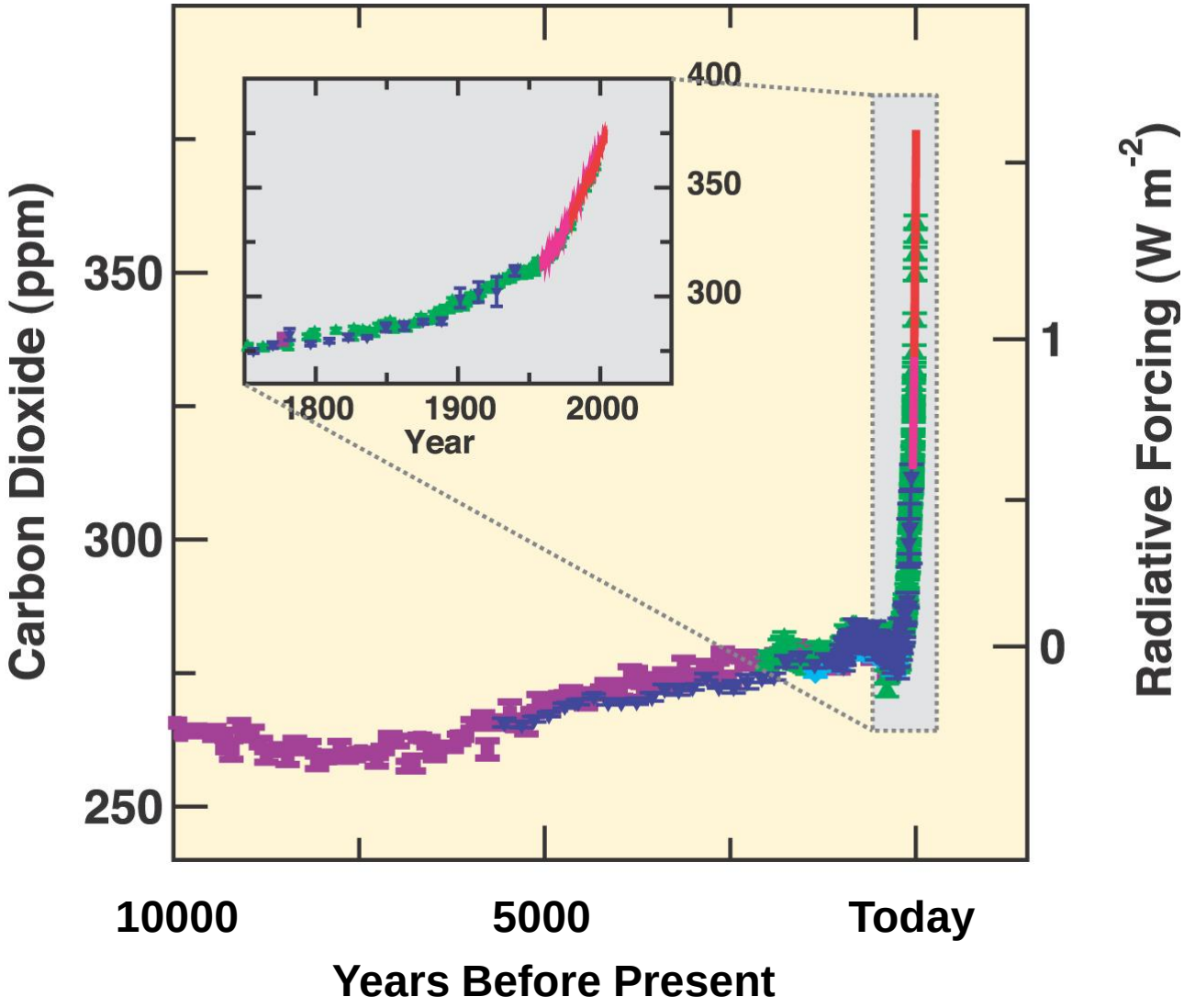
# The Early Signs of Global Warming and the Long-term Outlook for the Oceans

