Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111

photos from Emily Pierce

Quiz #2 next Tuesday on material through Thursday

Reading Assignment Revisions

Carbon Cycle required supplemental reading posted on moodle and noted on schedule (see class web site) by Turco
read **p307-308 FOR THURSDAY (for quiz #2)**, skim 309, read p 310-313 up to the integrated carbon cycle For Tuesday (so not on quiz #2)

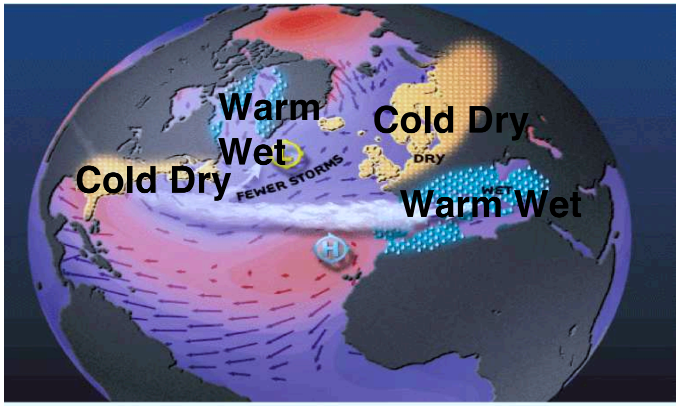
New Extra Credit Opportunity Posted

Review a news article FROM OUR LIST

See course homepage

Summary of Heat waves, Floods, and Droughts

Extreme cold and snow on US east coast and in Europe is an case of a southward shift of the Atlantic storm track. This pattern is known as a the Northern Annular Mode (shifted negative, see RG p 118)



Individual events can not be attributed to global warming but warming can make events more/less frequent

Excess deaths are deaths above normal that occur in heat wave. There is often a dip in mortality rates after heat waves as 20-30% of people were fated to die shortly. Prolonged warming and warm nights are major killers. High pollution often exacerbates heat waves.

Low daily temperature range is found in regions with high soil moisture and high vegetation

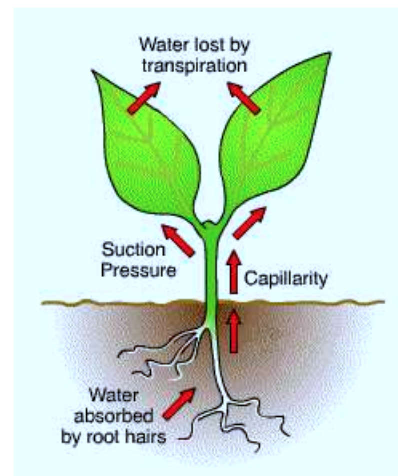
Summary of Heat waves, Floods, and Droughts

An urban heat island is heating from IR radiation emitted from buildings. Greatest at night. Surface temperature measurements must be corrected for it.

Higher water vapor concentration is expected to converge more water and hence cause greater precipitation in the equatorial region (deep tropics), at the expense of drying in the already dry subtropical regions is expected. The rich get richer and poor get poorer.

Heavy rain is expected to get worse

Plants are fertilized with CO2 so they open pores less and lose less water. This would cause less moisture recycling. However population changes may be even more important.



A decrease in forest area would likely increase flood frequency and duration (though there has been some debate about this).

Summary of Heat waves, Floods, and Droughts

It is hard to know if heat waves and/or floods are increasing because daily data is needed to tell.

Monsoonal circulations ought to transport more moisture as the water vapor concentration increases, hence monsoon rains should strengthen.

The Indian Monsoon is affected strongly by aerosols too. Sulfate aerosols should cool the land preferentially, which should weaken summer differential heating and hence the monsoon rain. Black carbon aerosols do the opposite.

The Sahel experienced a drought starting in 1970s that appears to be recovering now. It is very hard to know how it will change in the future. Roughly the same goes for SW Australia.

Night time minimum temperatures have warmed at a faster rate than day time maximum. Increased water vapor, clouds, and reflecting aerosols could be factors.

The big melt (RG p. 75-105)

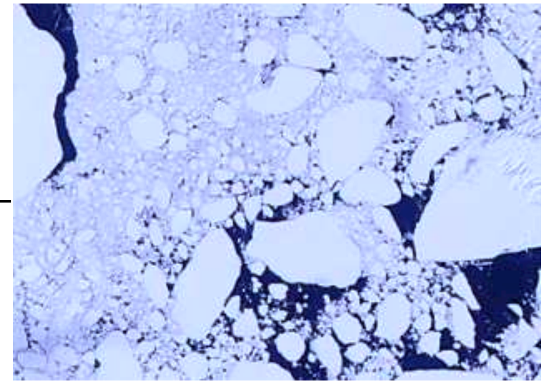
A softening landscape

- How will Greenland's fate affect ours?
- What about Antarctica?
- Tropics and mid-latitudes: Goodbye glaciers
- Trouble towards the equator?
- Mid-latitude belt
- More than melting?

The ***cryosphere***

sea ice

a.k.a. *pack ice*



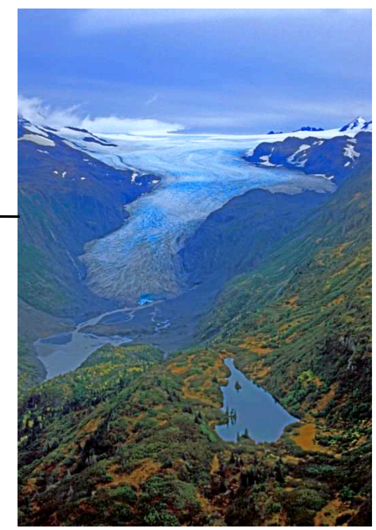
continental ice sheets

ice caps

permafrost

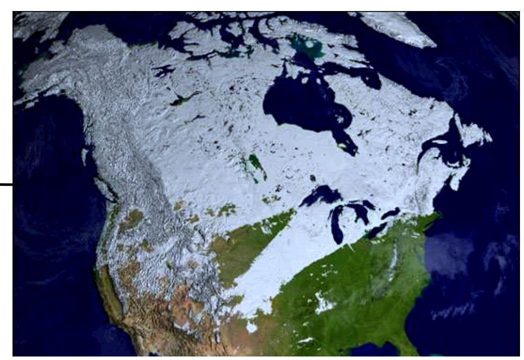
mountain glaciers

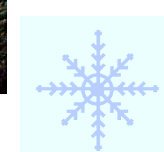
alpine glaciers

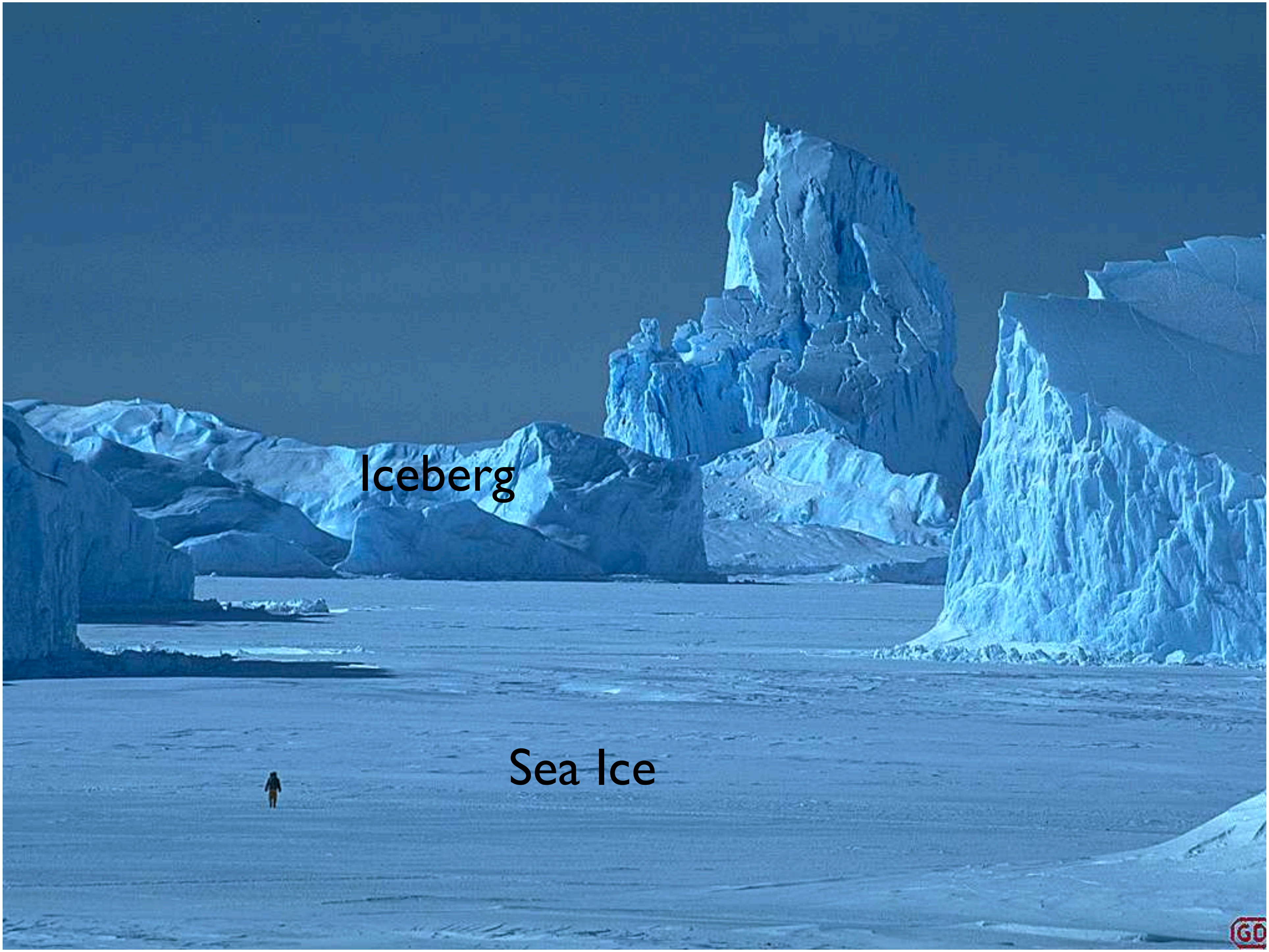


snow cover

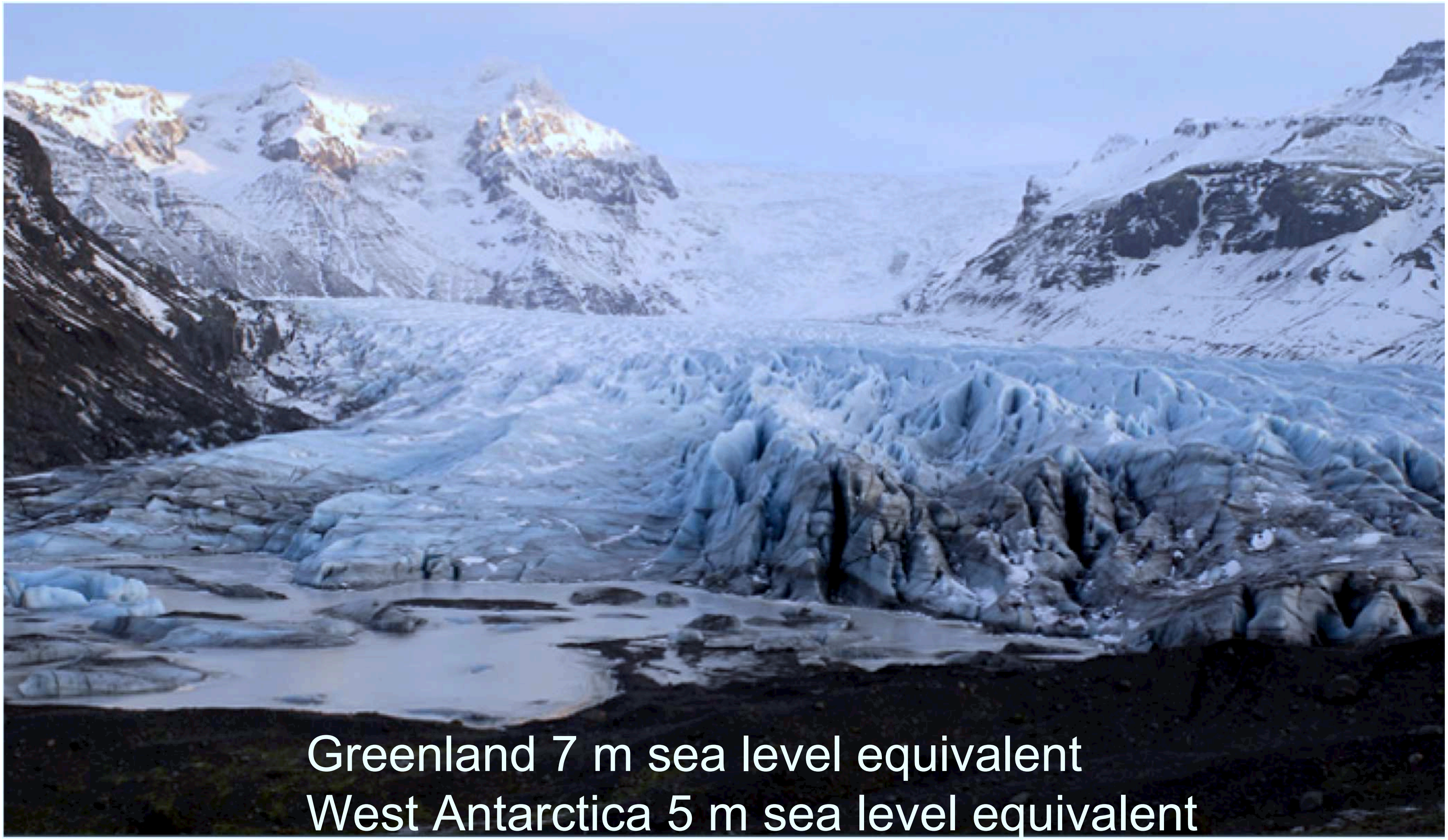
snow pack

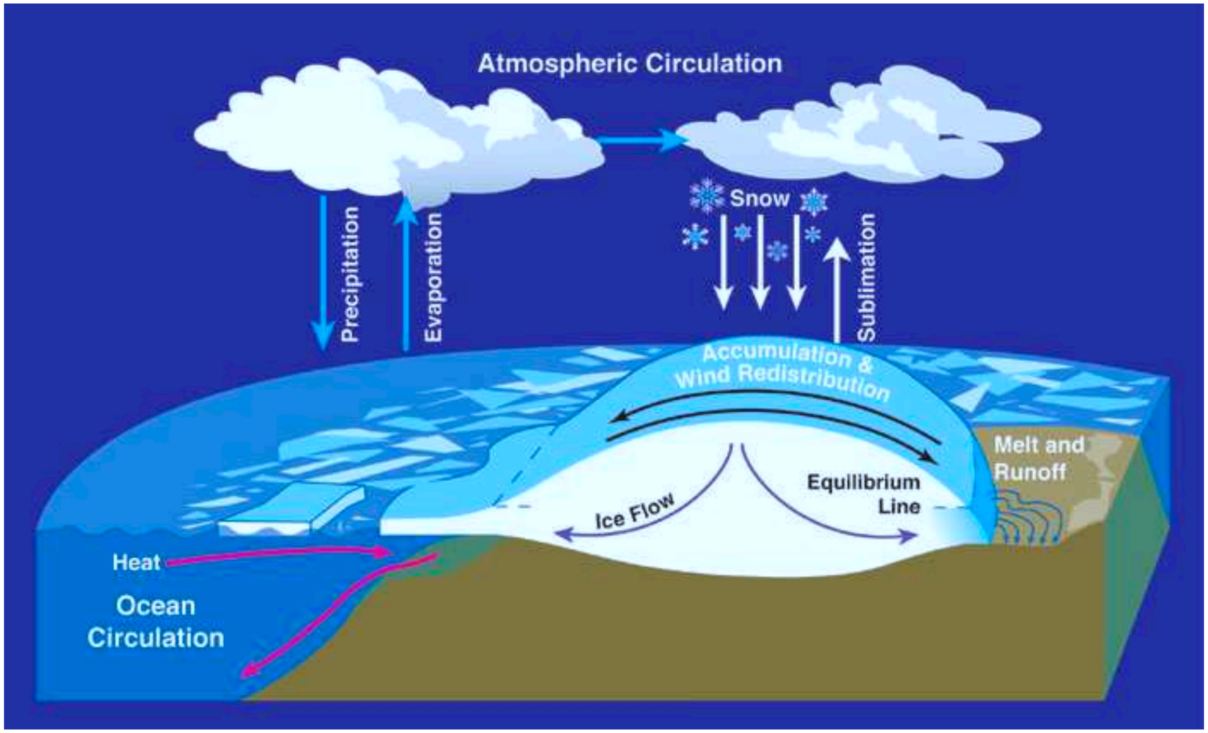





Iceberg
Sea Ice

What about land ice?





