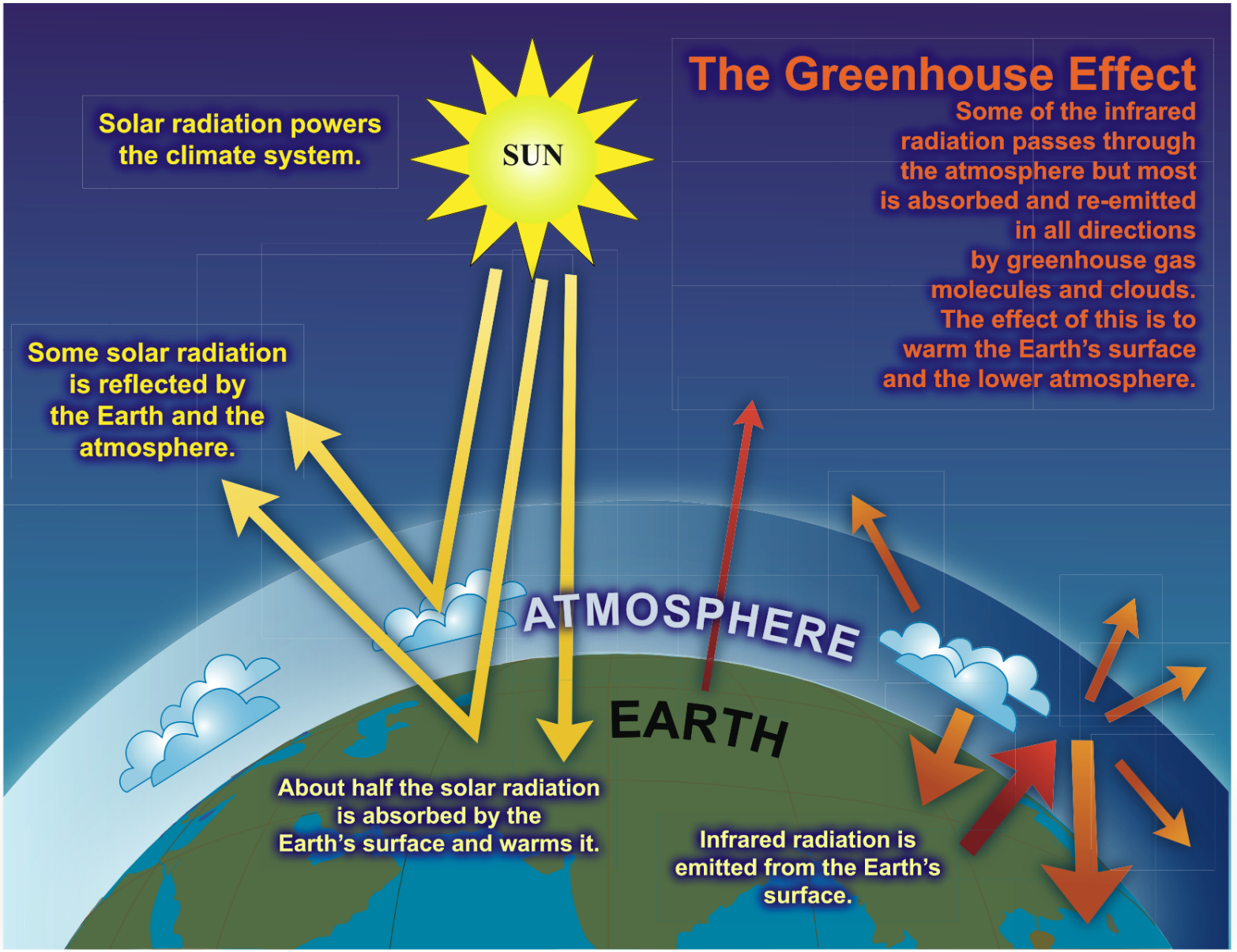
Oceans and climate change

Denis Gilbert
Maurice Lamontagne Institute
Fisheries and Oceans Canada
Mont-Joli, Québec, Canada

Canadian Meteorological and Oceanographic Society
2013 Tour Speaker
January 15 – February 8, 2013

Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation (global conveyor belt)
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
  - Gulf of St. Lawrence case study
  - Mixing of Gulf Stream with Labrador Current waters
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?



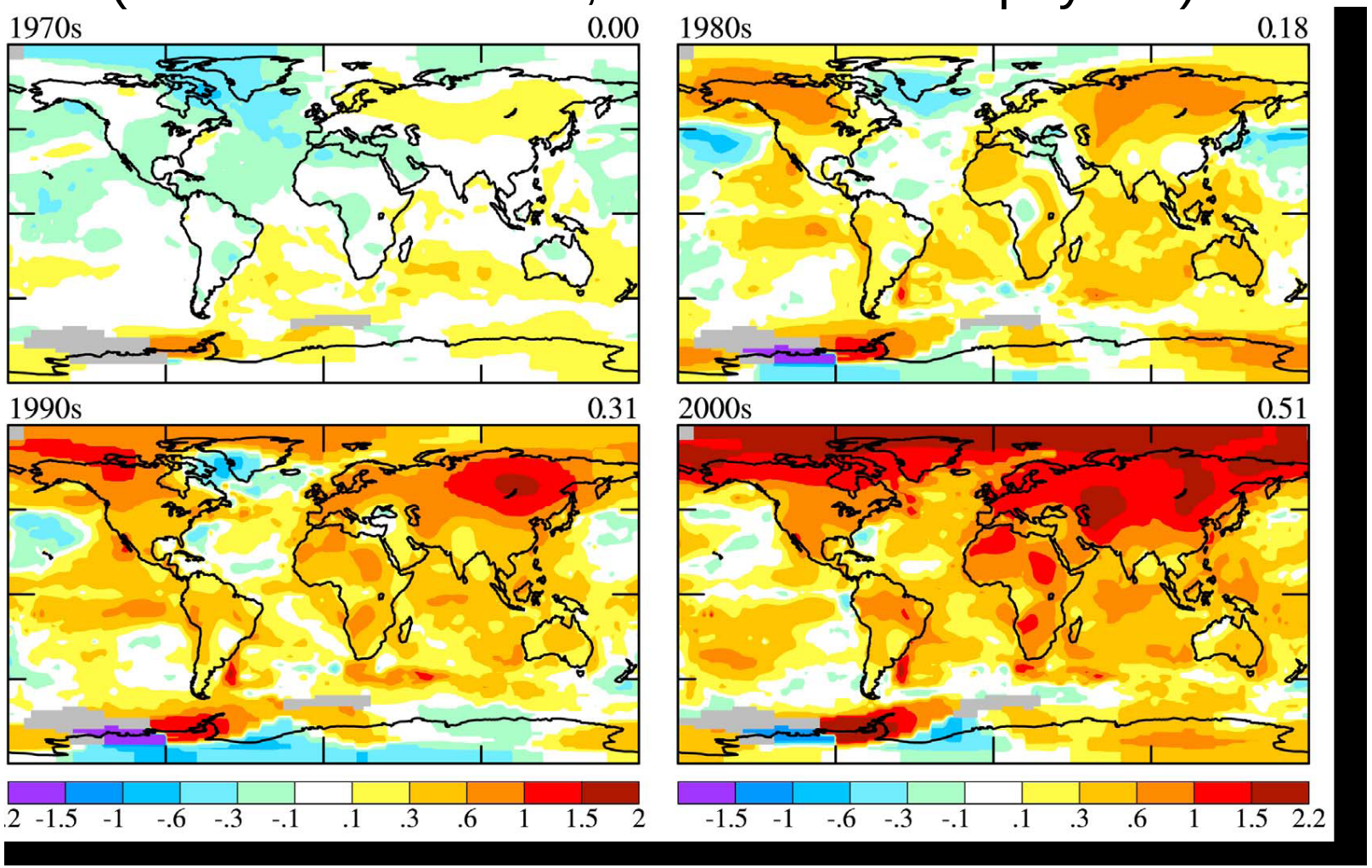
IPCC AR4, WG1, FAQ 1.3

Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Temperature difference with respect to 1951-1980 reference period

(Hansen et al. 2010, Reviews of Geophysics)



Denis Gilbert

2013-01-15

Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Energy Content in the Climate System

IPCC AR4 (2007)

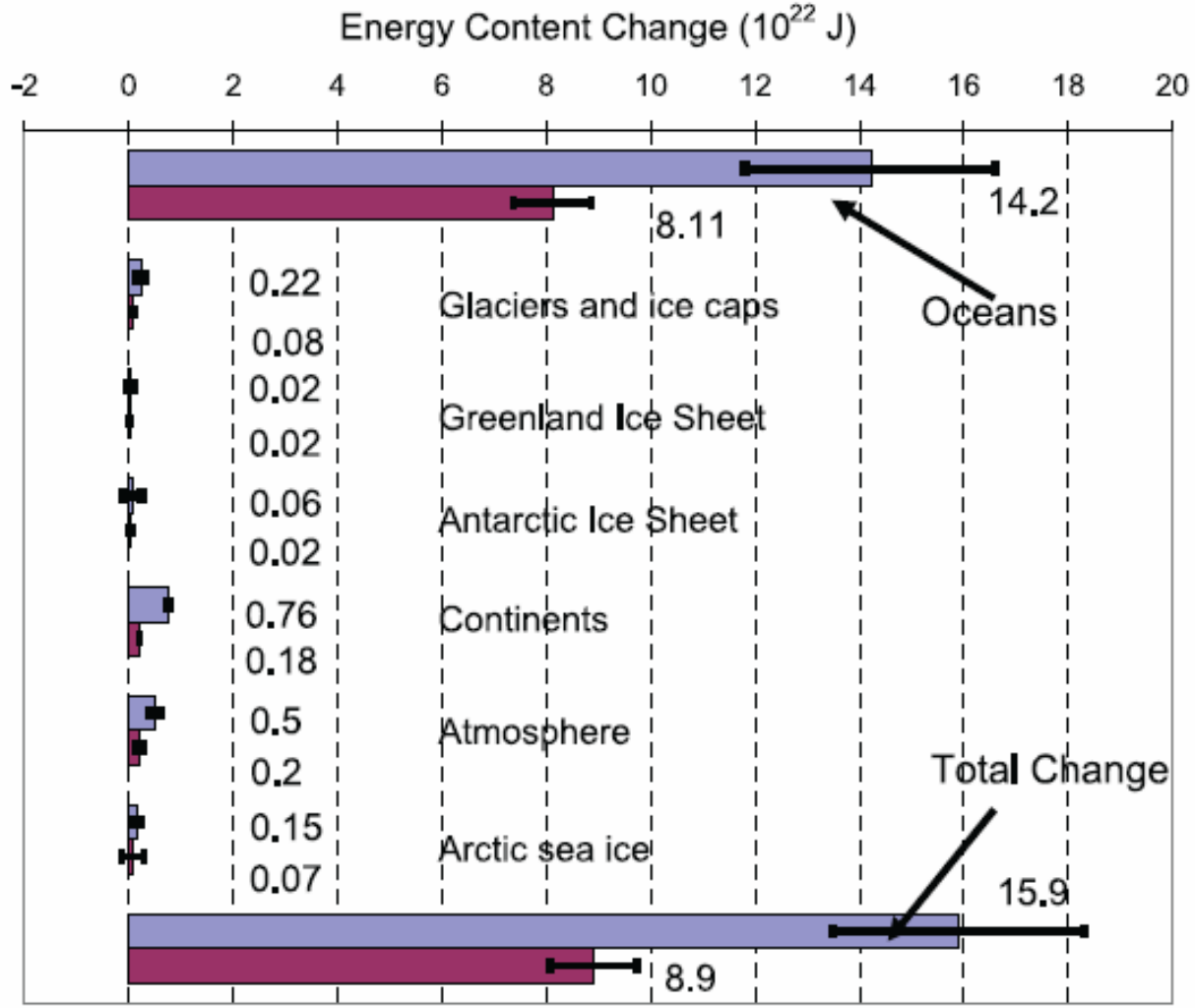


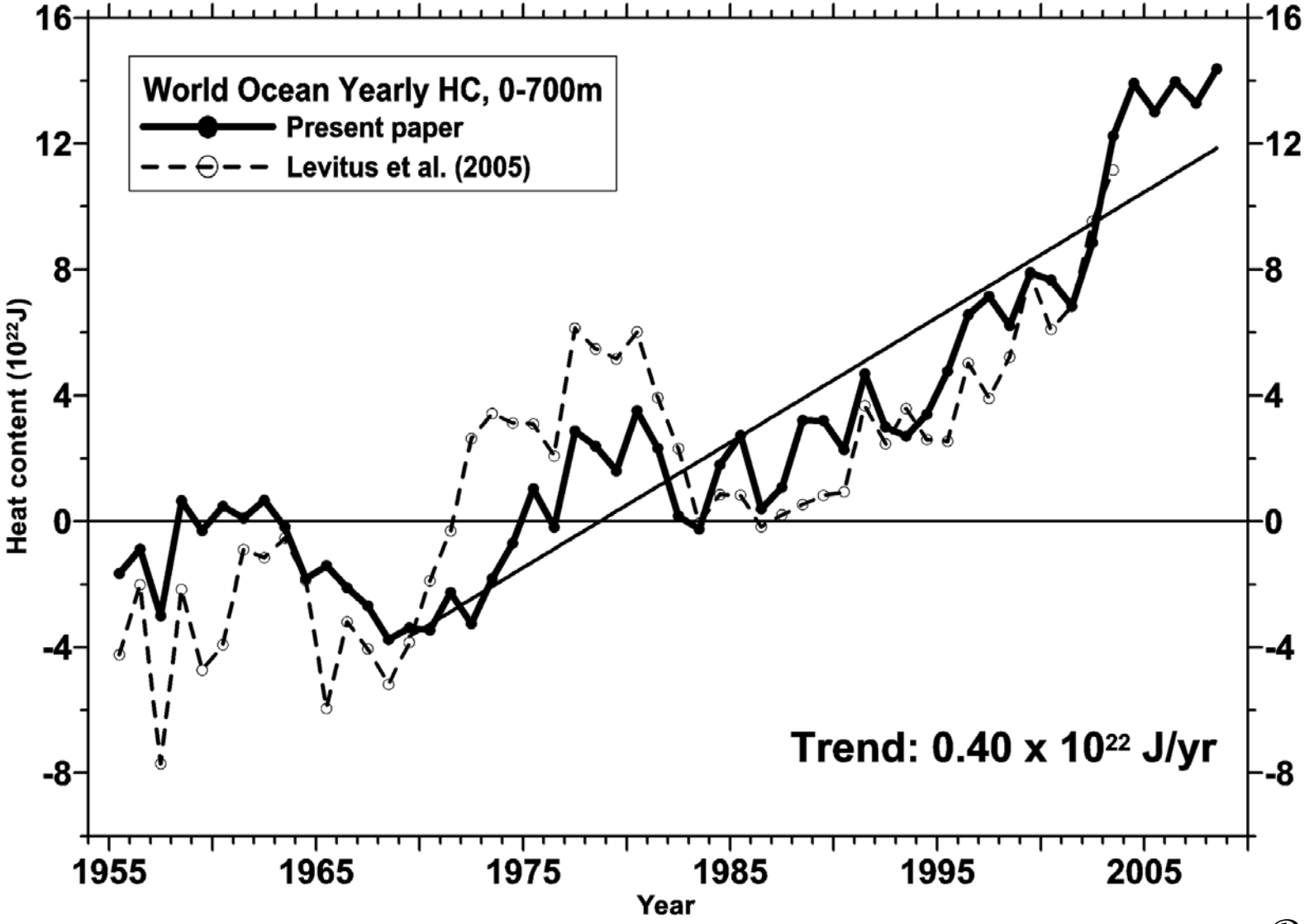
Figure TS.15. *Energy content changes in different components of the Earth system for two periods (1961–2003 and 1993–2003).*

90% of heat content change occurred in the oceans.

(93% according to more recent estimates)

Denis Gilbert
2013-01-15

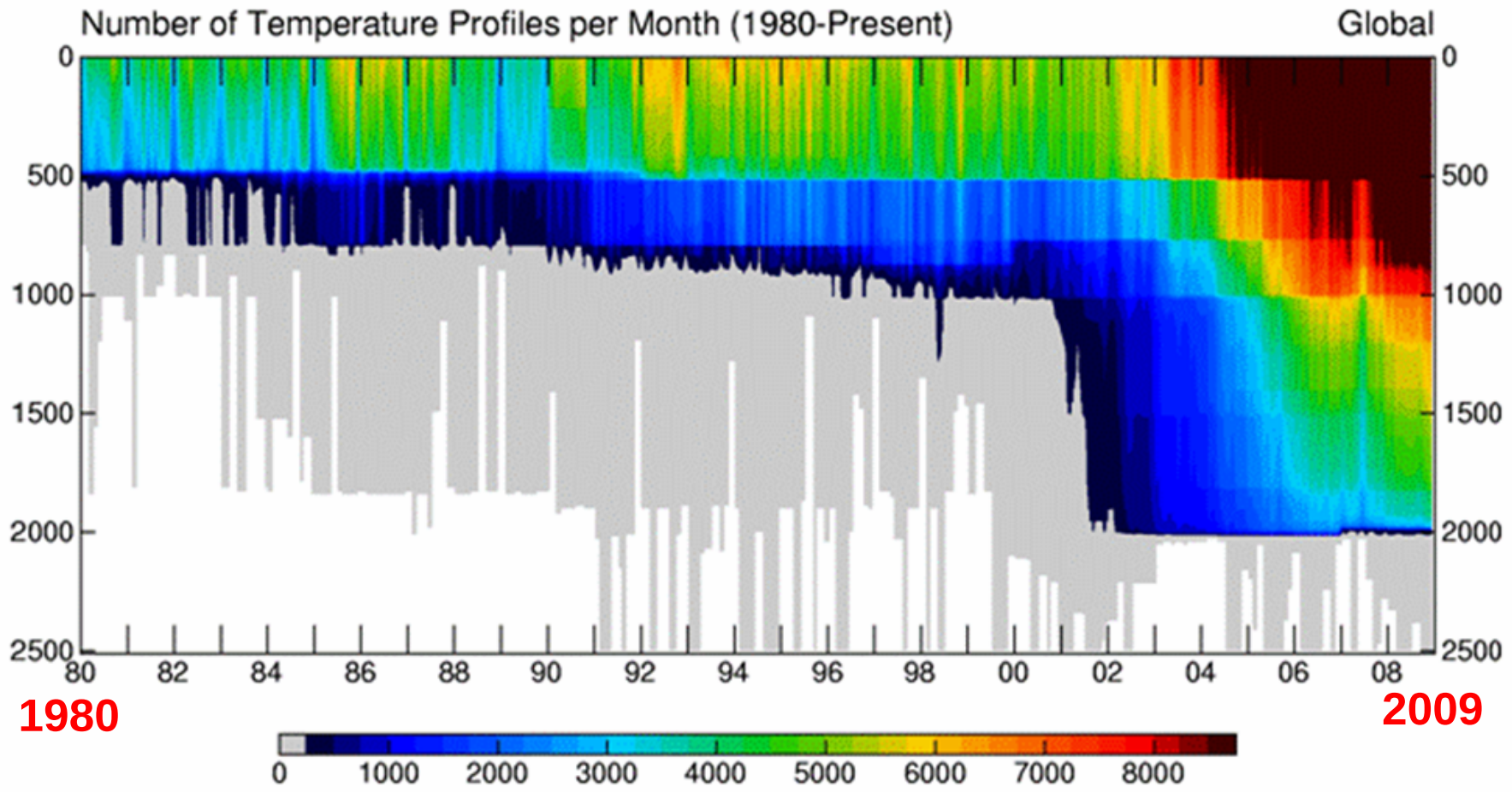
Ocean heat content



Levitus et al. (2009, Geophysical Research Letters)