William Curry
Bermuda Institute of Ocean Sciences

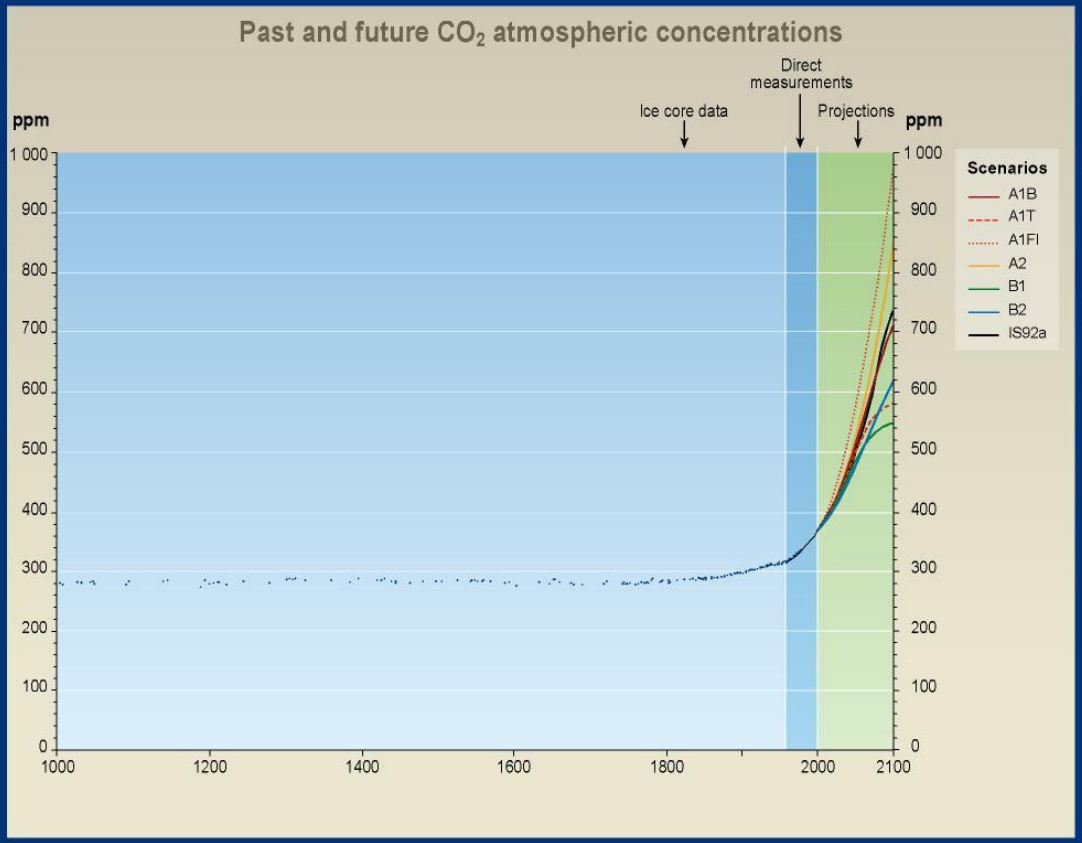
November 2012

# How has Atmospheric $CO_2$ Changed



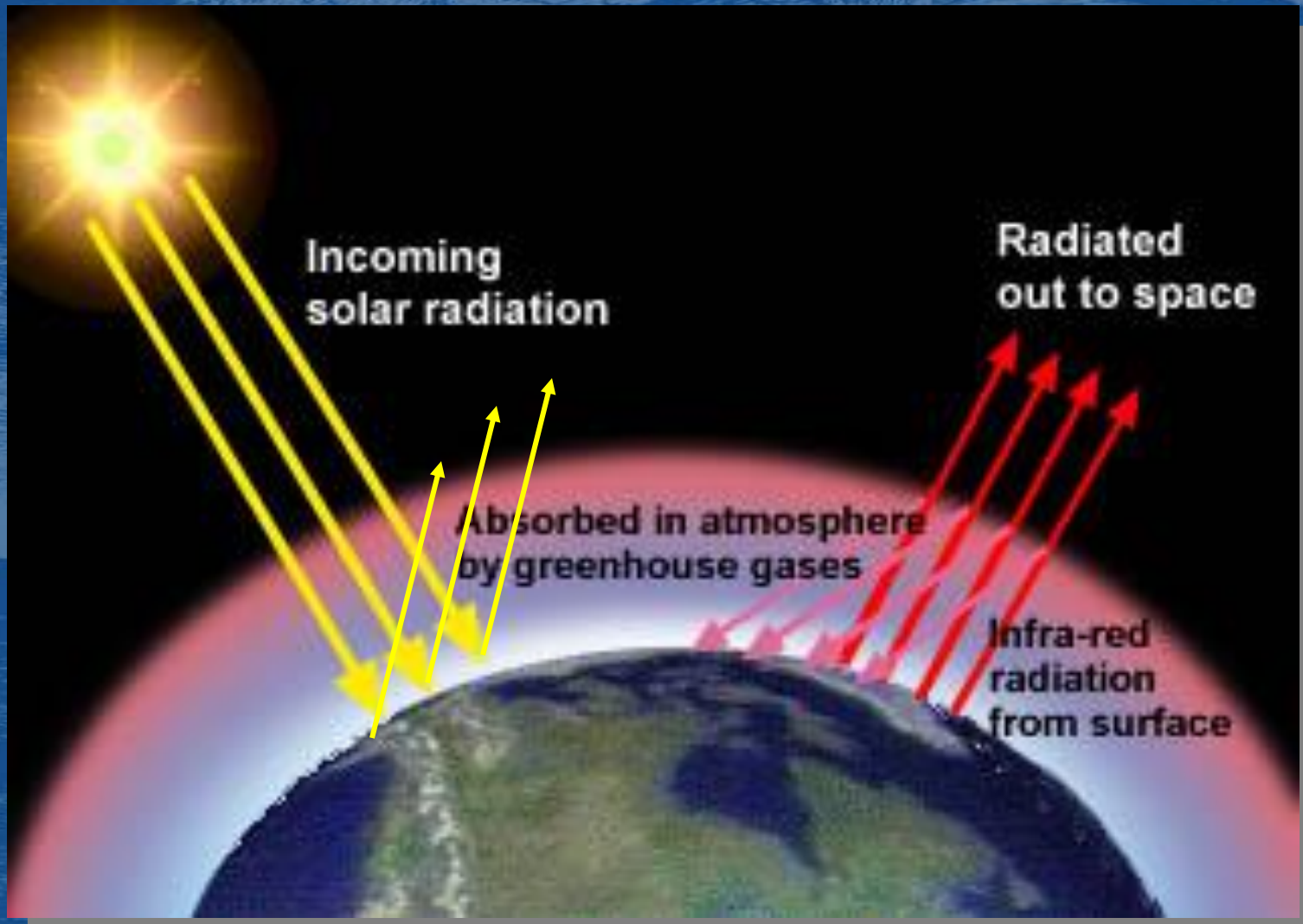

IPCC 4

# What about the Future?

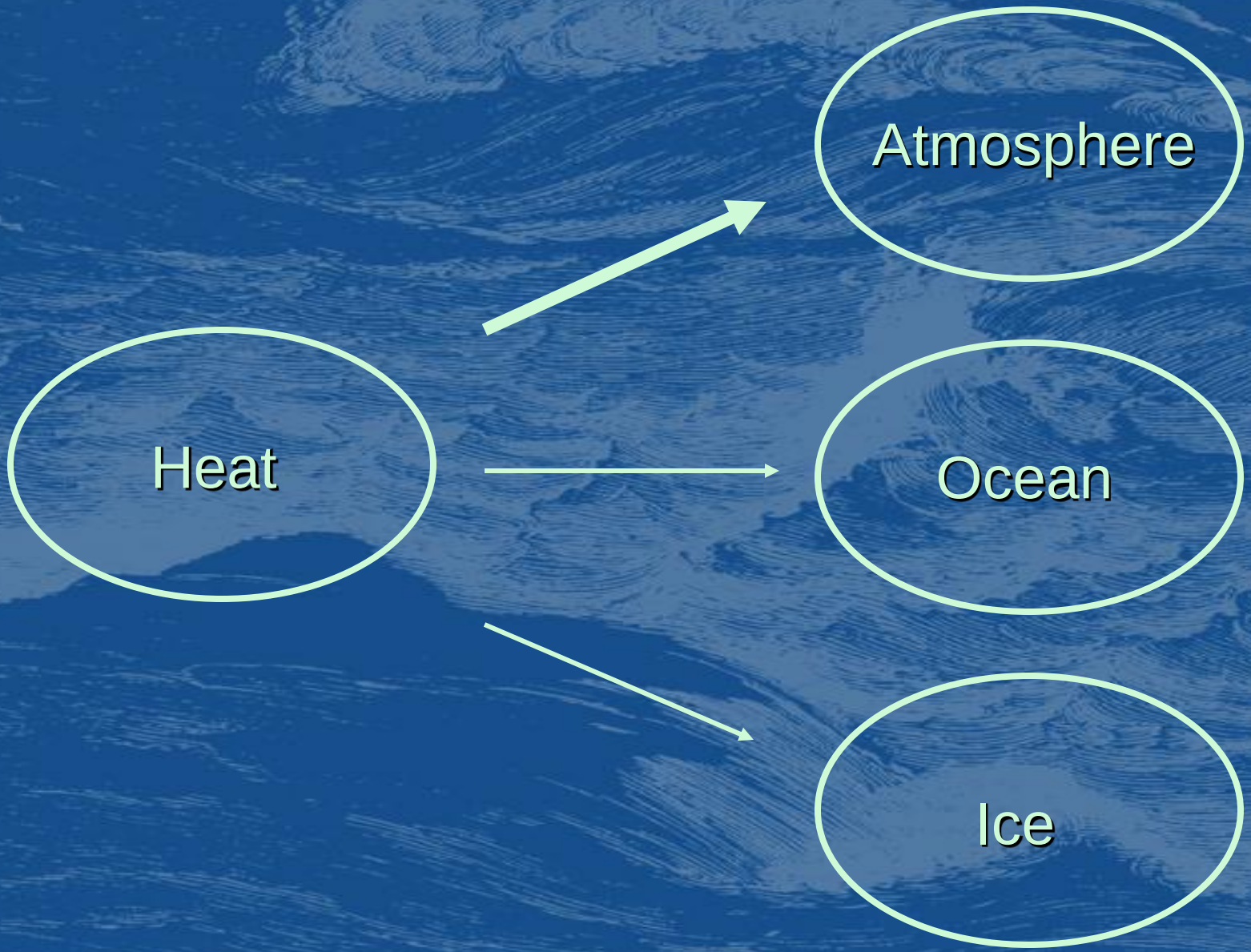



SYR - FIGURE 9-1a

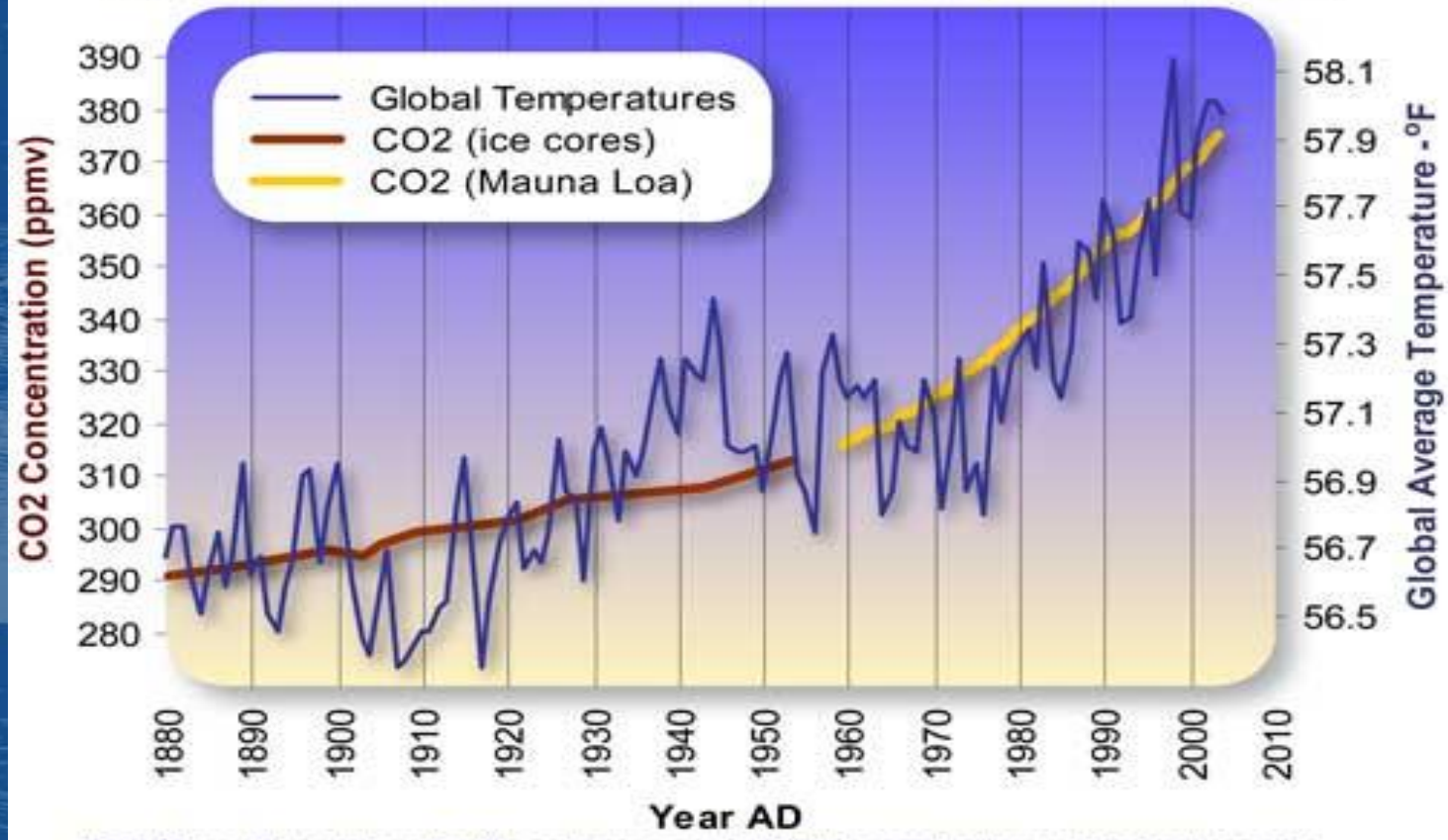
# The Greenhouse Effect



# Where does the heat go?



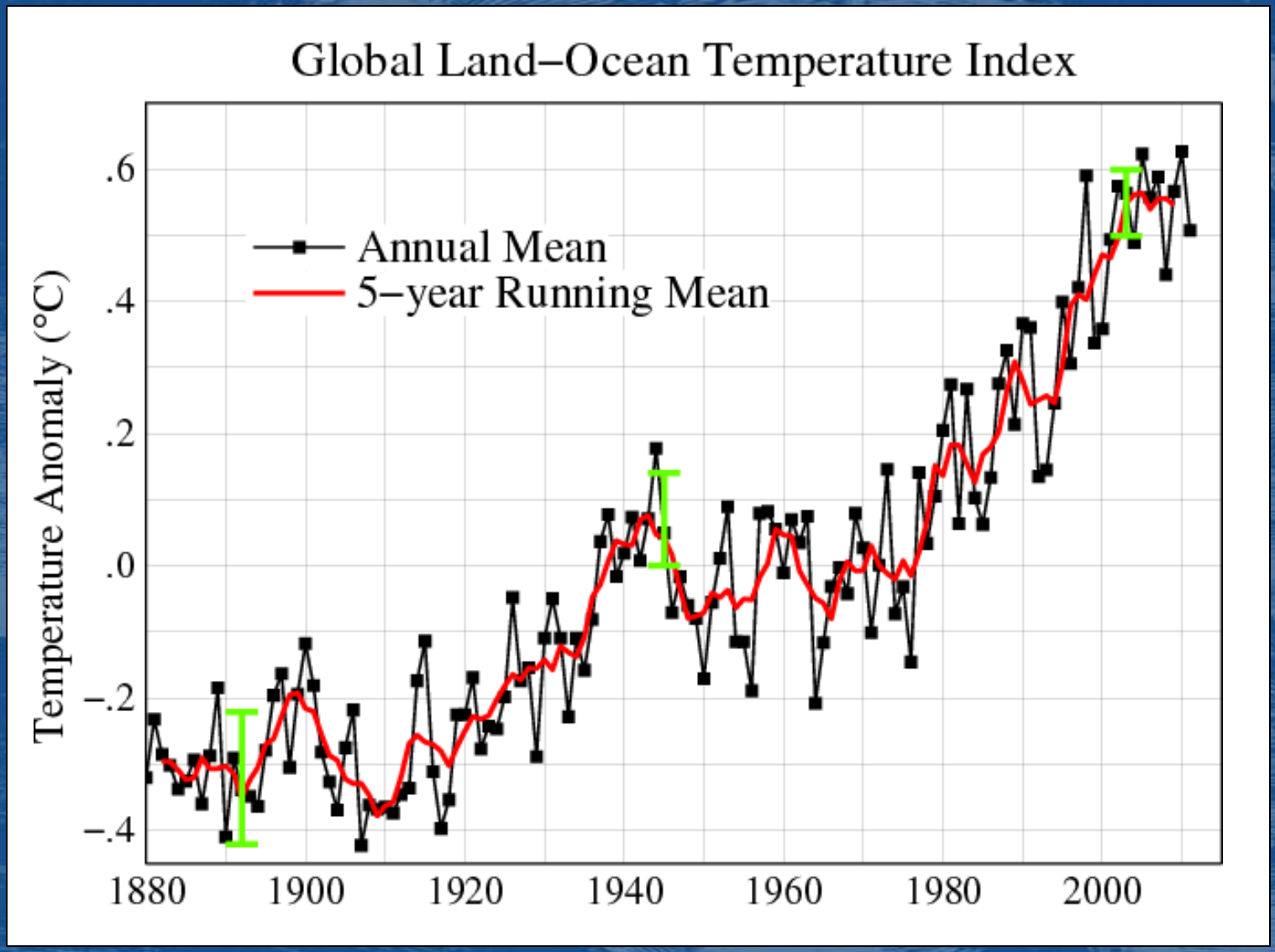
# Global Average Temperature and Carbon Dioxide Concentrations, 1880 - 2004




Data Source Temperature: ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual_land.and.ocean.ts
Data Source CO2 (Siple Ice Cores): http://cdiac.esd.ornl.gov/ftp/trends/co2/siple2.013
Data Source CO2 (Mauna Loa): http://cdiac.esd.ornl.gov/ftp/trends/co2/maunaloa.co2

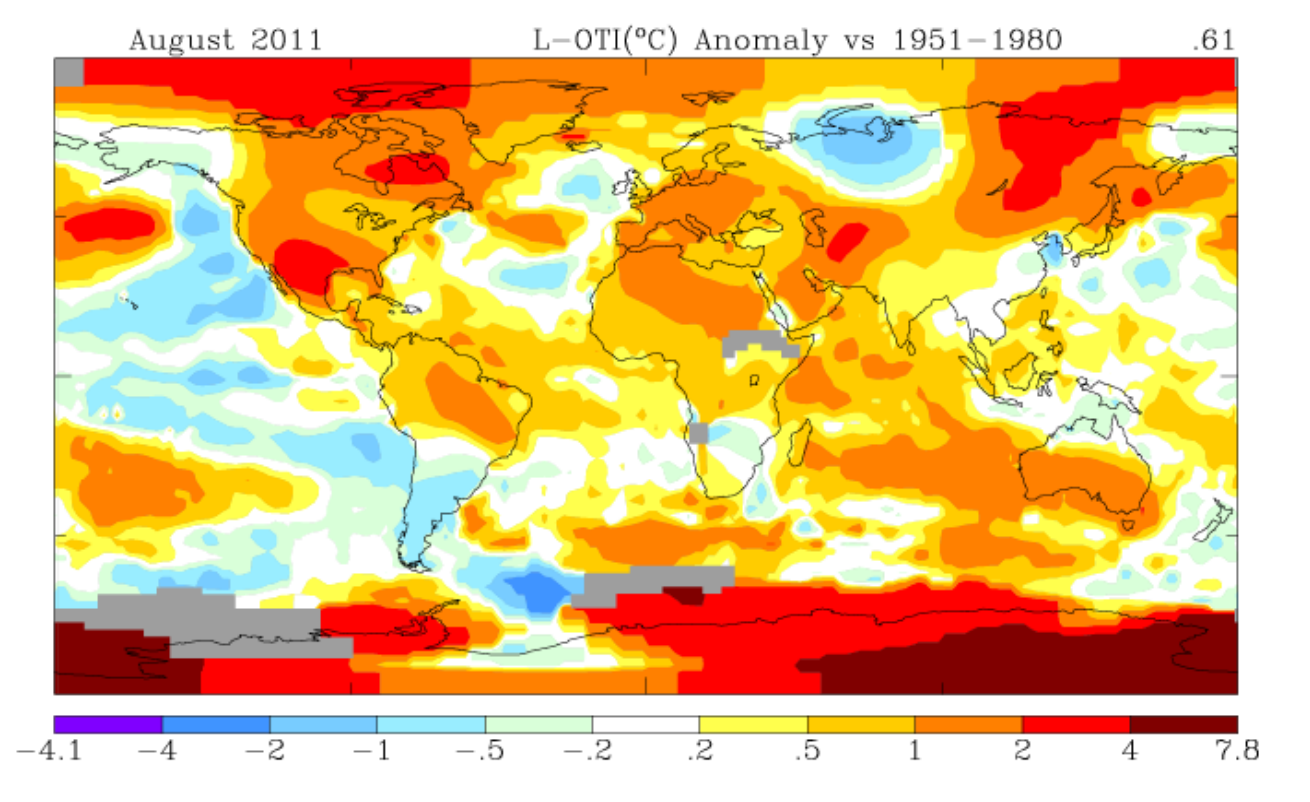
Graphic Design: Michael Ernst, The Woods Hole Research Center

# Most up to date record



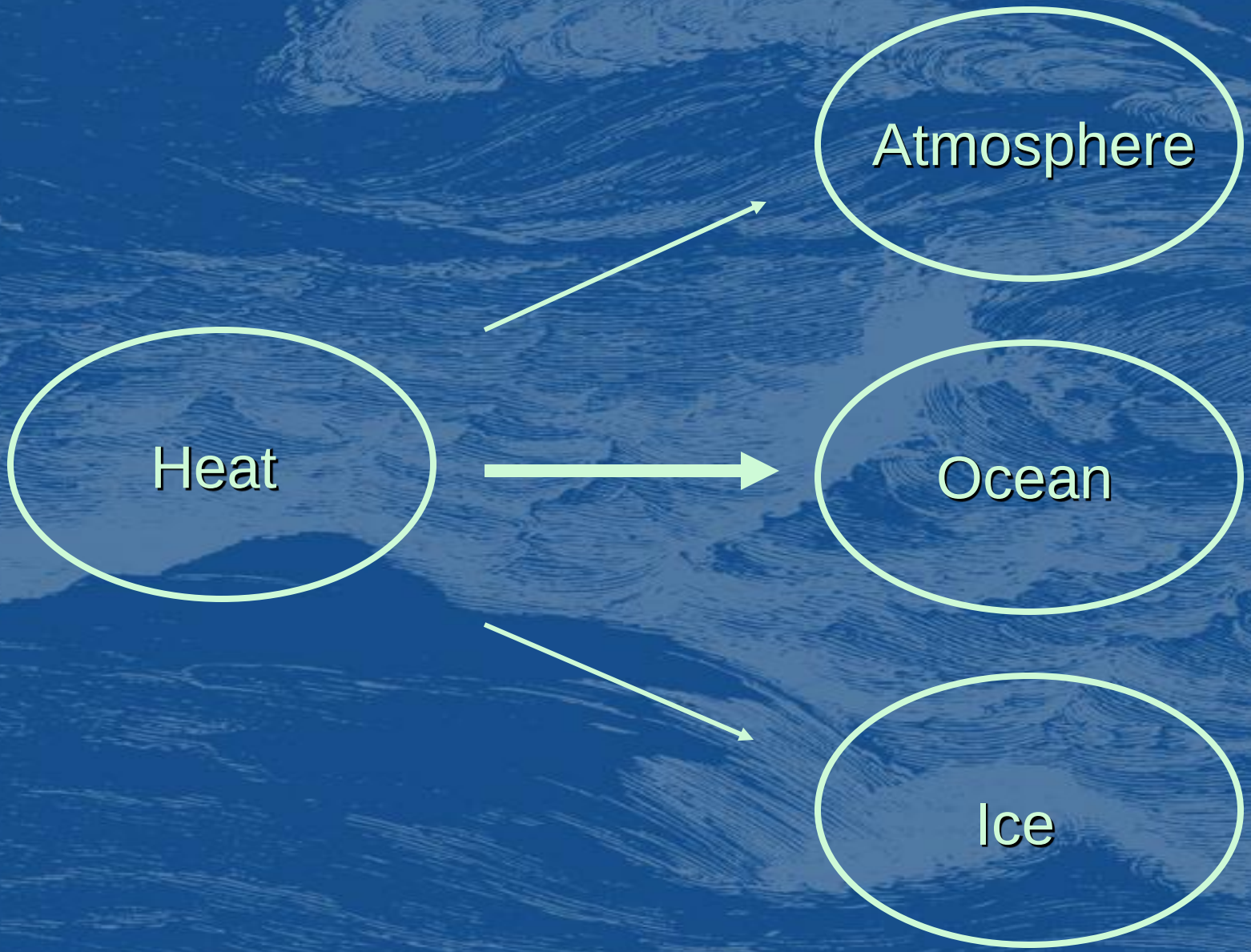

*Source: NASA GISS (2012)*

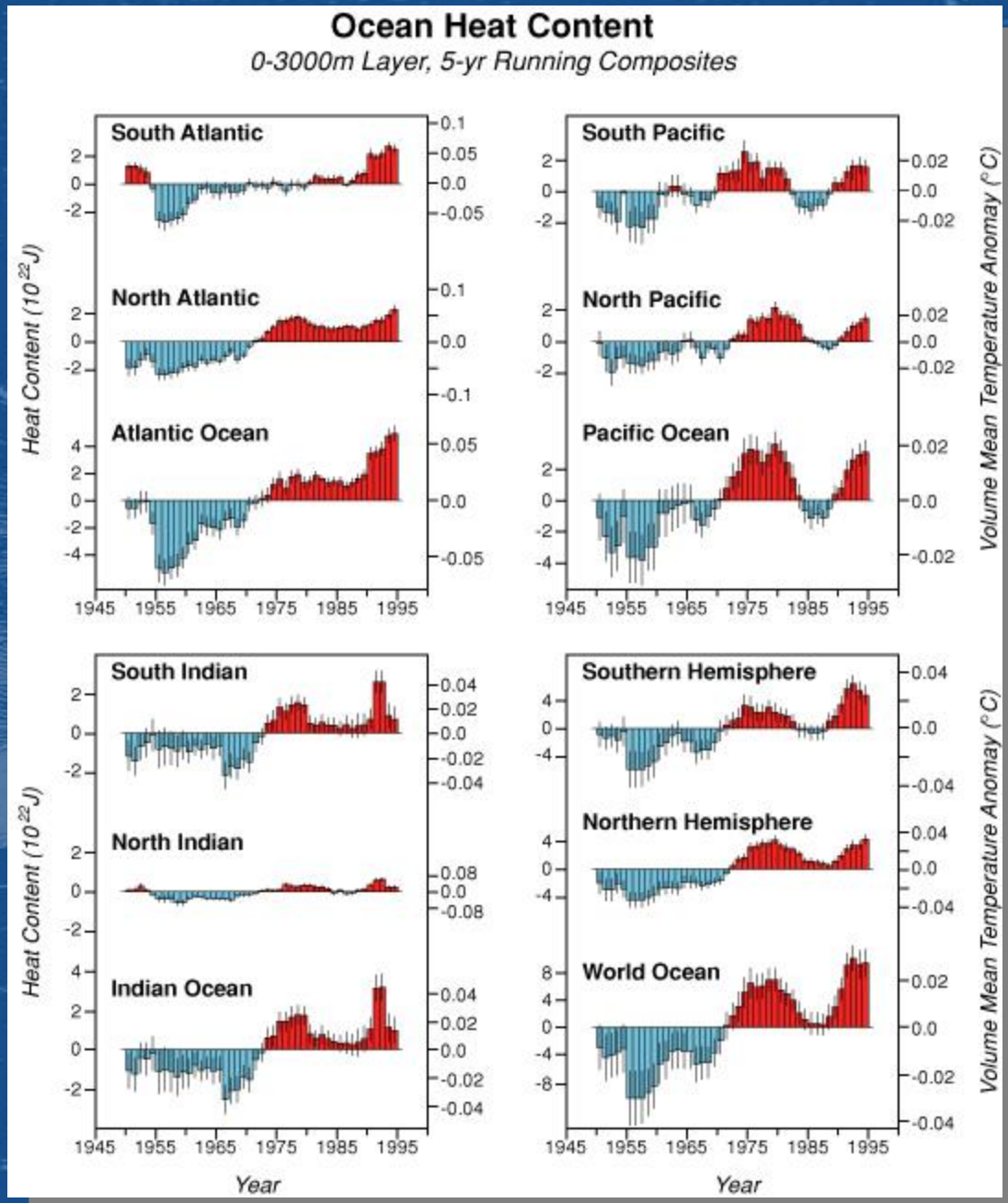
# Global warming is not uniformly distributed