http://en.wikipedia.org/wiki/Current_sea_level_rise

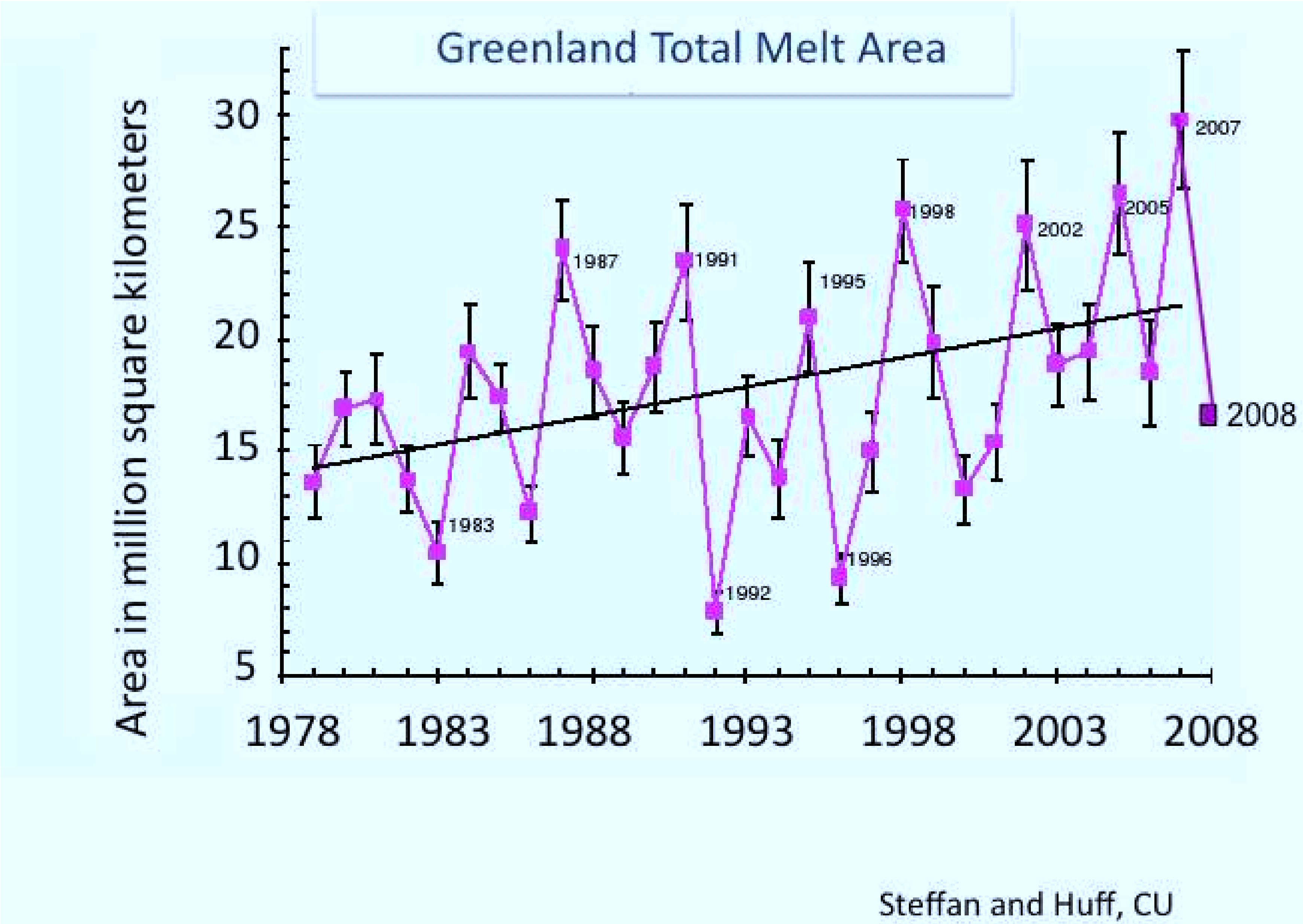
Mass balance of an ice sheet

Rate of change of mass = Rate of accumulation – Rate of ablation

Ablation is the rate of loss of mass of the ice sheet

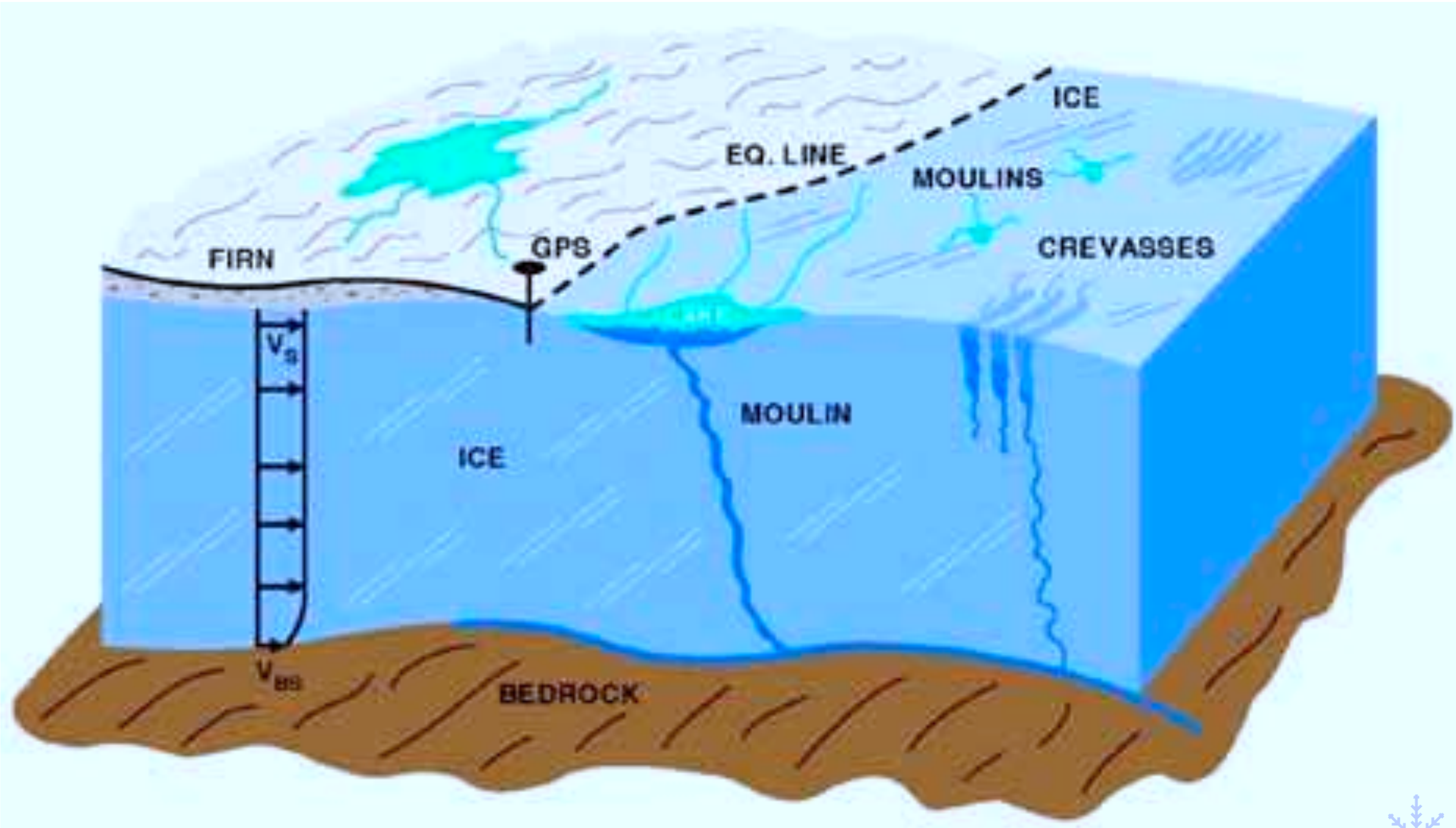
which can include **dynamic losses by calving**

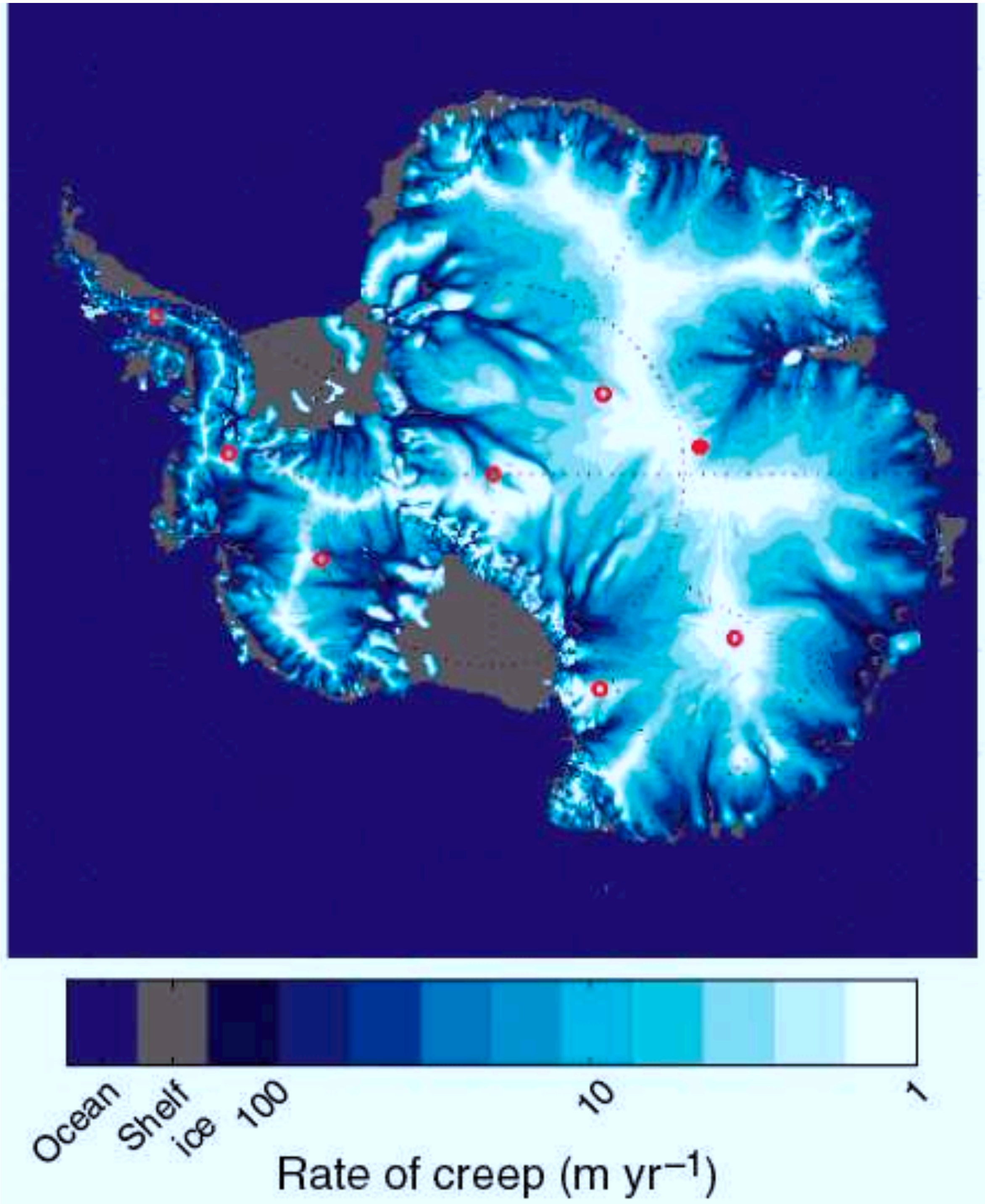
Greenland is surrounded by fjords filled with ice streams



Melting so far has amounted to a minute fraction of total volume

Higher melt may cause greater dynamic loss


ICE
EQ. LINE
MOULINS
FIRN
GPS
CREVASSES
V_S
MOULIN
ICE
V_{BS}
BEDROCK



Antarctica Facts

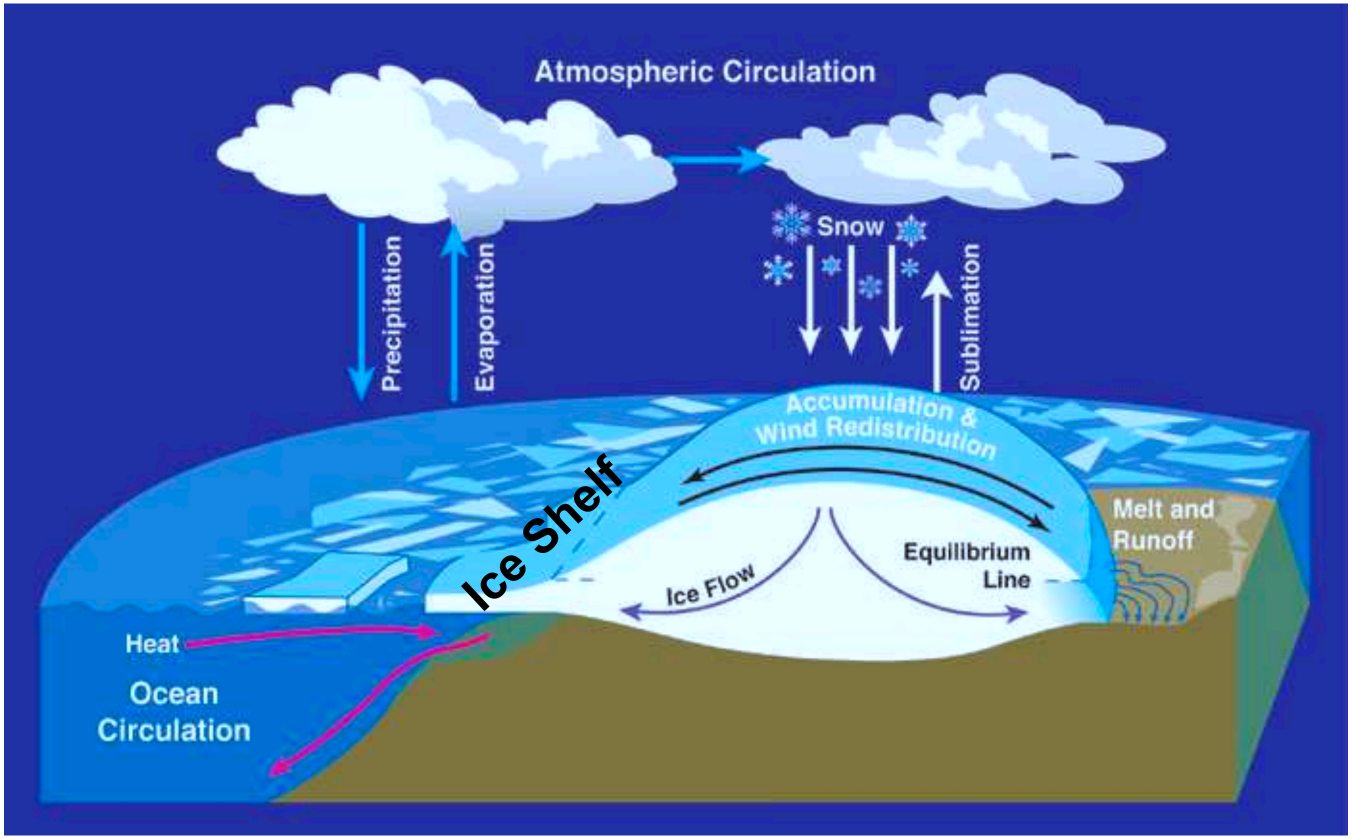
Has two giant ice shelves and many more smaller ones.

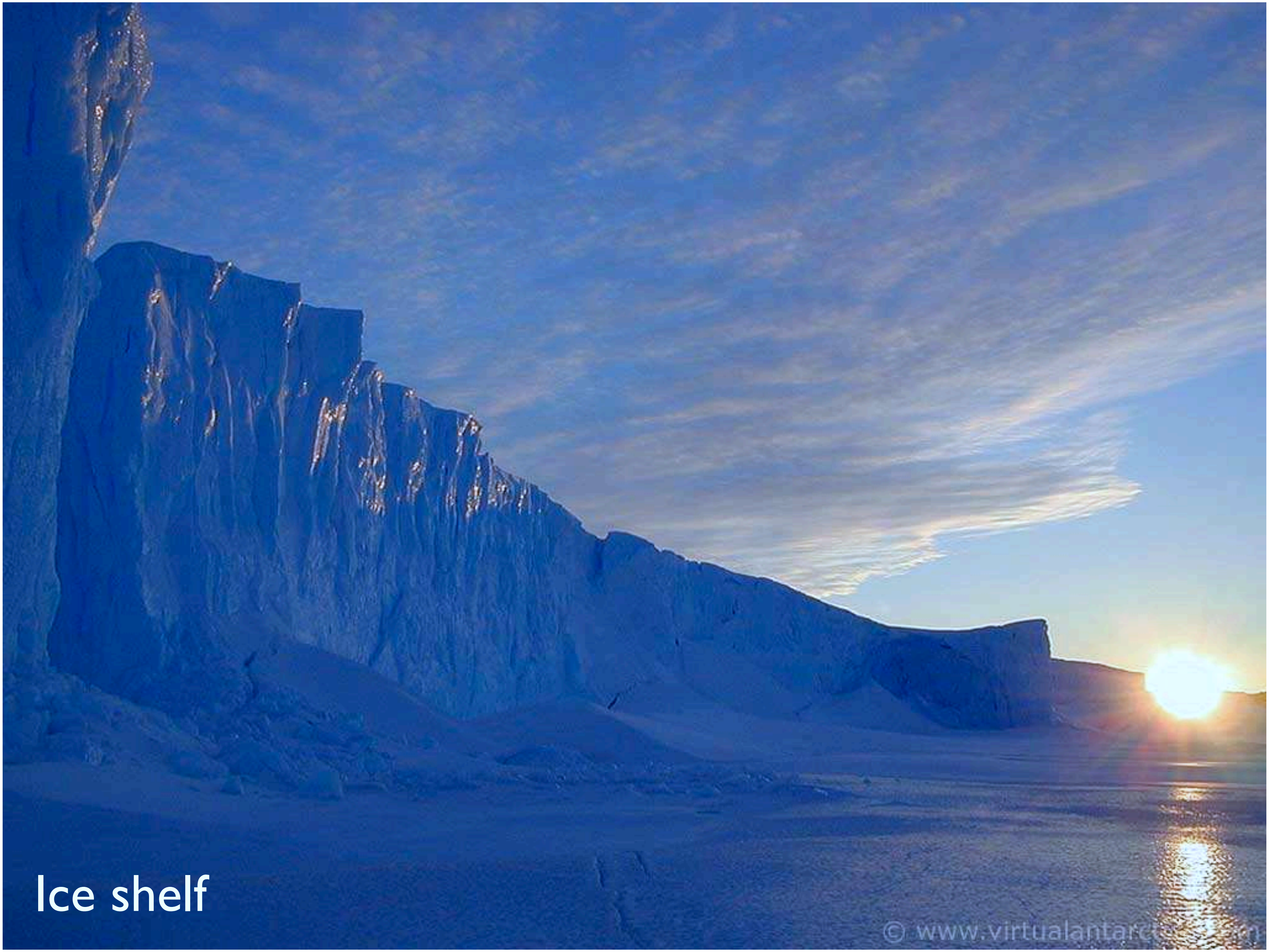
Drained by about a dozen ice streams (white features at left). It is unknown if recent acceleration is normal or a symptom of instability.