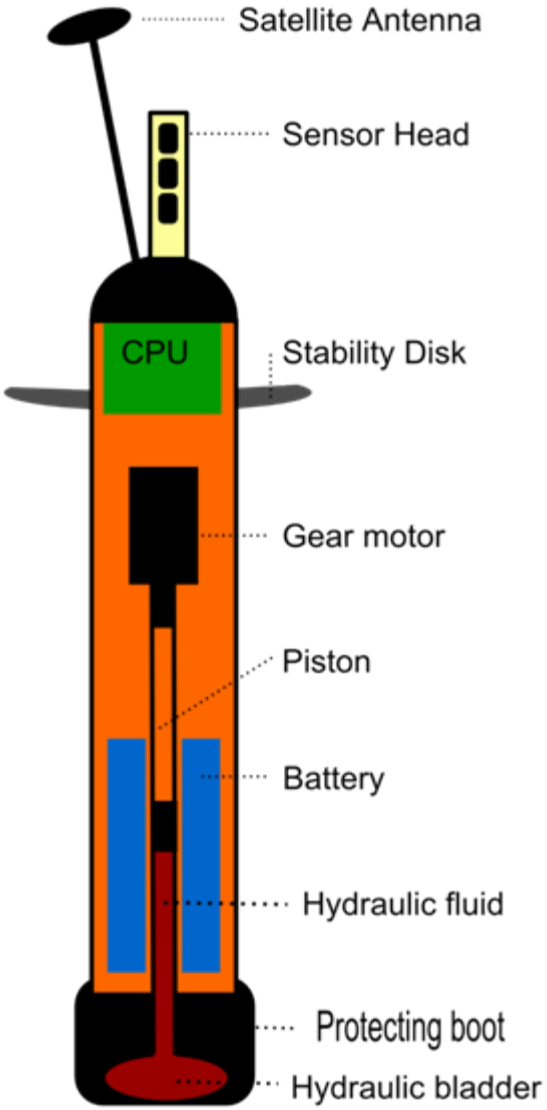
Denis Gilbert
2013-01-15

Global number of ocean temperature profiles

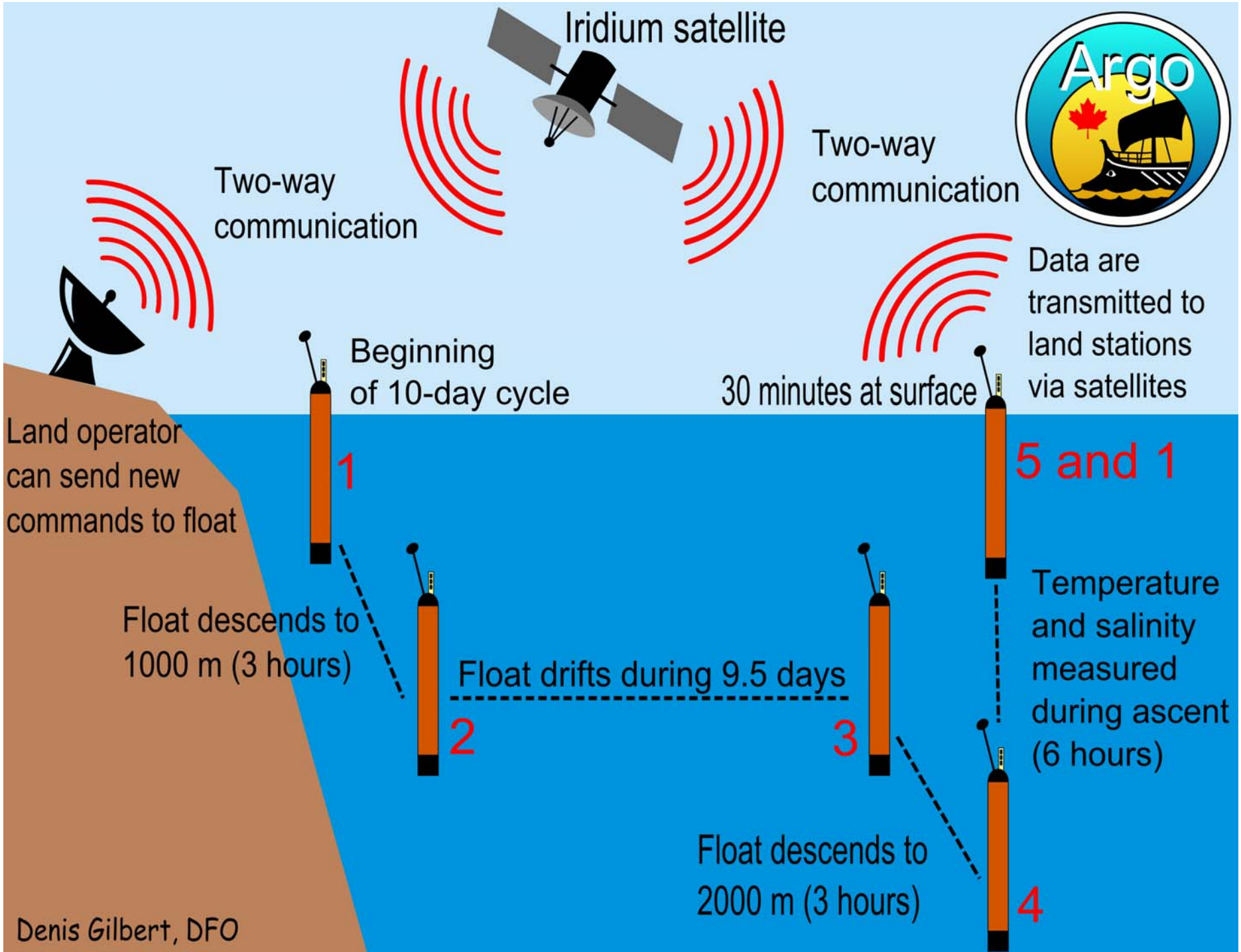


Where does the improved sampling come from? Argo

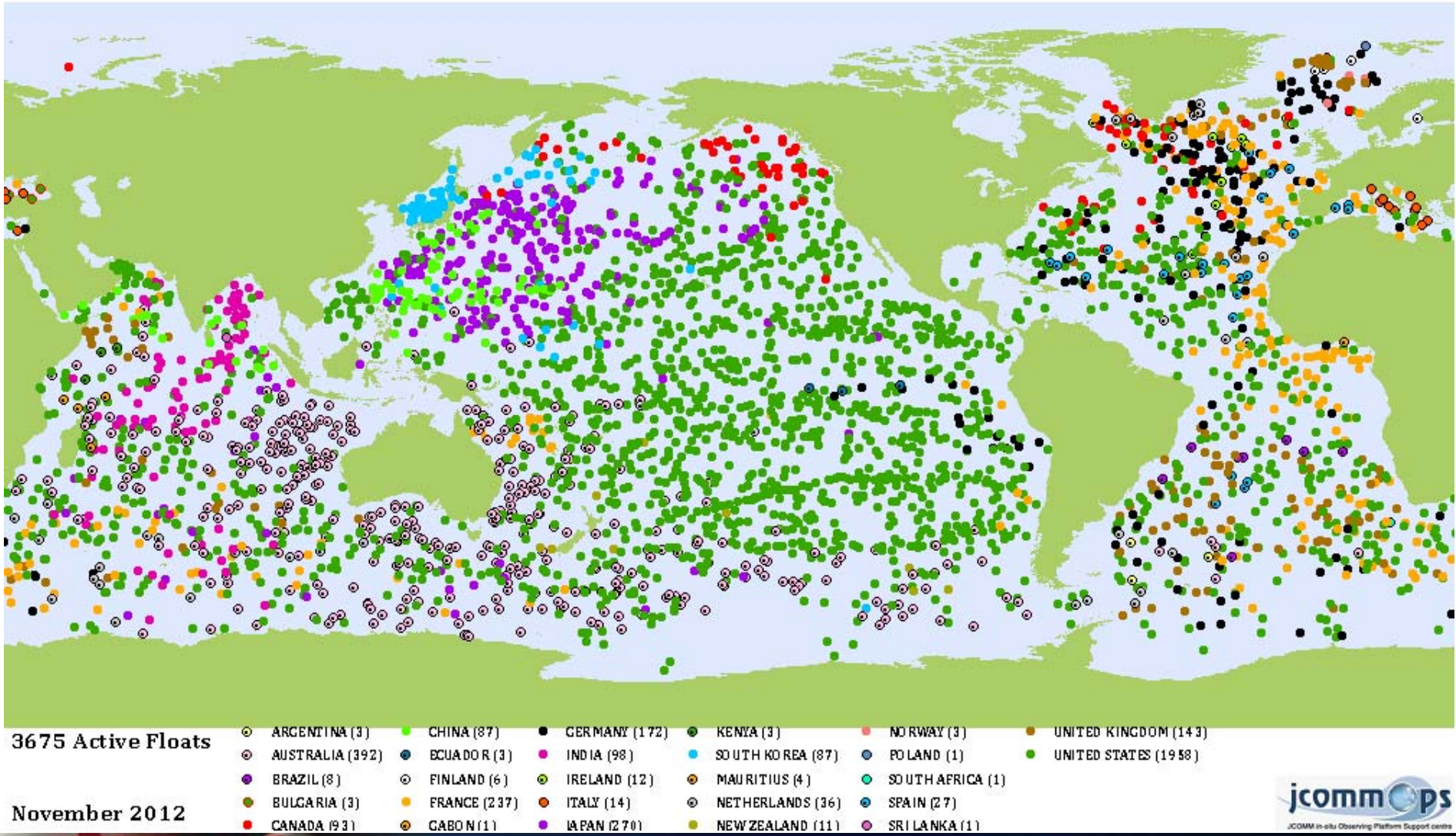
Archimedes' principle



- We can pump fluid from an external bladder to the interior of the float, and vice-versa.
- This pumping action changes the volume of water displaced by the float.
- This makes the float either denser or lighter allowing it to sink or rise through the water column.

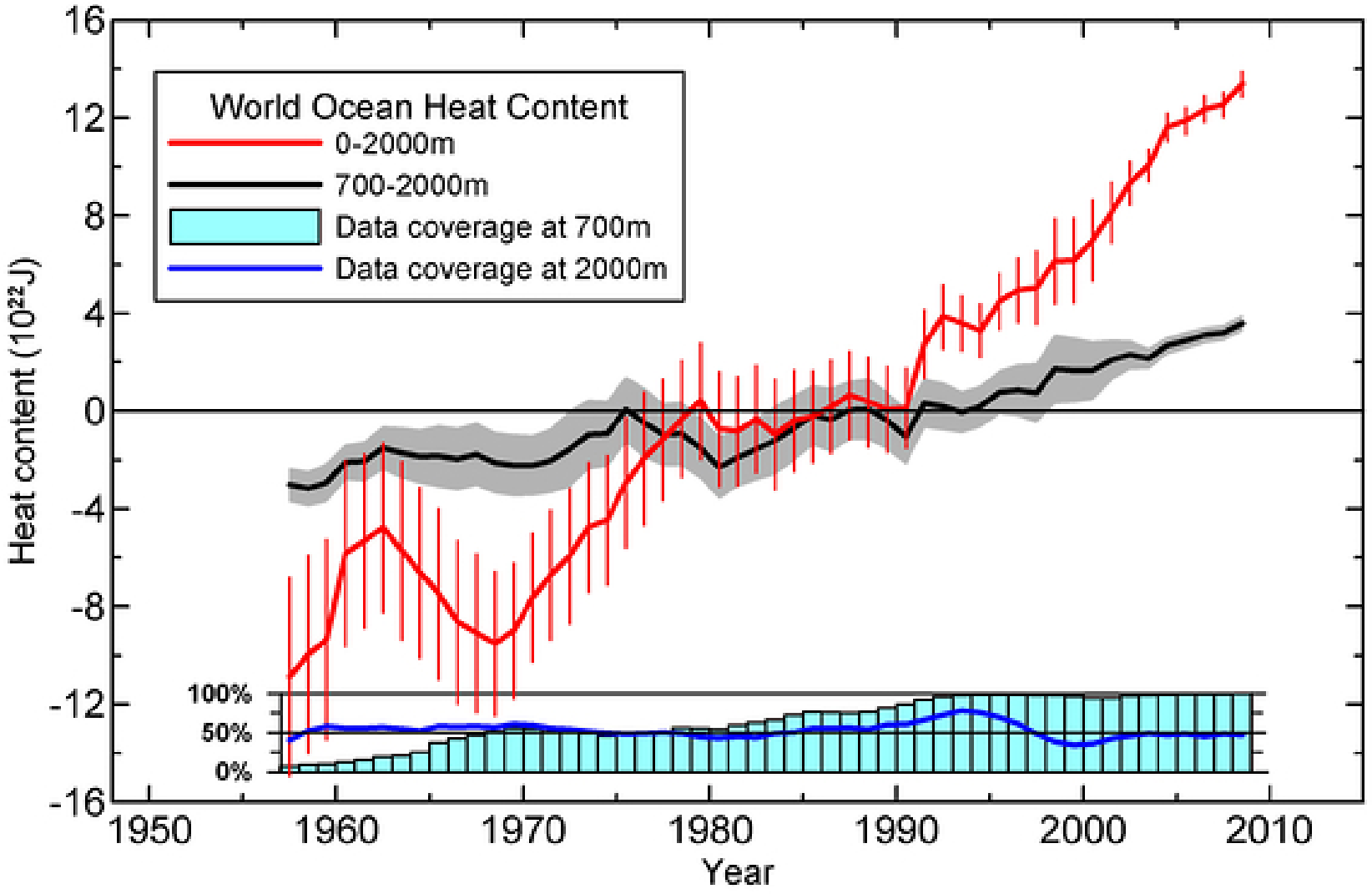

Iridium satellite
Argo
Two-way communication
Two-way communication
Data are transmitted to land stations via satellites
Beginning of 10-day cycle
30 minutes at surface
Land operator can send new commands to float
1
5 and 1
Float descends to 1000 m (3 hours)
Float drifts during 9.5 days
Temperature and salinity measured during ascent (6 hours)
2
3
Float descends to 2000 m (3 hours)
4
Denis Gilbert, DFO

Floats - COUNTRIES



jcommops
JCOMM in-situ Observing Platform Support centre

Ocean heat content



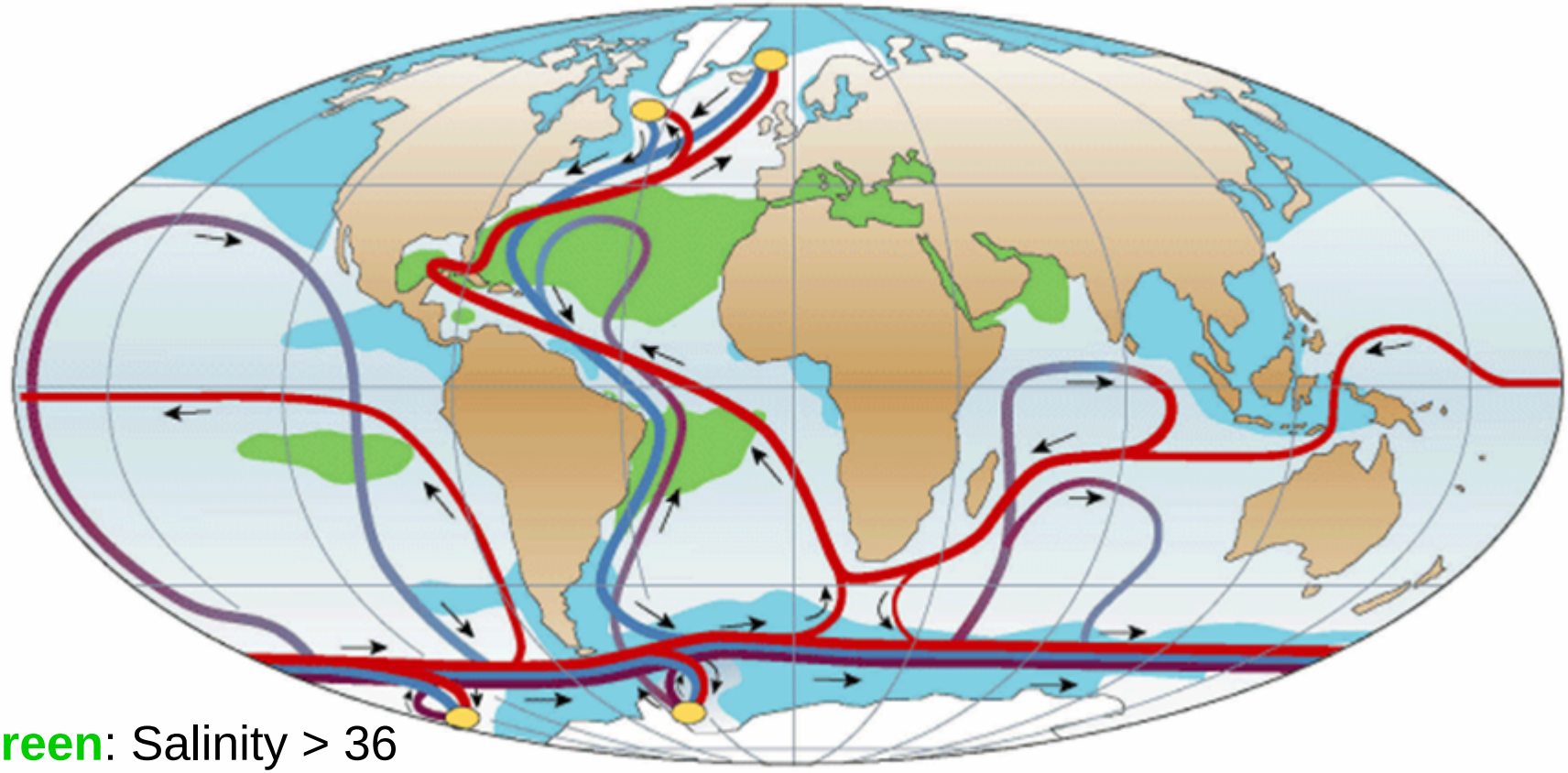
Levitus et al. (2012, Geophysical Research Letters)