*Source: NASA GISS (2011)*

# Where does the heat go?

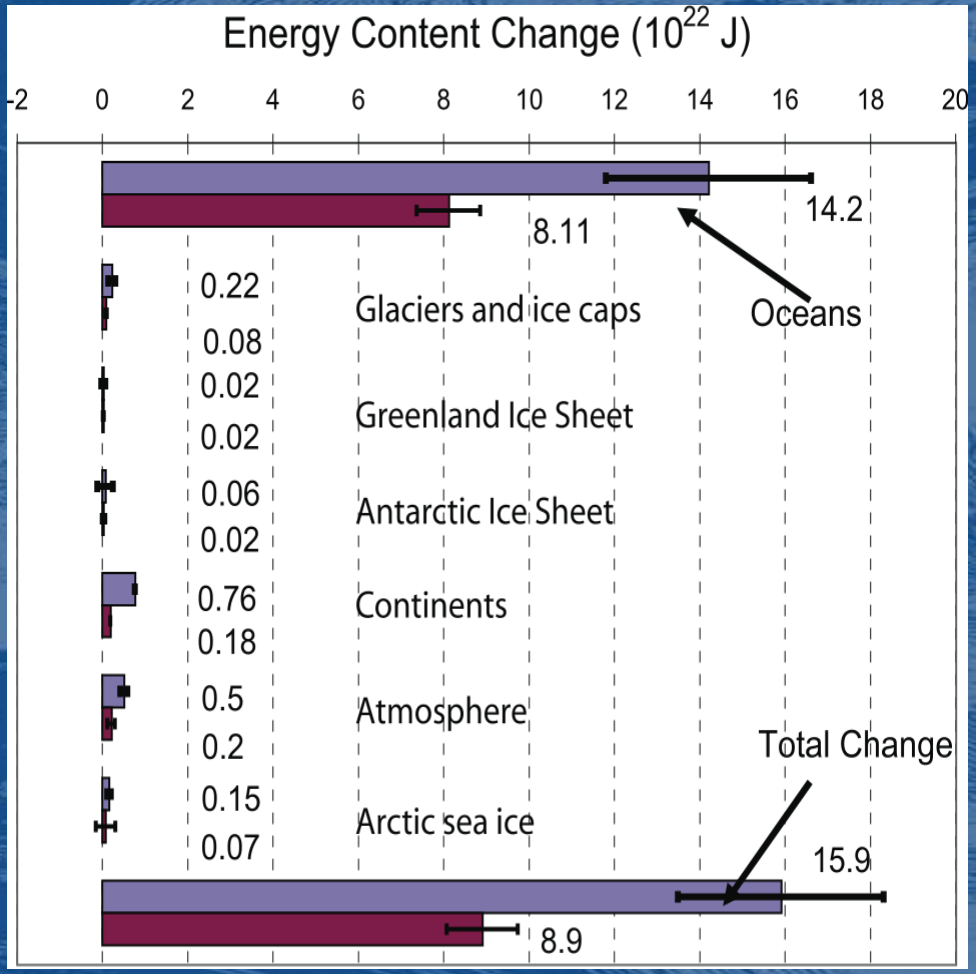





All oceans have been warming for the last 50 years

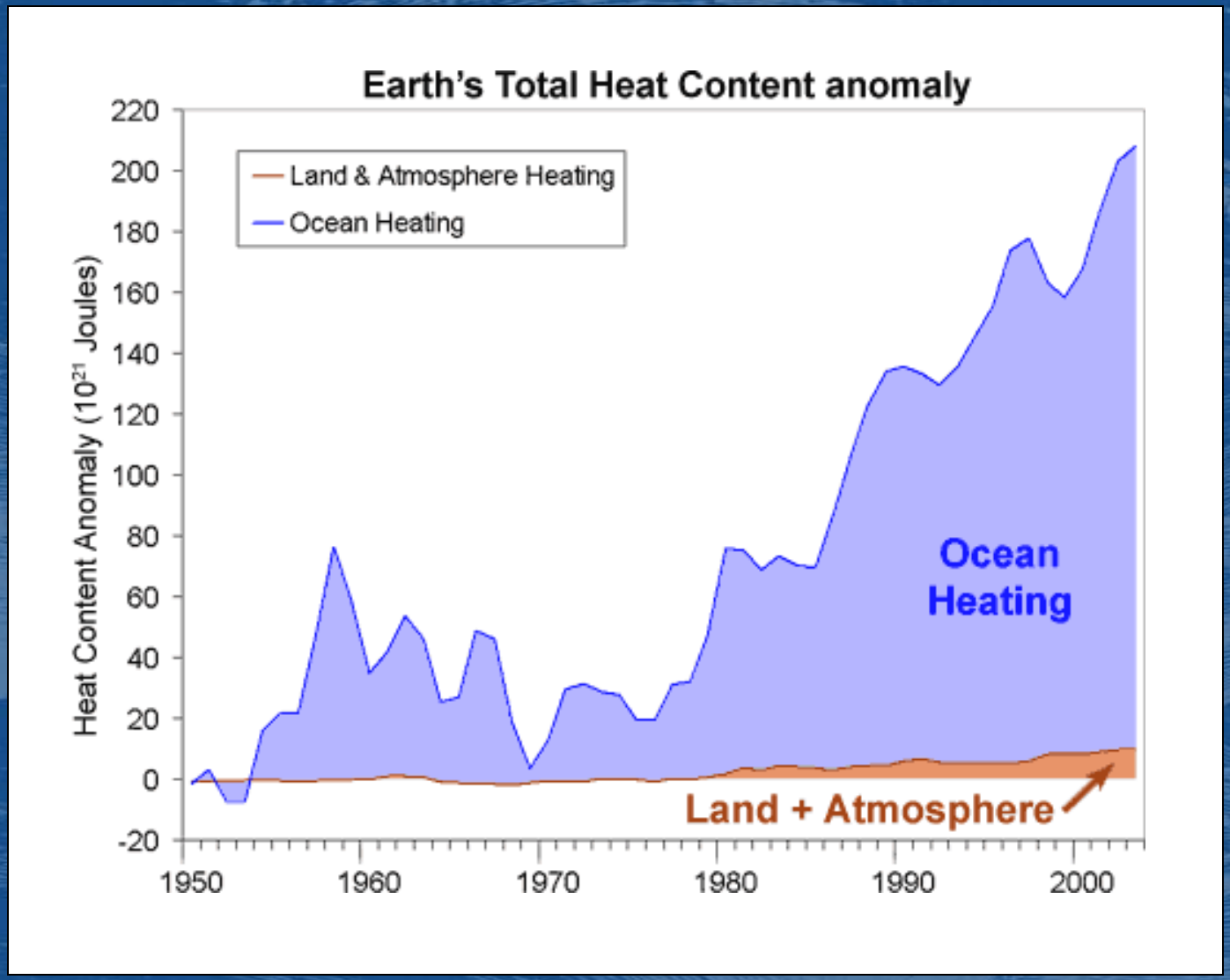
*Levitus et al., 2000*

# Most of the heat goes into the oceans



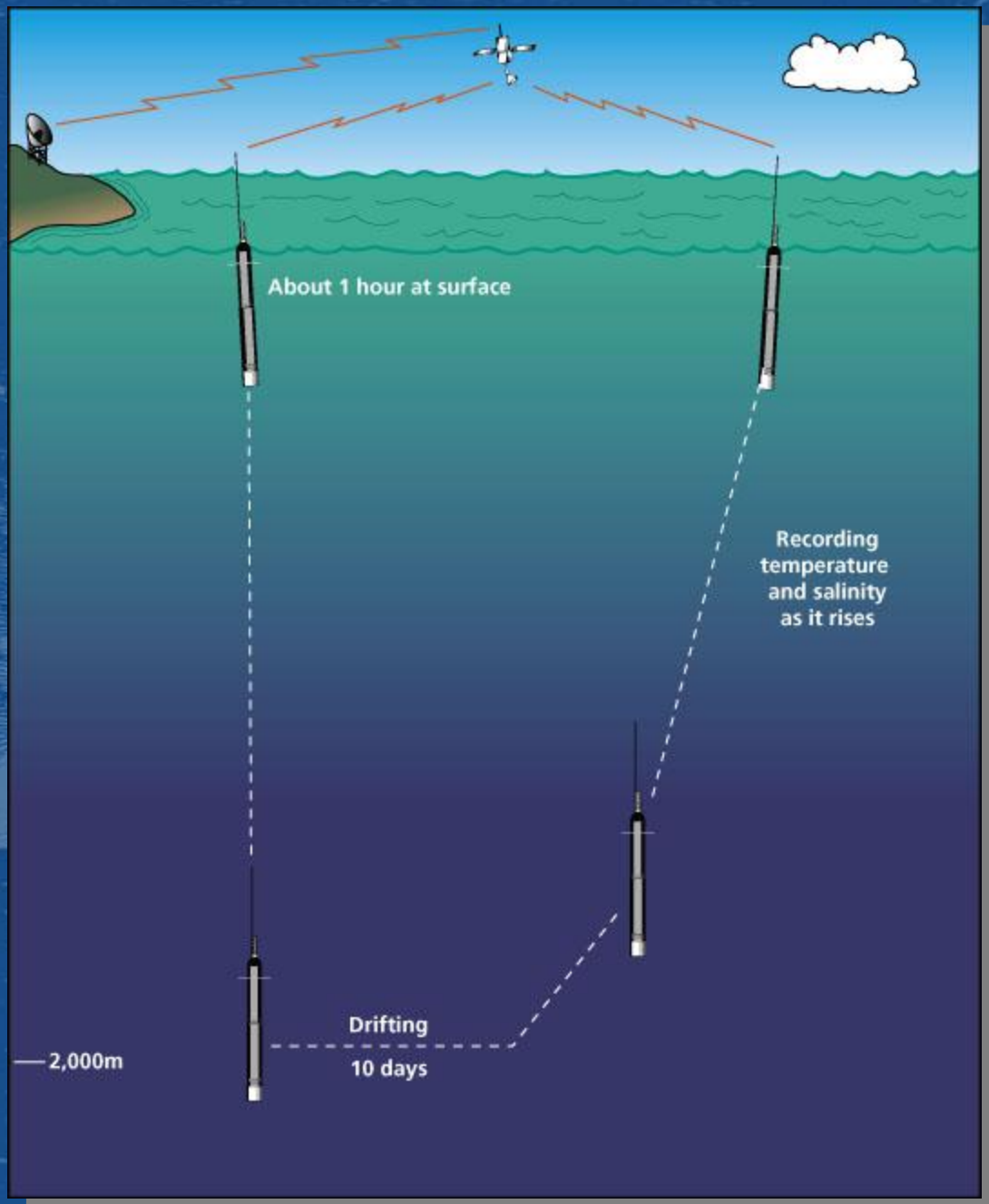

1961-2003 Blue
1993-2003 Burgundy

*IPCC AR4WG1 (2007)*

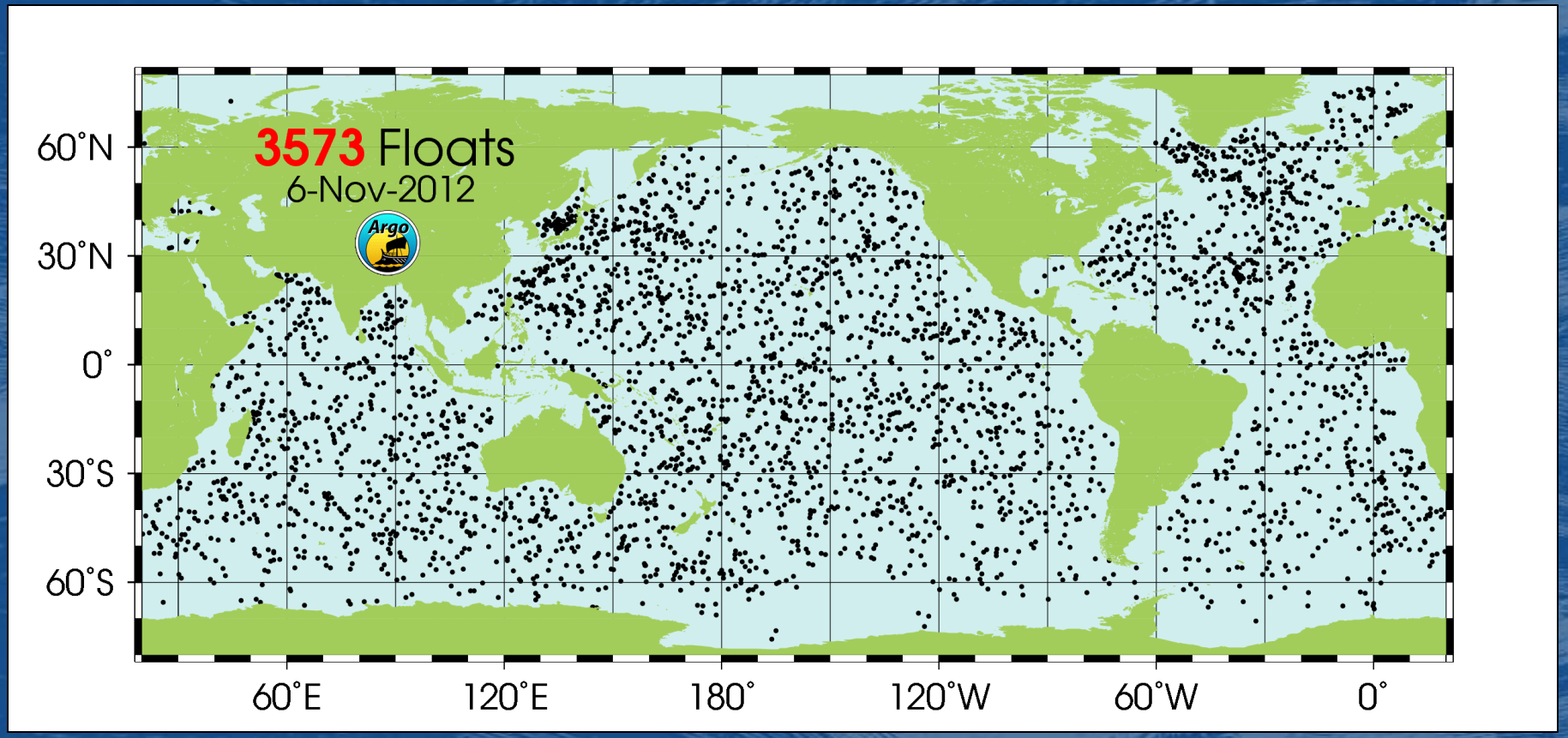



*Murphy et al. 2009 – figure from John Cook at skepticalscience.com*

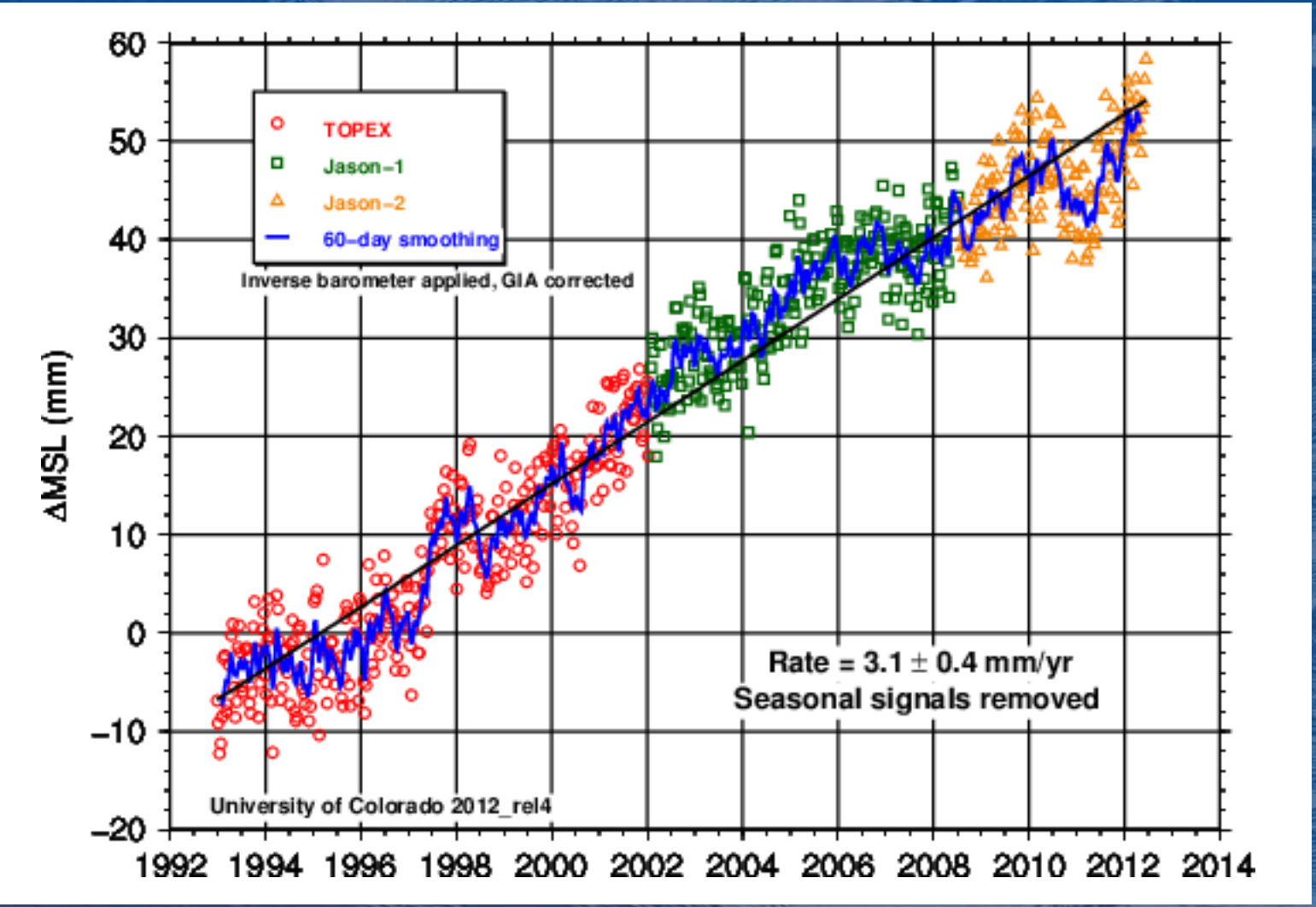
# Argo Float


About 1 hour at surface
Recording temperature and salinity as it rises
Drifting
10 days
2,000m

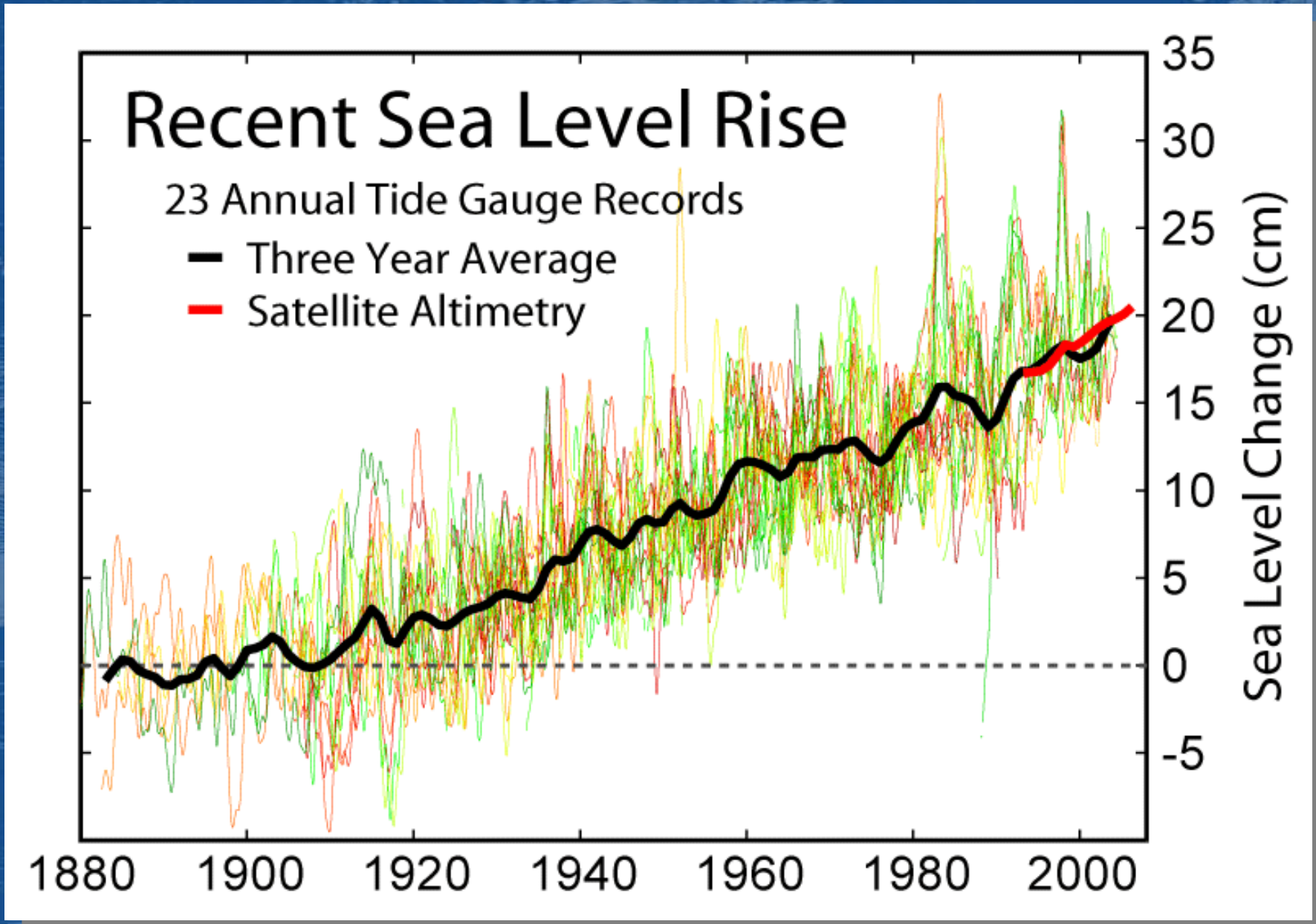
# As of November 6……..