Antarctica Facts

The shelves reduce dynamic ice loss

Antarctica's icy surfaces are very cold, but warming in the surrounding ocean is a problem for the shelf base



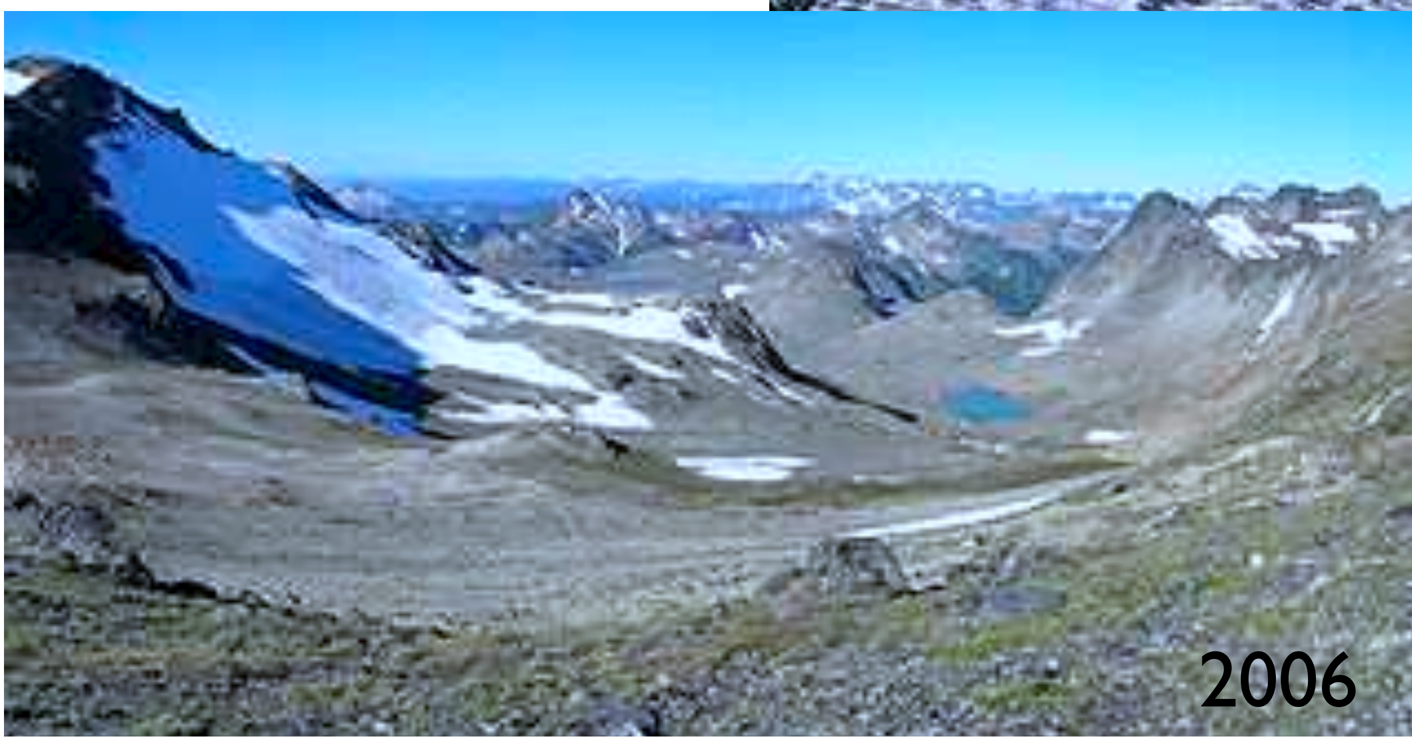

Ice shelf
© www.virtualantarctica.com


Icebergs

mountain glaciers

Presently mountain
glacier meltwater is
contributing more to
sea level rise than
Greenland and Antarctica
combined. This probably
won't be the case in 50 years

Mountain glaciers



White Chuck glacier
North Cascades

Deglaciation

~~Glacier~~ Park, Montana

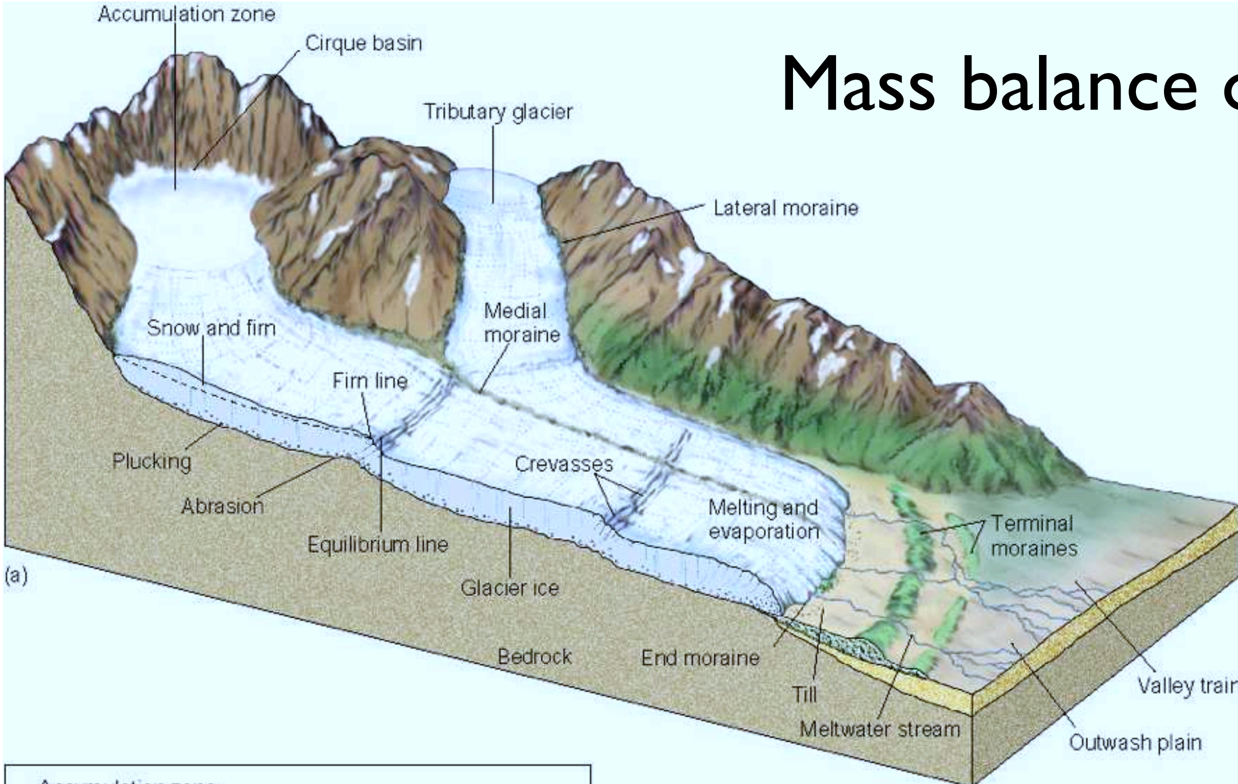
Switzerland

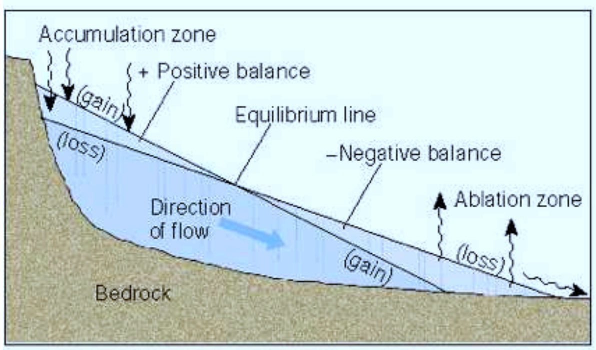
Advancing glaciers

Patagonia

Hubbard Glacier, Alaska

Mass balance of a glacier



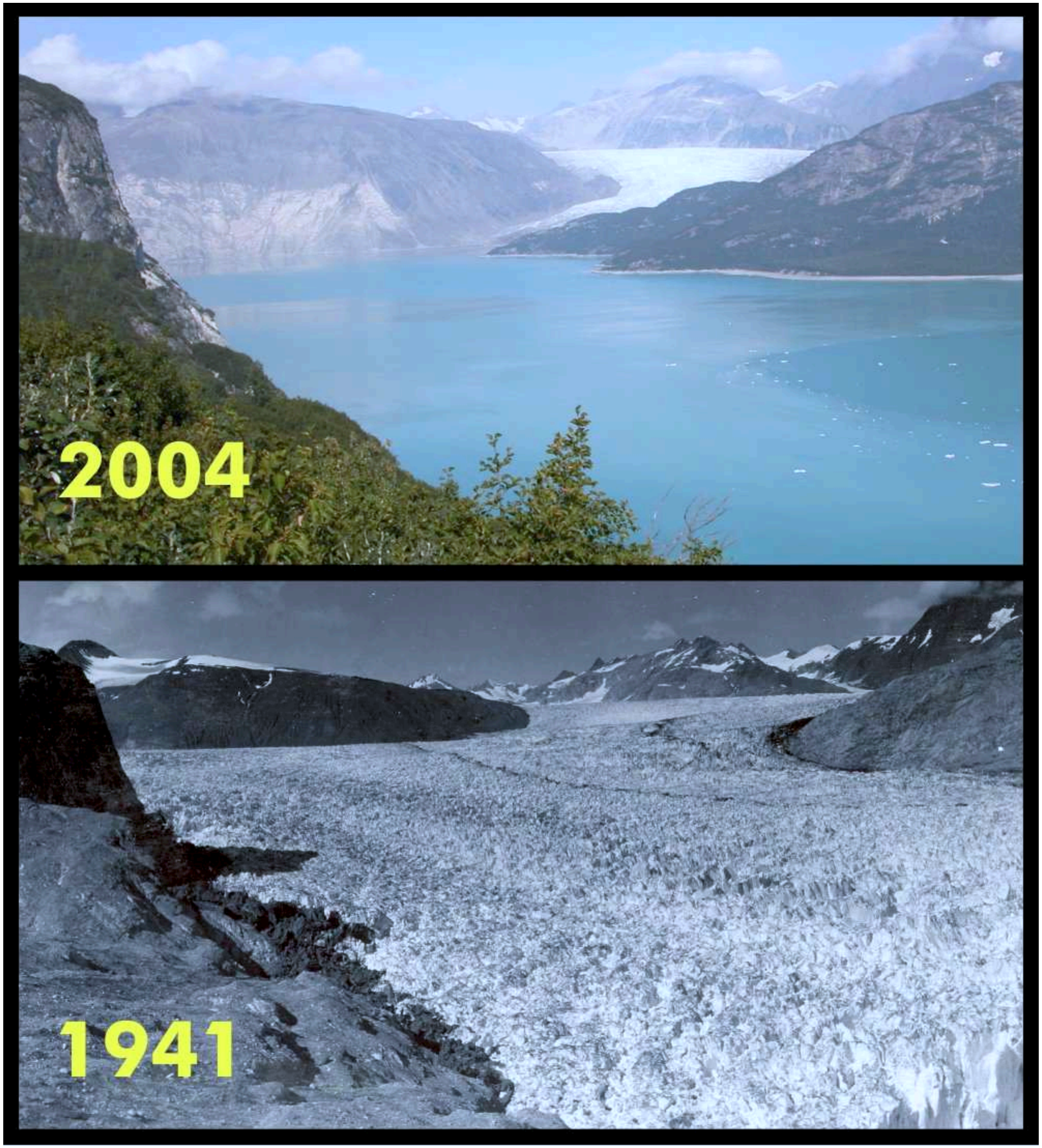


(b)

Accumulation due to excess snowfall

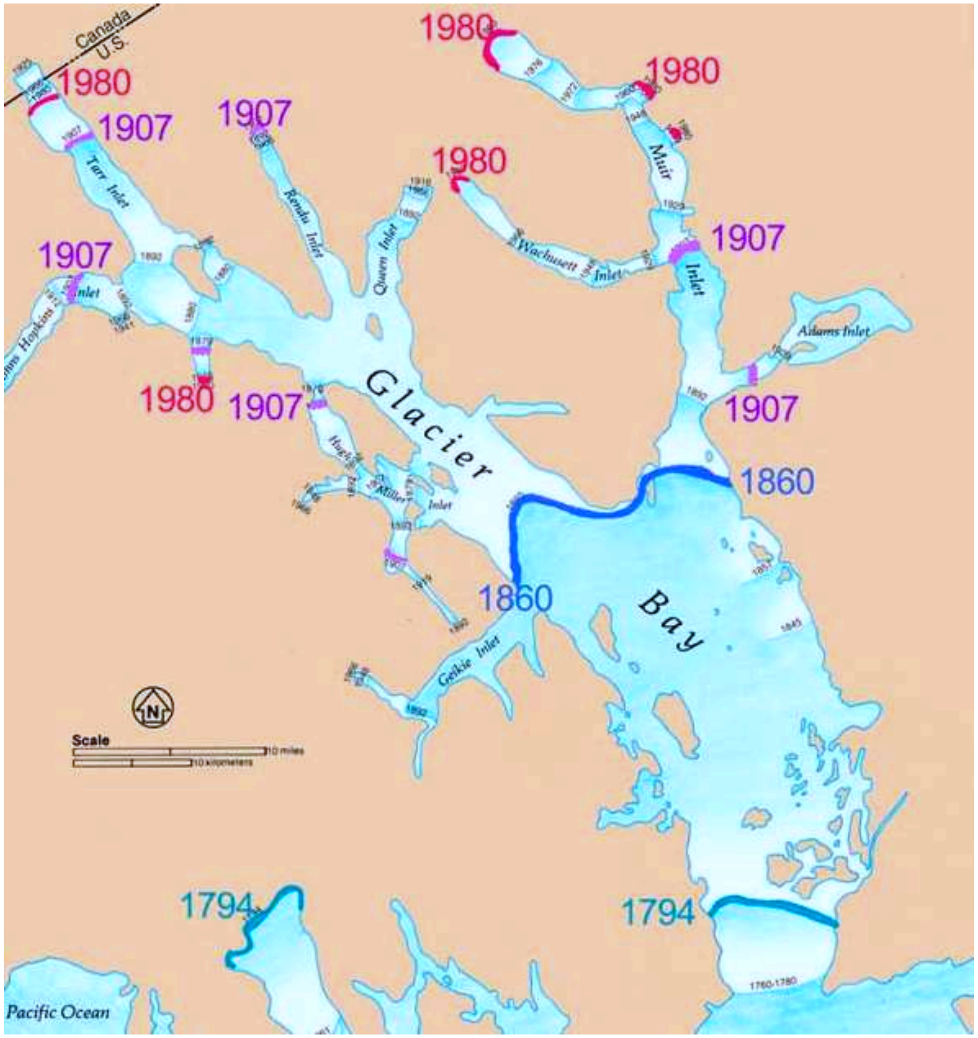
Ablation due to melting, sublimation

Must contact sea, to calve



Glacier Bay
Alaska

When did the retreat of mountain glaciers begin? Are we still witnessing the recovery from the "Little Ice Age" 200 years ago?



Probably yes, in the case of Glacier Bay. Long reported roughly steady retreat since 1794

Field, 1947; Hall et al., 1995

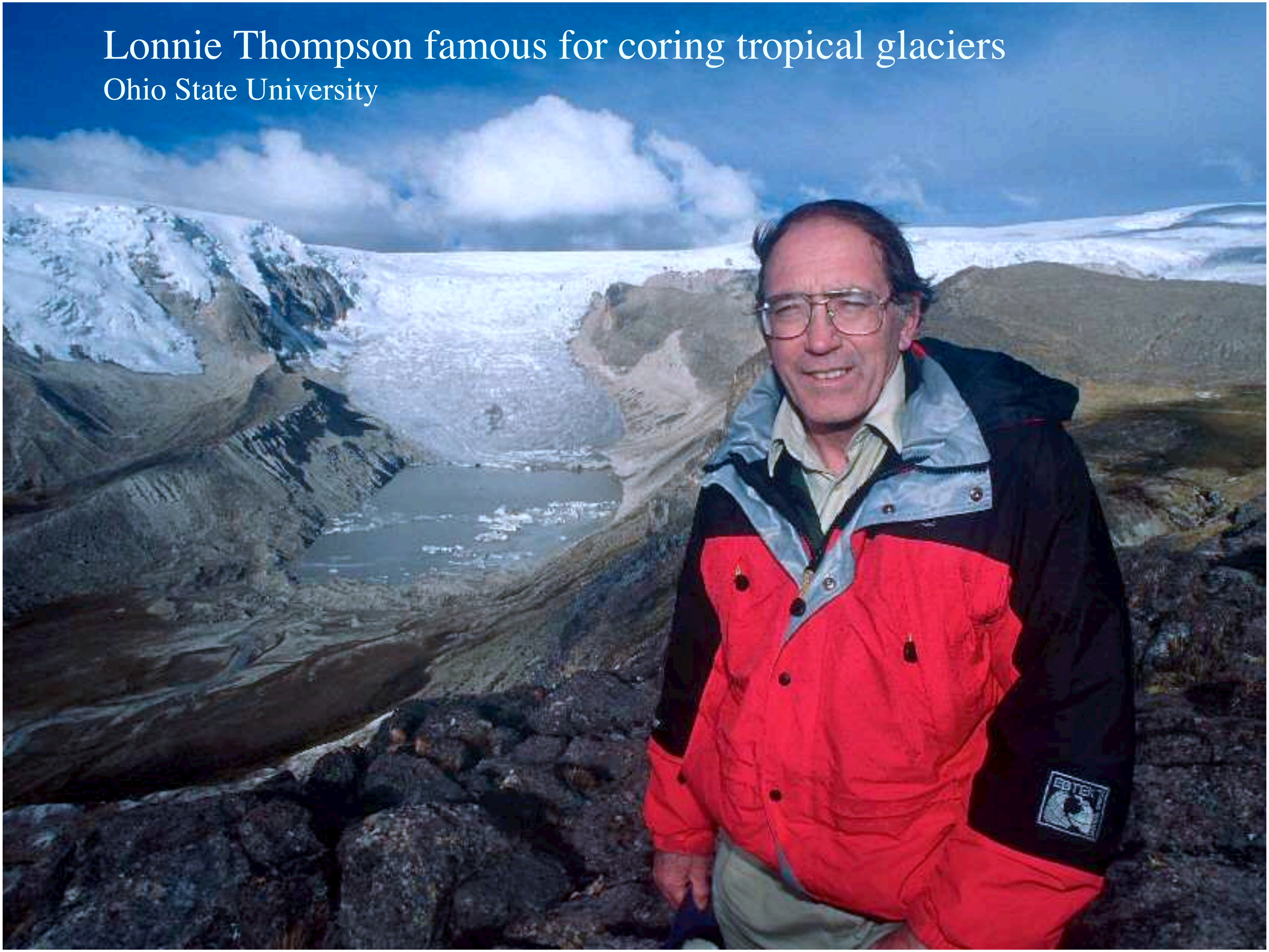
For more info see
http://glacierbay.gsfc.nasa.gov/hall.science.txt.html

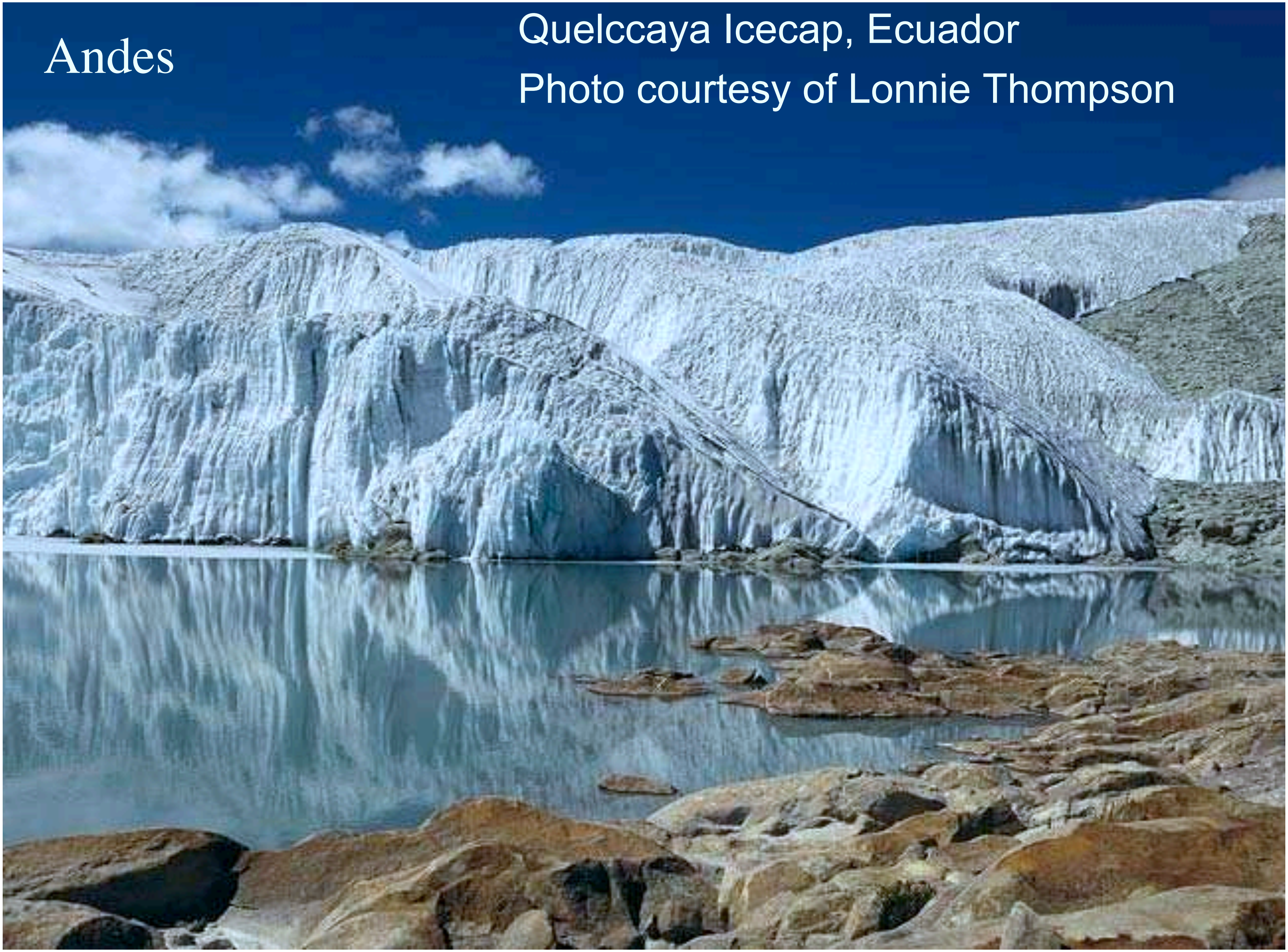
But in many other places the ice exposed near the top (which must be in the accumulation zone of a healthy glacier) has been dated to be ~1000 yrs old. Hence all younger ice has melted.