Denis Gilbert
2013-01-15

Outline

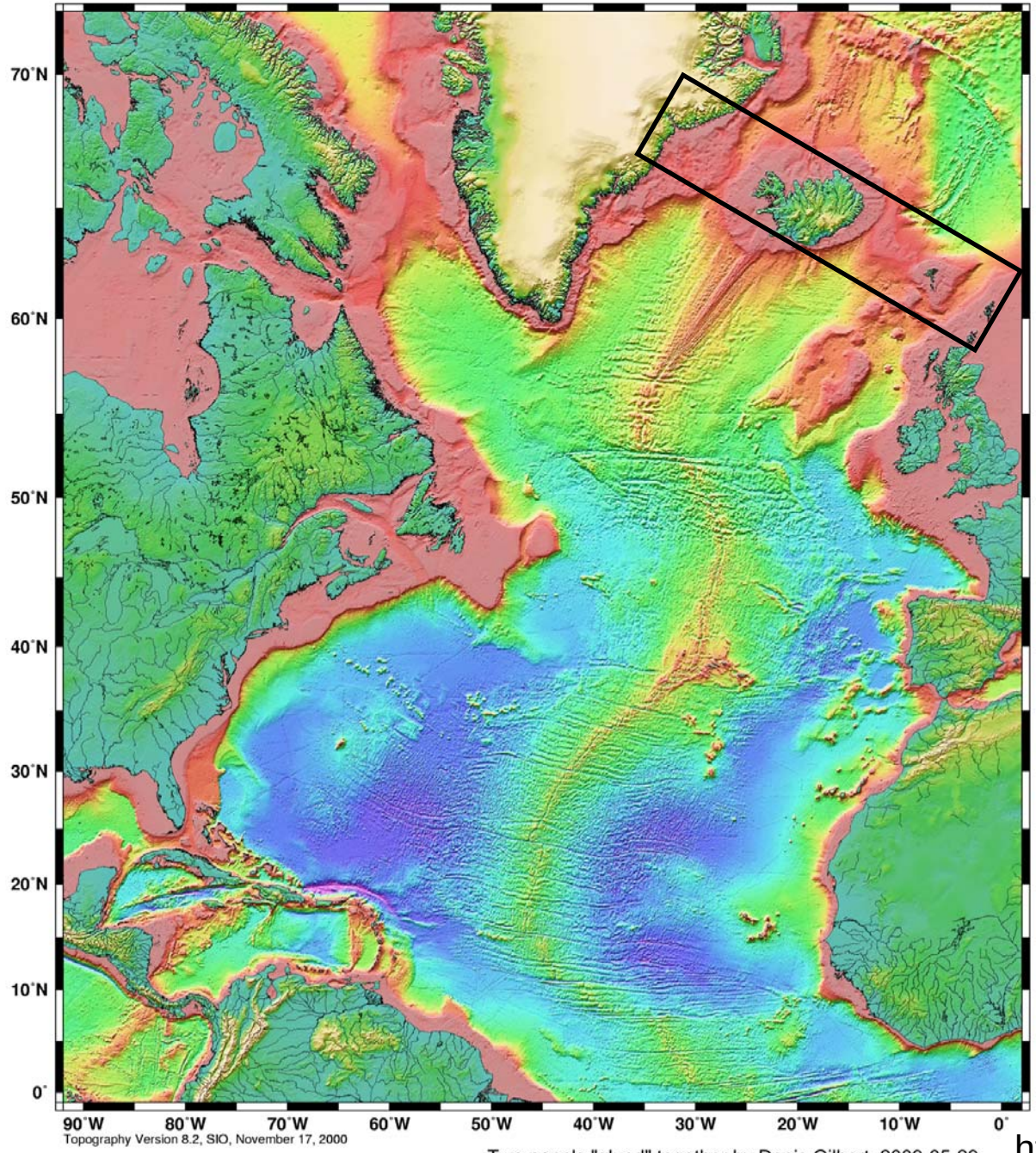
- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation (global conveyor belt)
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Thermohaline circulation



Green: Salinity > 36
Blue: Salinity < 34

Rahmstorf (2002, Nature)



Ridge separates Norwegian Sea from the North Atlantic

http://topex.ucsd.edu/marine_topo/

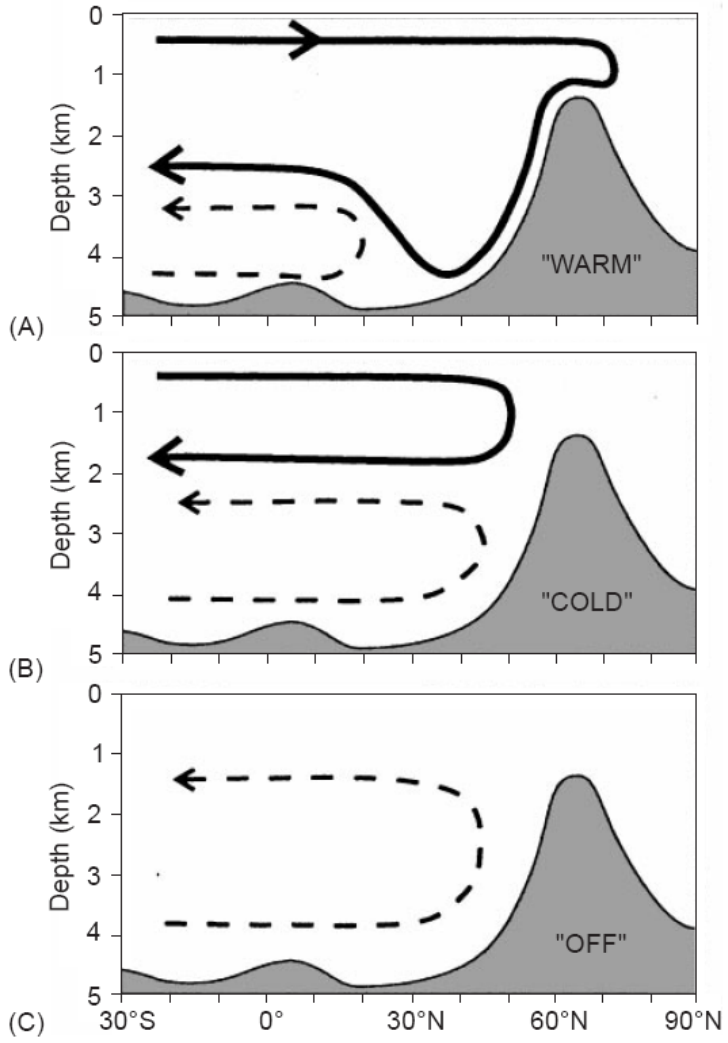


Figure 4 Schematic of three major modes of Atlantic ocean circulation. (A) Warm or interglacial mode; (B) cold or stadial mode; (C) 'off' or Heinrich mode. In the warm mode the Atlantic thermohaline circulation reaches north over the Greenland–Iceland–Scotland ridge into the Nordic Seas, while in the cold mode it stops south of Iceland. Switches between circulation modes at certain thresholds can pace and amplify climatic changes.

Modes of Atlantic Ocean Circulation

- Numerical models and paleoceanographic data indicate three stable modes of circulation.

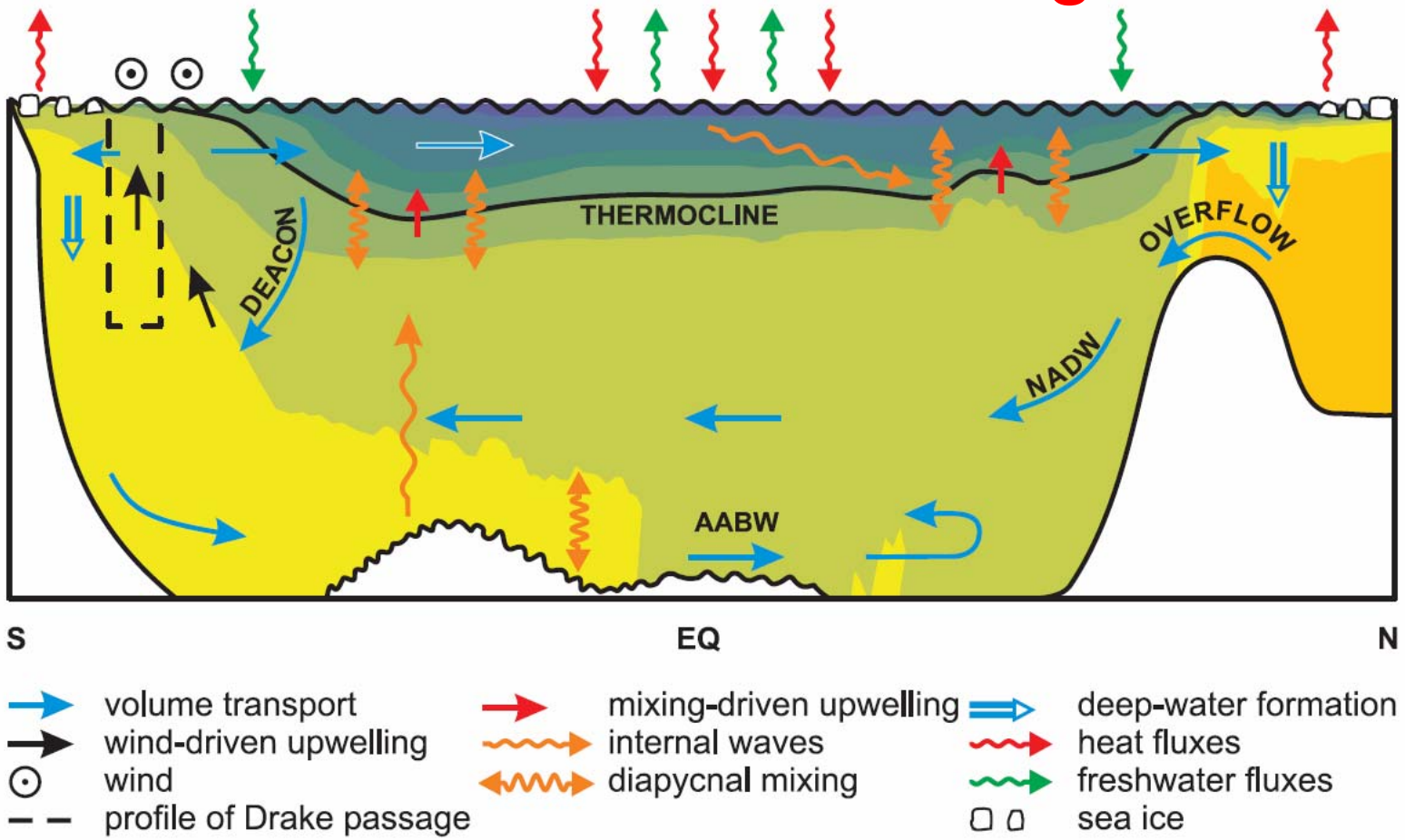
- The Atlantic can remain in a given circulation mode for centuries to tens of thousands of years, and then abruptly switch to another circulation within a few decades.

- Two factors could weaken the circulation and bring it closer to a threshold: 1) the warming of the surface and 2) a dilution of high-latitude waters with fresh water.

S. Rahmstorf, 2001
Abrupt climate change.
Encyclopedia of Ocean Sciences

AMOC

Atlantic Meridional Overturning Circulation



Kuhlbrodt 2007, Rev. Geophys.

AMOC Projection

Ortega et al. (2012, Climate Dynamics)

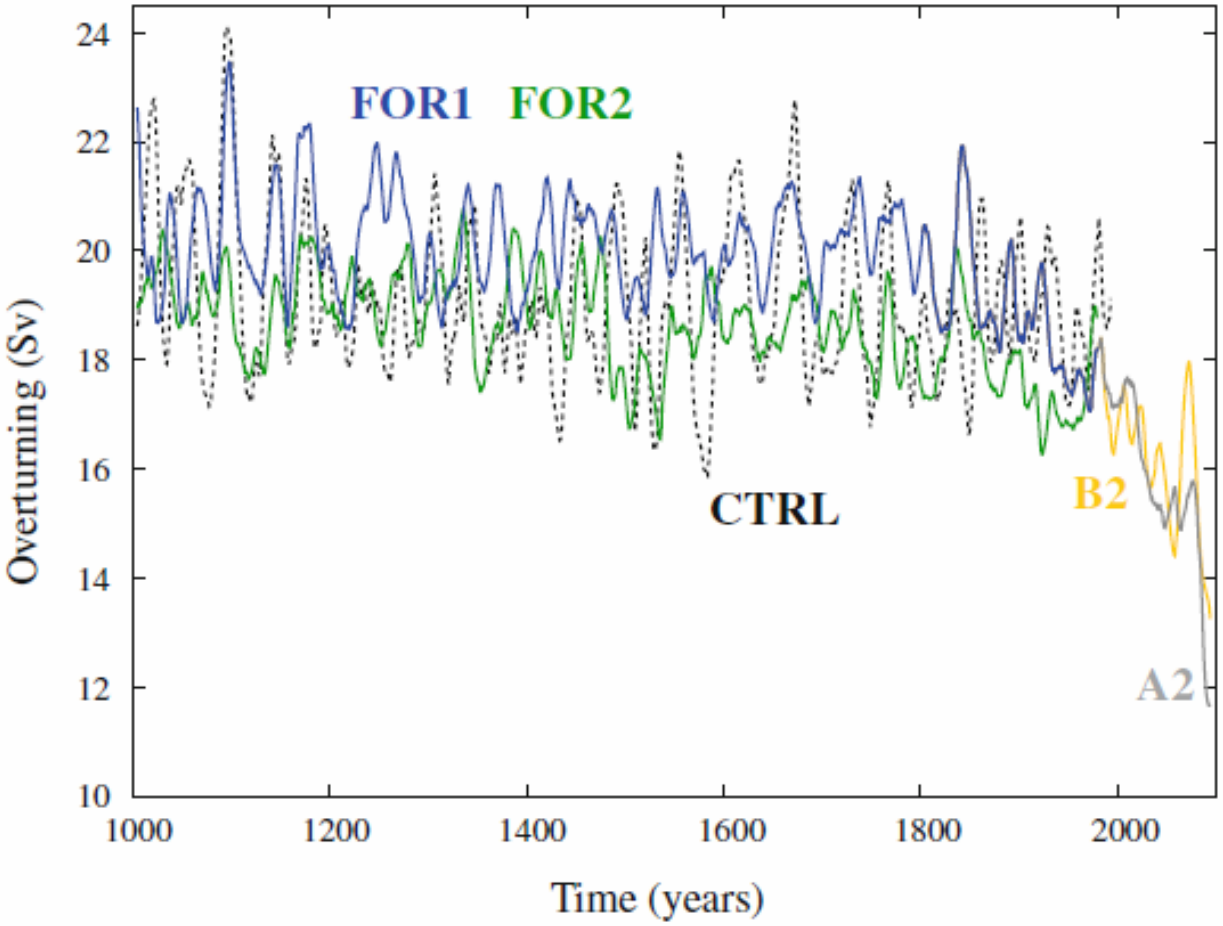
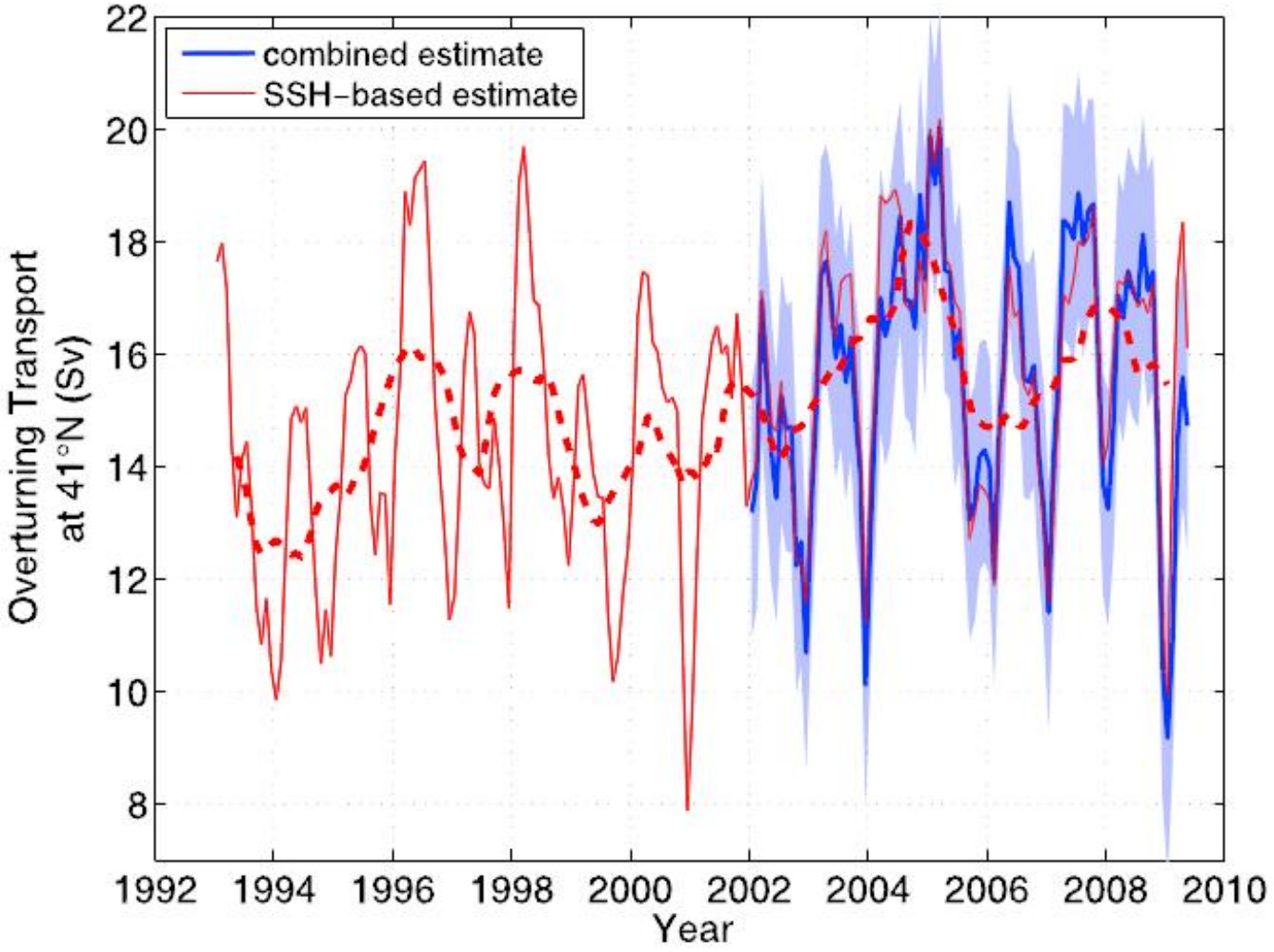