# Sea Level Rise



# Sea Level Rise



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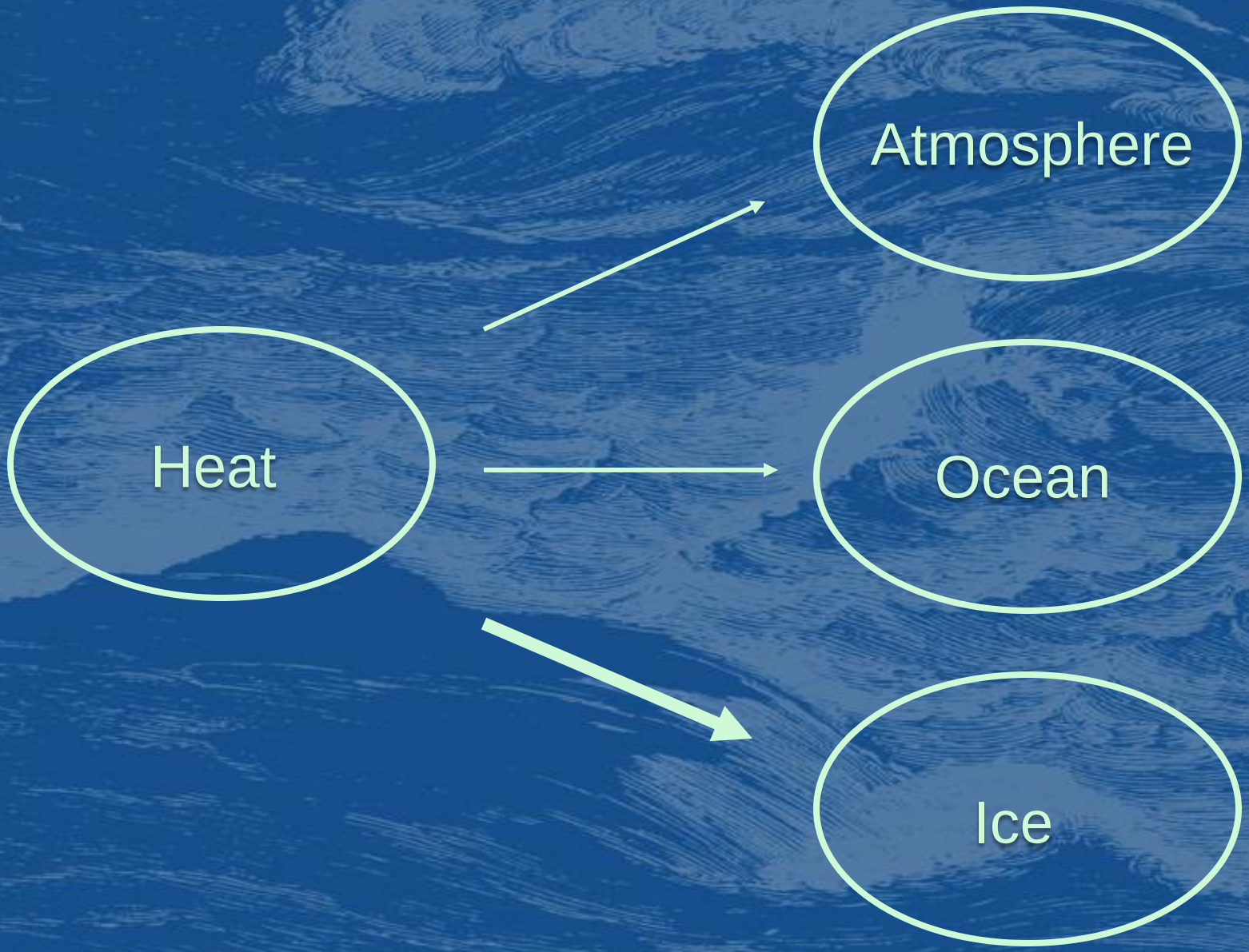
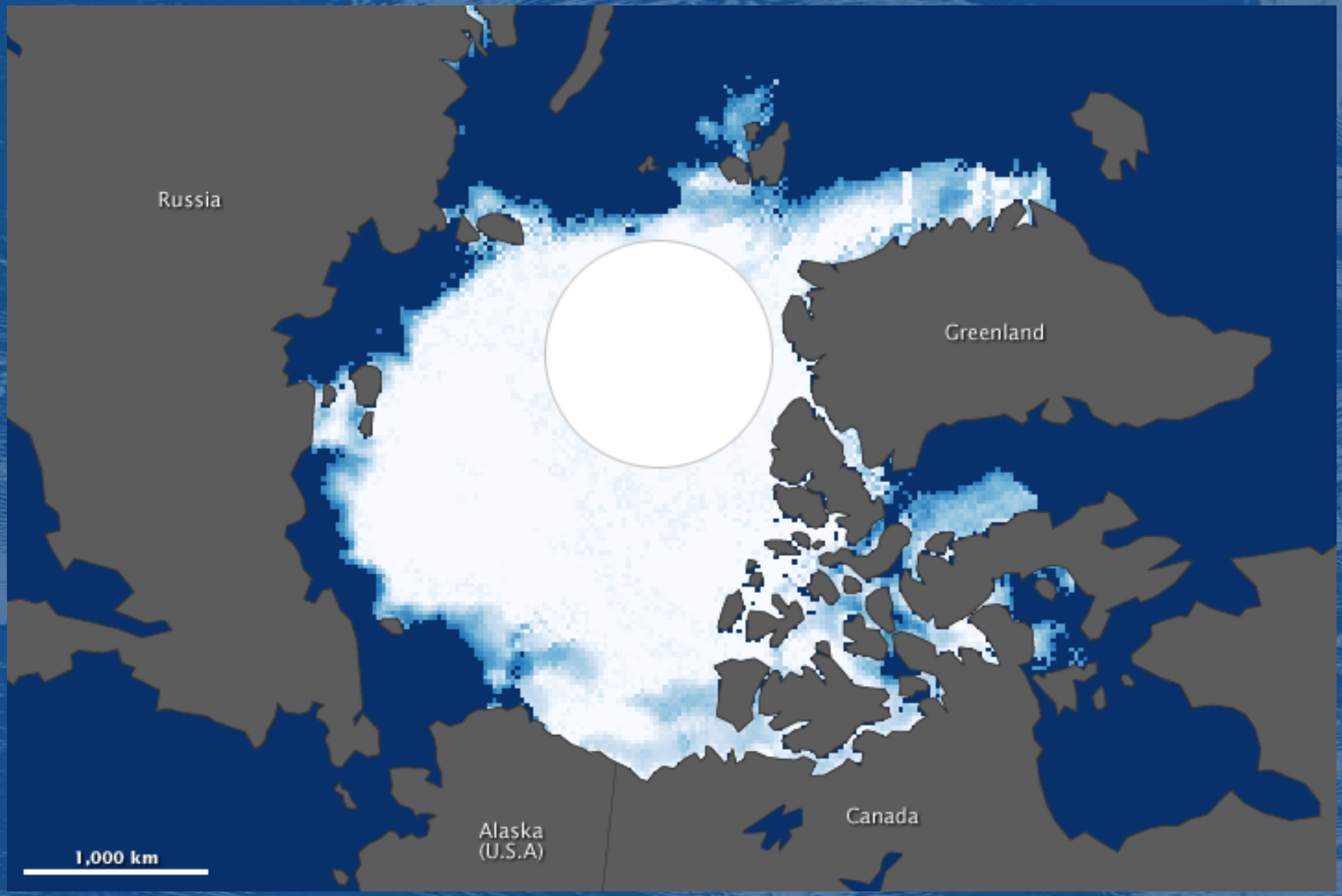