Himalayan glaciers may be melting from black carbon deposition too

Lonnie Thompson famous for coring tropical glaciers

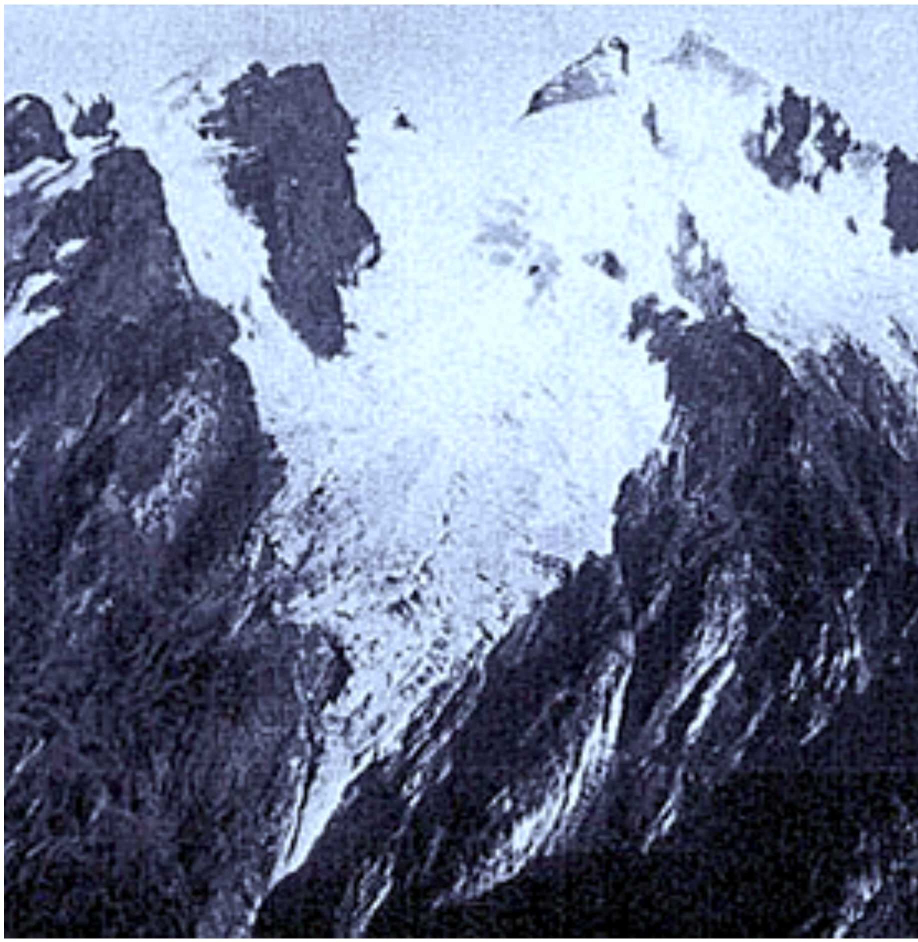
Ohio State University




Andes
Quelccaya Icecap, Ecuador
Photo courtesy of Lonnie Thompson

Tropical glaciers

Ruwenzori
Uganda



1906

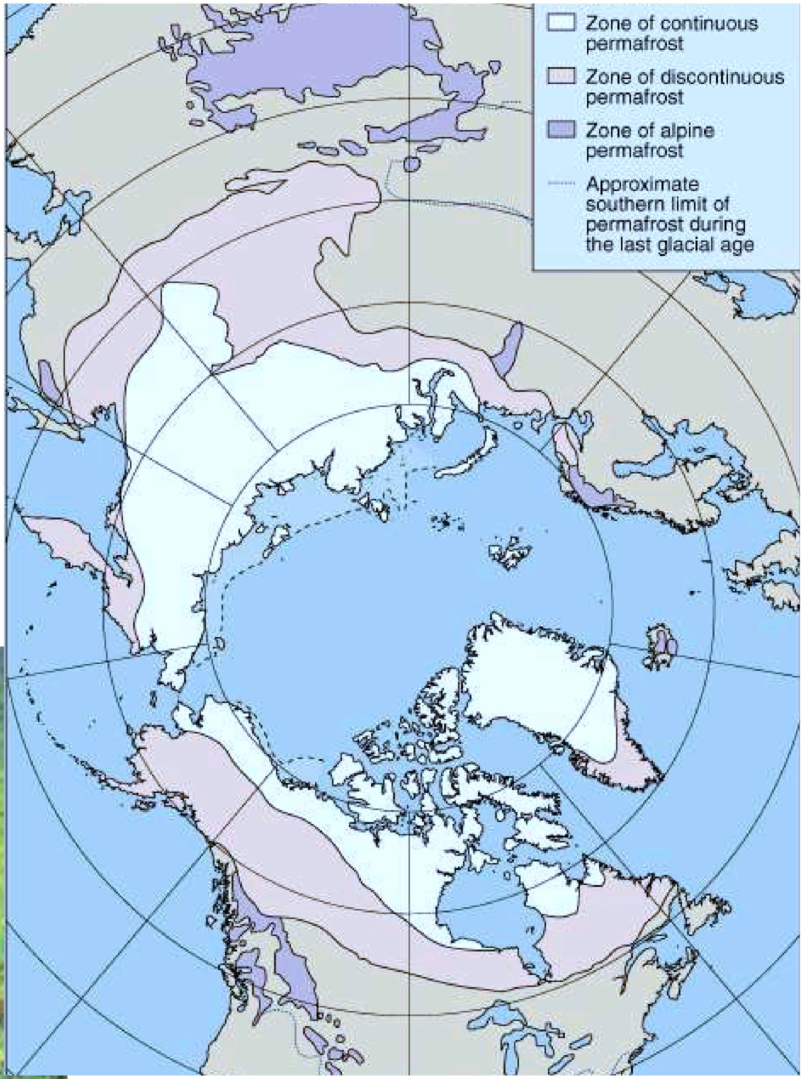
present day

Kilimanjaro

Kilimanjaro snow is disappearing from sublimation because the atmosphere there is more arid now. May still be caused by humans. But not directly by warming.

Permafrost

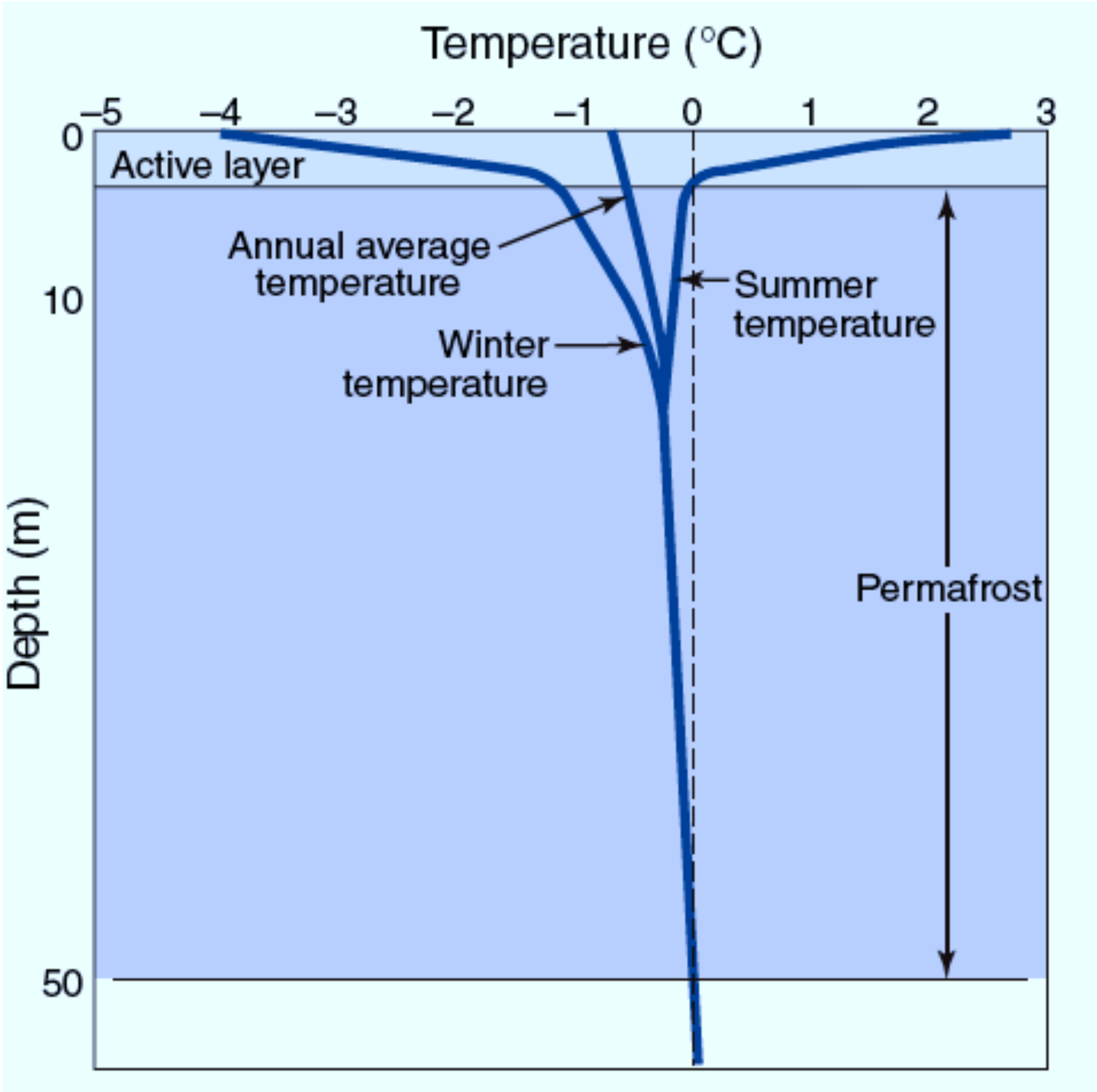
Snow-free season is short so plant growth rates are low. Plants are cold adapted, which is there strategy for survival. Not adapted for much competition.

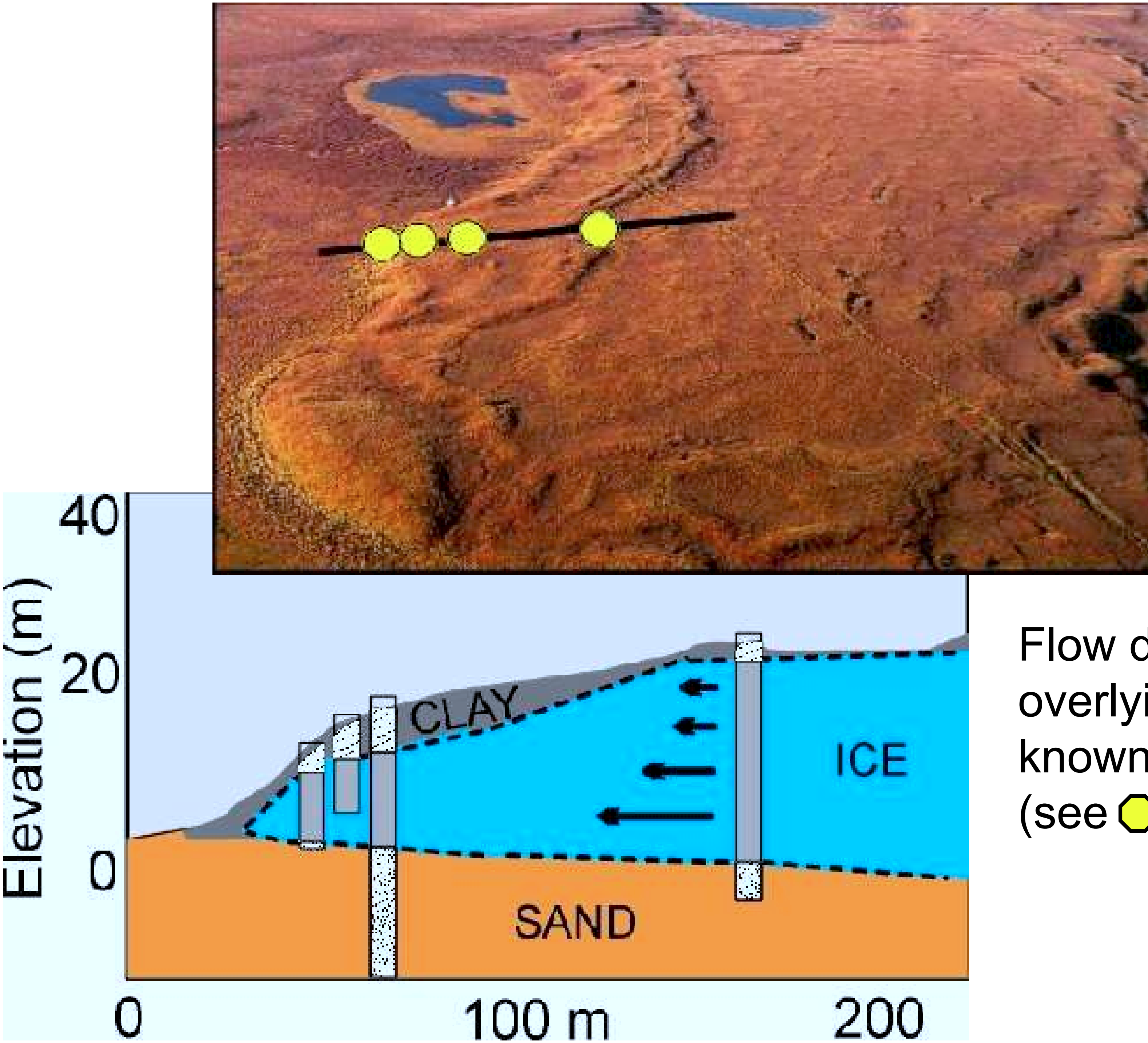


Soils are carbon rich. Some fear methane release from thaw. Others say greater vegetation, will draw down CO2.

Ice is usually underground. Can be visible at river channel. This picture shows ice massive (the blue stuff) and active layer (grey above).

http://gsc.nrcan.gc.ca/permafrost/suppdoc_e.php

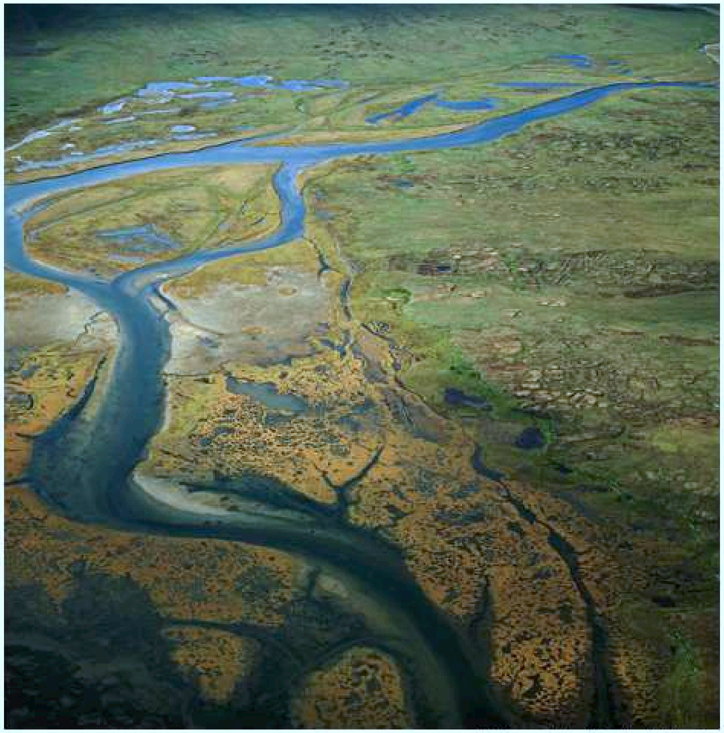

Temperature (°C)
–5
–4
–3
–2
–1
0
1
2
3
0
10
50
Depth (m)
Active layer
Annual average temperature
Winter temperature
Summer temperature
Permafrost



Flow deforms overlying surface known from cores (see ⯃ above)

Lakes can’t drain and evaporation is low in cold climate


Bemhard Edmair (National Geographic)



Photograph by Bernhard Edmaier

Rivers are heavily braded as stream channel moves frequently due to permafrost and low vegetation

http://www.gi.alaska.edu/snowice/Permafrost-lab/

Thawing permafrost

- widespread evidence of melting
- causing:
  - damage to roads and buildings
  - methane to be liberated
  - vegetation to increases
- to melt all the permafrost will take centuries
- permafrost thawing will be accelerated if summer sea ice continues to retreat