Fig. 3 Time series of the MOI (in Sv) in the Atlantic for CTRL (*black dashed line*), FOR1 (*blue line*), FOR2 (*green line*), A2 (*grey line*) and B2 (*yellow line*). The series are smoothed with an 11 year running-mean filter

AMOC Observations



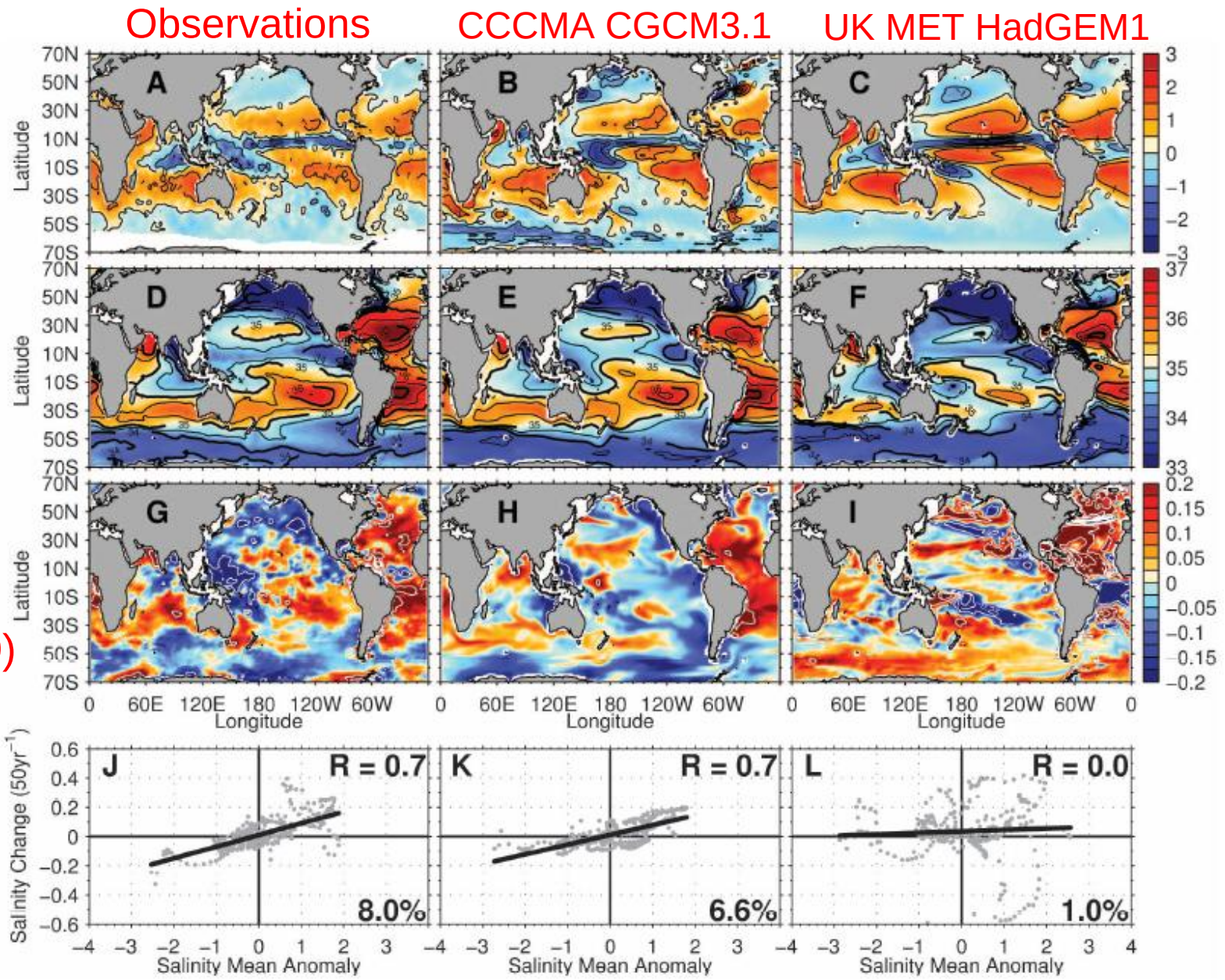
Willis (2010, Geophys. Res. Lett., 37, L06602)

Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Hydrological cyle intensification (1950-2000)

Durack et al. (2012, Science)



Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
  - Gulf of St. Lawrence case study
  - Mixing of Gulf Stream with Labrador Current waters
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

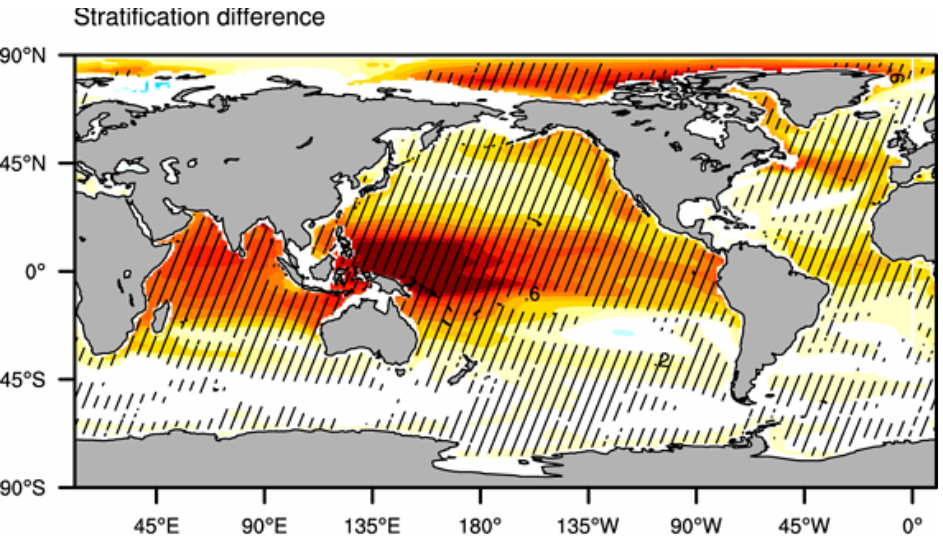
Sarmiento et al. (1998, Nature)

Simulated response of the ocean carbon cycle to anthropogenic climate warming

« Another possible tracer of change is oceanic oxygen, whose global mean decreases by 8 mmol m^{-3} between 1990 and 2065. »

O2 decrease rate = **11 µmol kg^{-1} $century^{-1}$**

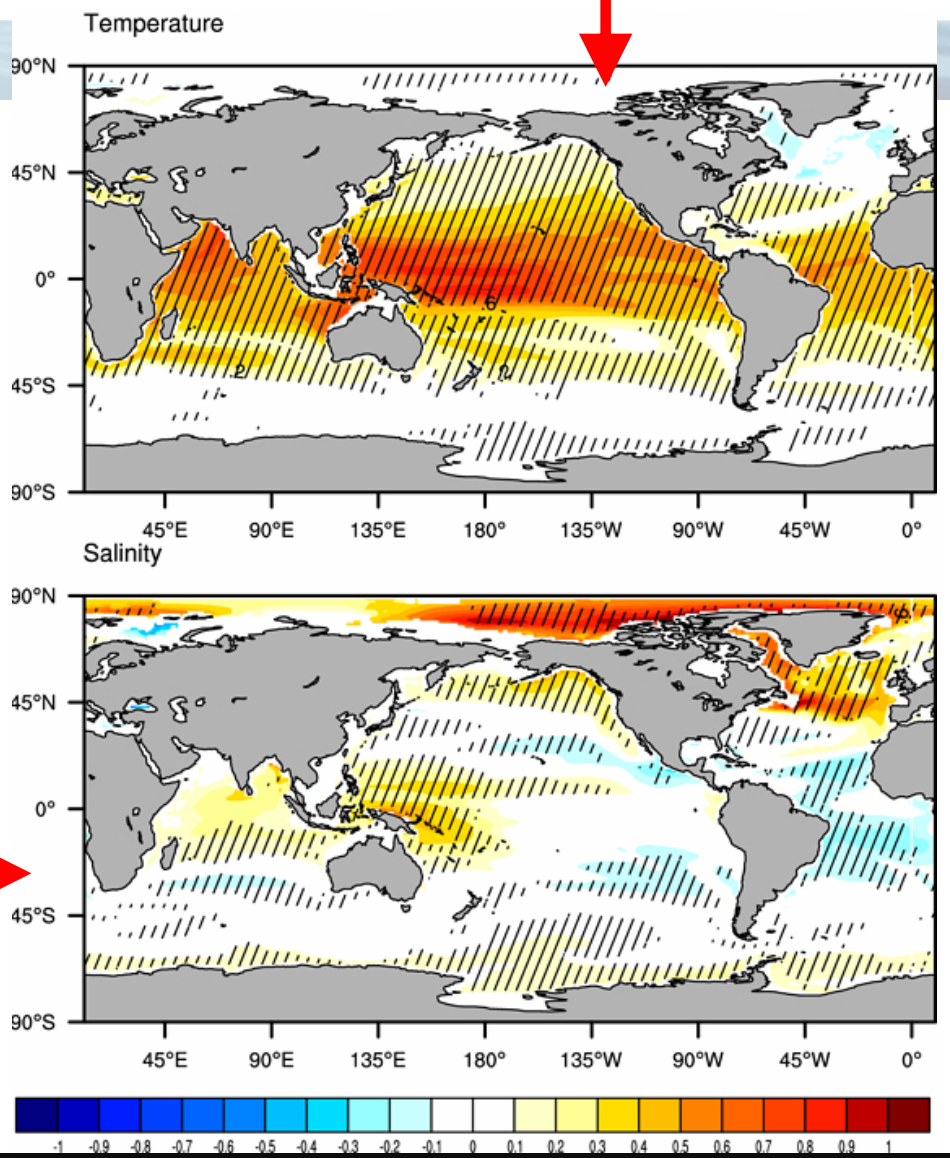
Stratification change



Capotondi et al (2012, J. Geophys. Res.)

Salinity only →

Temperature only ↓



The ventilated thermocline

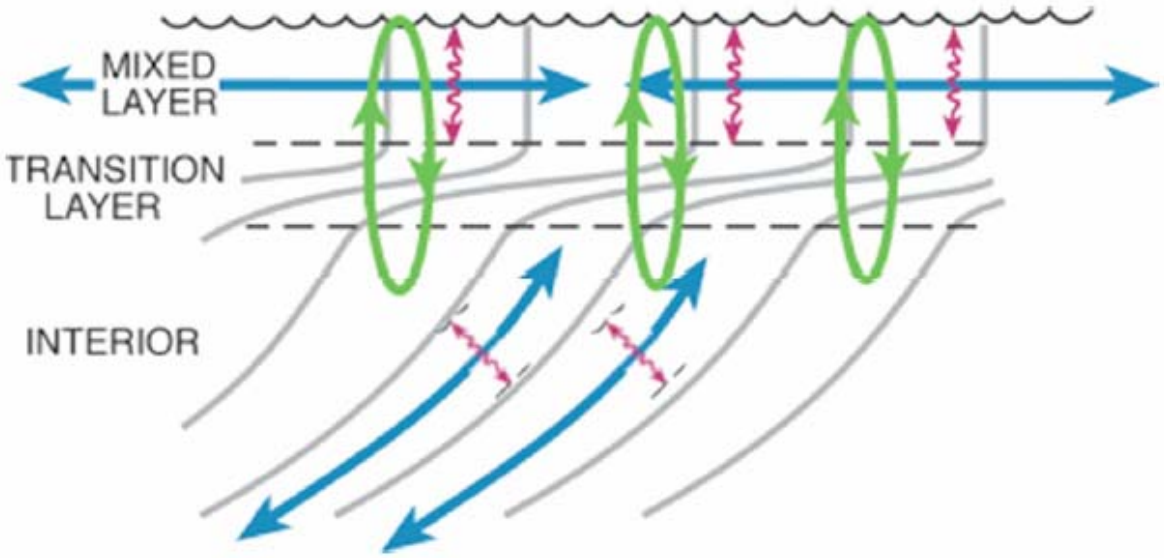
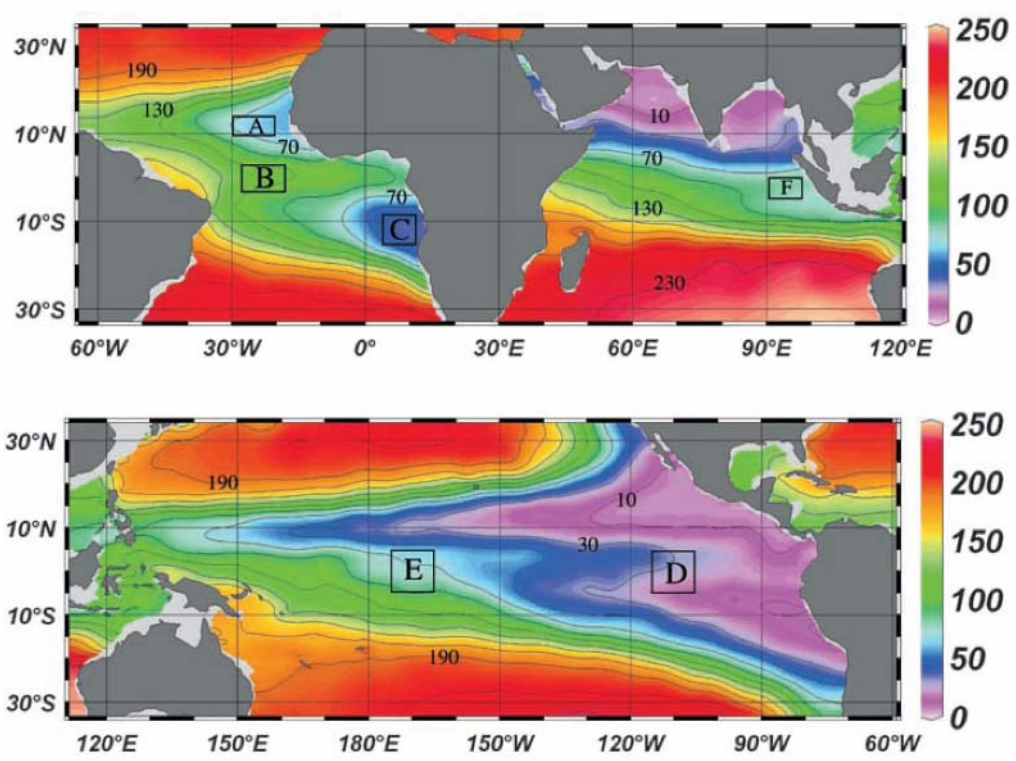
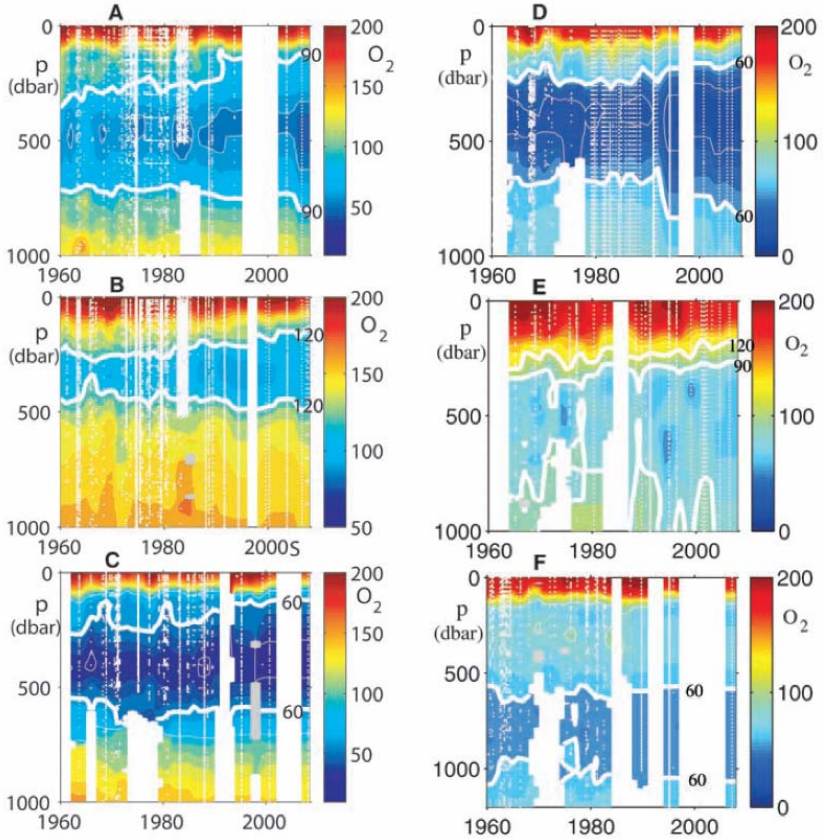


Figure 2. The oceanic motion at submesoscales (1–100 km, in green color) are effective in transferring heat, carbon dioxide, and other water properties from ocean surface to the deep ocean. Blue color represents motions at mesoscales (100–500 km) transferring ocean properties mostly horizontally and red color represents mixing processes at scales less than 1 km (courtesy of R. Ferrari of MIT).