# Summer Sea Ice 1984

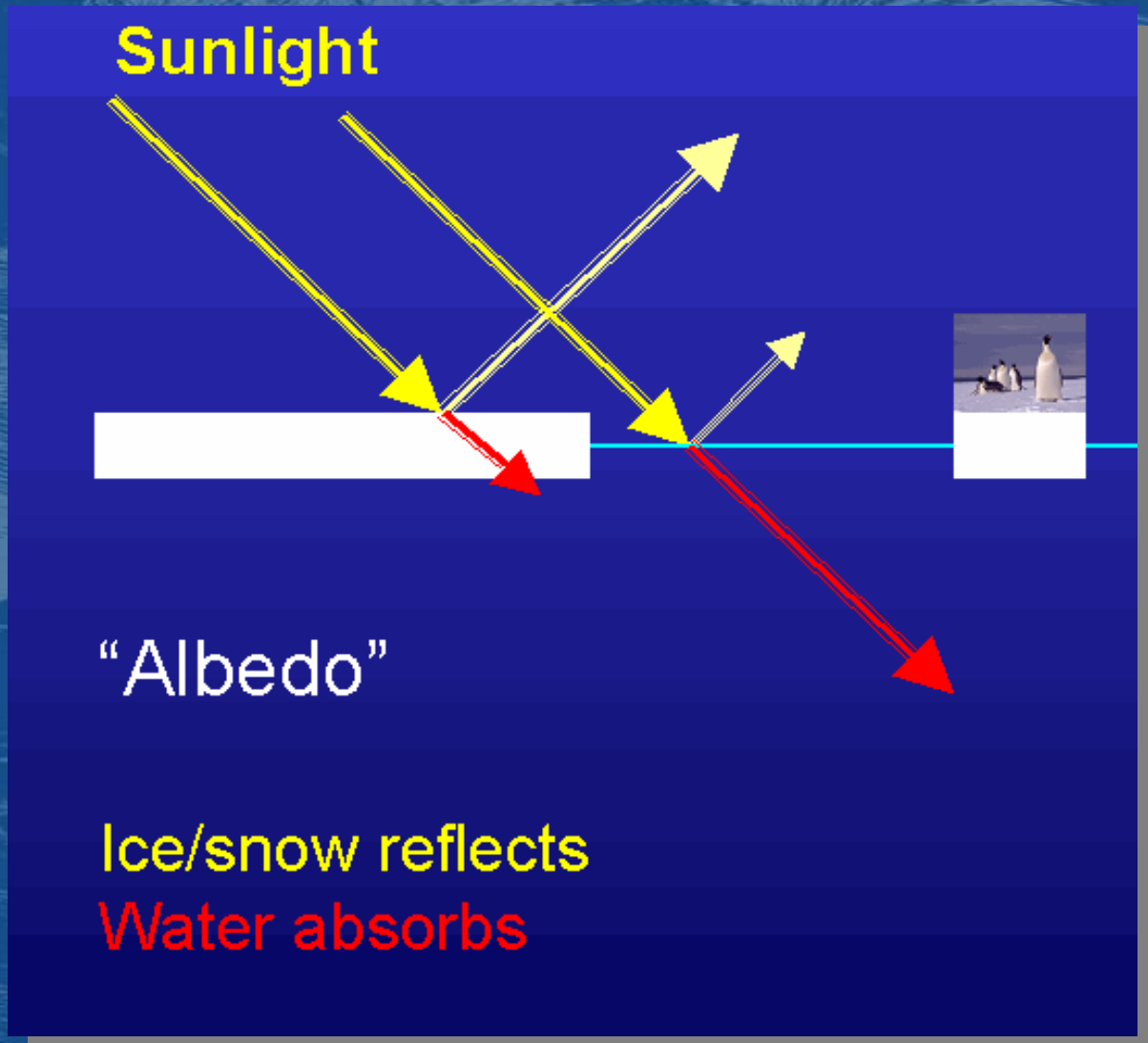



*NASA Goddard Space Flight Center*

# Summer Sea Ice 2012

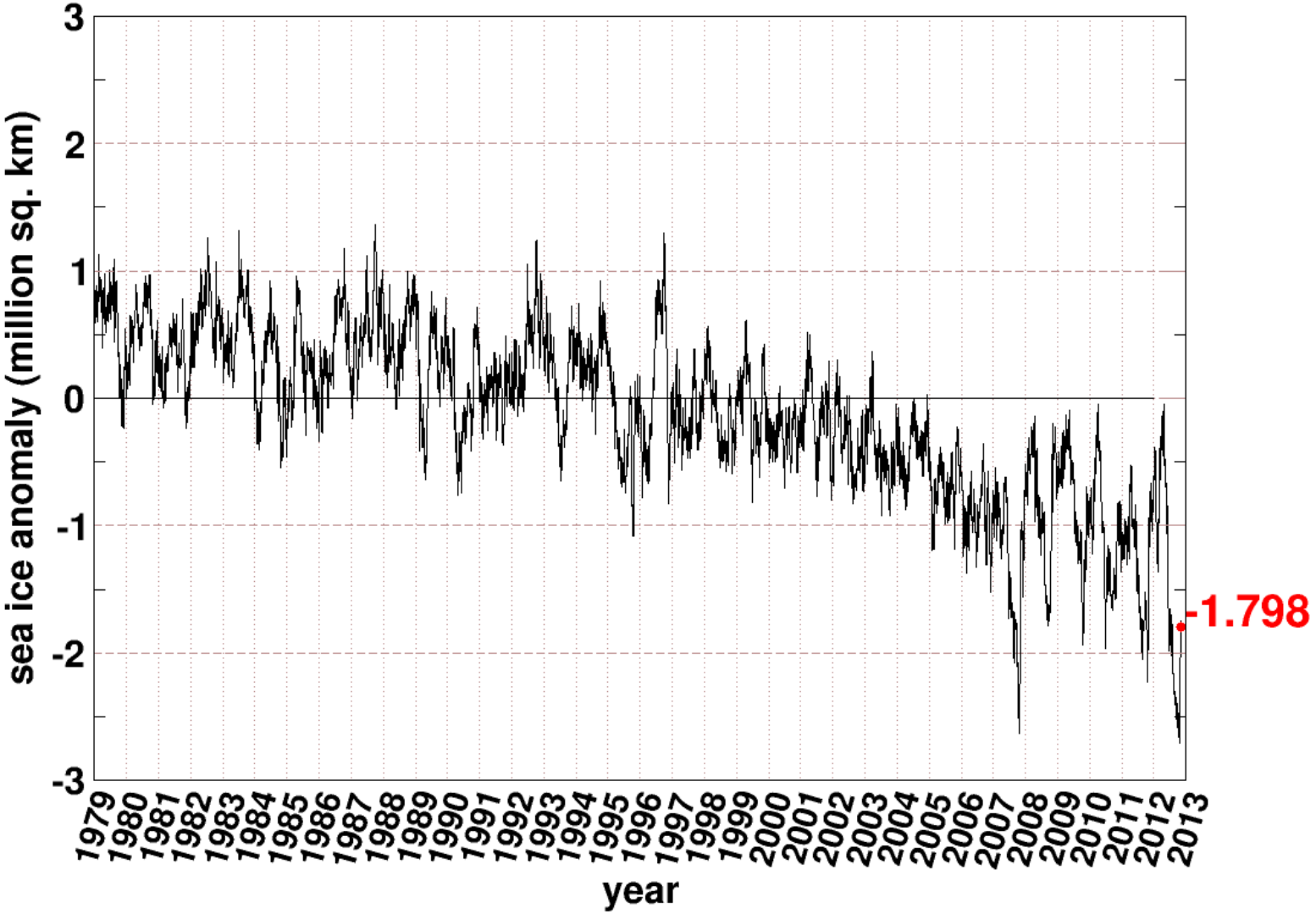

*NASA Goddard Space Flight Center*

# Ice - albedo feedback

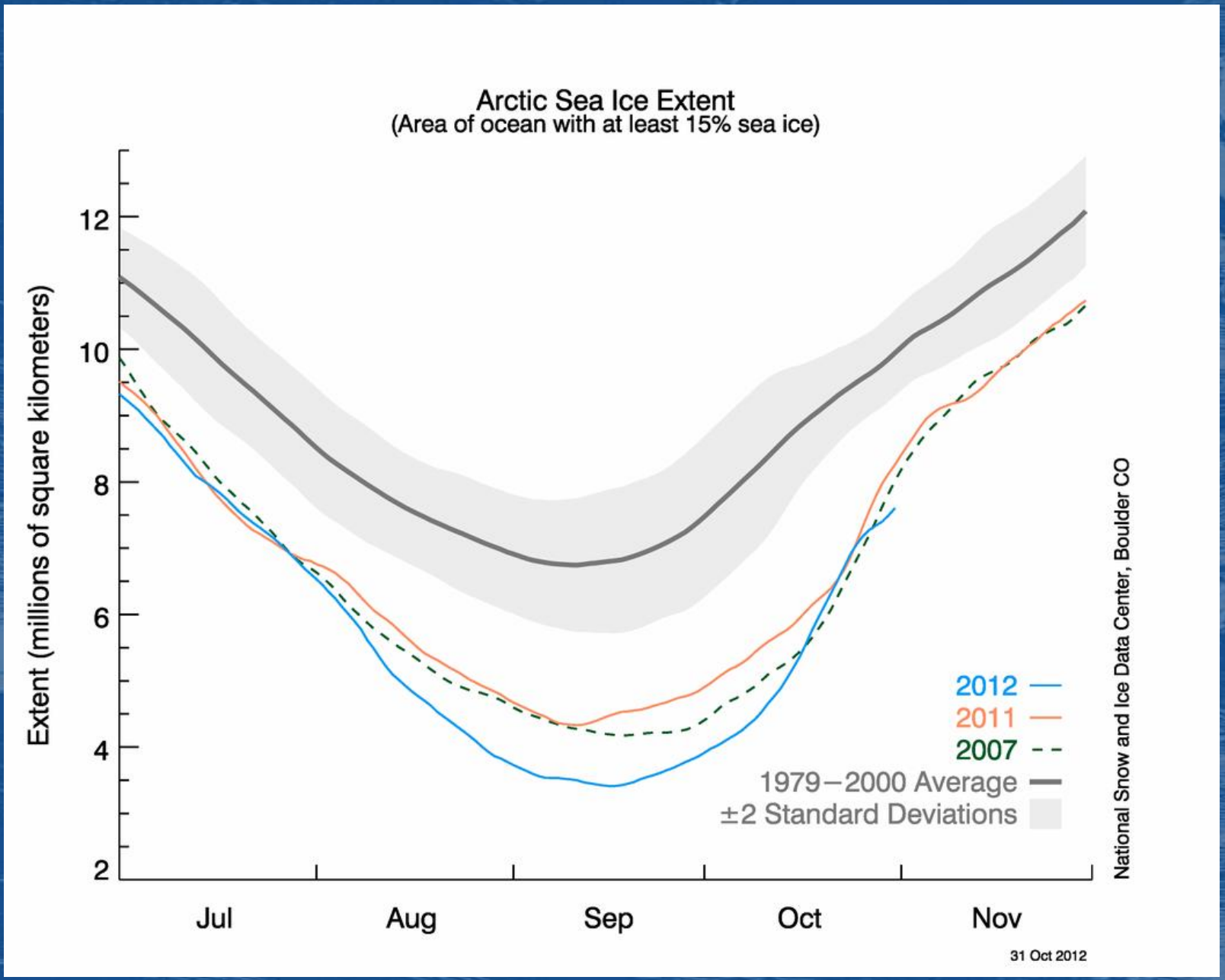


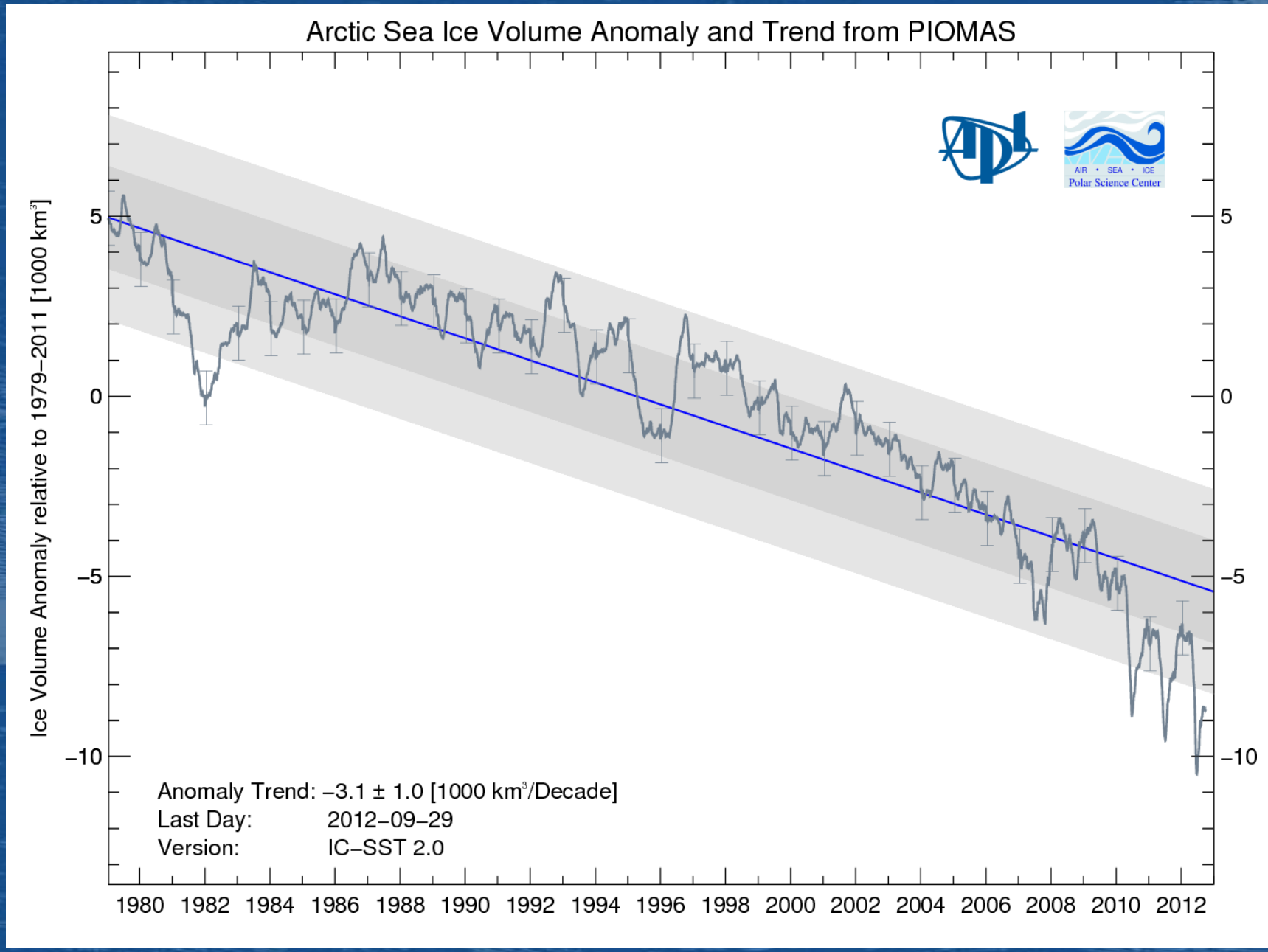
# Northern Hemisphere Sea Ice Anomaly

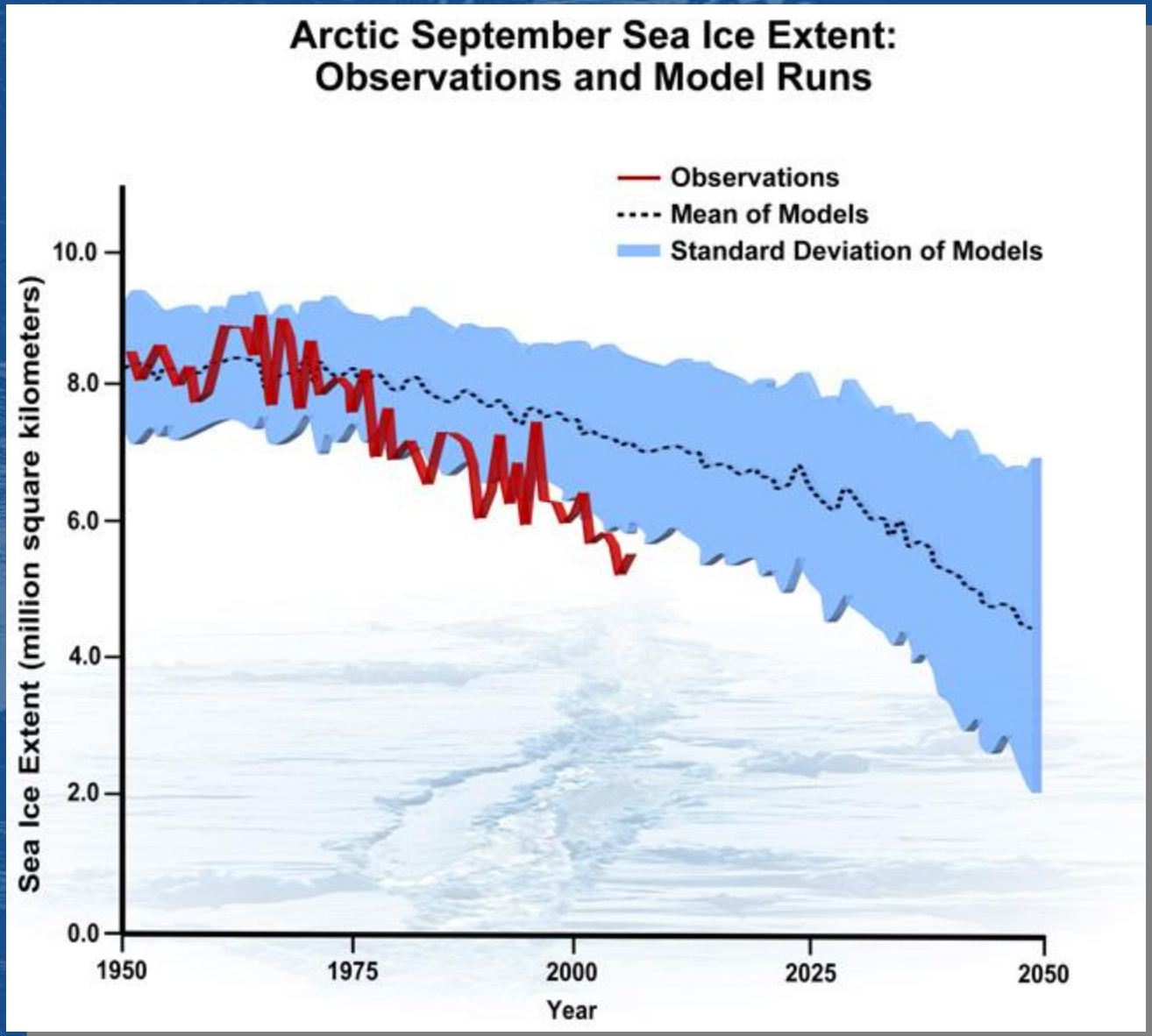
Anomaly from 1979-2008 mean




UIUC Polar Research Group

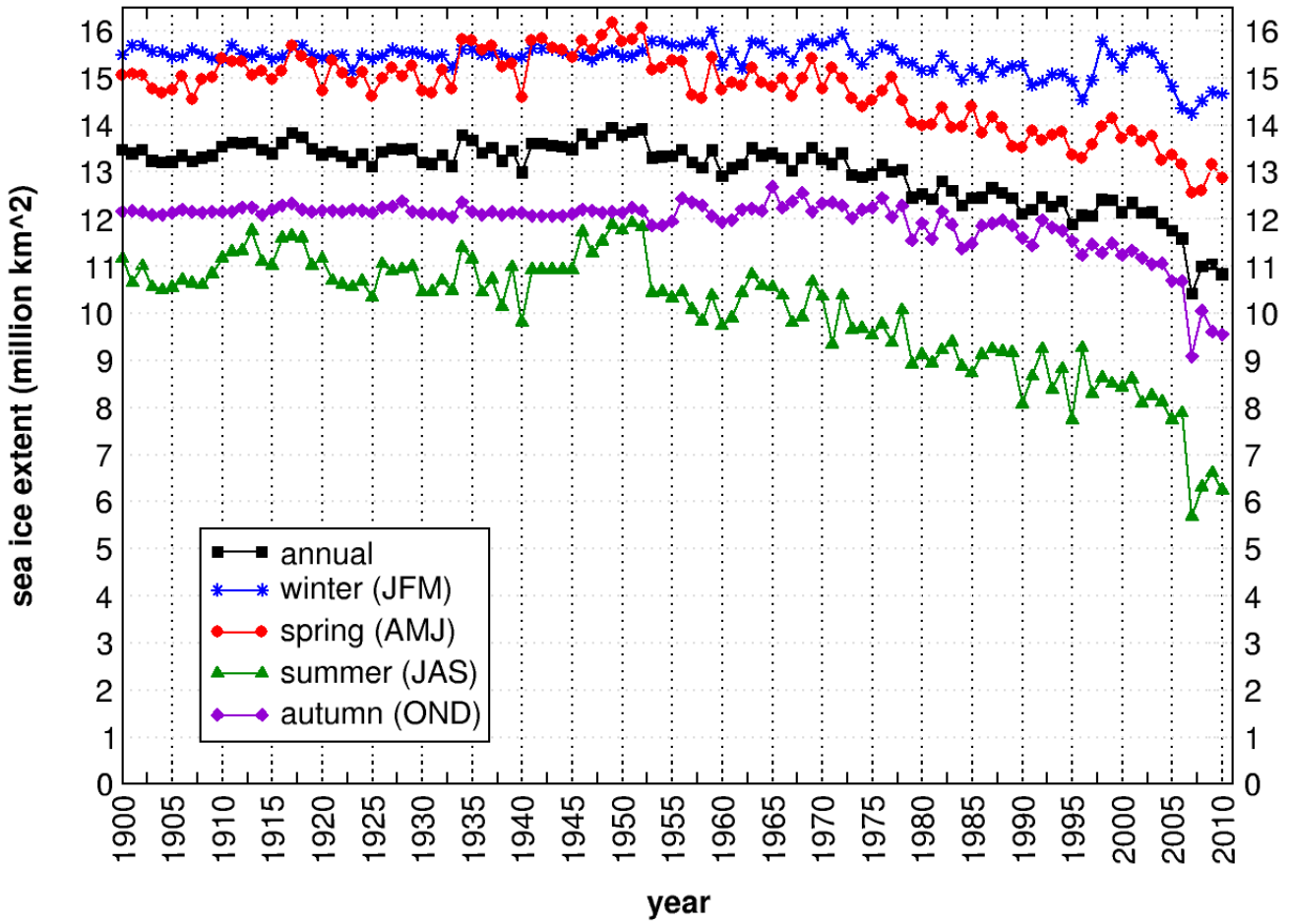

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
12
10
8
6
4
2
Jul
Aug
Sep
Oct
Nov
2012
2011
2007
1979–2000 Average
±2 Standard Deviations
National Snow and Ice Data Center, Boulder CO
31 Oct 2012


Arctic Sea Ice Volume Anomaly and Trend from PIOMAS
Ice Volume Anomaly relative to 1979–2011 [1000 km³]
5
0
−5
−10
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
Anomaly Trend: −3.1 ± 1.0 [1000 km³/Decade]
Last Day: 2012–09–29
Version: IC–SST 2.0
AIR • SEA • ICE
Polar Science Center