Methane or Clathrate Hydrates

are water ice cages enclosing methane

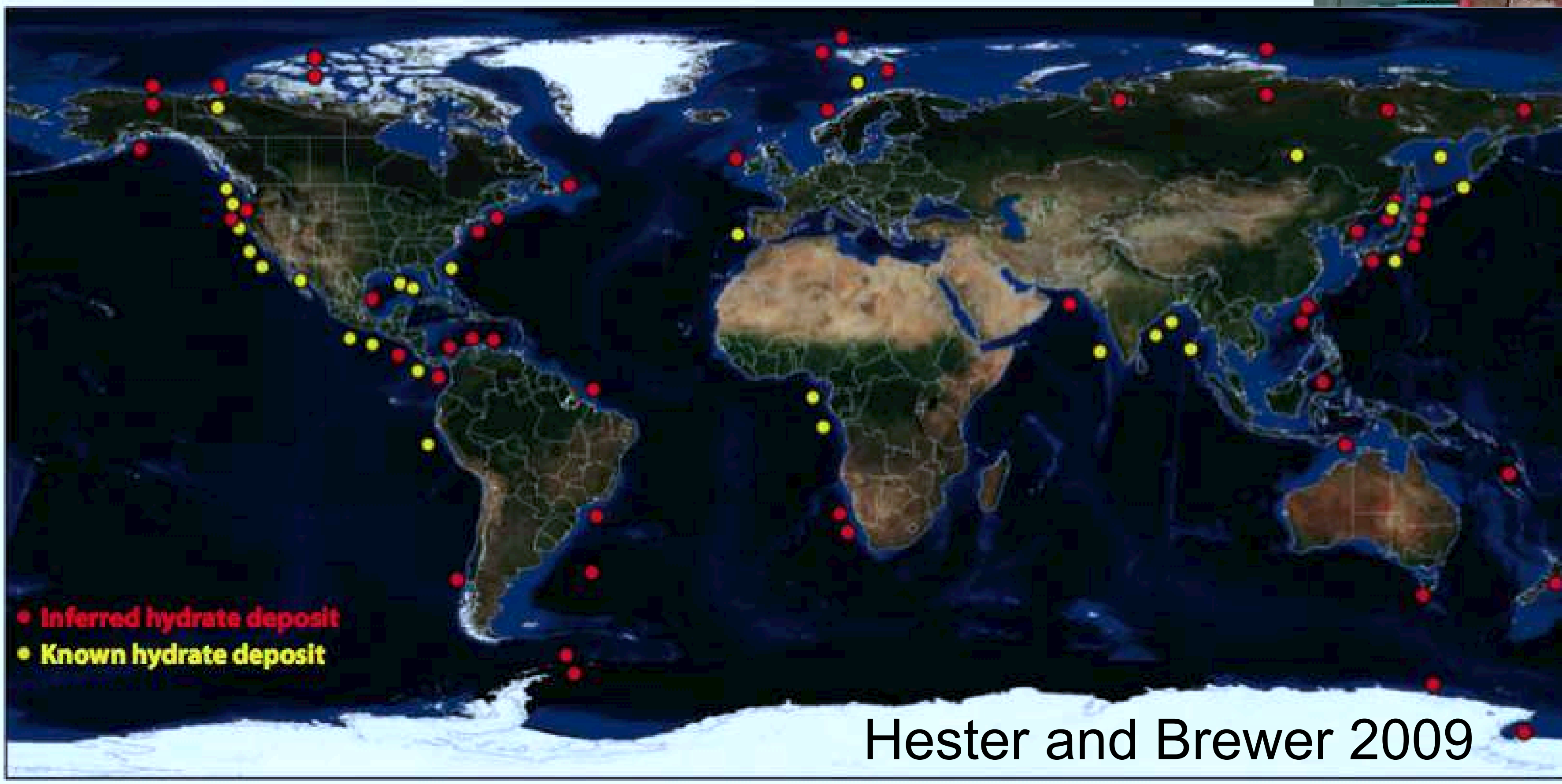


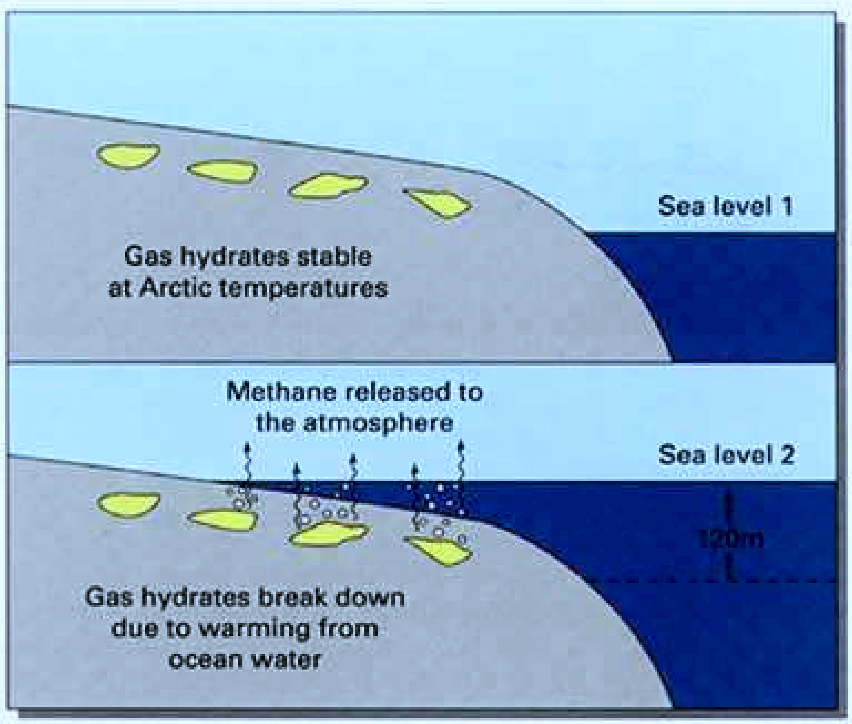
Figure 1

Worldwide map of more than 90 documented hydrate occurrences. Data from Kvenvolden & Lorenson (2001) and Milkov (2005).

Methane Hydrates

Carbon stored is 500-10,000 Gtons C (Coal is 3,200 Gtons C)

Need high pressure - under ice massive in permafrost
or ocean sediments



Sea-level rise causes relatively warm ocean water to cover cold Arctic strata. The resulting breakdown of stable gas hydrates within the sediment releases gas into the atmosphere.

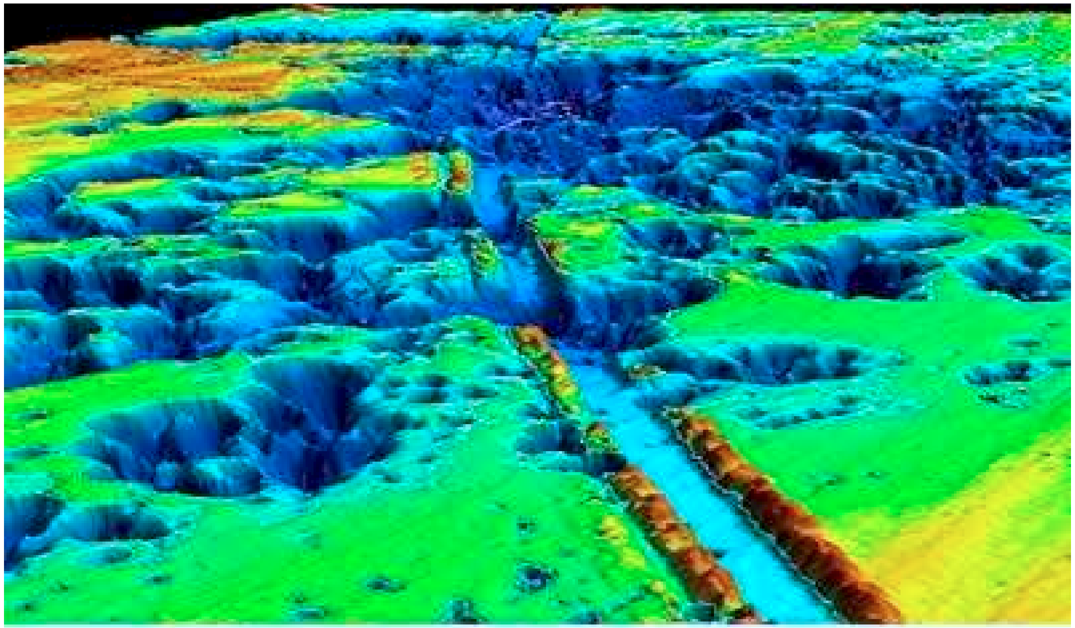
Methane ice diagram.
Source: http://marine.usgs.gov/fact-sheets/gas-hydrates/gas-hydrates-6.gif; accessed November 27, 2005.

The risk from them this century is speculative.

However their release would possibly create a positive feedback.

55 million years ago methane hydrates appear to have been released to the atmosphere at a time when the earth also warmed 2-3 C

There are pockmarks in ocean sediments as indication of past catastrophic release.



"Pockmarked" ocean floor suggesting shallow gas deposits; Canada's Beaufort Sea Geohazards Project
Source: http://gom.nrcan.gc.ca/beaufort/images/pockmarksdem.jpg; accessed November 27, 2005

Snow covered land is by far the largest area component of the cryosphere.

Snow is part of the positive ice-albedo feedback cycle, such that if snow melts earlier in spring, it causes spring warming and soil drying.

Snow is an important reservoir for water in some communities.

Table 2.1 Surface area and mass of the various components of the cryosphere[a]

Cryospheric component	Area	Mass
Antarctic ice sheet	2.7	53
Greenland ice sheet	0.35	5
Alpine glaciers	0.1	0.2
Arctic sea ice (March)	3	0.04
Antarctic sea ice (September)	4	0.04
Seasonal snow cover	9	<0.01
Permafrost	5	1

[a] Surface area is expressed as percentage of the area of the surface of the Earth. Mass is expressed in units of 10^3 kg m^{-2} (numerically equivalent to meters of liquid water) averaged over the entire surface area of the Earth. For reference, the total surface area of the Earth and the area of the Earth covered by land are 5.12 and 1.45×10^{14} m^2, respectively. [Courtesy of S. G. Warren.]

From Wallace and Hobbs, *Atmospheric Science: An Introductory Survey, 2nd Ed.,* Academic Press.

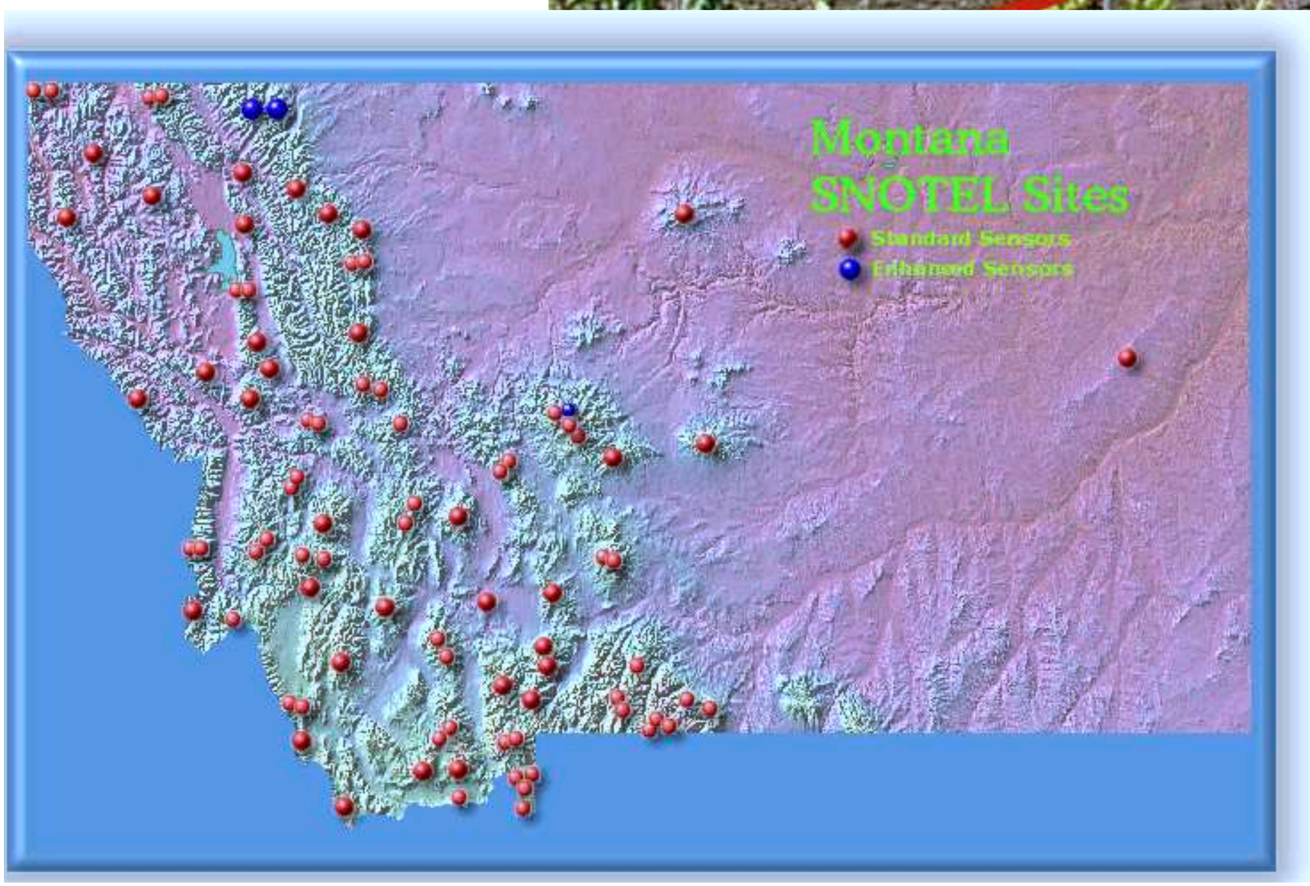
Precipitation is increasing in high latitudes with global warming

Snow covered season is shorter but depth may be greater

Musk Oxen

20,000 ^ DIE FROM BANKS ISLAND RAIN ON SNOW

Rennert et al 2009



SNOTEL measures snow weight

Summary of the Big Melt

Sea ice is typically 0.5-3m thick and its area coverage is 5-15 million sq. km. In the Arctic, the September area has decreased more than 10%/decade and the ice thickness has decreased by about 40% in the last 40 yrs. Antarctic sea ice has no known significant trends.

Climate models project a sea ice free Arctic in the month of September by about 2050-2100 in models that compare reasonably well with the past observations. Even with a steep downward decline over the century, sea ice can appear to on a recovering trend for a decade.

What is so special about climate in the polar regions? Ice-albedo positive feedback (sea ice and snow on land) amplifies warming.

Poleward amplification reduces pole-to-equator temperature gradient, which then reduces atmospheric heat engine. Heat is drawn less towards pole and tropics warm more too.

Summary of the Big Melt

Rising water vapor concentration and its transport poleward is expected to increase precipitation and possibly cloudiness

In winter, clouds have almost no albedo effect, so their GHE dominates

Erosion if sea ice disappears (it damps waves) and permafrost causes surfaces to soften

The polar bear was listed as a threatened species owing to global warming in May 2008 after more than 3 years of legal action. The ruling cites scientific research warranted the decision. However, it would not justify regulating GHGs.

Greenland ice sheet is up to 3000 m thick, the equivalent of 7m of sea level. The island is rimmed with fjords where outlet glaciers approach the sea. Their retreat reduces their ability to buttress outflow. Surface meltwater drains and lubricates the ice-bedrock interface. These processes cause dynamic thinning.

Summary of the Big Melt

The Antarctic ice sheet is up to 4000 m thick, the equivalent of 70m of sea level. It is has a number of floating ice shelves that are about 1000m thick. The shelves slow glacial outflow. There is little upper surface melt, but some shelves appear threatened by ocean heat. The loss of shelves (as in the case of the Larsen B) causes dynamic thinning. Some fear the West Antarctic Ice Shelf is unstable. It holds about 5 m of sea level equivalent.

Mountain glaciers are found from the tropics to the high latitudes. Healthy glaciers have an accumulation zone and an ablation zone. Most are retreating, but the cause is not uniformly global warming. Some no longer have accumulation zones.

Permafrost becomes spongy when it thaws. Under ground ice inhibits drainage, so landscapes have many small lakes and braided rivers. Low latitude plants that invade tend to be more aggressive competitors. Some fear methane release from thaw, while others expect CO_2 drawdown from plant growth.

Summary of the Big Melt

Methane (clathrate) hydrates occur in high pressure environments like under permafrost or in ocean sediments. They contain a large but uncertainty quantity of methane. Melting permafrost could start their release and initiate a positive feedback. Most think it is low probability/high risk.

Snow covered land is by far the largest area component of the cryosphere. Snow is part of the positive ice-albedo feedback cycle, such that snow melt earlier in spring causes spring warming and soil drying. Snow is an important reservoir for water in some communities.

Outstanding scientific issues

Why is sea ice retreating? Are changes in wind playing a role?
Why is it retreating in the Arctic but not in the Antarctic?

Is the summer melting of the Greenland ice cap unprecedented?
Is the trend real?
Will the melting accelerate?

How long has the permafrost been thawing?
Are there places where it is advancing?
Are changes in land use a factor?

How far back in time can the retreat of the mountain glaciers be traced?

The Oceans (*RG p. 106-127*)

From sticks to satellites: measuring sea level

Monitoring the ocean below the surface

Balancing the sea level budget

How high the sea?

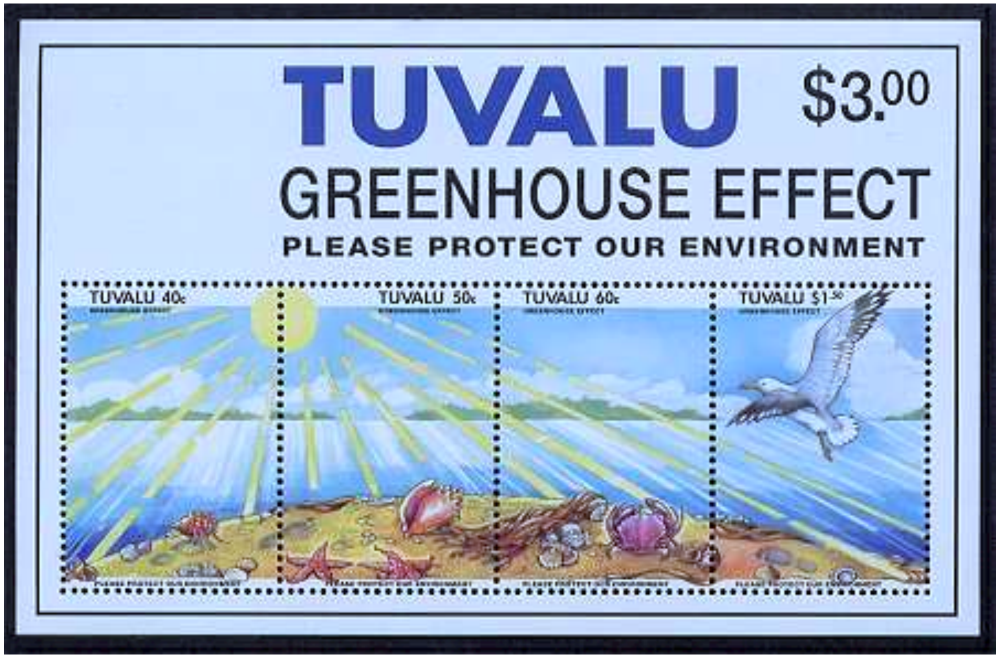
Climate change and El Niño

Will the Atlantic turn cold on Britain

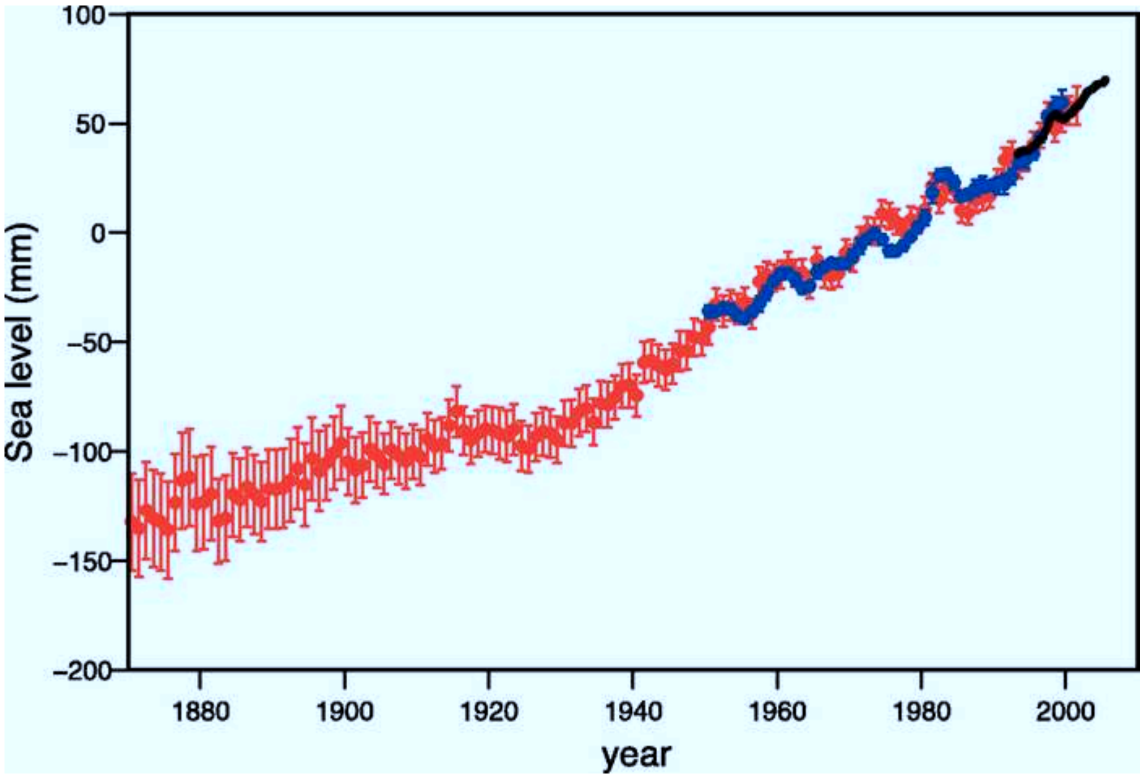
Living in a changing sea

Coral reefs at risk

ocean acidification



20th century rise was 1.2-2.2 mm/yr on average



IPCC 2007 Figure 5.13

red = “reconstructed” from tide gauges and other

blue = tide gauges

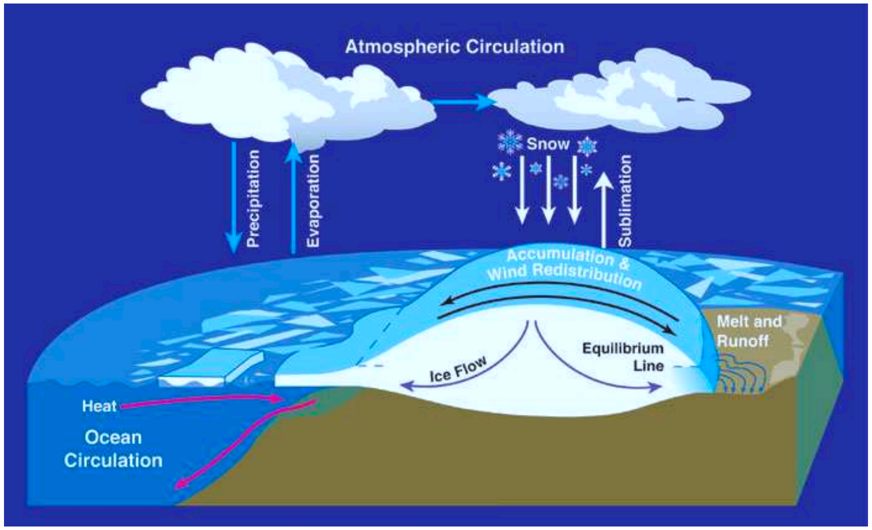
black = satellite altimetry

Mean Sea Level - The average height of the ocean at a given location

What controls it?