Fu et al. 2010 (OceanObs'09)

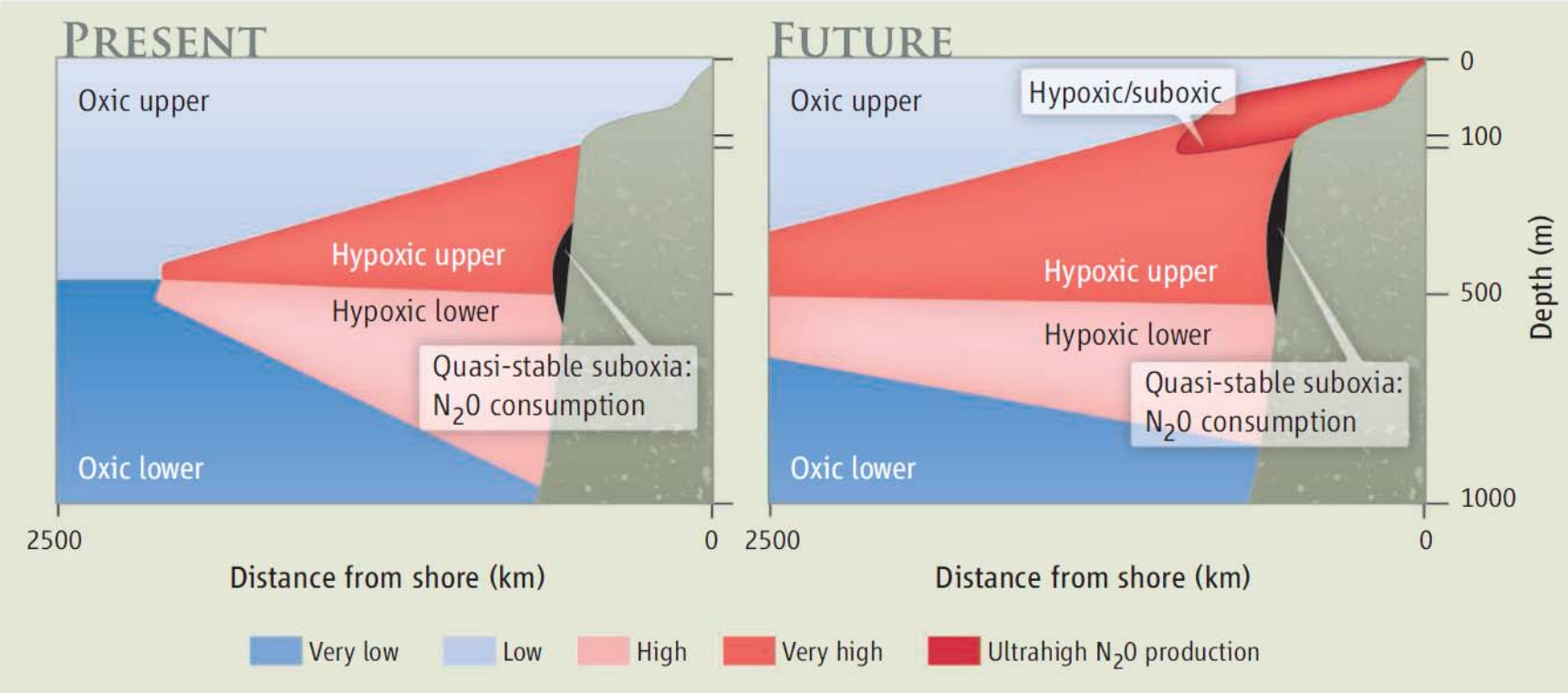
Expansion of the Oxygen Minimum Zone (OMZ) in subtropical areas





Stramma et al. (2008, Science)

Impacts of hypoxia on N_2O production



A generic eastern boundary in present-day and future oceans. Suboxia can extend further offshore than shown here, but is absent from a large portion of the oceanic eastern boundary.

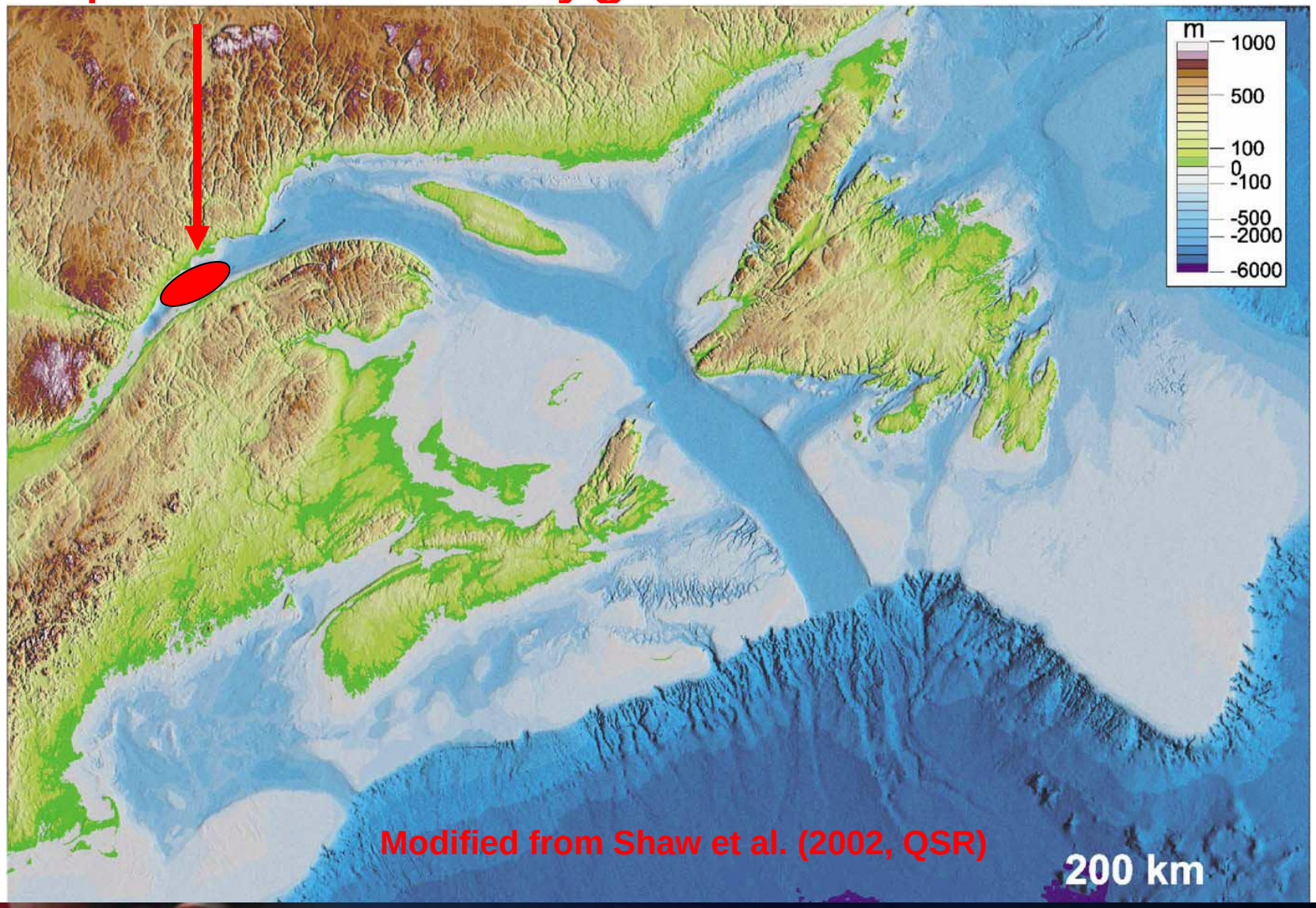
L. A. Codispoti Science 327, 1339-1340 (2010)

Published by AAAS

Outline

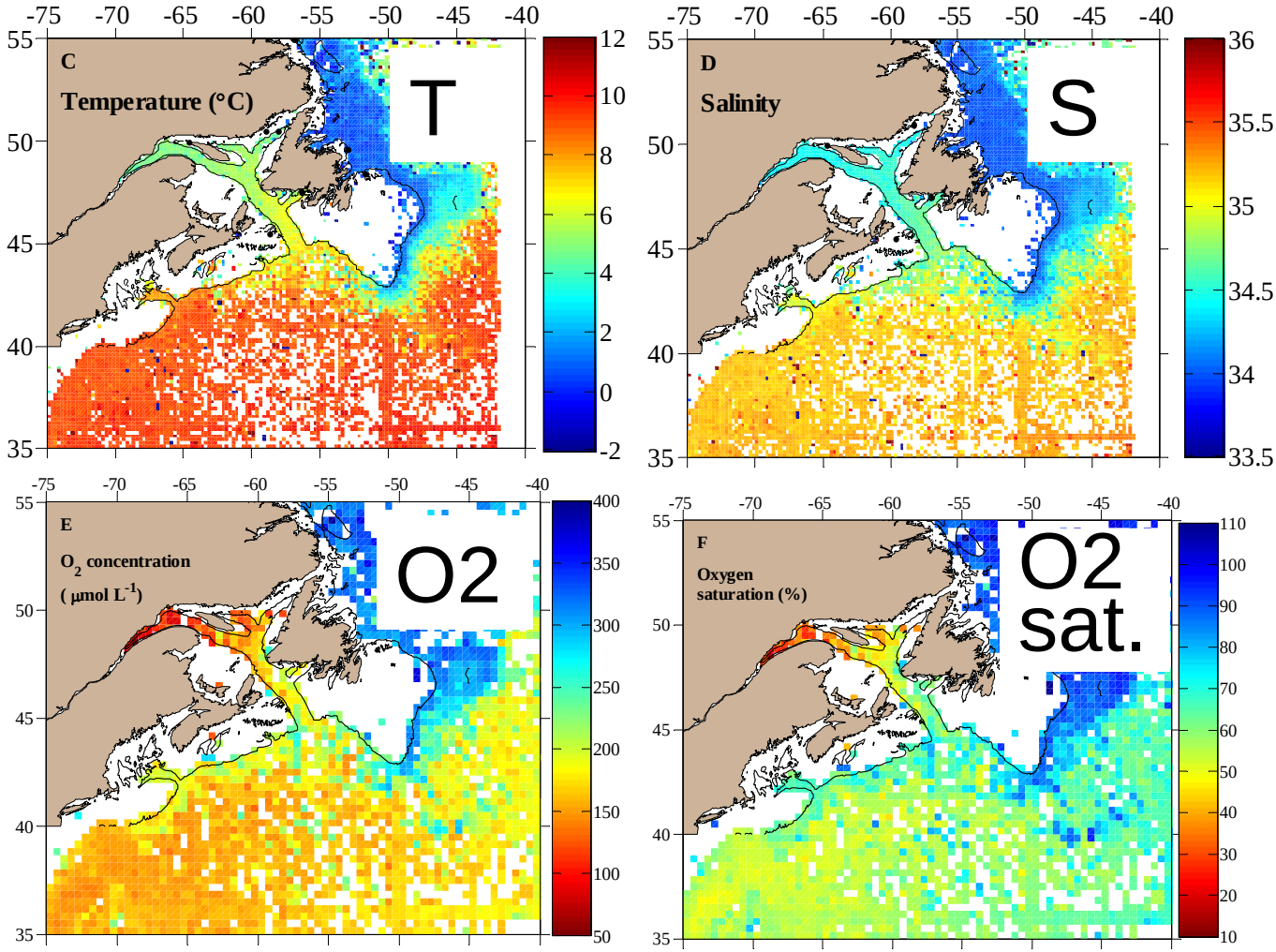
- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
  - Gulf of St. Lawrence case study
  - Mixing of Gulf Stream with Labrador Current waters
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Temperature and oxygen timeseries from LSLE

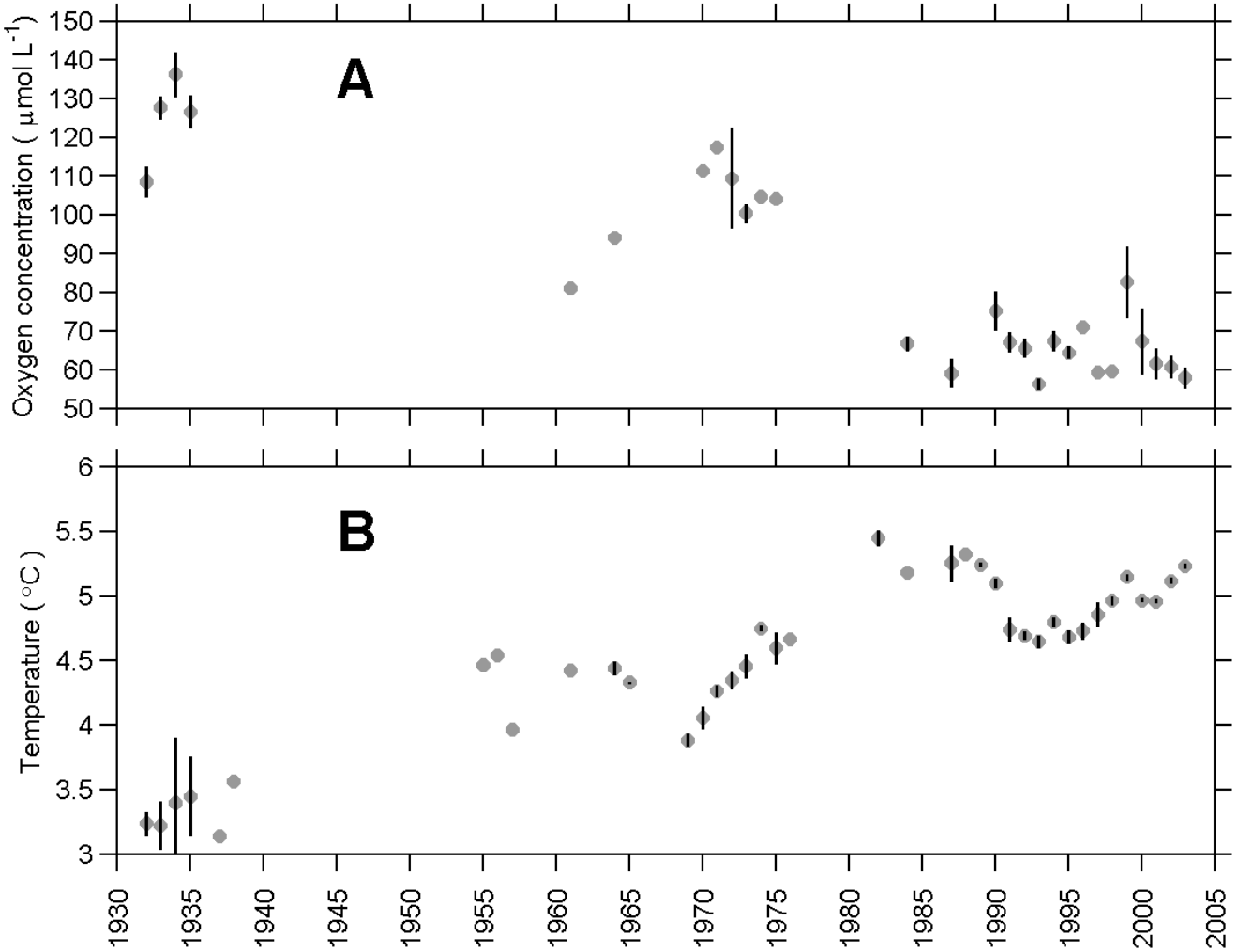


Canada

Water properties on the 1027.25 kg/m^3 density surface



Oxygen and temperature in St. Lawrence Estuary (300m)

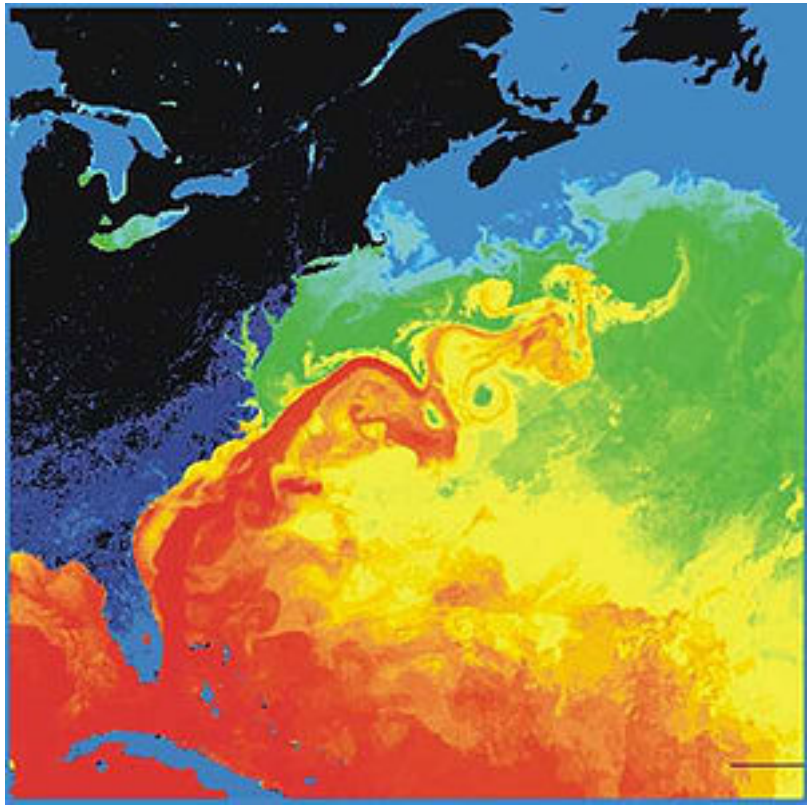


Gilbert et al. (2005, L & O, **50**: 1654-1666)

Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
  - Gulf of St. Lawrence case study
  - Mixing of Gulf Stream with Labrador Current waters
- Ocean acidification
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

The Gulf Stream



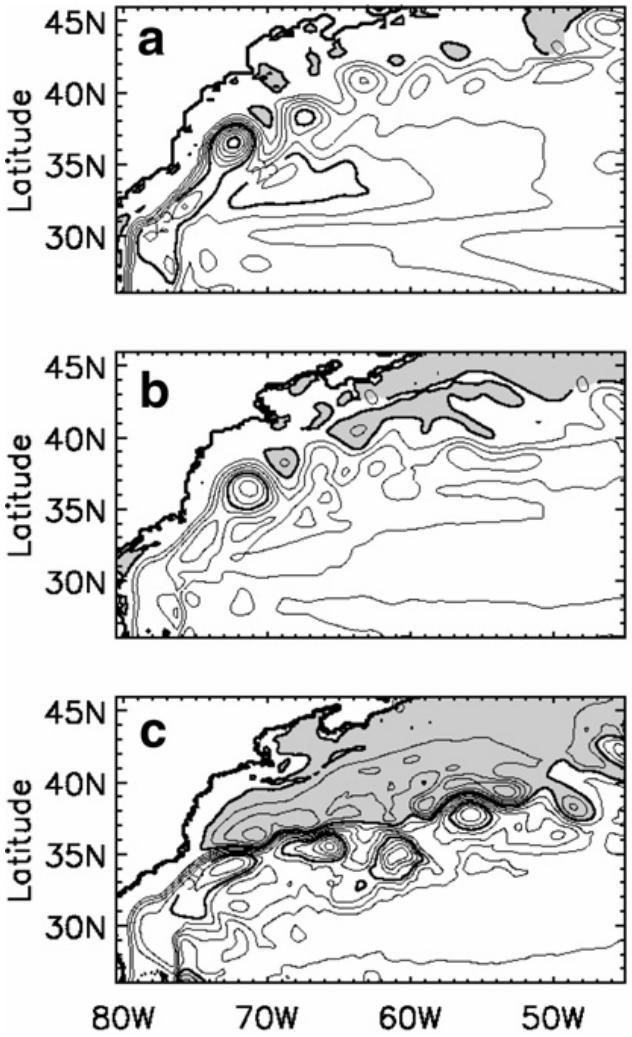
Major issue:
Will the Gulf Stream migrate northwards with climate warming?