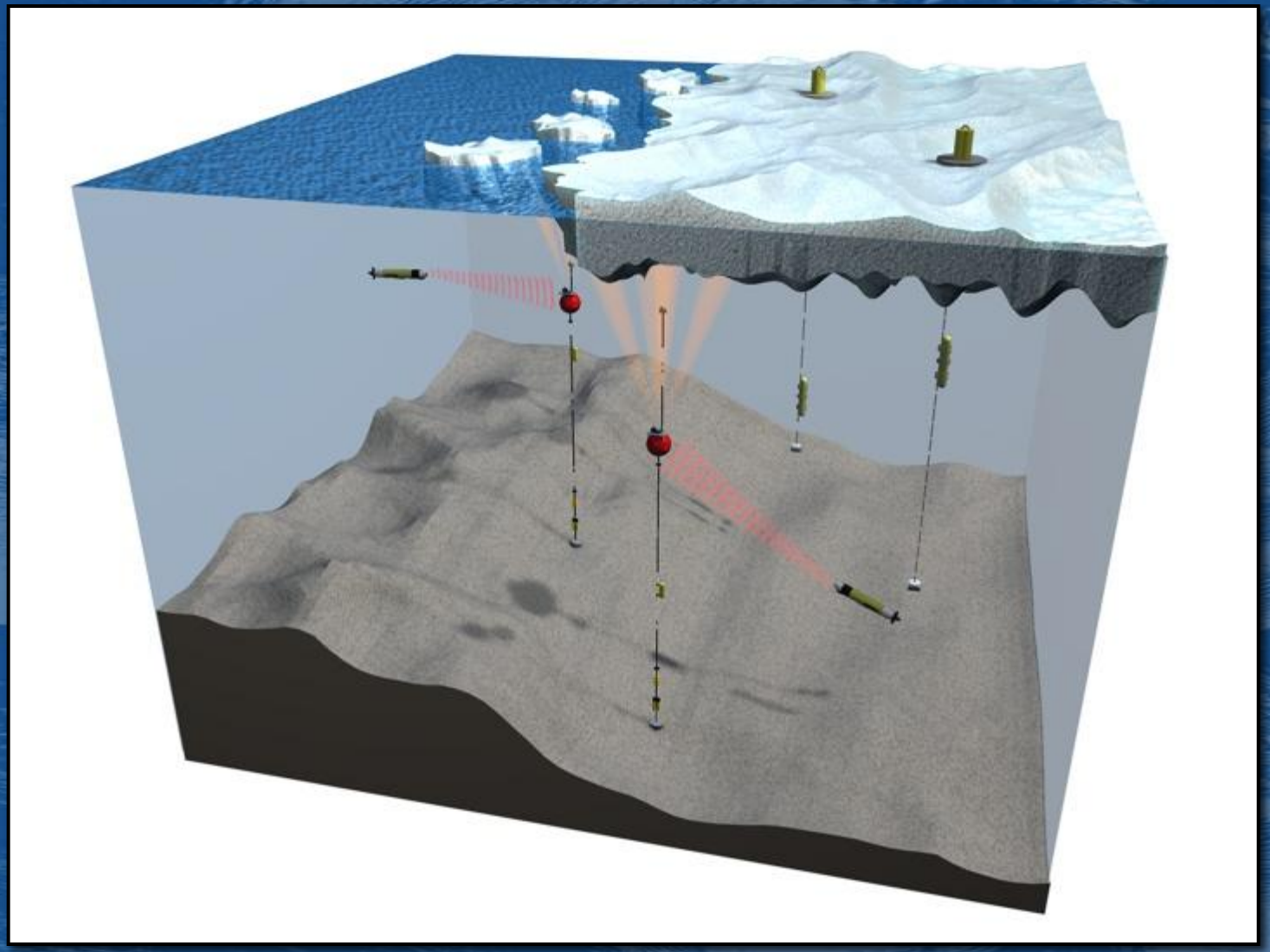

*(Stroeve et al., 2007)*

# Sea Ice – 1900 to 2010

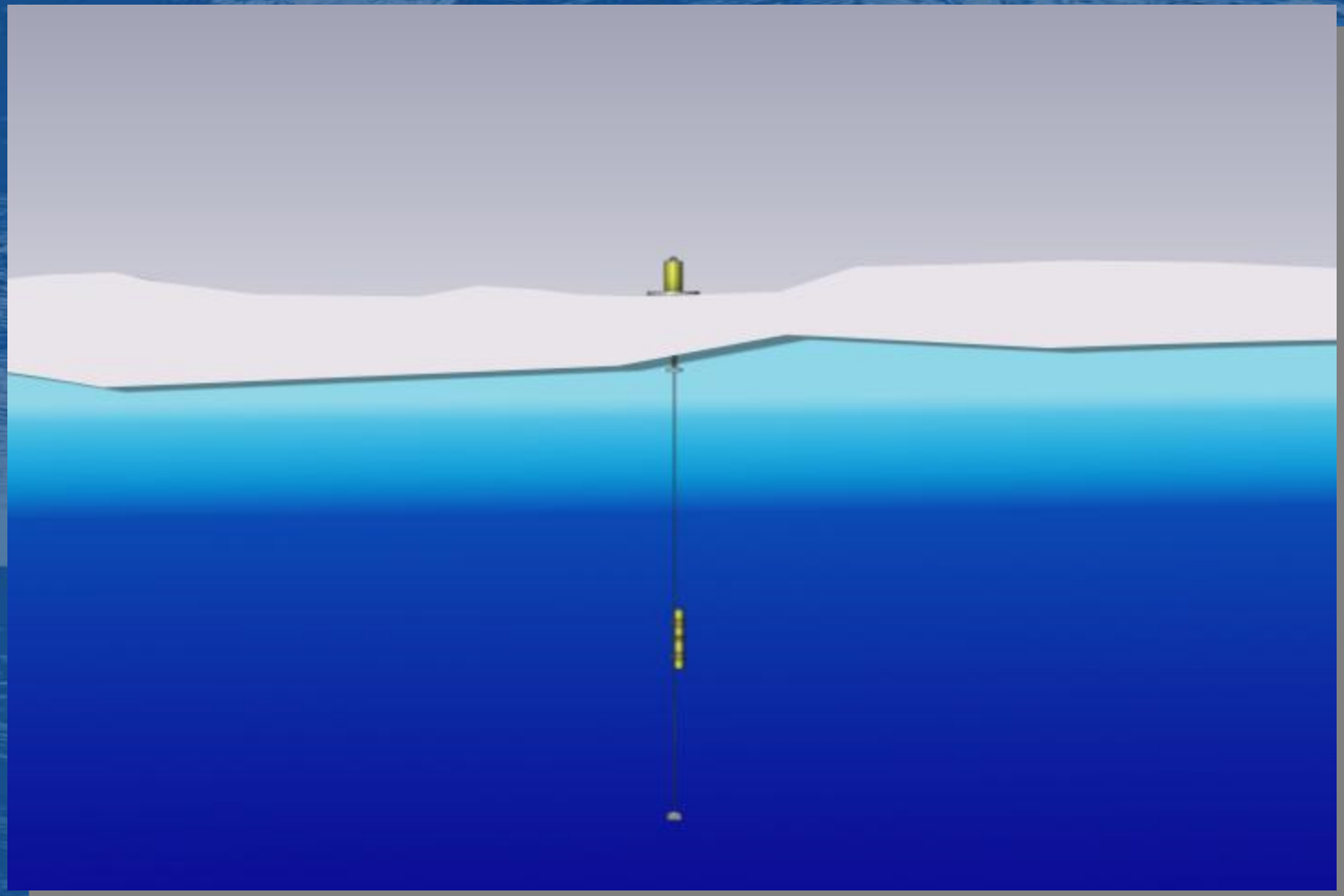


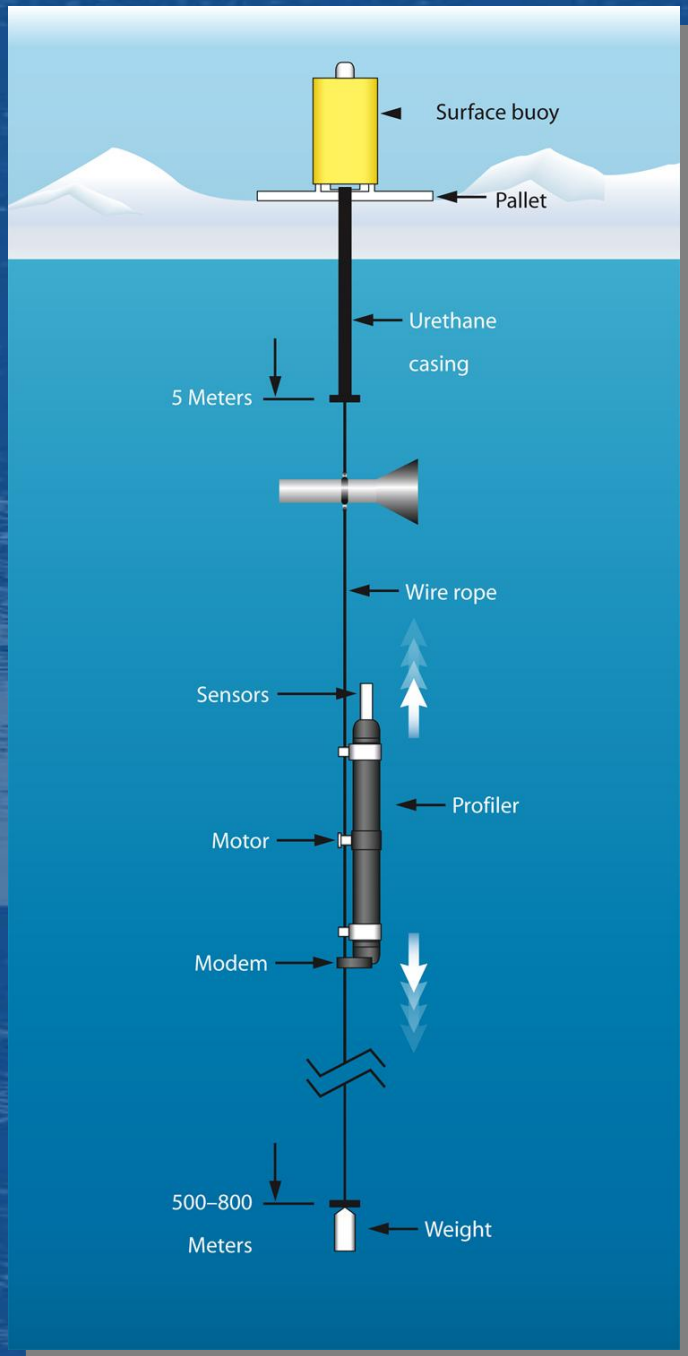

*UIUC Polar Research Group*

# Arctic Observing Systems



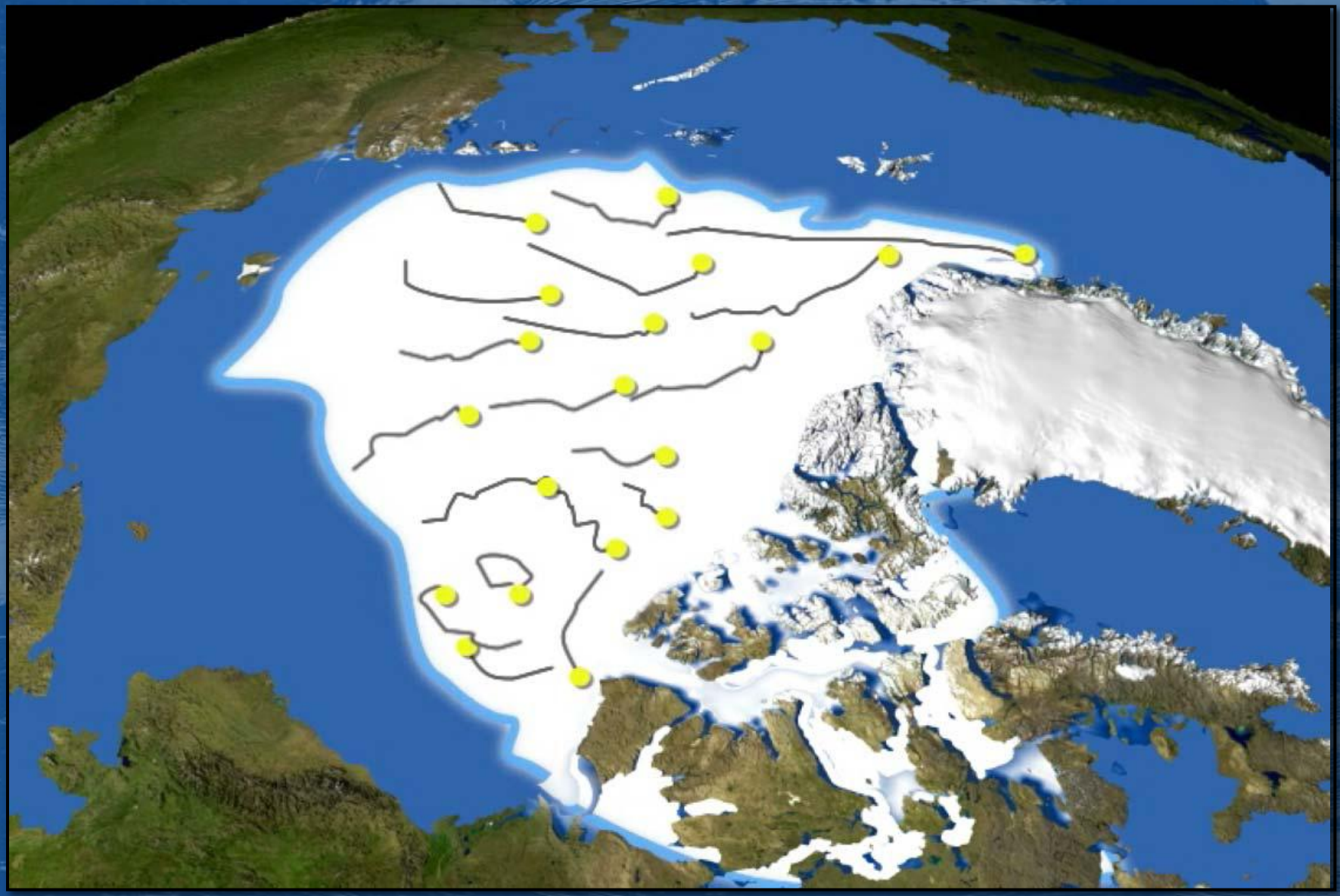
# Ice Tethered Moored Profiler

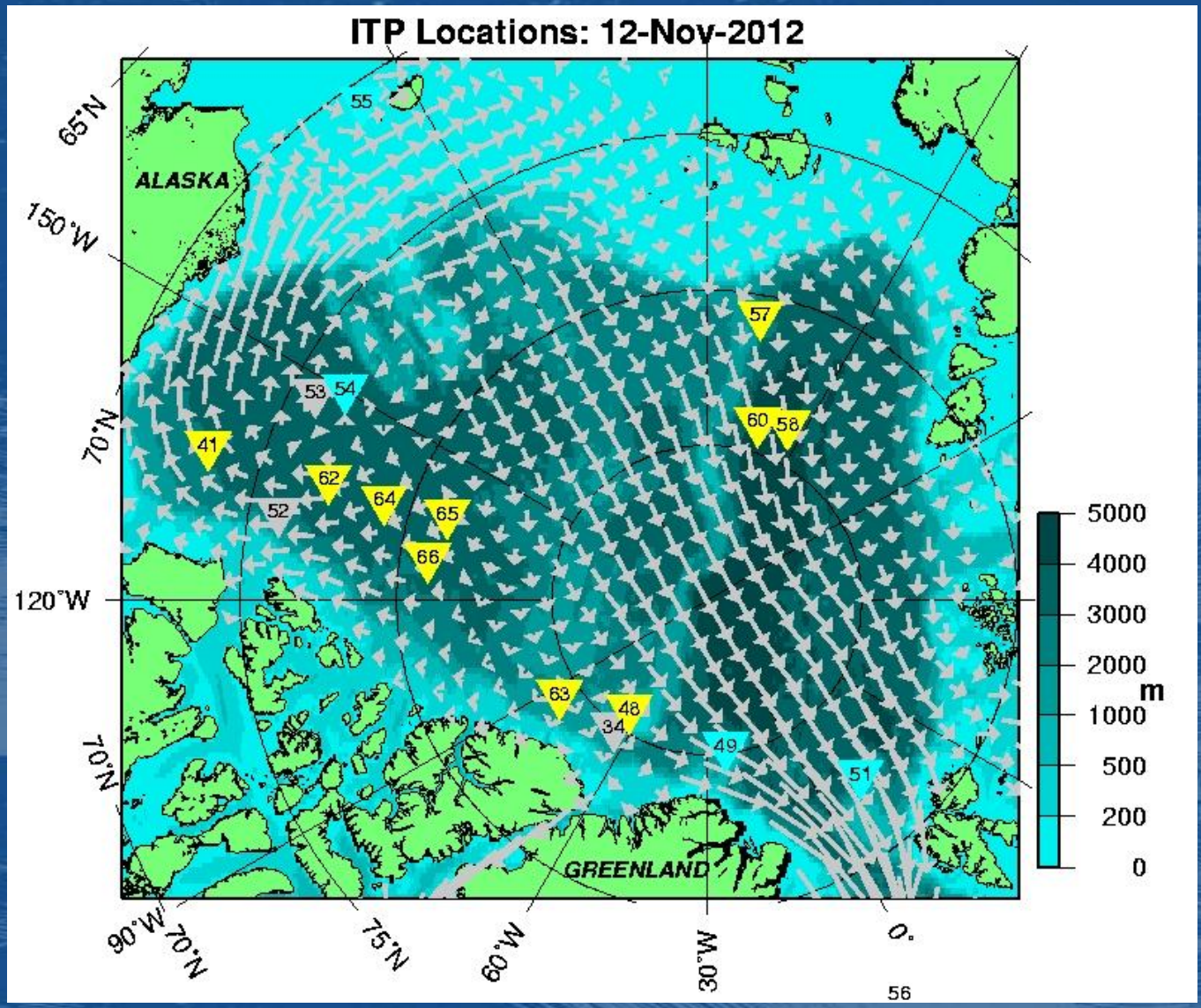





# ITP System with environmental sensors and AUV docking station

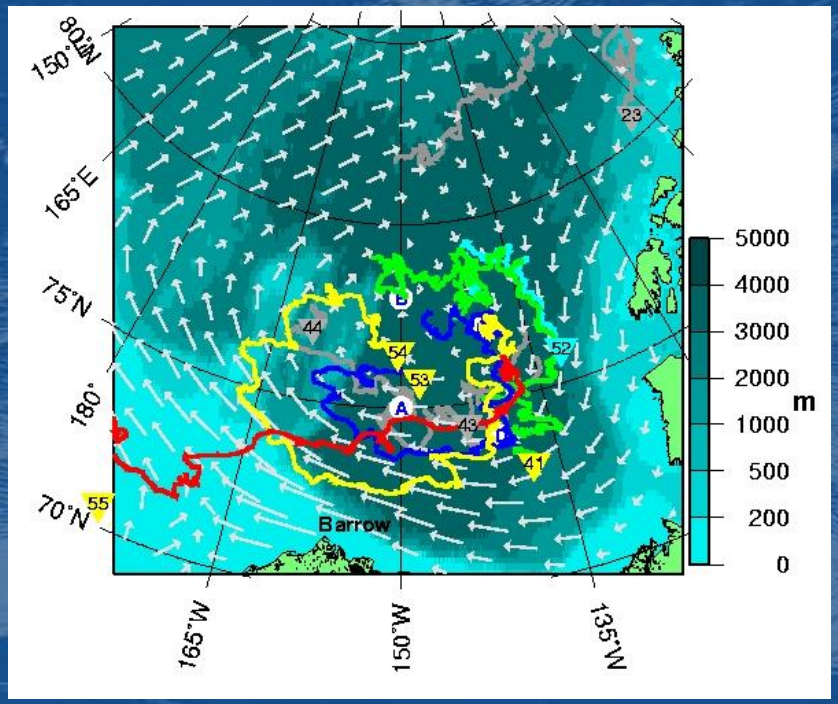