Thermal expansion of the ocean
The exchange of seawater/ice with lake/soil water or land ice
Tides
Tsunamis
Subsidence and uplift
Currents converging/diverging
Atmospheric pressure

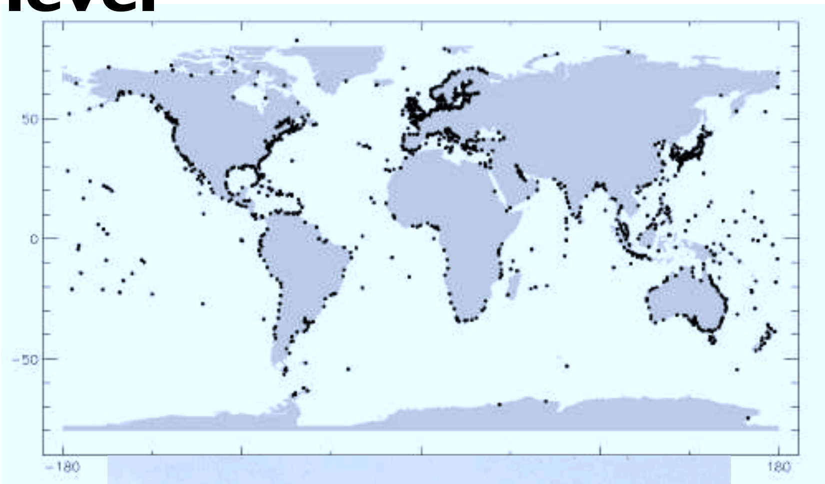
The first two vary with global warming



Why is sea level rise in the past so uncertain?

Pre satellite data are sparse

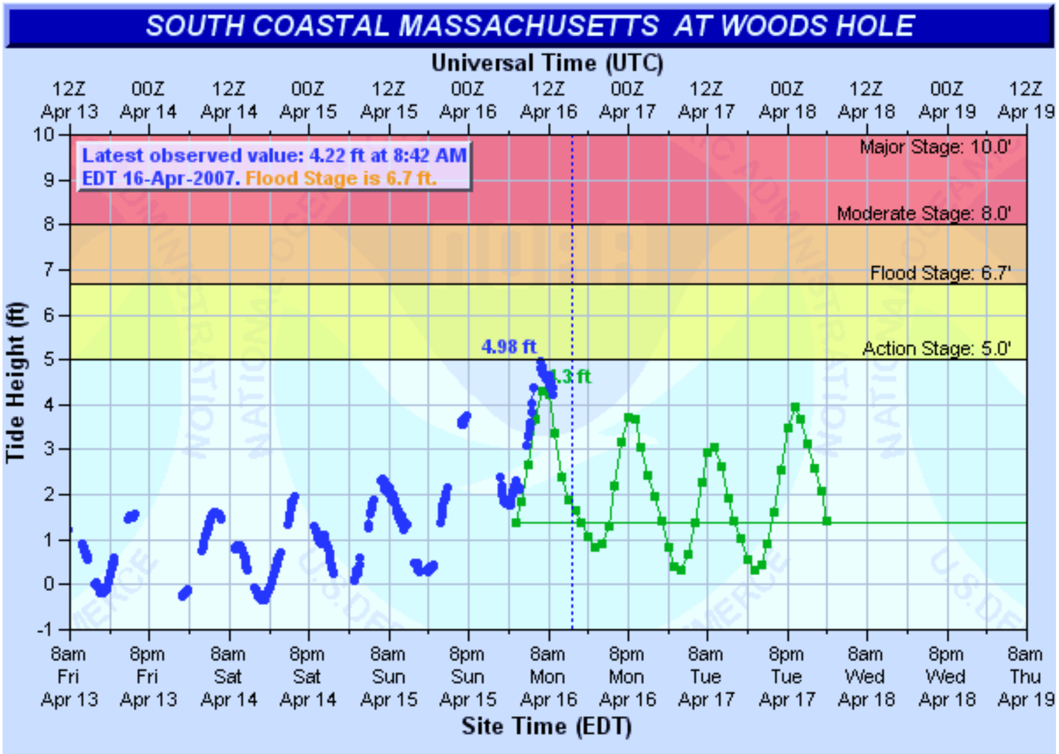
From sticks to satellites: measuring **sea level**



Tide gauges are measuring sticks or sometimes floats in wells

Always coastal

Few long records



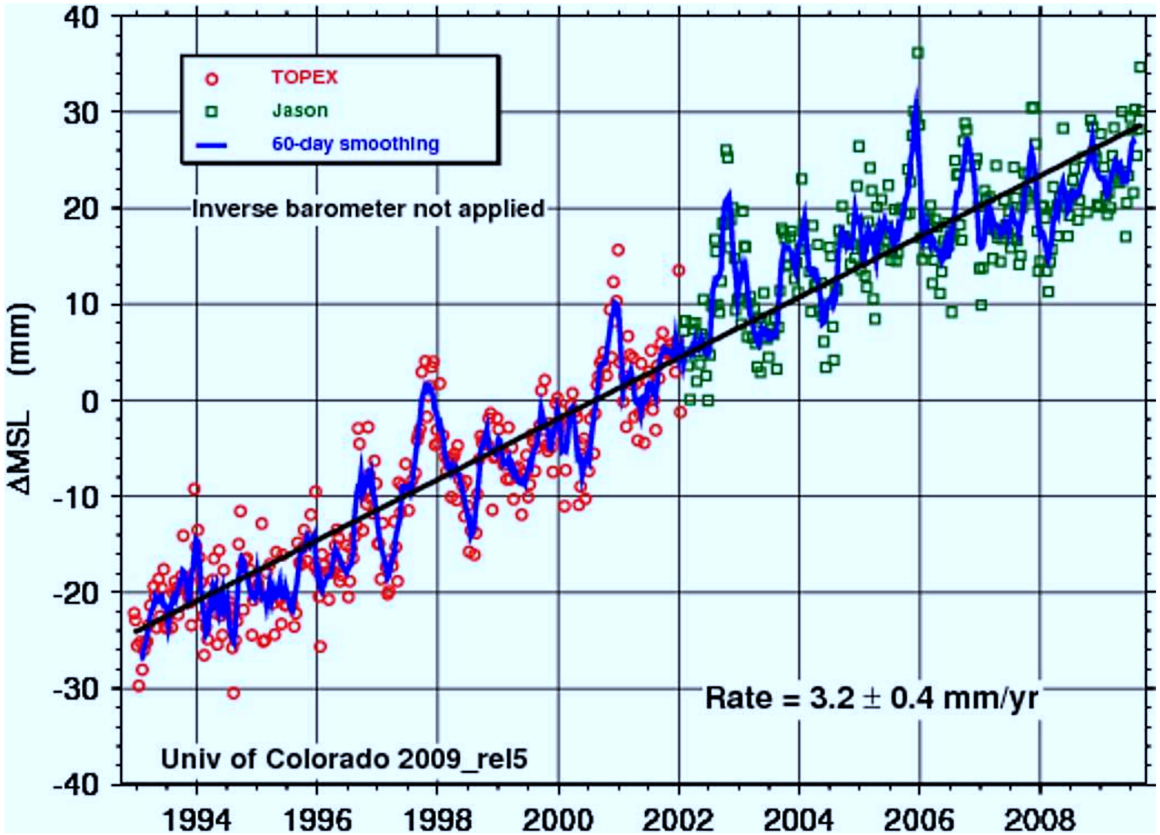
From sticks to satellites: measuring **sea level**

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

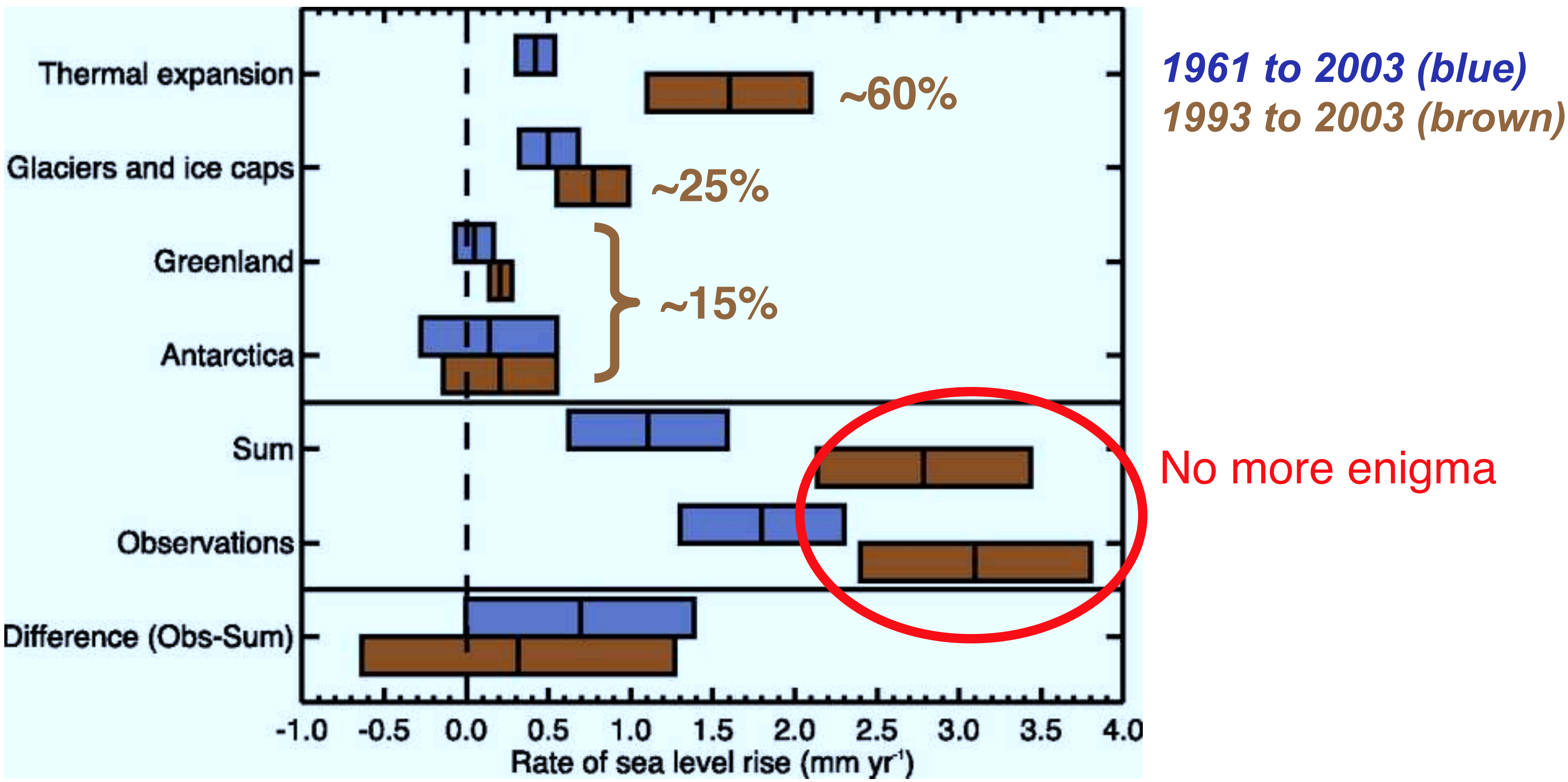
Sea level rise from TOPEX-Poseidon Radar Altimetry



Each 10 day measurement has an accuracy of 3-4 mm

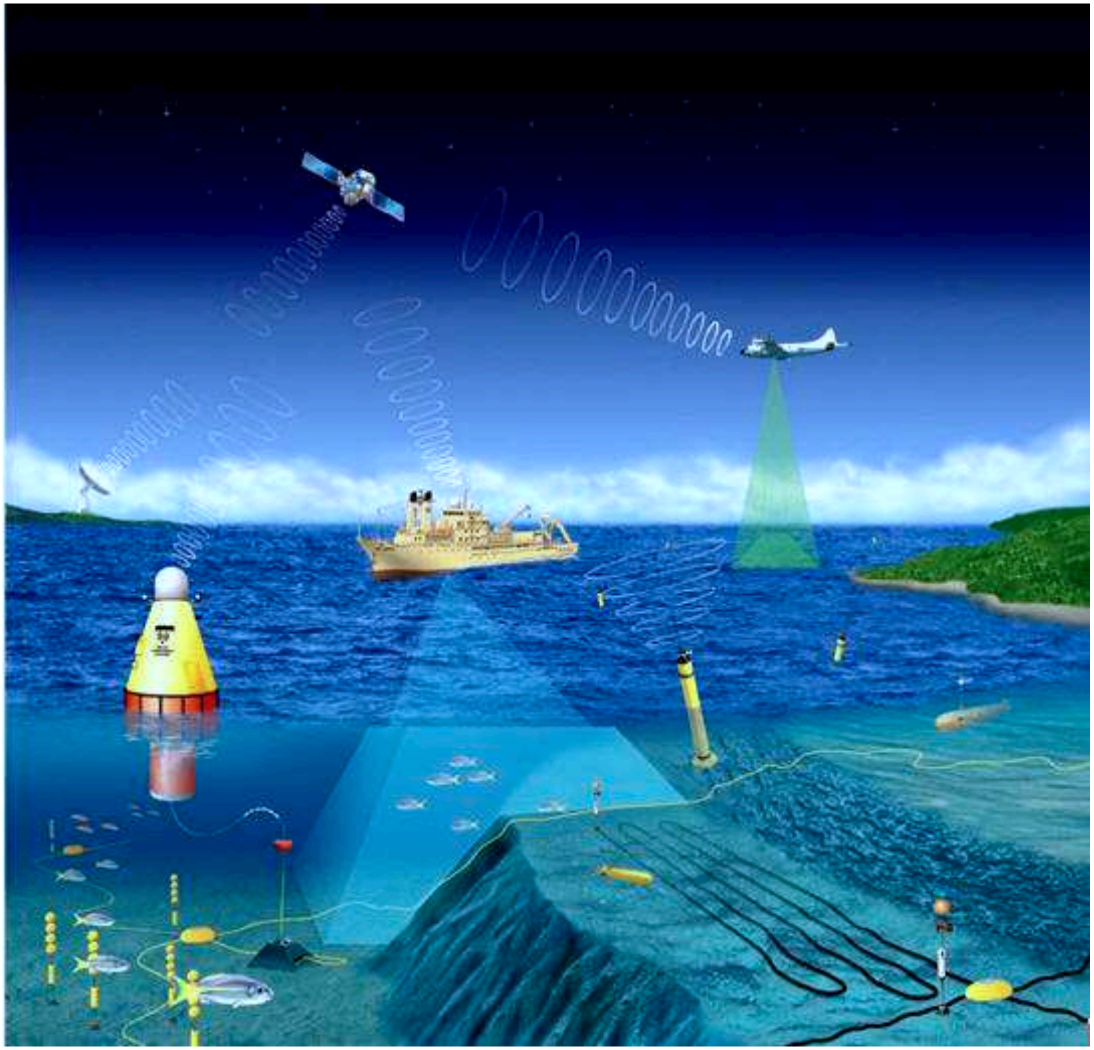
Updated version of IPCC 2007 Fig 5.14
http://sealevel.colorado.edu and
Leuliette, et al (2004) *Marine Geodesy*, **27**(1-2), 79-94

Balancing the Sea Level Rise Budget



IPCC 2007 Figure 5.21.