Modeled Gulf Stream at different resolutions

0.4° ~ 40 km

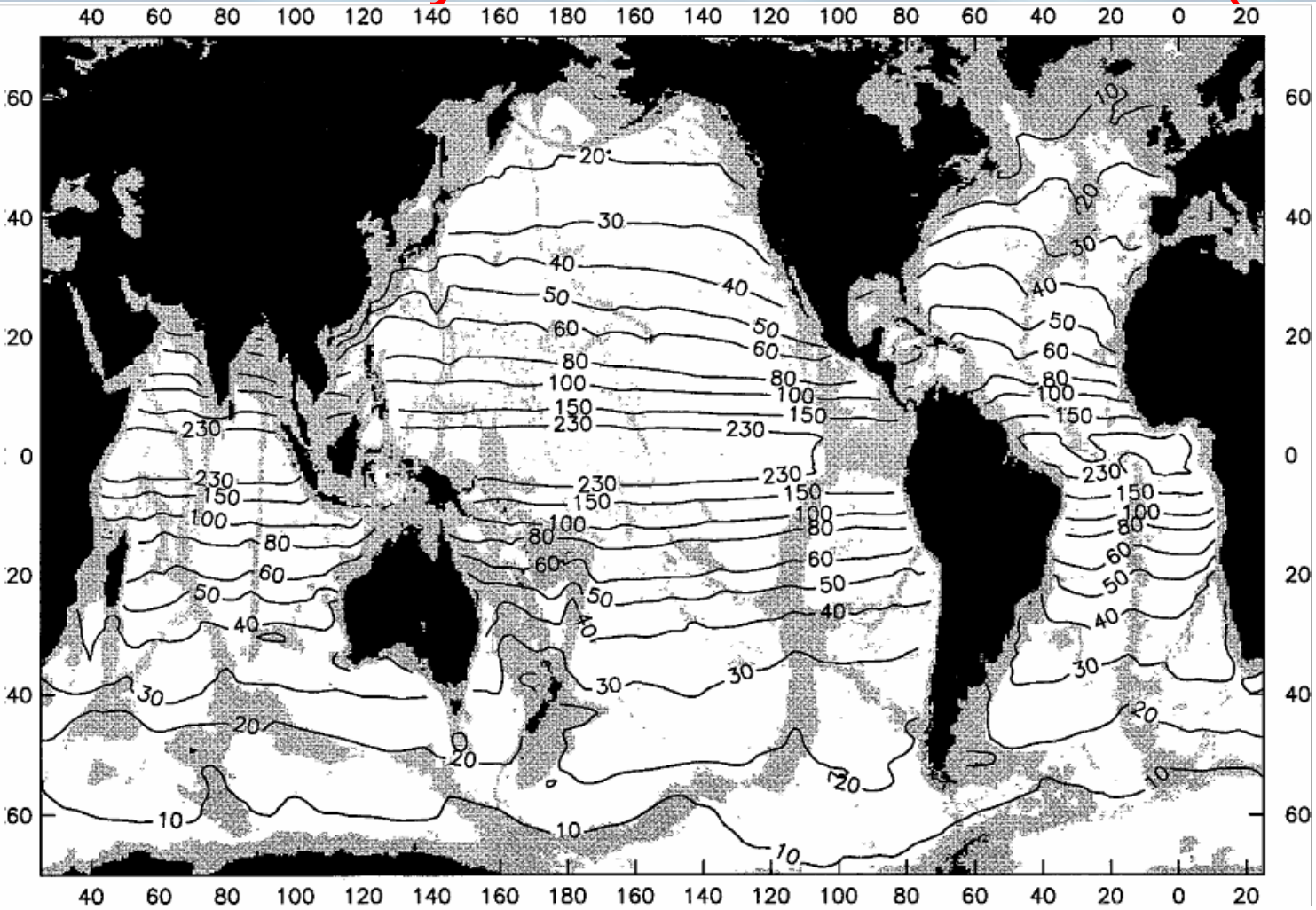
0.2° ~ 20 km

0.1° ~ 10 km



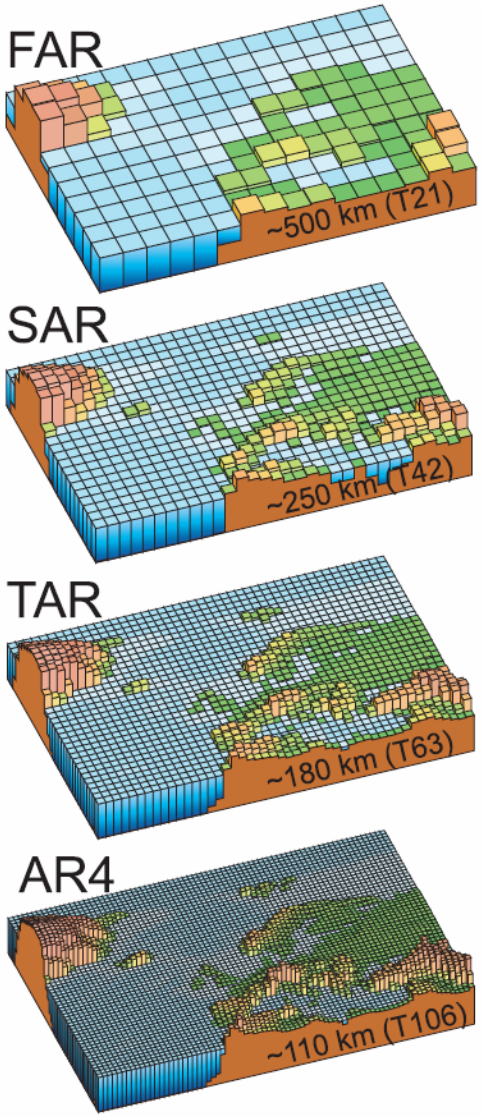
Bryan et al. (2007, Ocean Modeling)

Internal Rossby radius of deformation (km)



Chelton (1998, J. Phys. Oceanogr., 28: 433)

IPCC Assesment Reports - resolution



1990, with "swamp" ocean, no ocean dynamics

1996, full depth 3-D ocean

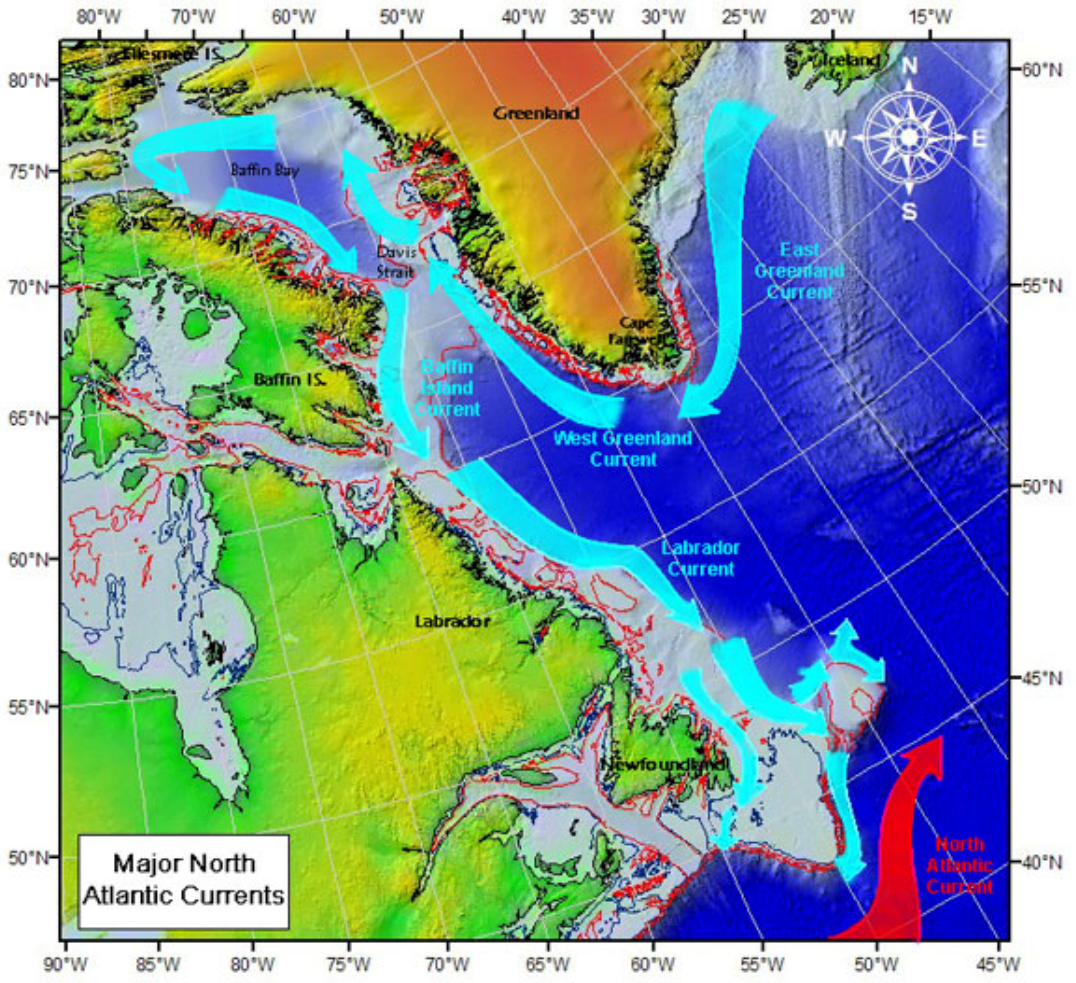
2001, prediction that the ocean will take up CO_2 more slowly in the future

2007, prediction that oxygen concentrations will decrease at a rate about 3 times faster than we might expect from changes in oxygen solubility alone due to temperature increase.

Canada

The Labrador Current

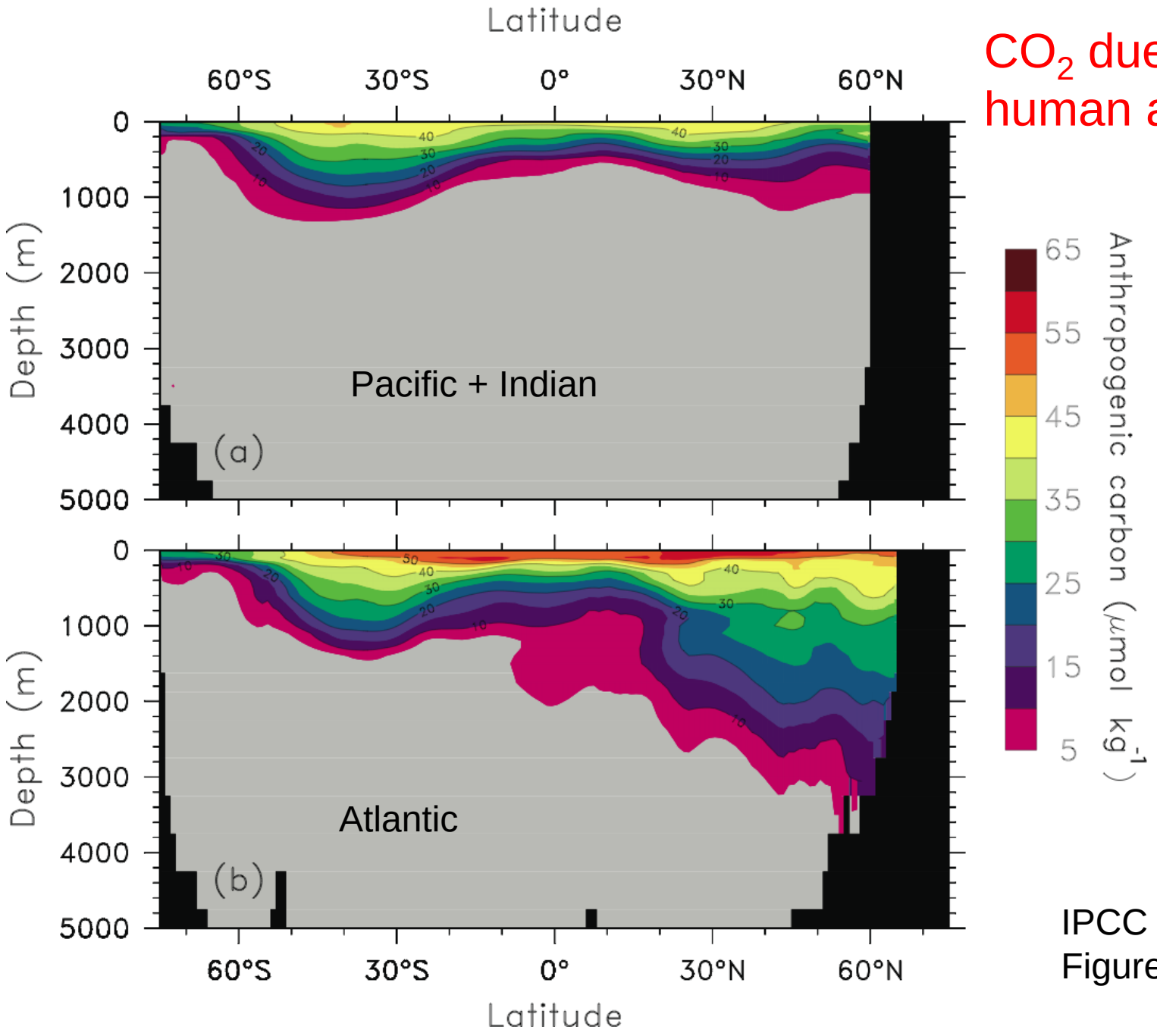
How will the mixing of the Labrador Current with Gulf Stream waters near the Tail of the Grand Banks be affected?



Outline

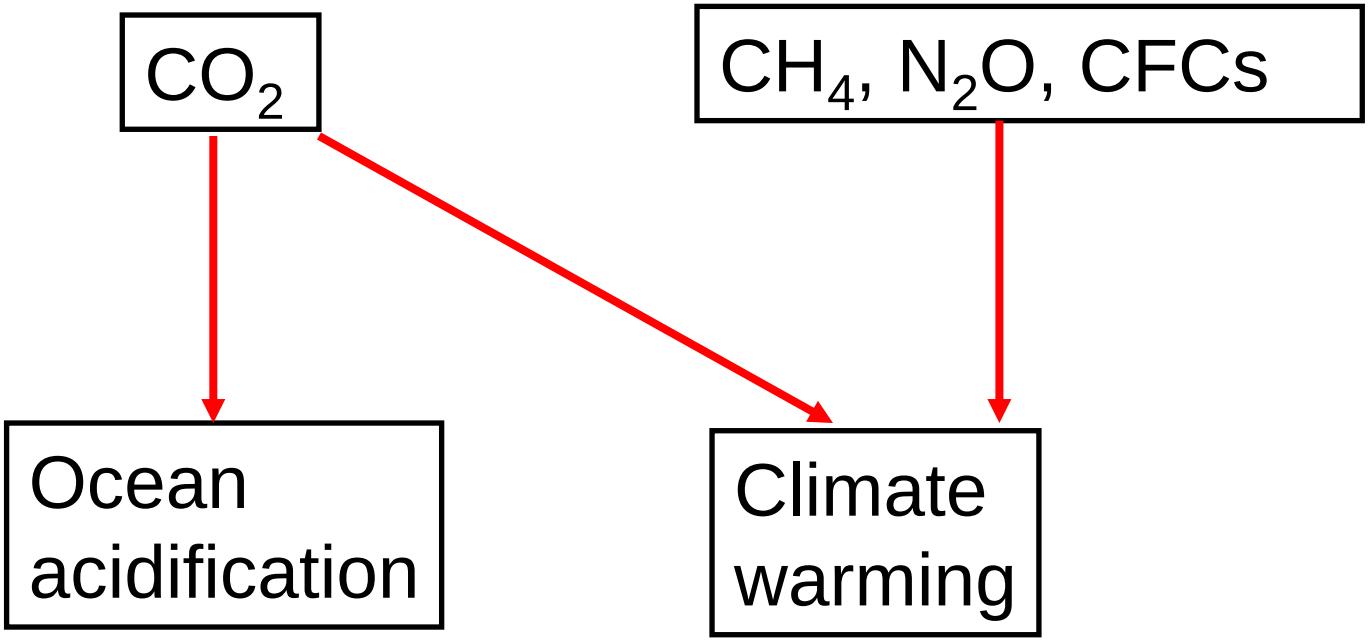
- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification (related to CO_2 uptake)
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

CO_2 due to human activities



IPCC AR4
Figure 5.11

CO_2 versus other greenhouse gases

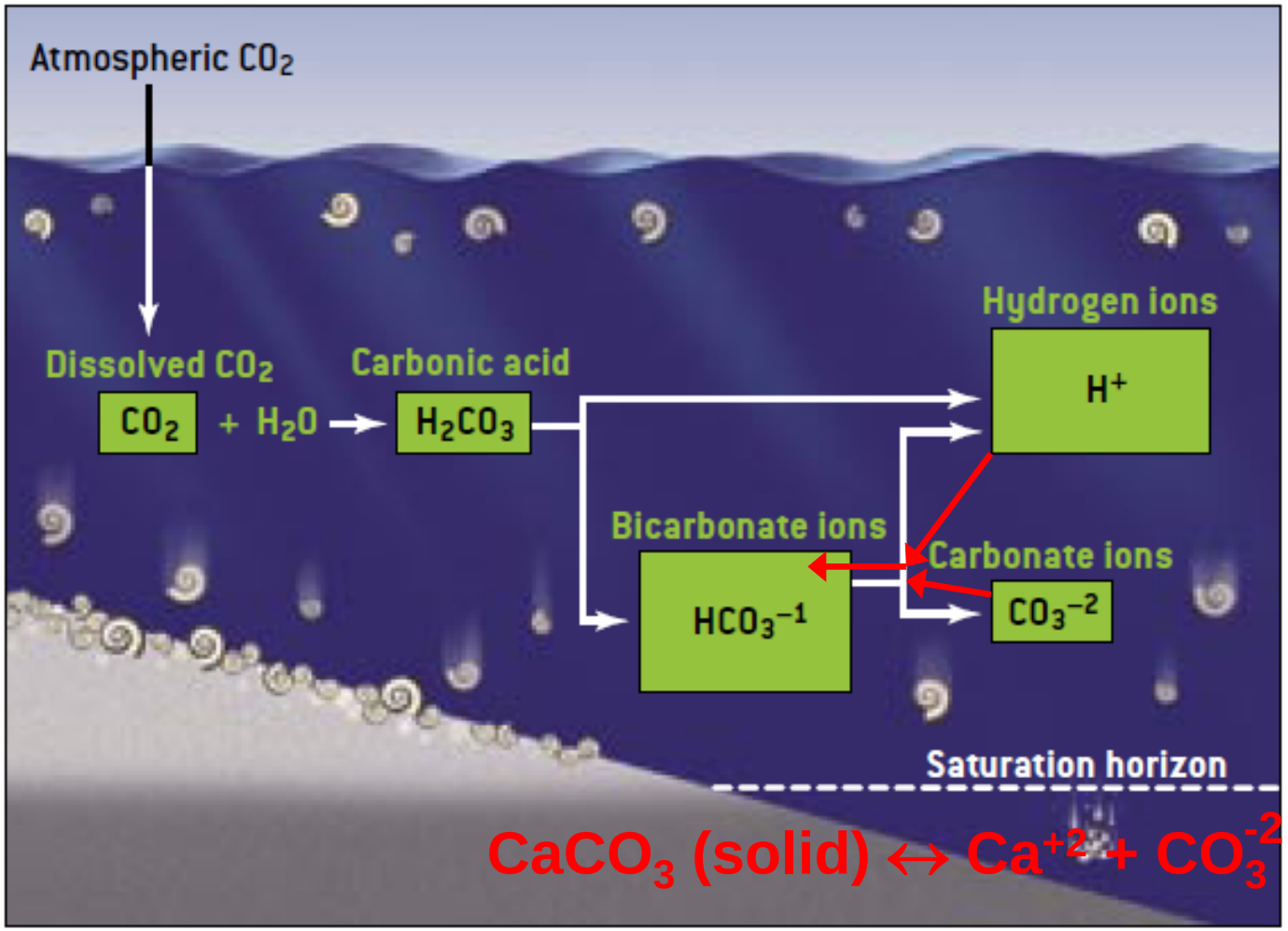


Ocean acidification

- The « other » CO_2 problem
  - Caught scientists' attention in early 2000's
- Impacts on marine organisms