# ITP Drift – One year



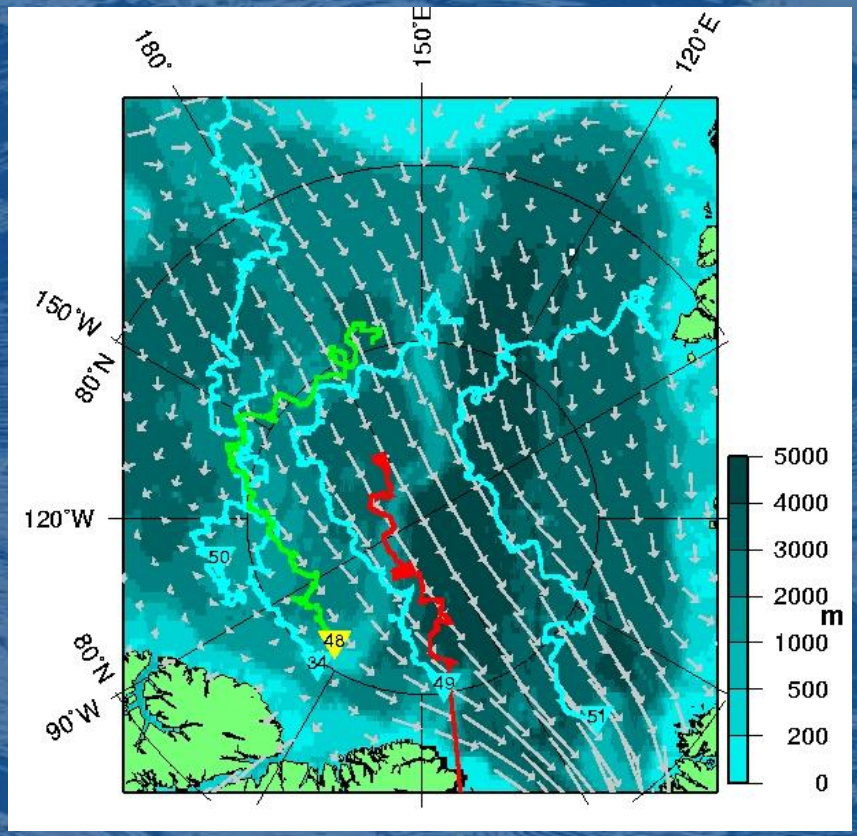



*www.whoi.edu/itp*

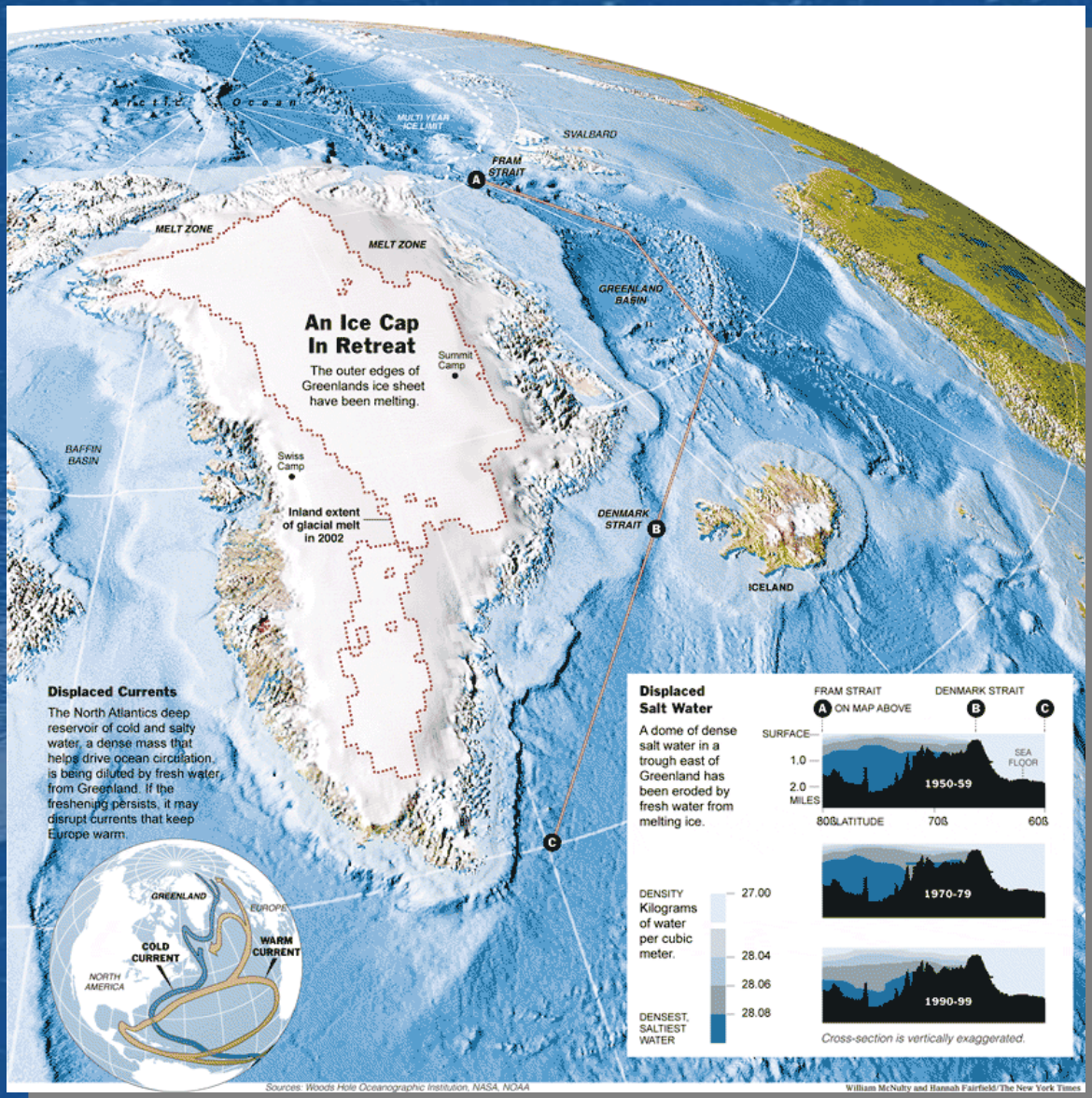
## Western Arctic




## Eastern Arctic



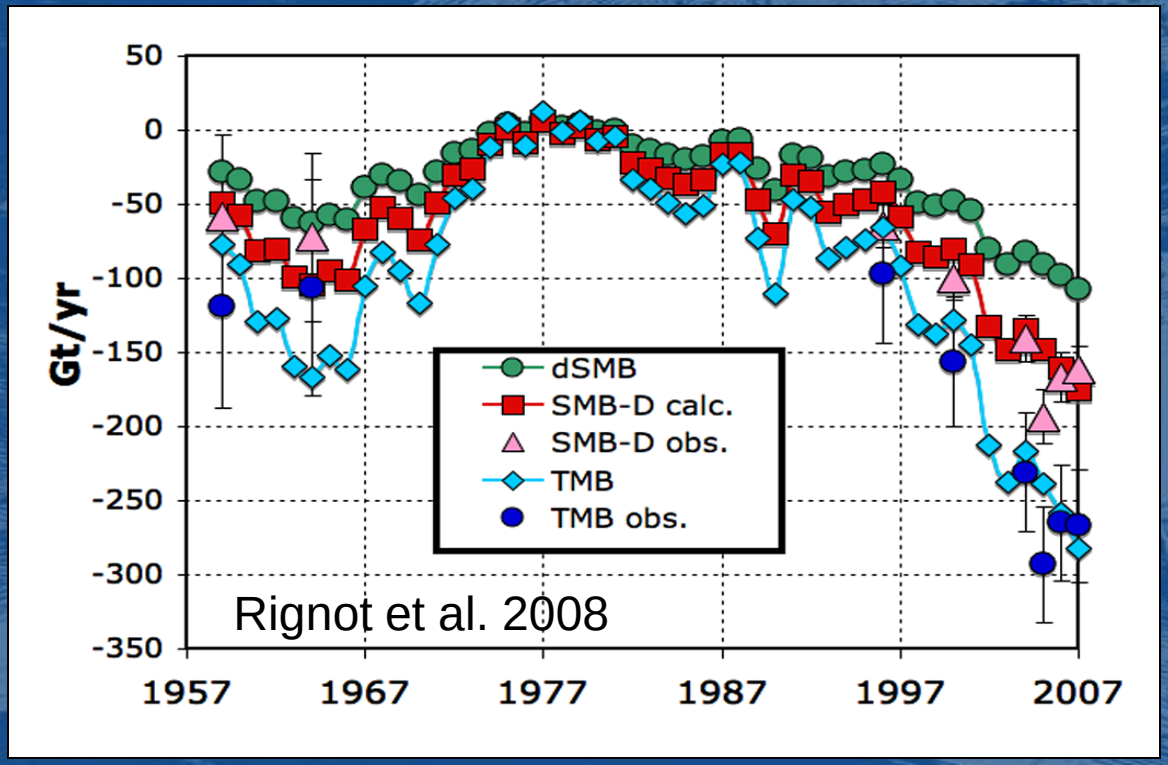

*www.whoi.edu/itp*




# Greenland is melting

*NY Times June 8, 2004*

# Mass loss from the Greenland Ice Sheet

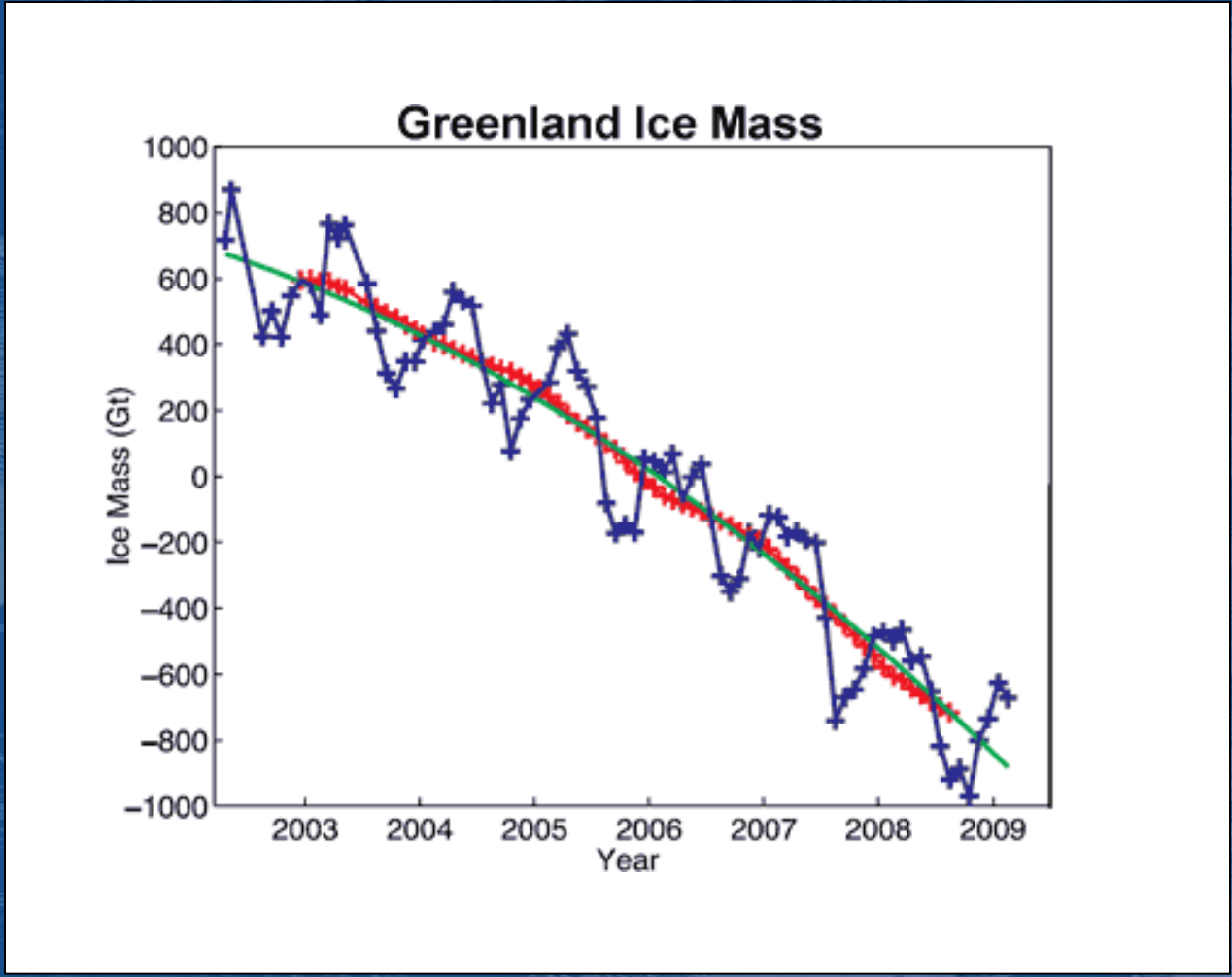



Sea-Level Rise

340 Gt/yr ~ 1 mm/yr

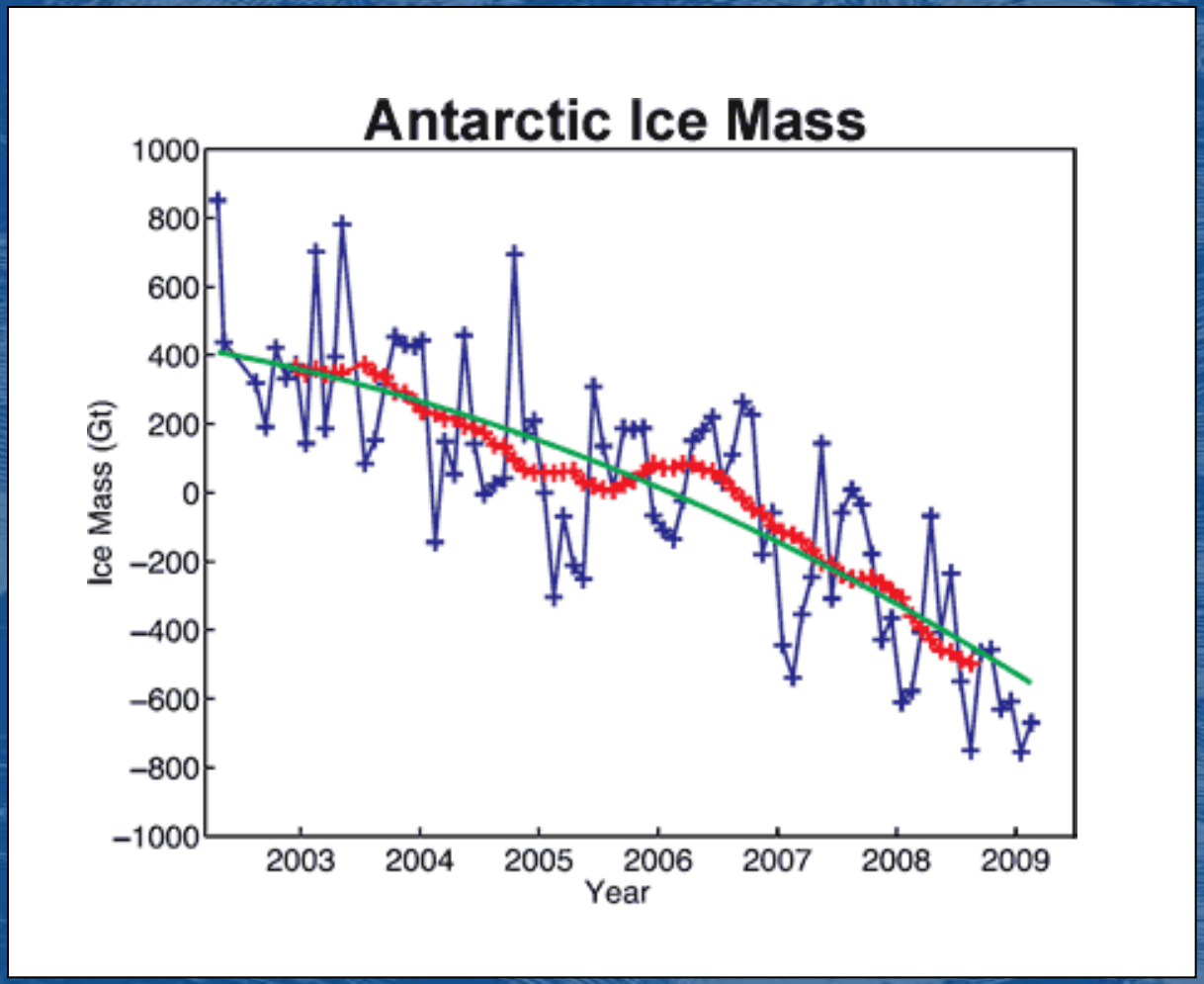
Greenland's contribution to sea-level rise has doubled since 2000