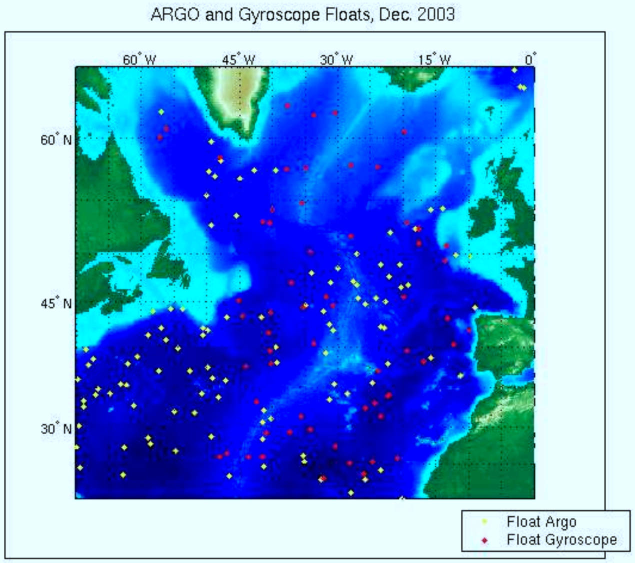
Monitoring the ocean

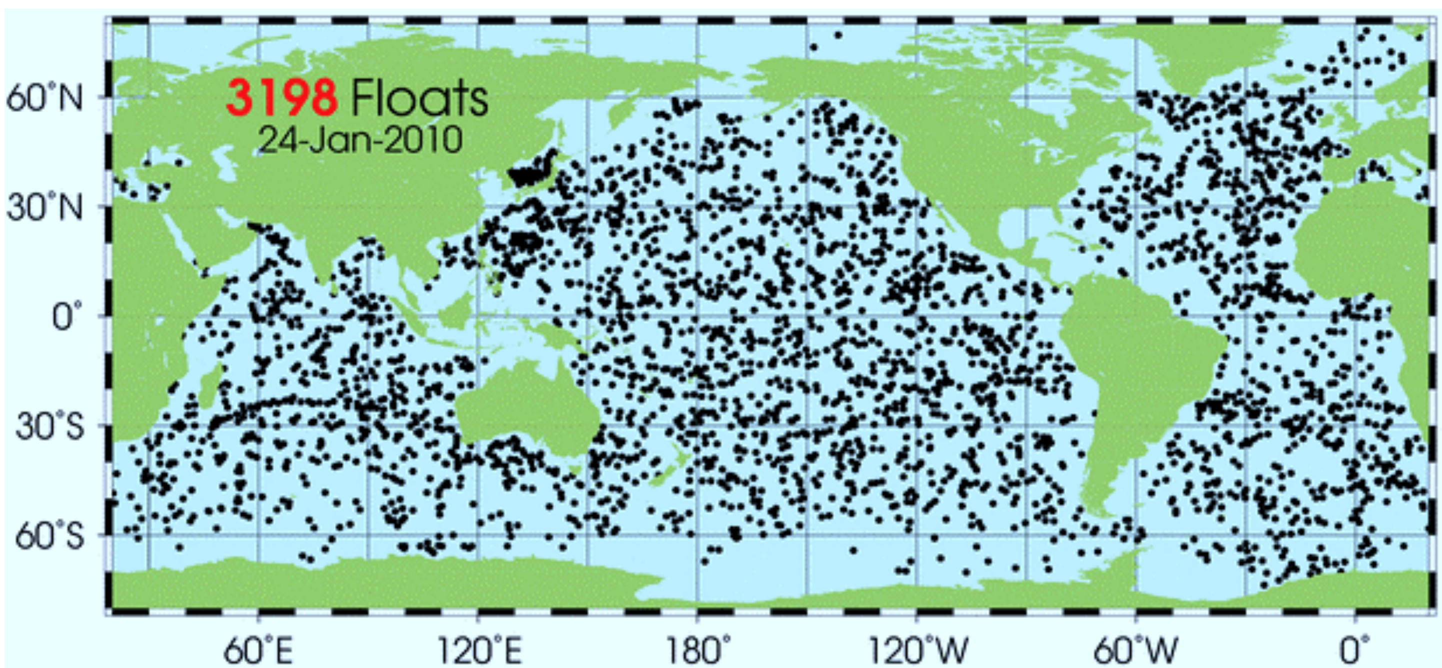


Many instruments are used to measure **ocean heat content**

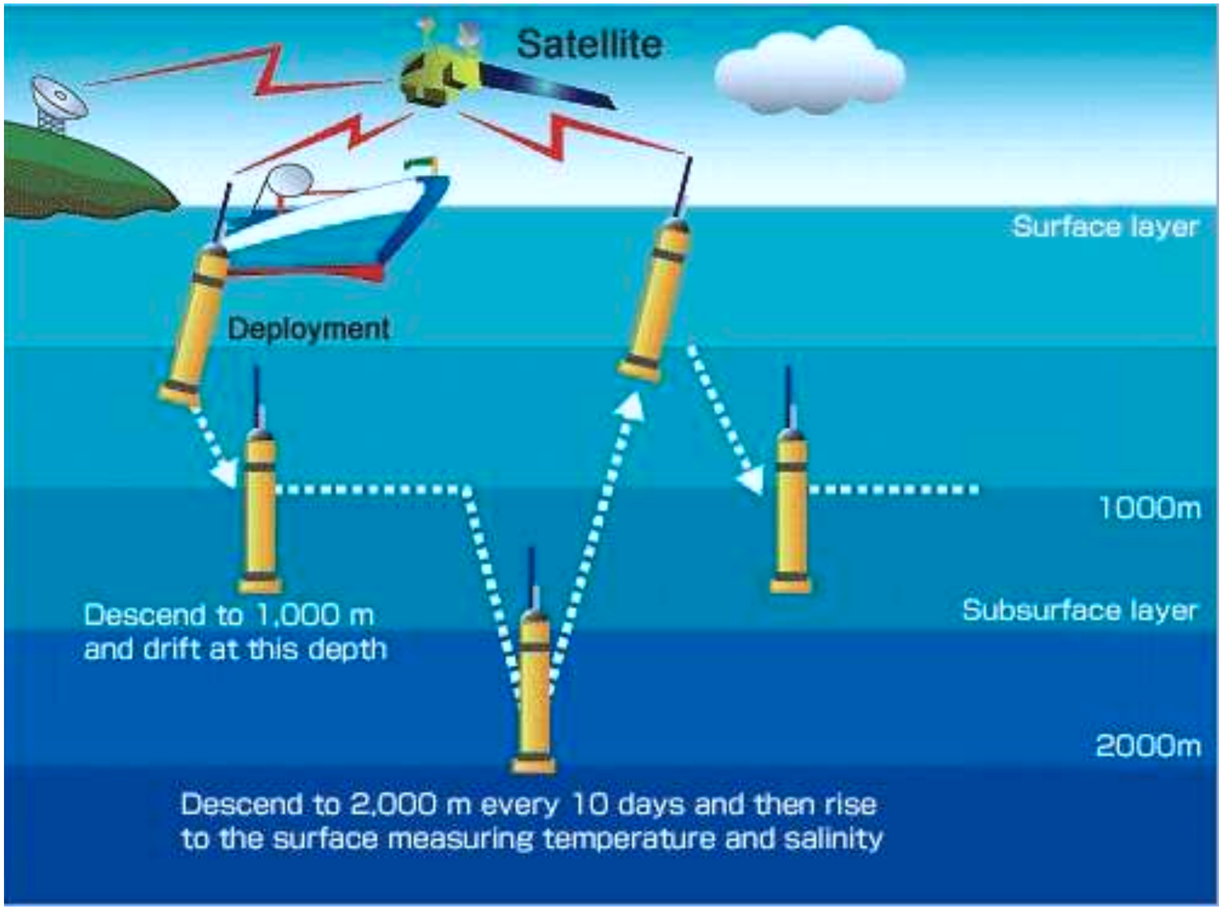
Argo floats

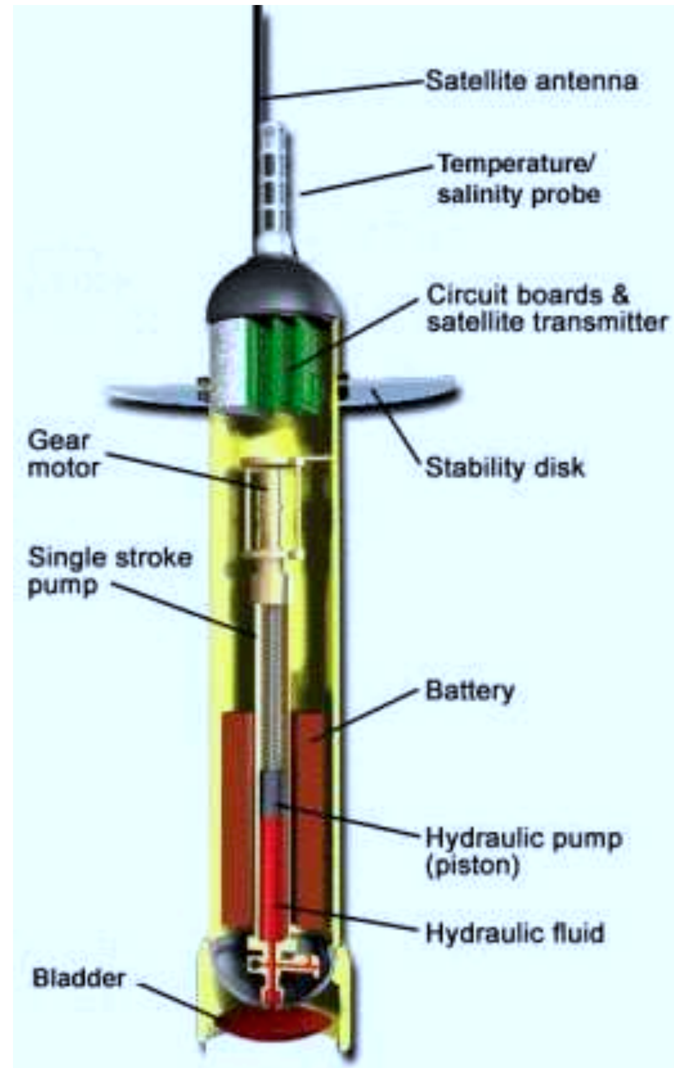
Stephen Riser,
UW Oceanography





Monitoring the **ocean heat content**





Argo floats, since ~2000 measure to 2000m depth

Monitoring the **ocean heat content**

Expendable 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

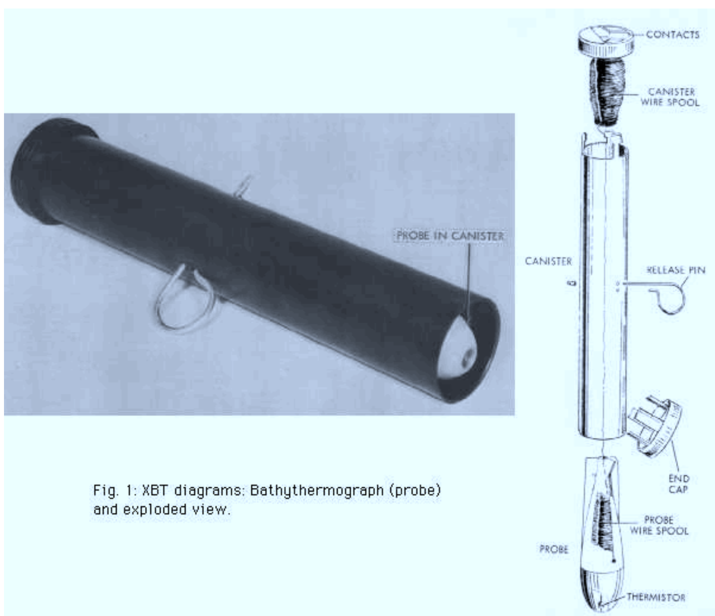
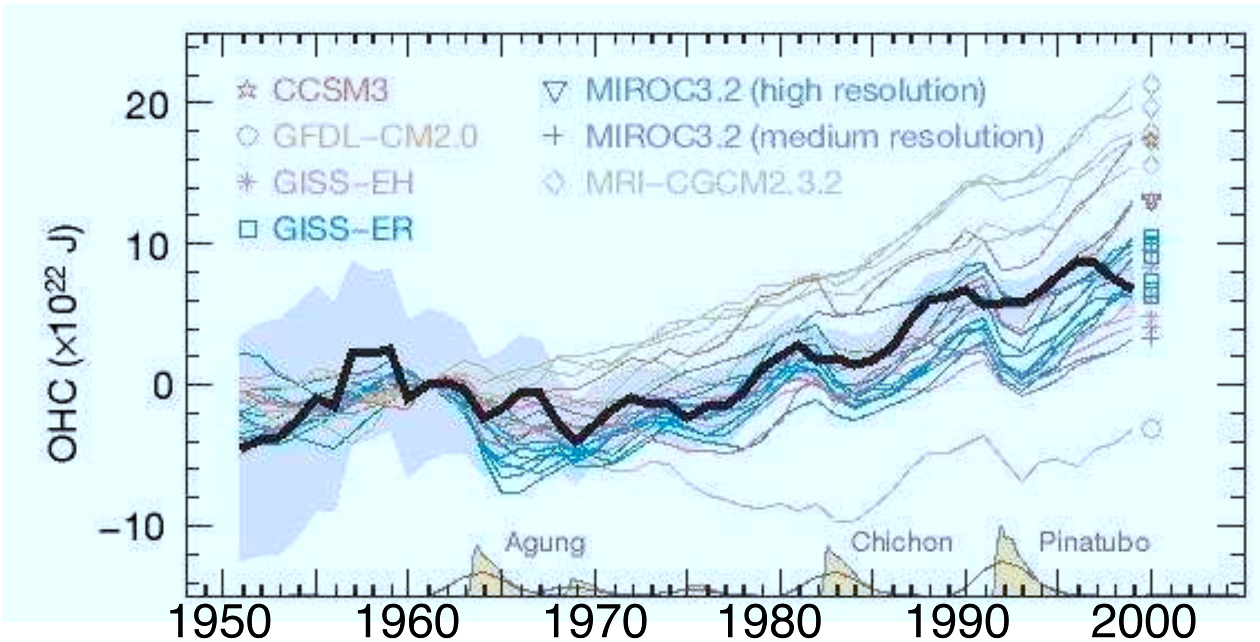


Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.

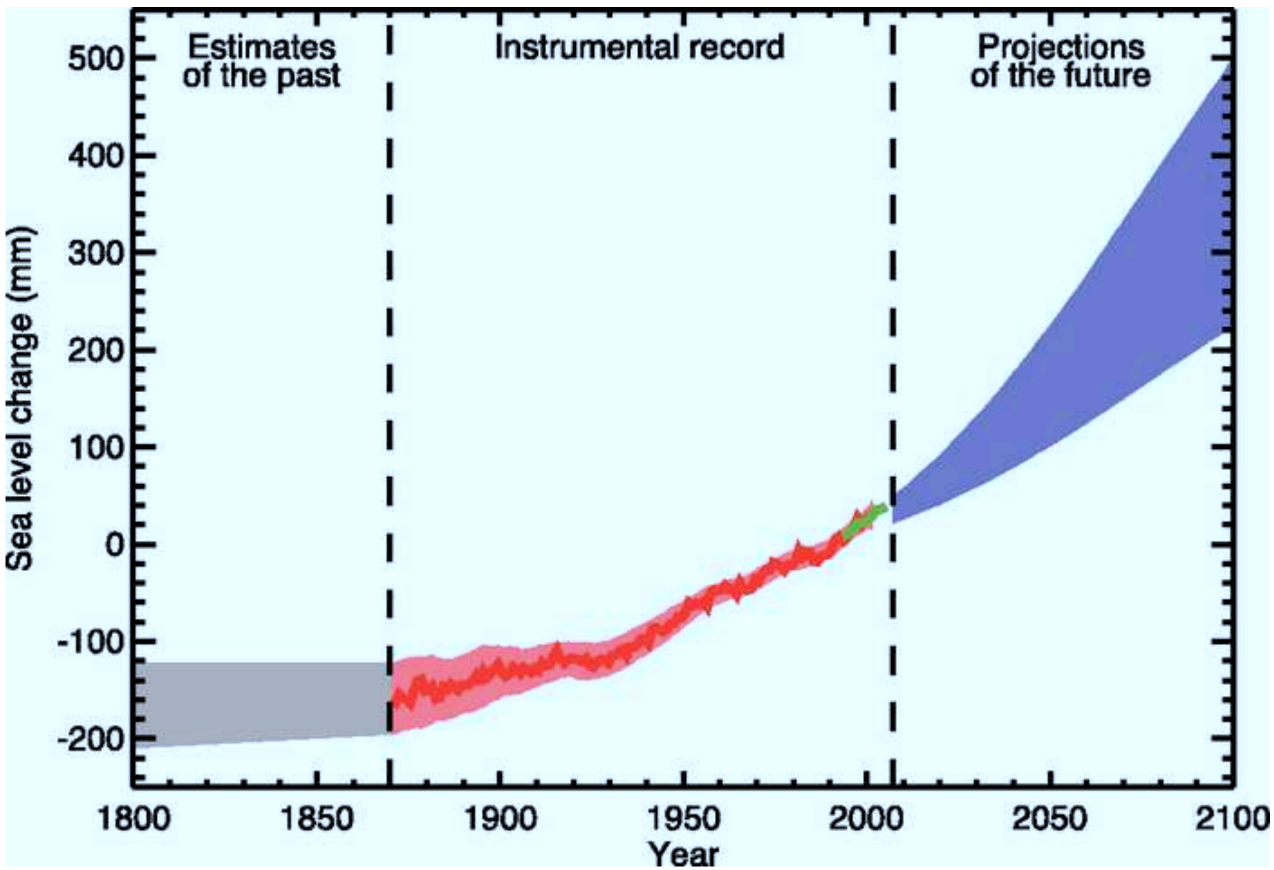
Ocean Heat Content

Observations in black with uncertainty shaded grey
Models are colored lines - span the observations



Domingues et al 2008

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



FAQ 5.1, Figure 1

200-500 mm
for 3 intermediate scenarios

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

Criticized by James Hansen

More recent estimates:

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

The very latest on Greenland from the GRACE superstar

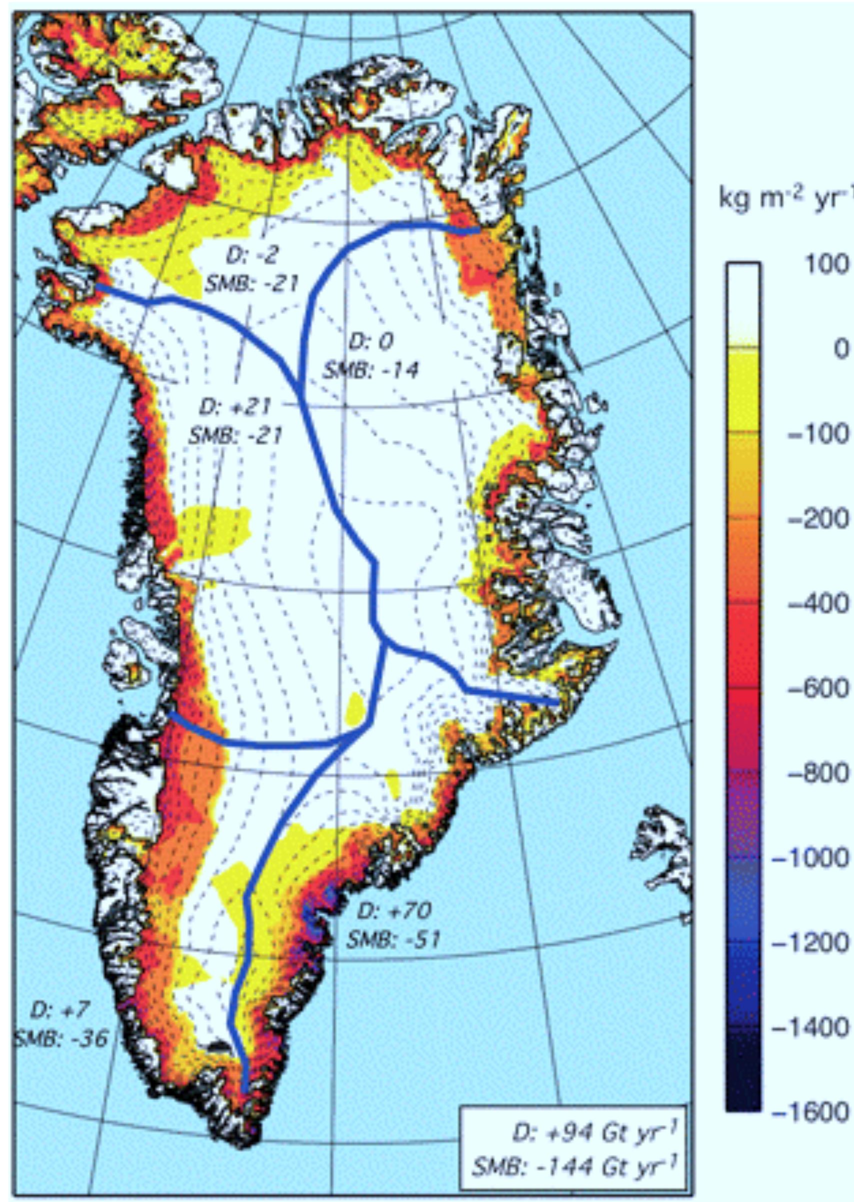
GRACE - Gravity Recovery and Climate Experiments