CO_2 reacts chemically with water

$pH = -\log_{10}[H^+]$



Doney (2006, Scientific American)

Decreasing pH is impacting organisms that form calcium carbonate shells and skeletons because acidity increases the solubility of $CaCO_3$

Phytoplankton
Cocolithophore

Zooplankton
Pteropod
(sea butterfly)

Zooplankton
Foraminifera

Echinoderm
Sea urchin

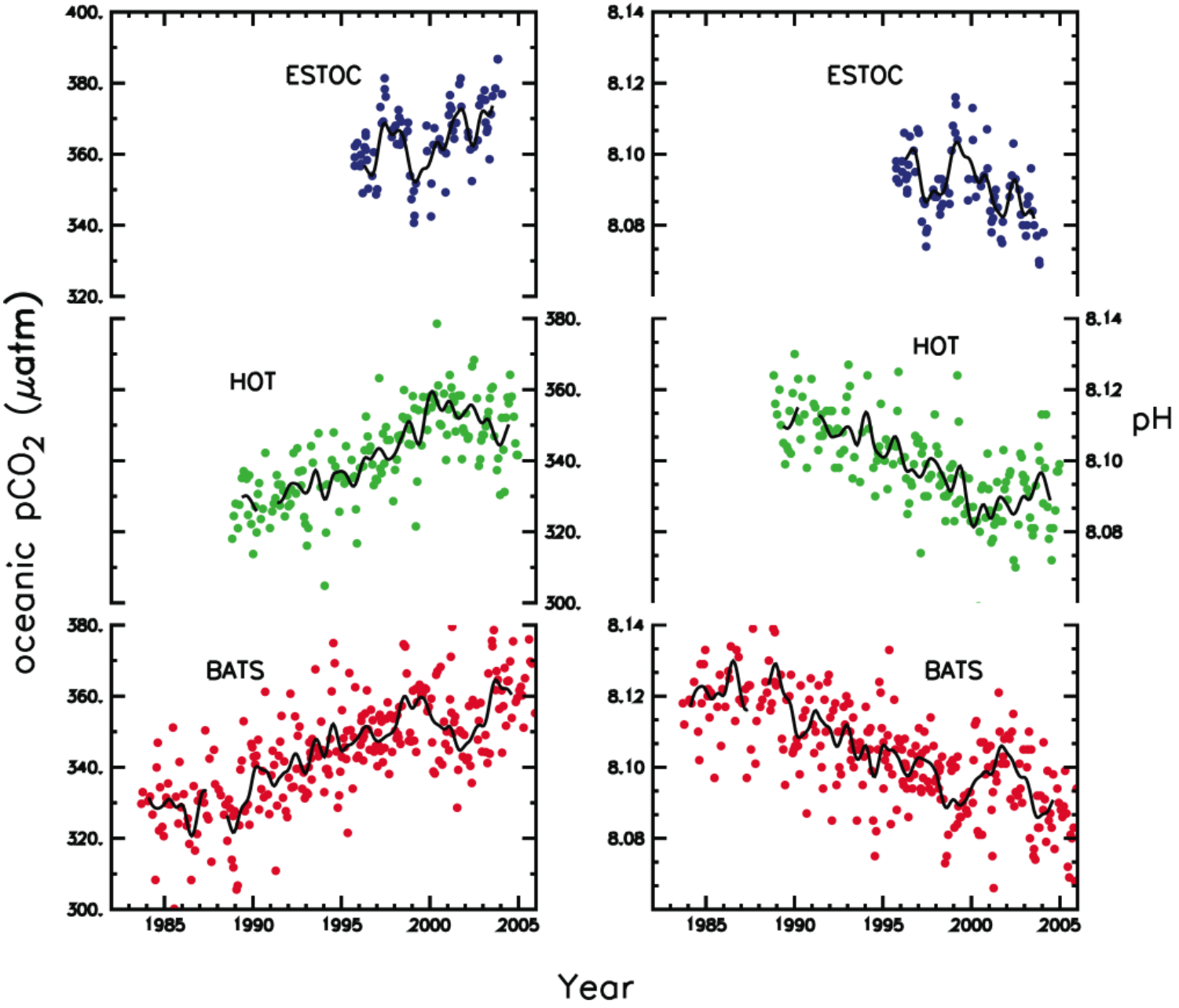
Crustacean
Lobster

Echinoderm
Brittle star

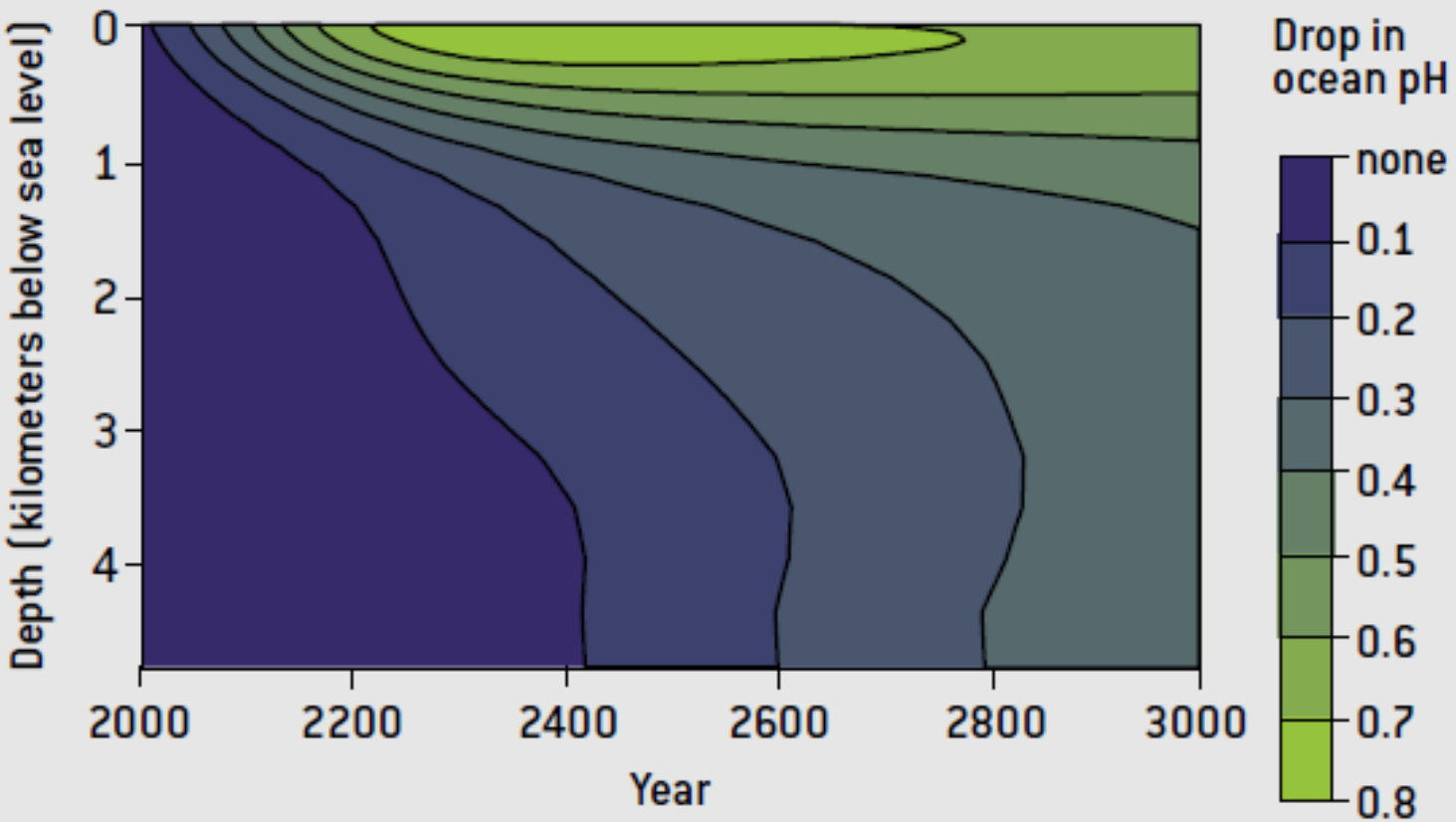
Deep-sea coral

Mollusc
Scallop
Oyster
mussel

pCO2 and pH at monitoring stations



Projected change in pH



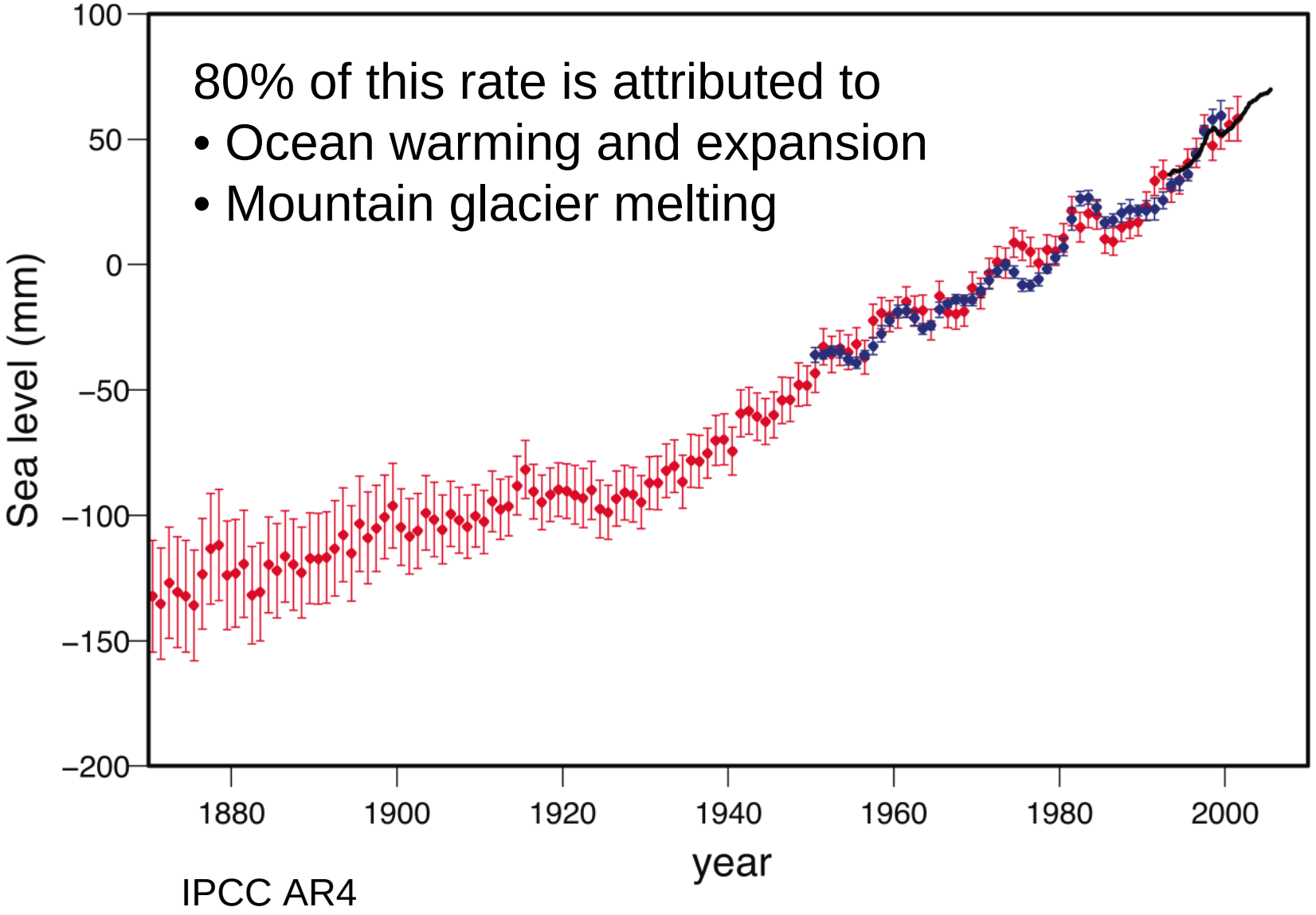
Although acidification of the sea (as measured by the drop in pH) has so far been small, scientists expect larger shifts in the future. The greatest changes will take place near the surface, but over time the full depth of the ocean will feel these effects.

Doney (2006, Scientific American)

Outline

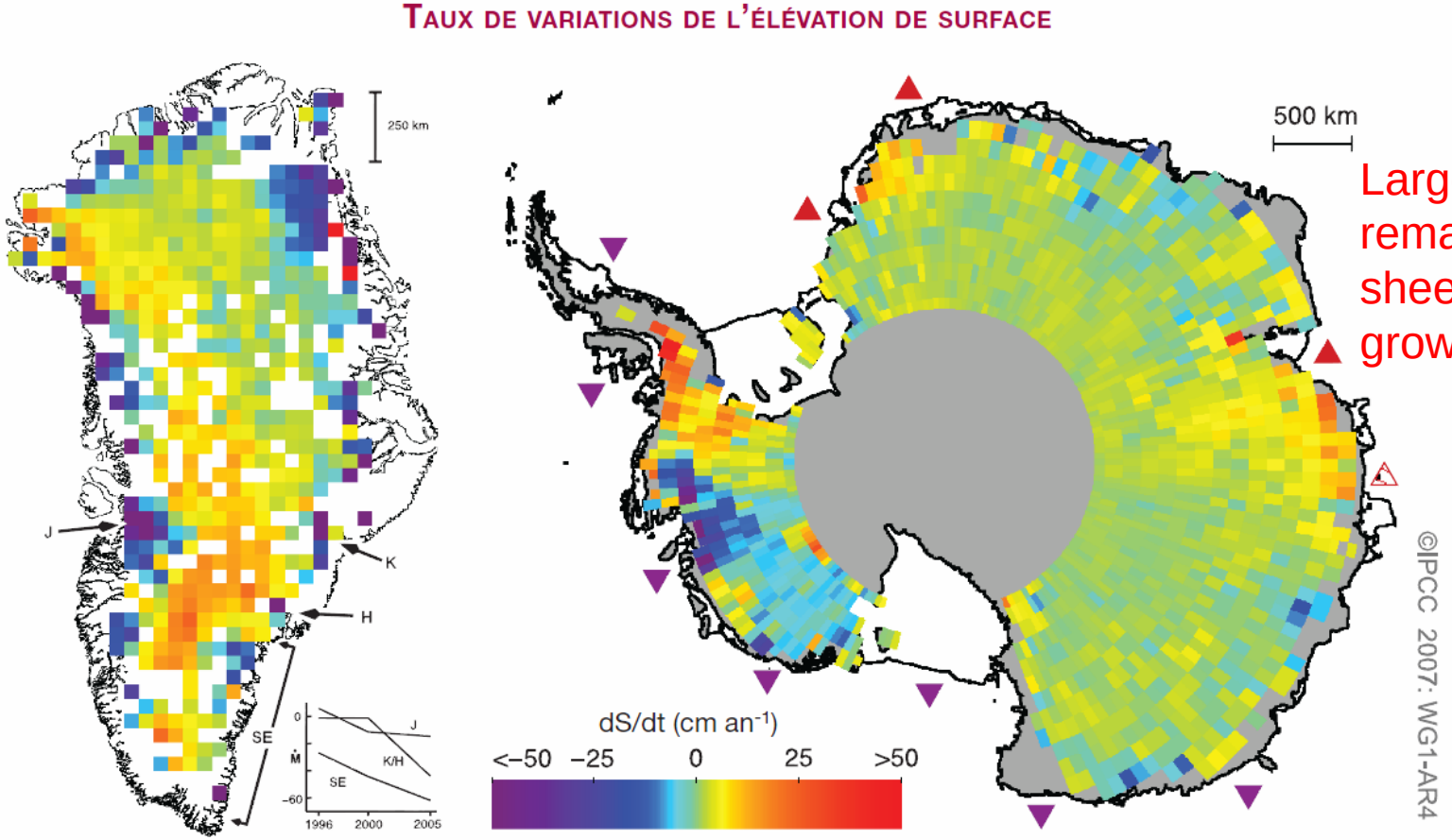
- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification (related to CO_2 uptake)
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Global mean sea level rise @ 32 cm per century