# Most Recent Satellite Measurements



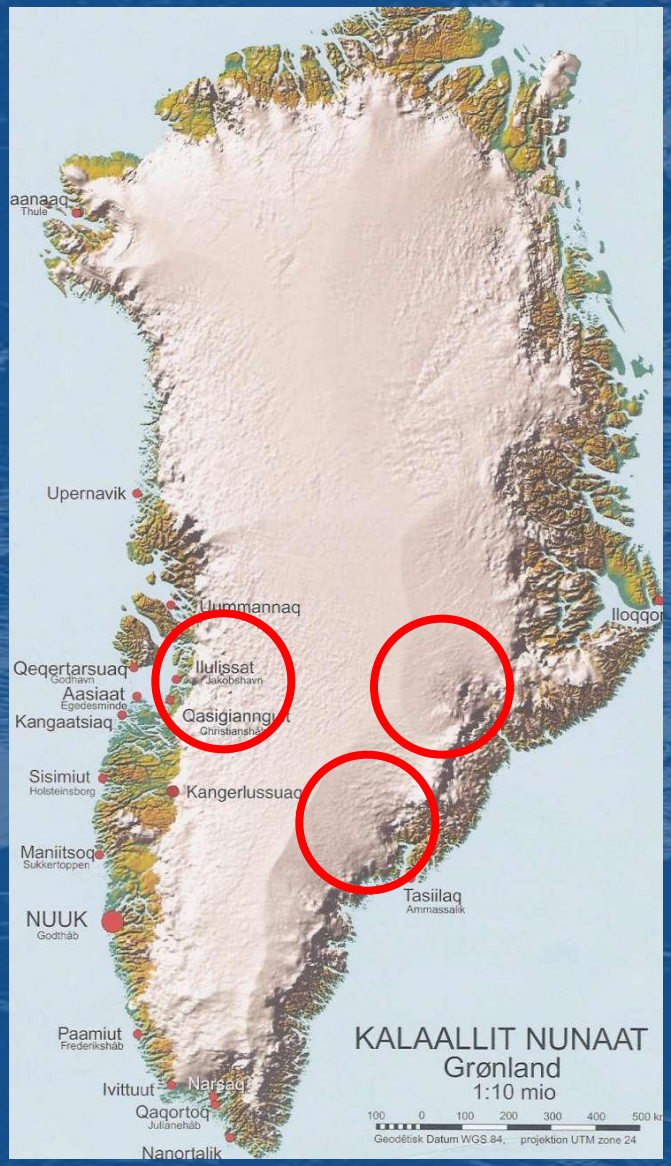

*Velicogna, 2009*

# Antarctica is melting too…….



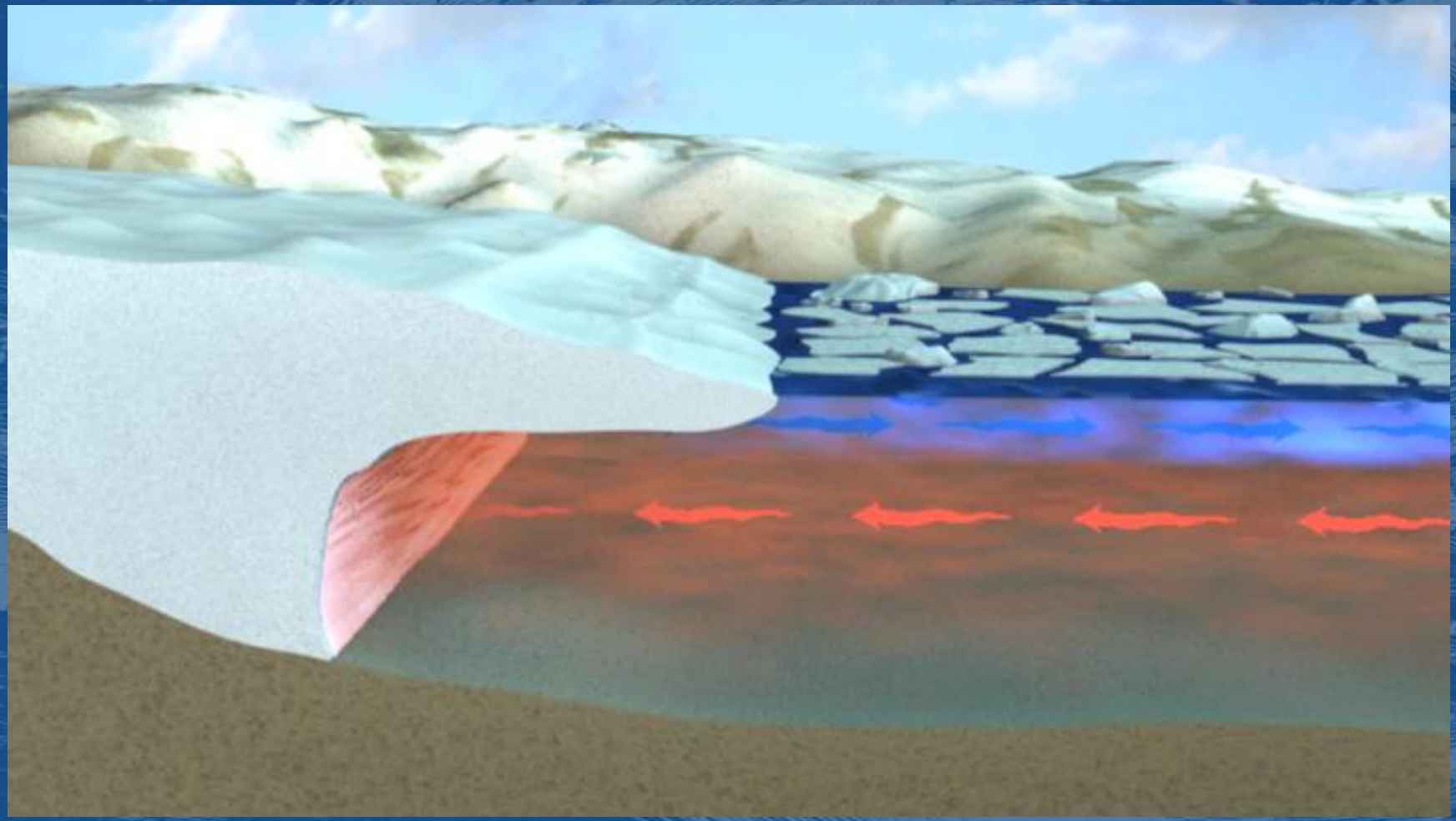

*Velicogna, 2009*

# Ocean – Ice Sheet interactions

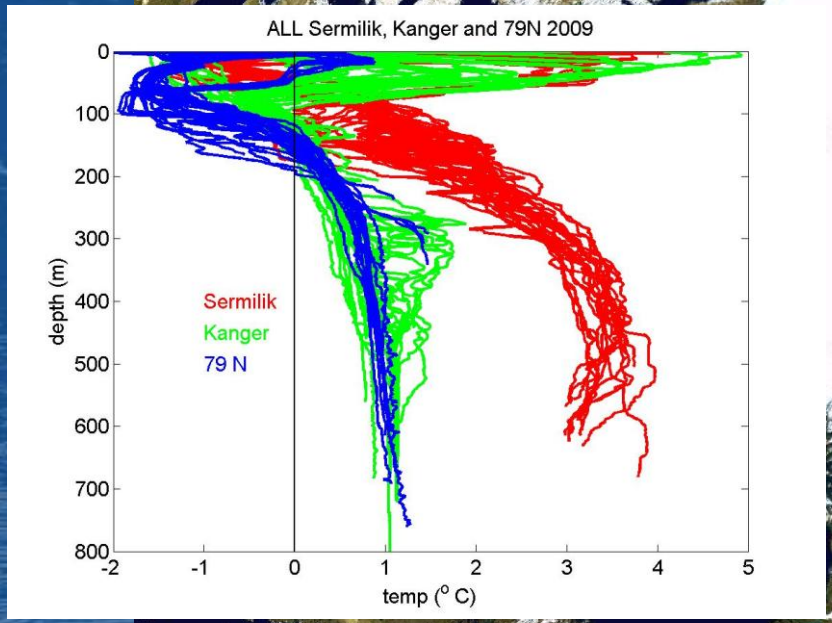



Warm subtropical waters flushing through the subpolar seas and into Greenland fjords appear to be linked to the recent surge (since early 2000) in the 3 largest outlet glaciers.

The ocean is more than just recipient of meltwater from the ice sheets (affecting surface density and sea level rise), ocean heat content appears to play an active role in accelerating their decline.



WHOI researchers are adapting existing technologies and developing new ones to make measurements under the Arctic sea ice, in Greenland's fjords -- and other challenging environments -- to determine how the ocean is interacting with these components of the climate system.


79° N
Fjord/Glacier

Kangerdlugssuaq
Fjord/Glacier

Sermilik Fjord
Helheim Glacier

# The “Other” $CO_2$ Problem

# Fate of Anthropogenic $CO_2$ Emissions (2000-2007)

1.5 Pg C $y^{-1}$

+

7.5 Pg C $y^{-1}$

4.2 Pg $y^{-1}$

Atmosphere

46%

2.6 Pg $y^{-1}$

Land

29%

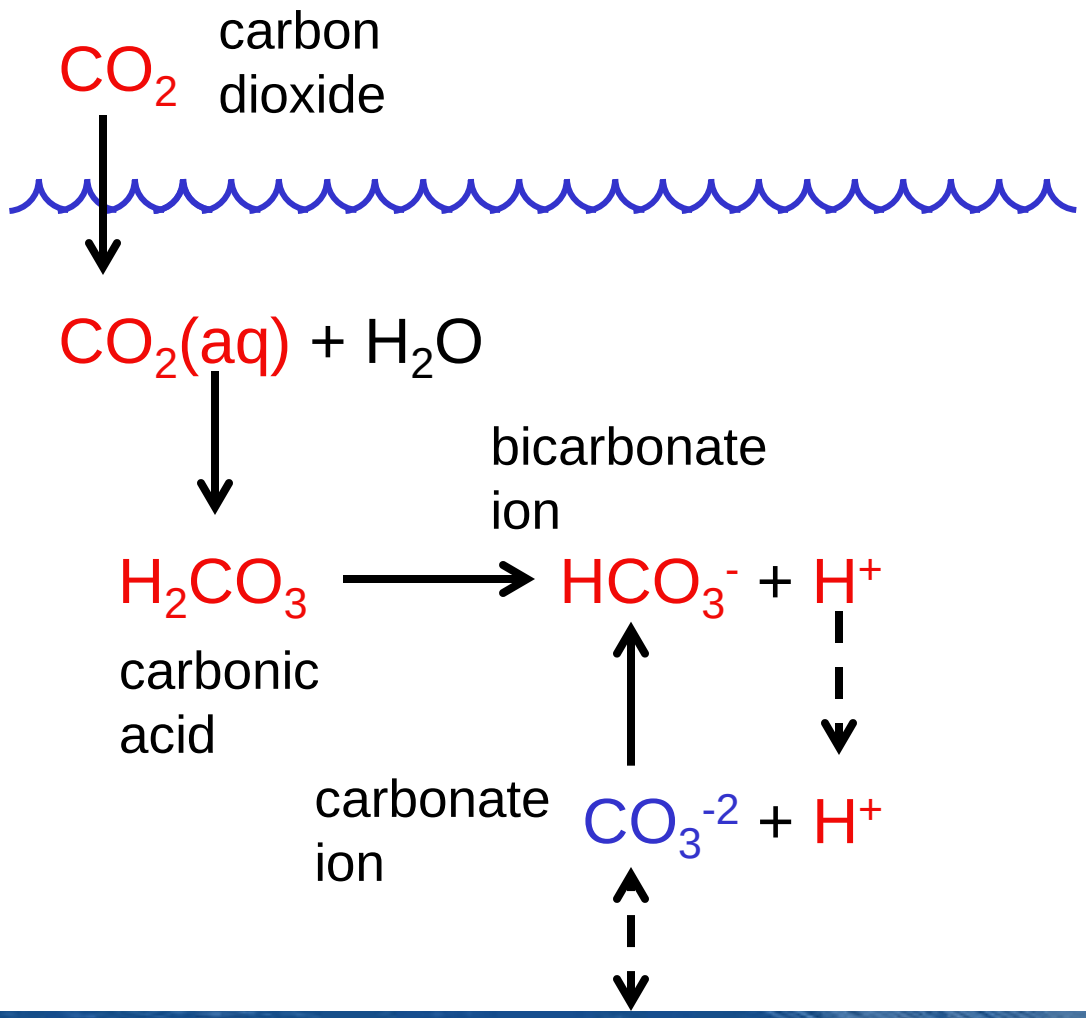
2.3 Pg $y^{-1}$

Oceans

26%

Canadell et al. 2007, PNAS (updated); http://www.globalcarbonproject.org/

# Ocean Acidification Primer




## High $CO_2$ World

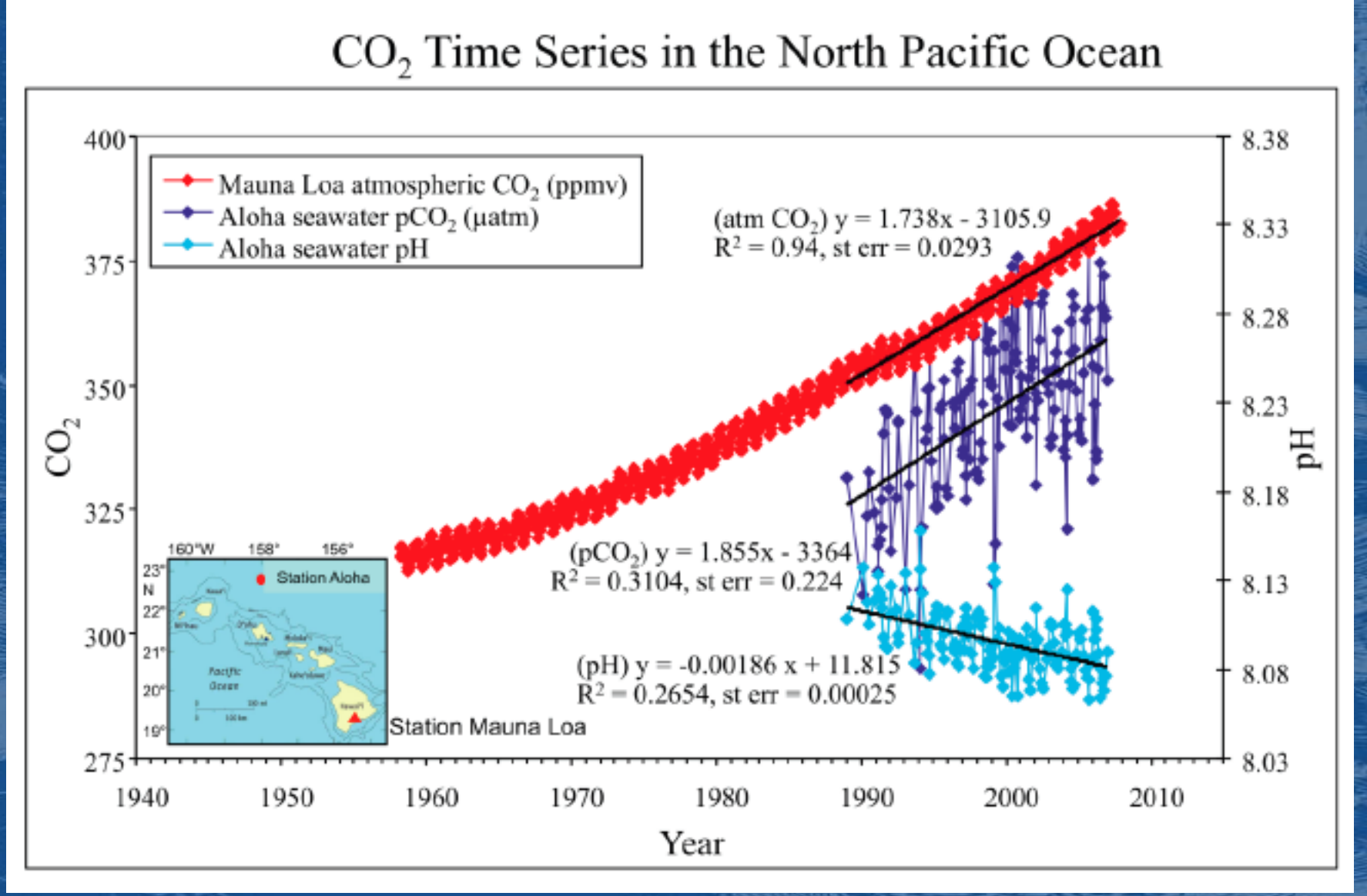
-Higher $[CO_2](aq)$

-Higher acidity $[H^+]$ (lower pH)

-Lower $[CO_3^{-2}]$ & carbonate saturation state

$\Omega = [CO_3^{-2}][Ca^{2+}]/K_{sp}$

*(Scott Doney, pers. comm.)*




-Rising $CO_2$ causes water to become more acidic -
Endangering shell-forming plants & animals

*Doney et al., Ann. Rev. Mar. Sci. 2009 Dore et al. PNAS 2009*

# Acidification Impacts

- Shell forming plants & animals
  - reduced shell formation (calcification)
  - lower growth rates
- Habitat loss (reefs)
- Less food for predators
  - humans, fish, whales
- Possible negative effects on fisheries & ecosystem services


warm-water corals


lobsters, crabs


some plankton

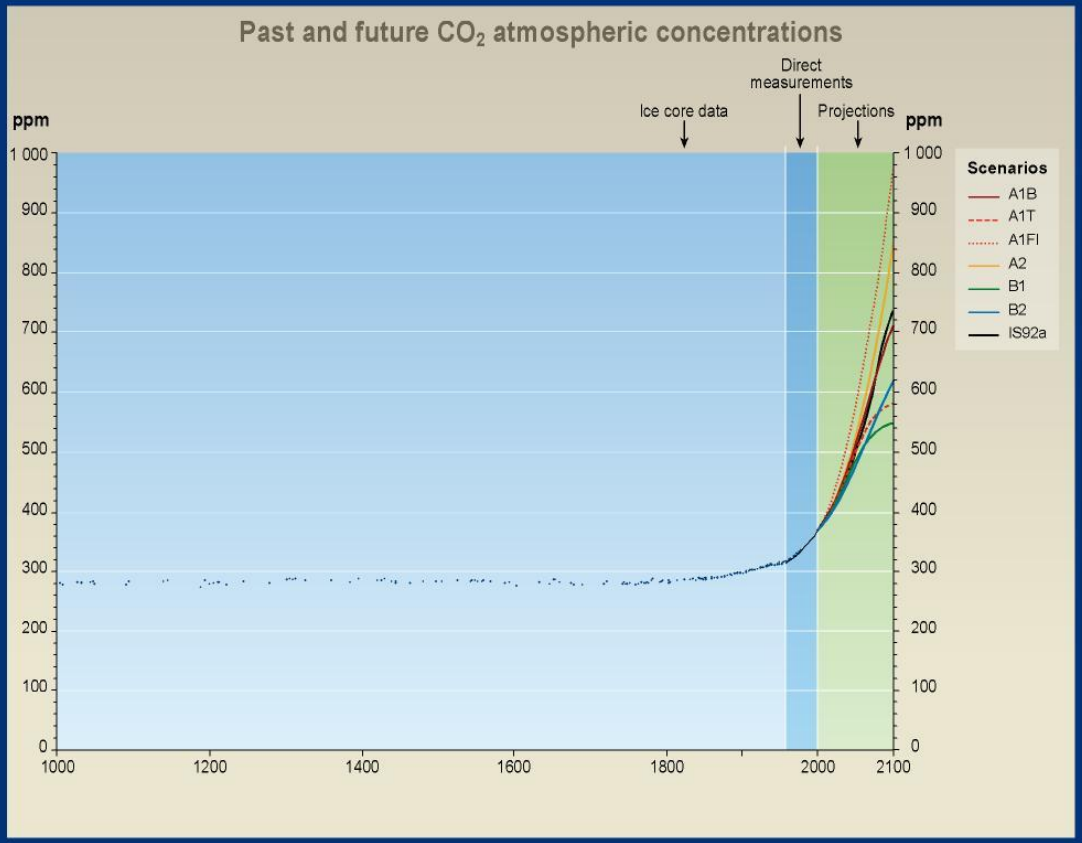

cold-water corals


pteropods
planktonic snails


scallops, clams, oysters

*(Scott Doney, pers. comm.)*

# What about the Future?




SYR - FIGURE 9-1a

# Summary

The evidence is strong that increasing atmospheric $CO_2$ is altering climate and ocean chemistry:

- Atmospheric temperatures
- Sea level
- Glacier melting and sea ice retreat
- Ocean chemistry and acidification

# Bermuda Institute of Ocean Sciences

For more information: www.bios.edu