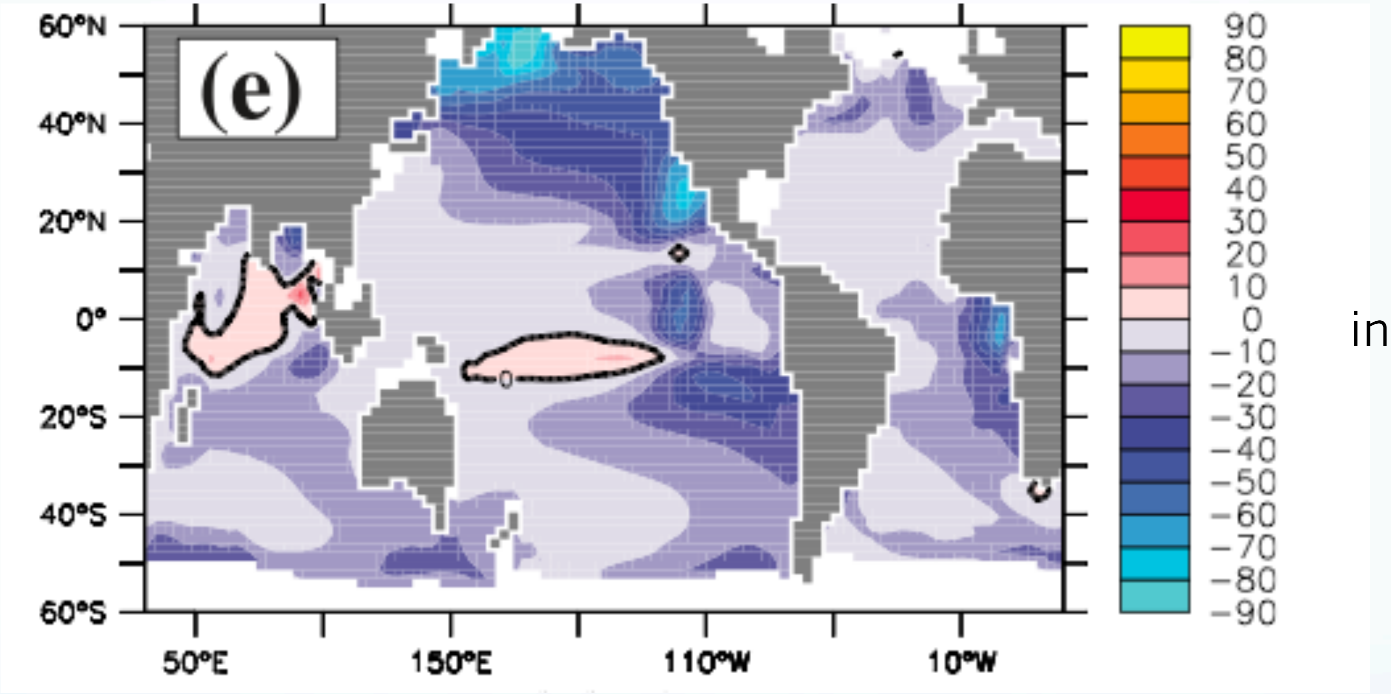
"Carbon dioxide fertilizes biological production," says Oschlies. "It's really like junk food for plants. When the carbon-fattened excess biomass sinks it gets decomposed by bacteria which first consume the oxygen, and then the nutrients."

Reported by Schiermeier 2008

So **more CO_2** may cause increases in dead zones…

Also **warmer water** can hold **less oxygen**

Global Warming and Dead Zones



in mmol/m³

Oschlies et al 2007

Currently 2% of ocean is classified as a dead zone. Projections of Global Warming increase this volume of water to ~ 50% by 2100; largest impacts off the west coast of the Americas.

Climate Change will cause species movements

Biological invasions result when environmental conditions change to be more favorable to non-native species and/or less favorable to the native species

Summary of Ocean Ecosystem Changes

Ocean warming bleaches corals

Increased CO_2 is taken up by ocean, increasing ocean acidity, damaging shells/corals

Higher CO_2 stimulates photosynthesis (CO_2 -> O_2)

Algal blooms are harmful at the surface

Greater raining of dead organic material, the decay of which depletes O_2 at depth (O_2 -> CO_2) causing dead zones