Greenland contributed 0.5 mm/yr to SLR between 2000-2008

or 237 Gt/yr loss

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

van den Broeke et al 2009

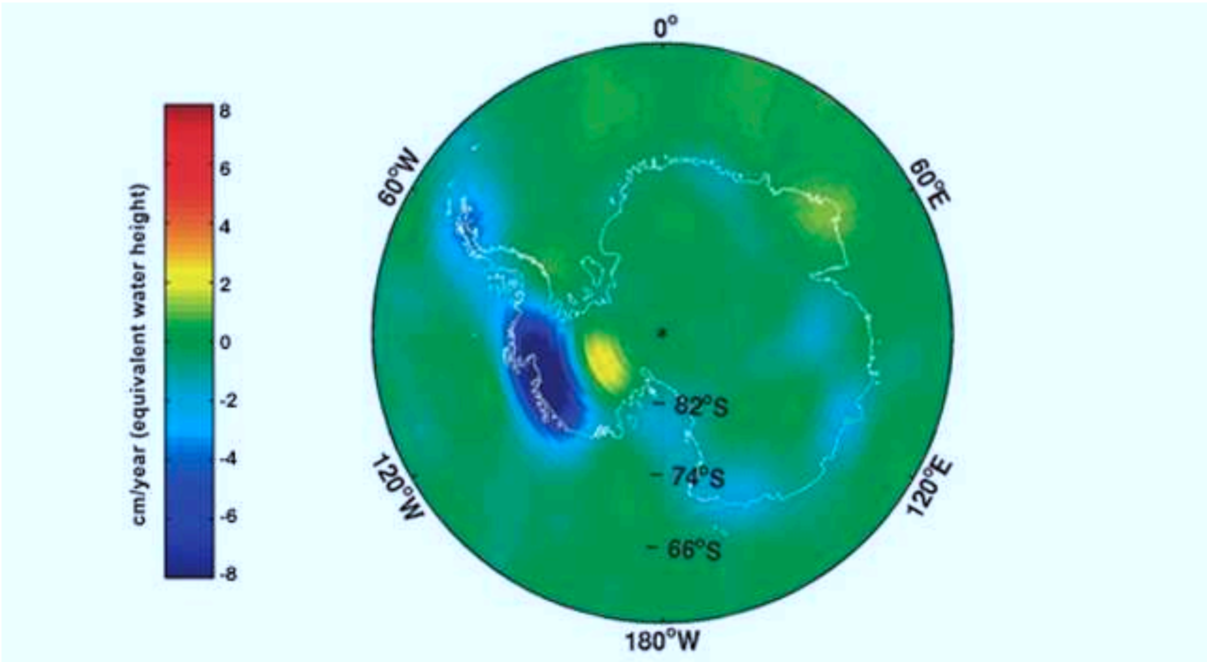


D=dynamic loss (+ = loss),
SMB = accumulation - ablation

The very latest on Antarctica from the GRACE superstar

2002-2009 Antarctica losing ice - despite increased snowfall

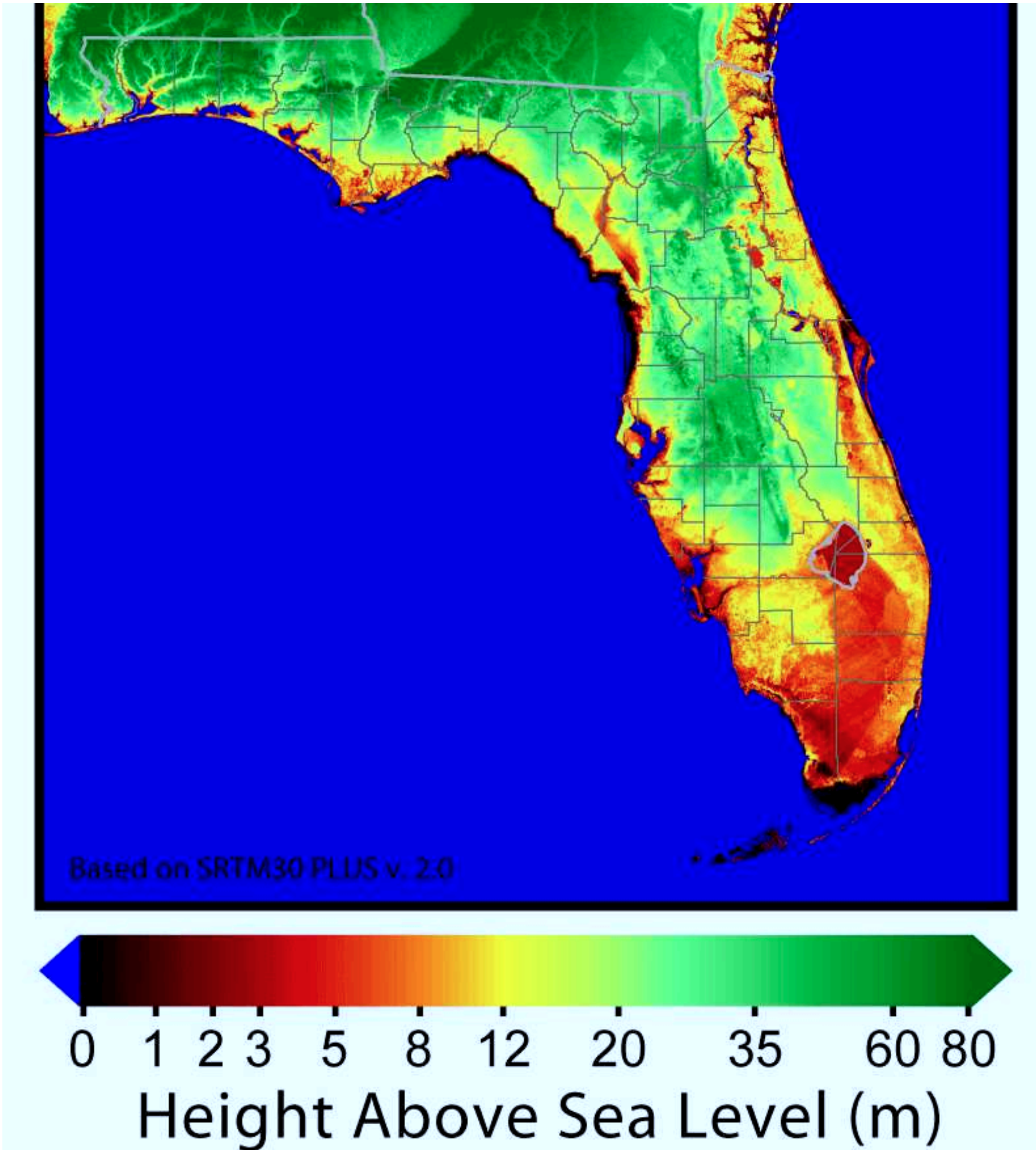
cause - dynamic thinning

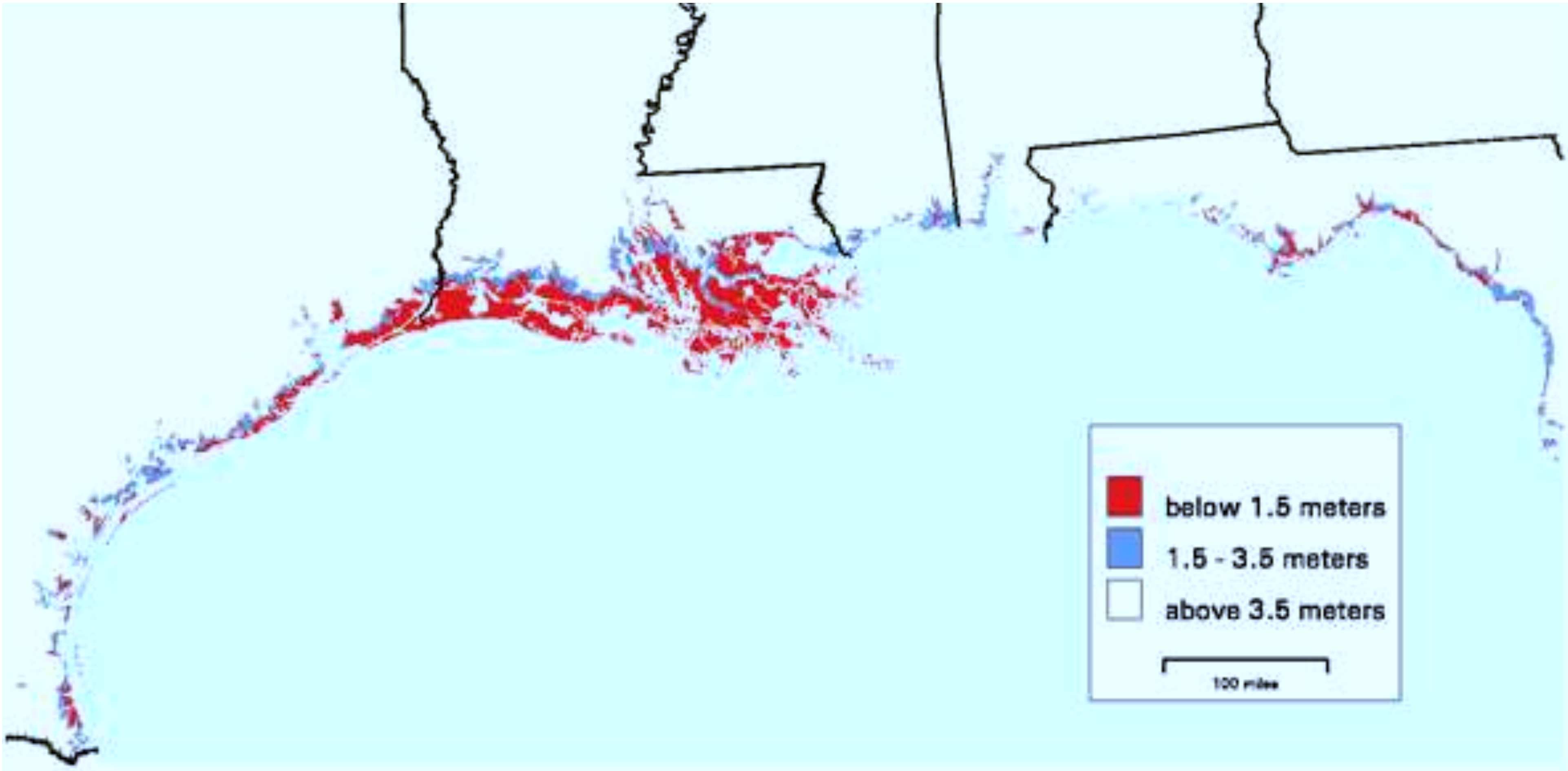


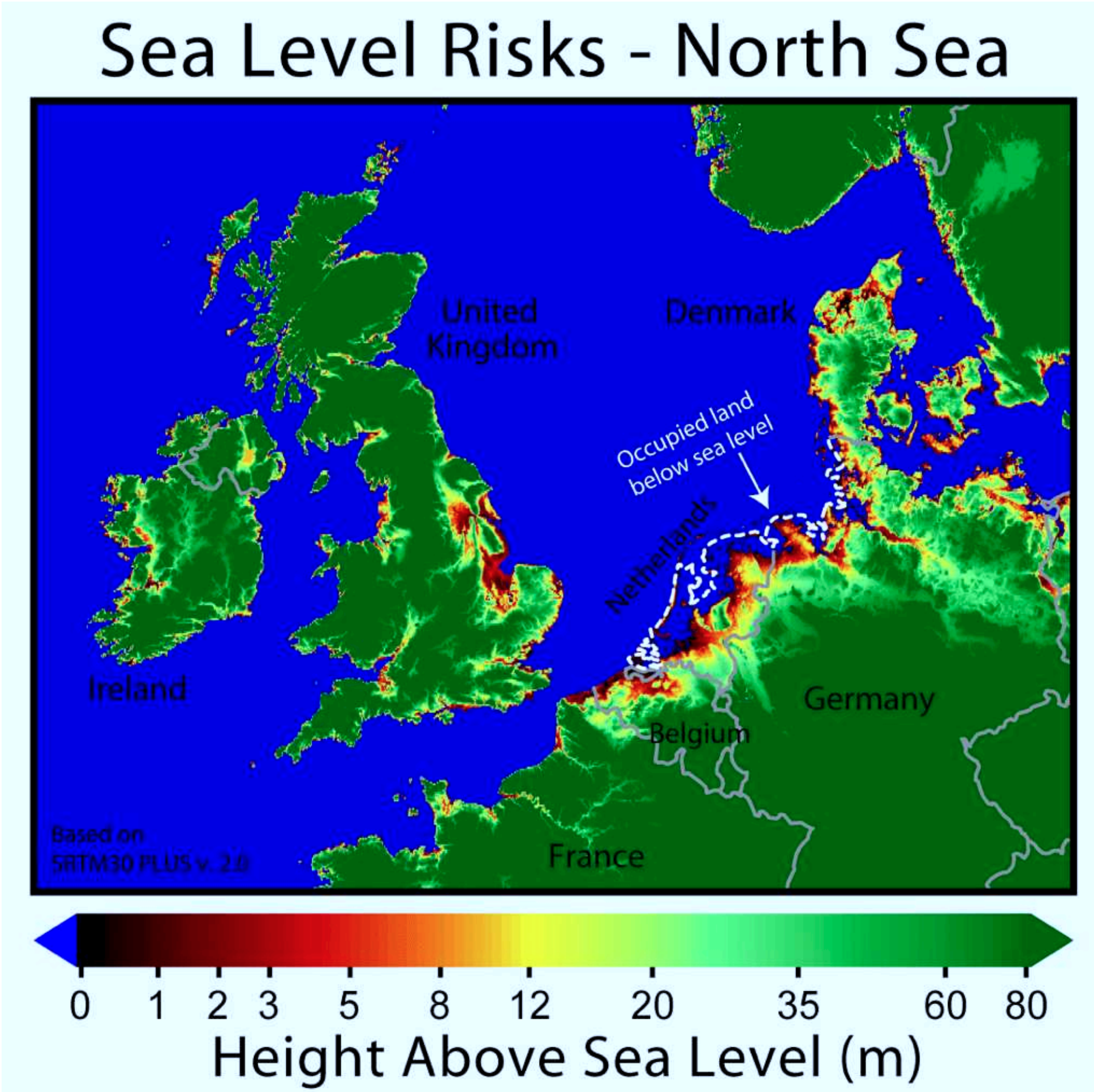
http://grace.jpl.nasa.gov/news/index.cfm?FuseAction=ShowNews&NewsID=33

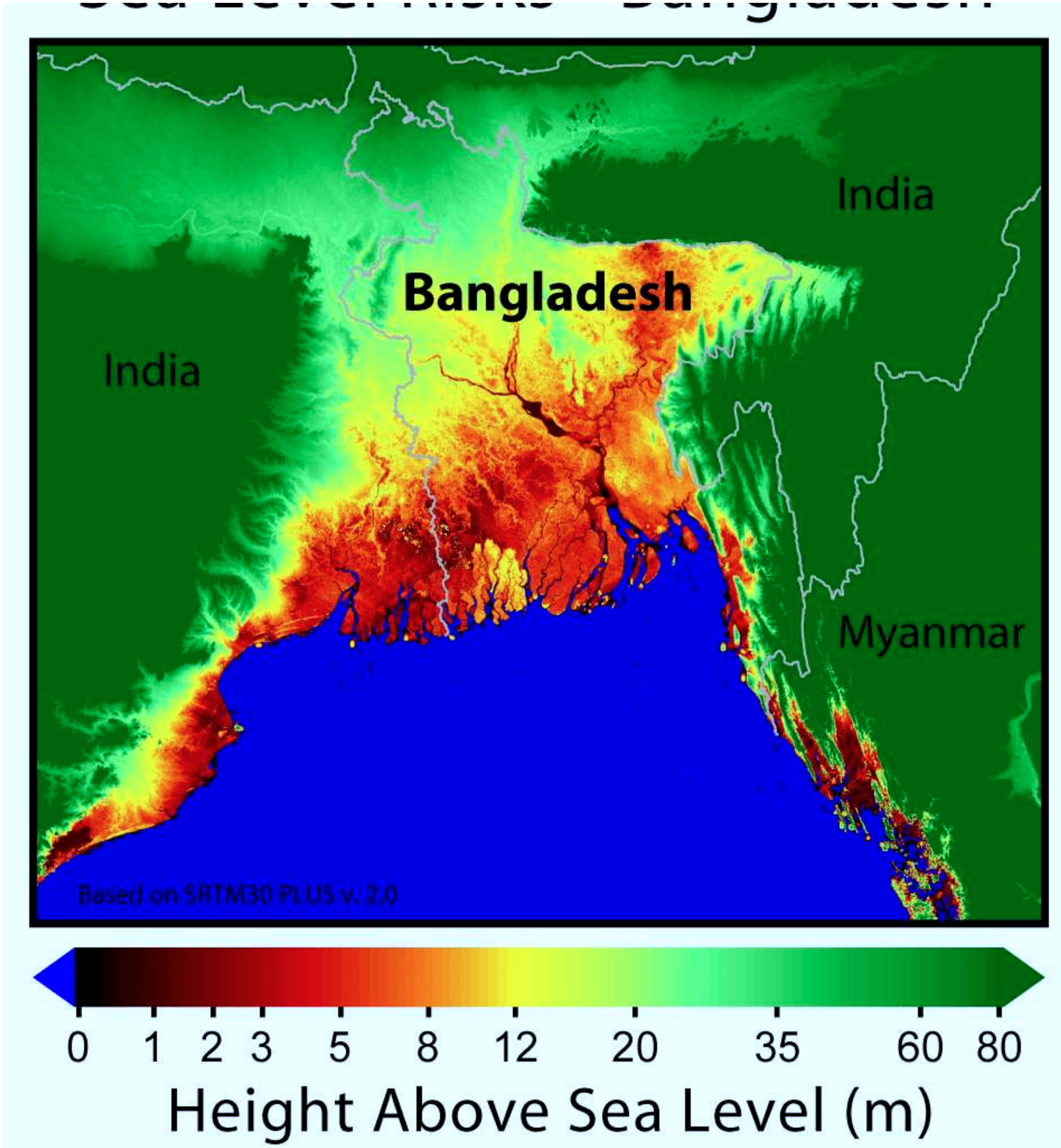
192 +/- 92 Gt/yr from 1996-2006 according to Rignot et al 2008

Frequency of storm surge passing a given threshold is likely to be as serious as MSLR


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
United Kingdom
Denmark
Occupied land below sea level
Netherlands
Ireland
Germany
Belgium
France
Based on SRTM30 PLUS v. 2.0
0 1 2 3 5 8 12 20 35 60 80
Height Above Sea Level (m)


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