IPCC AR4

Greenland and Antarctica ice sheets

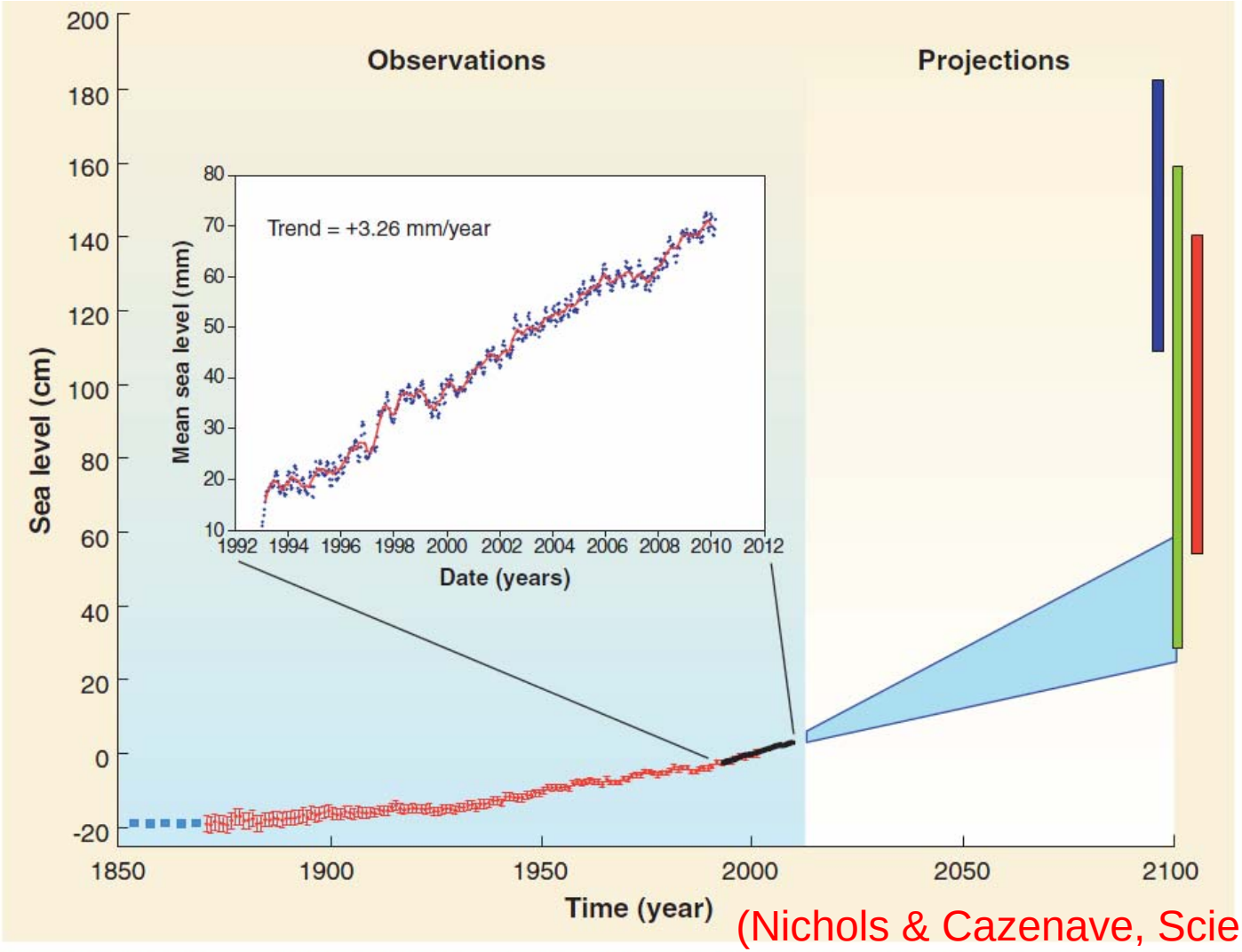


Large uncertainties remain about ice sheet melting and growth

Figure RT.14. *Taux de variation de l'élévation de surface, observés pour le Groenland (à gauche ; 1989–2005) et l'Antarctique (à droite ; 1992–2005). Les nuances rouges indiquent les surfaces en expansion et les nuances bleues les surfaces en diminution, ce qui indique typiquement une augmentation ou une perte locale de la masse de glace, bien que les changements concernant l'élévation de la base et la densité proche de la surface puissent être importants. Pour le Groenland, le rapide amincissement des glaciers émissaires Jakobshavn (J), Kangerdlugssuaq (K), Helheim (H) et des régions situées le long de la côte du sud-est (SE) est présenté, associé à son bilan de masse, en fonction du temps (avec K et H combiné, en Gt/an, les valeurs négatives indiquant la perte de masse de la nappe glaciaire à l'océan). Pour l'Antarctique, des plates-formes glaciaires dont l'épaississement ou l'amincissement varie de plus de 30 cm/an sont indiquées par un triangle violet dirigé vers le bas (amincissement) et un triangle rouge dirigé vers le haut (épaississement), apposé sur les plates-formes glaciaires concernées. {Figures 4.17 et 4.19}*

Denis Gilbert
2013-01-15

Global mean sea level rise



(Nichols & Cazenave, Science, 2010)

Fig. 1. Global mean sea level evolution over the 20th and 21st centuries. The red curve is based on tide gauge measurements (*10*). The black curve is the altimetry record (zoomed over the 1993–2009 time span) (*15*). Projections for the the 21st century are also shown. The shaded light blue zone represents IPCC AR4 projections for the A1FI greenhouse gas emission scenario. Bars are semi-empirical projections [red bar: (*32*); dark blue bar: (*33*); green bar: (*34*)].

Denis Gilbert
2013-01-15

Post-glacial continental rebound

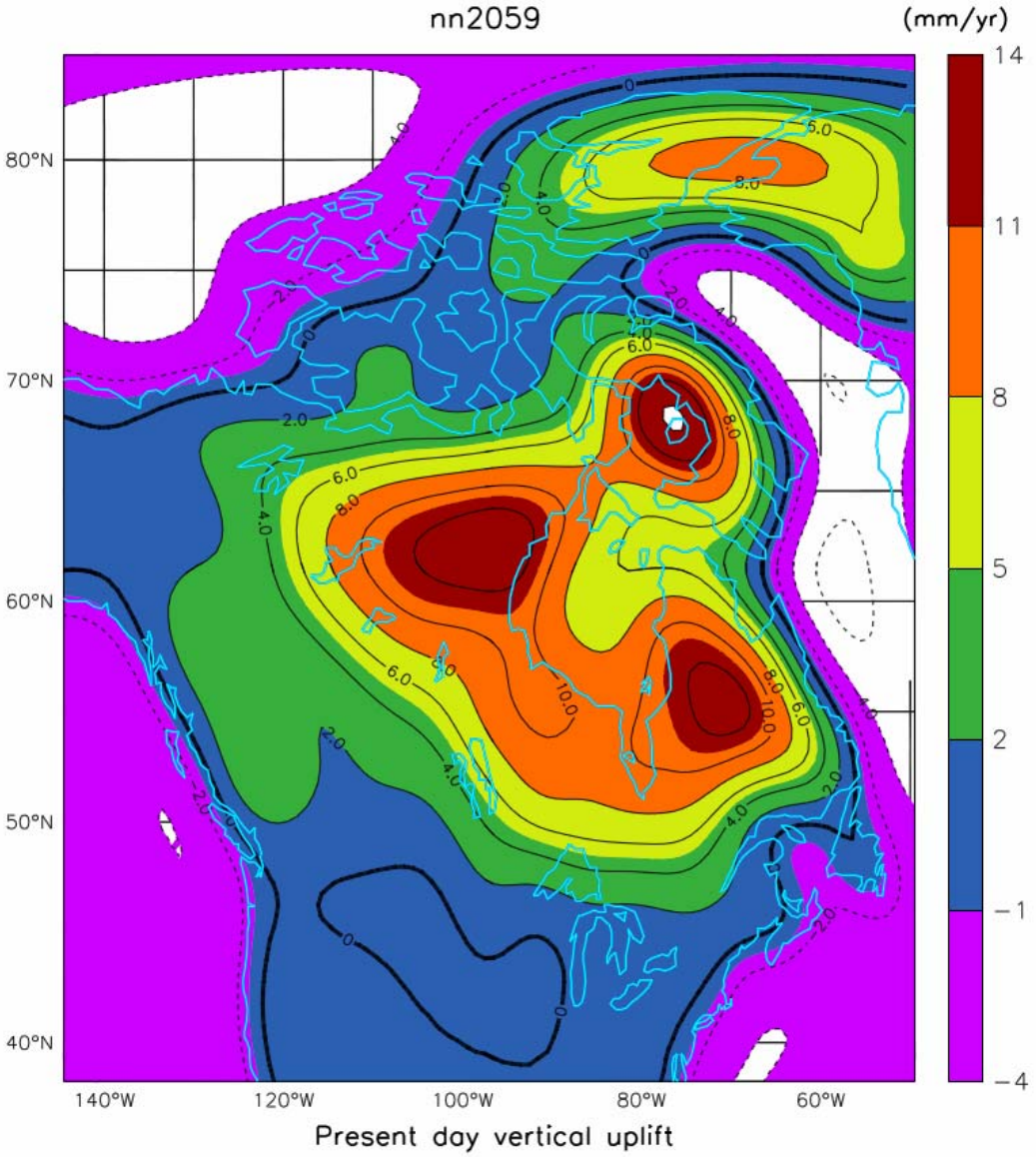


Fig. 13. Present-day rate of uplift for model nn2059.

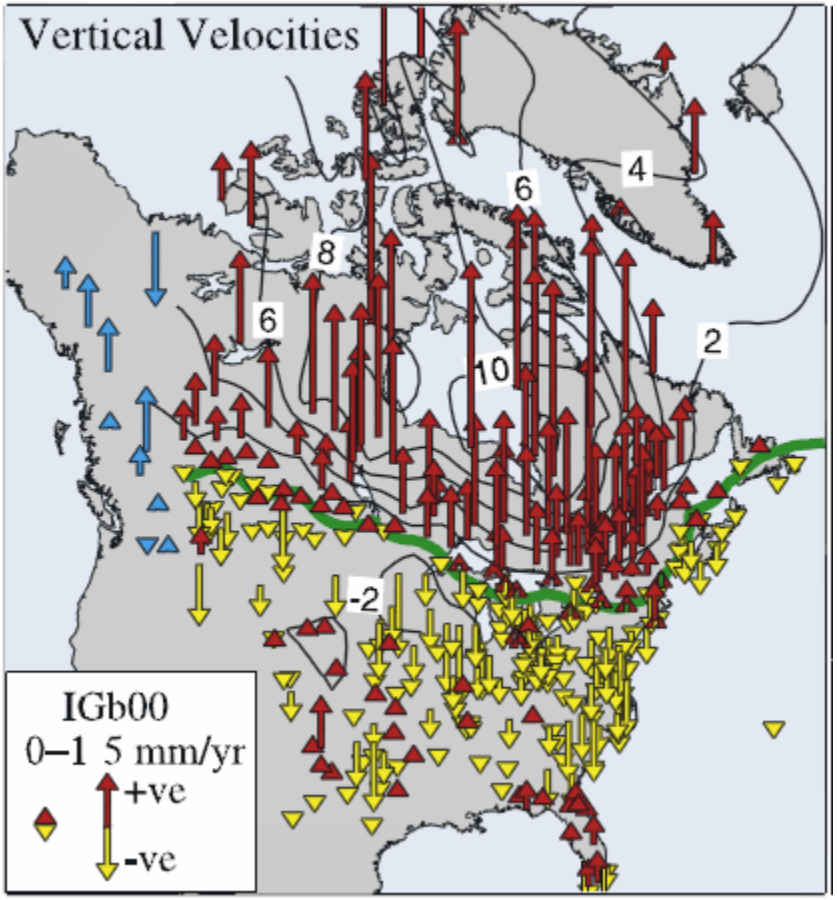
Tarasov & Peltier (2004, Quaternary Science Reviews)

3.2 mm per year =
32 cm per century

10 000 years ago, the most recent glacial period ended with the melting of a 4 km thick ice sheet. The Earth's crust is still « rebounding » from the melting of this enormous mass of ice. At the local scale, this vertical rebound speed can mask the global mean sea level rise of 32 cm per century.

Post-glacial continental rebound

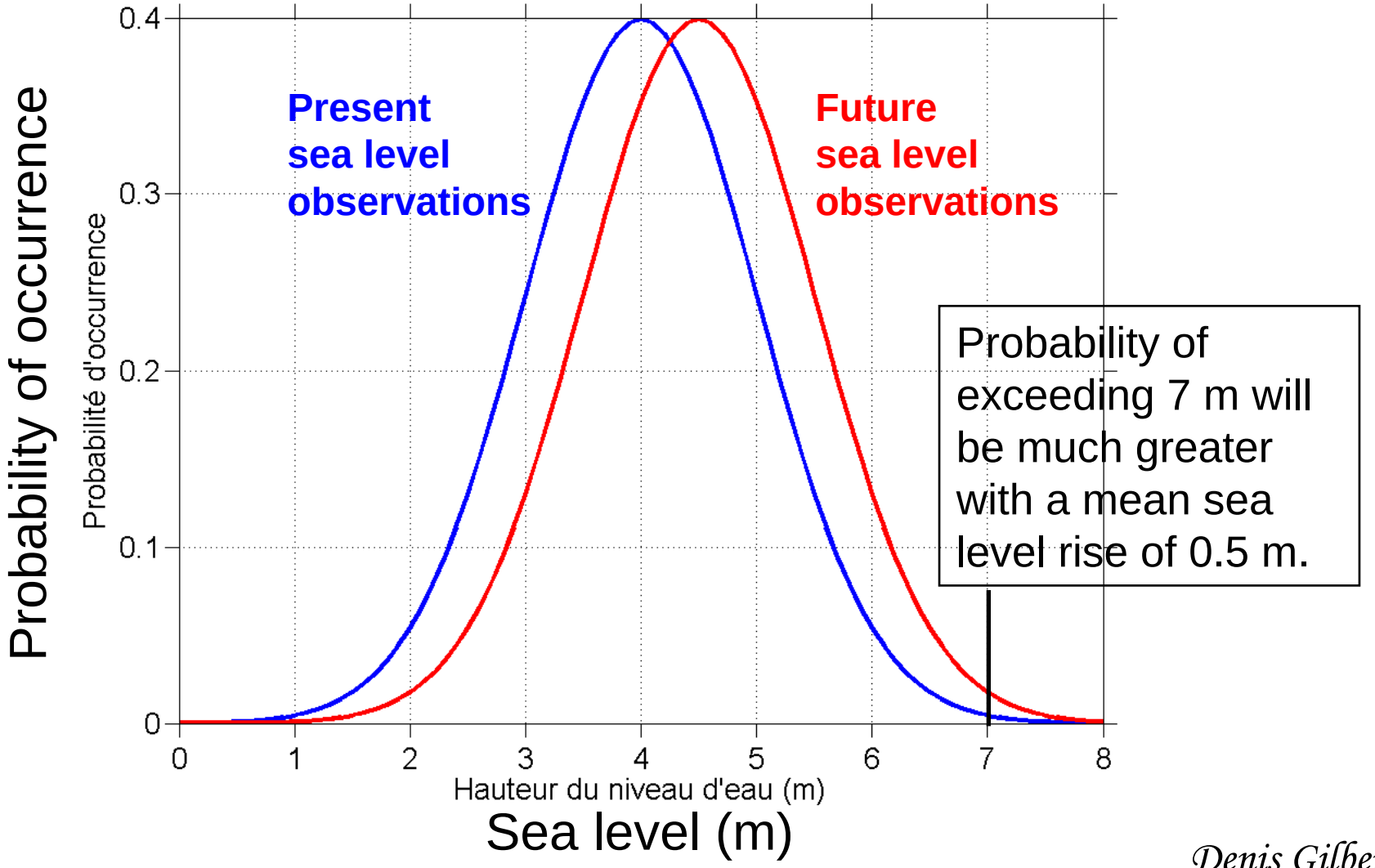
(GPS measurements)



3.2 mm per year =
32 cm per century

Sella et al. (2007, Geophys. Res. Letters, 34, L02306)

Extreme sea level events

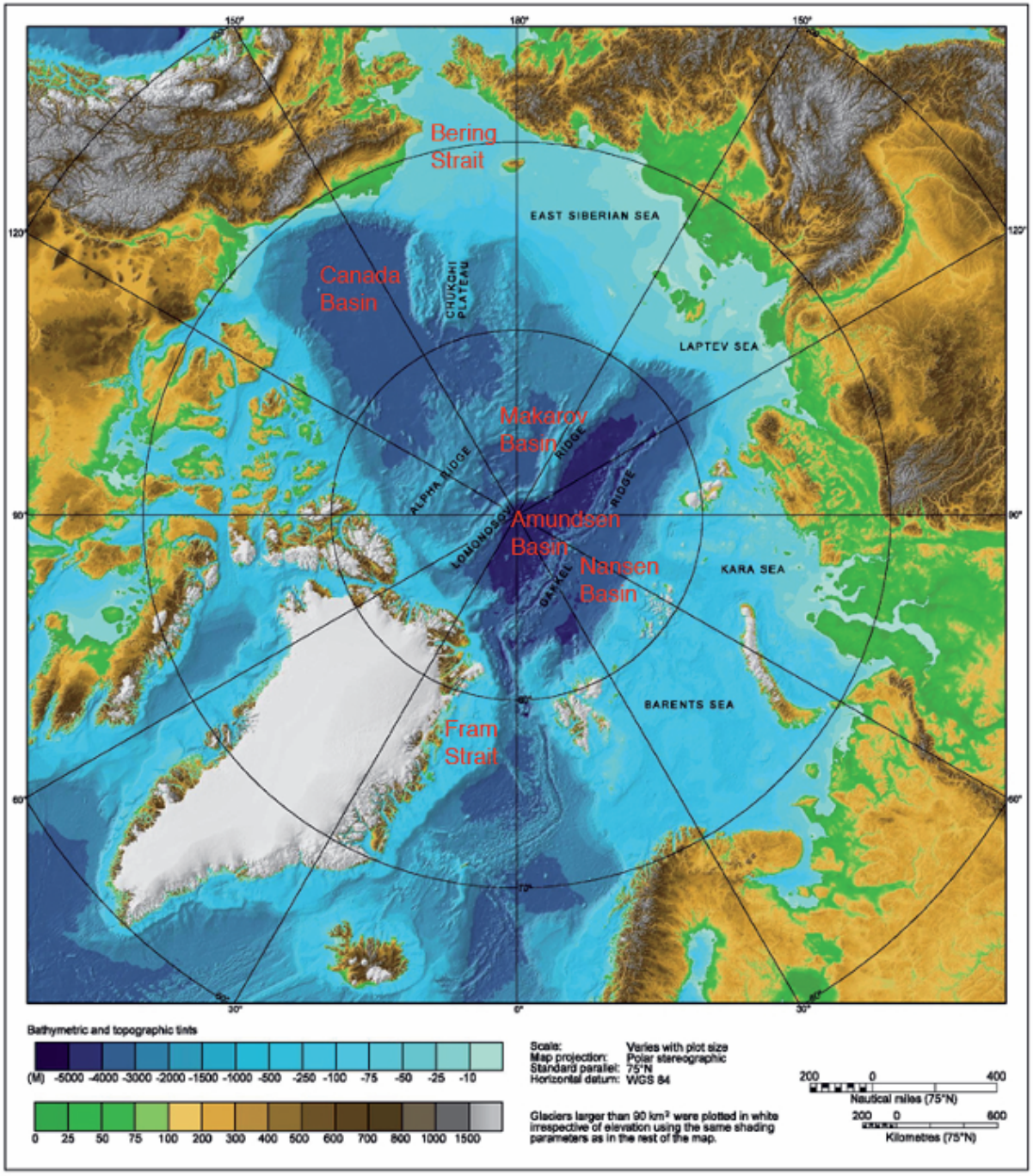


Denis Gilbert
2013-01-15

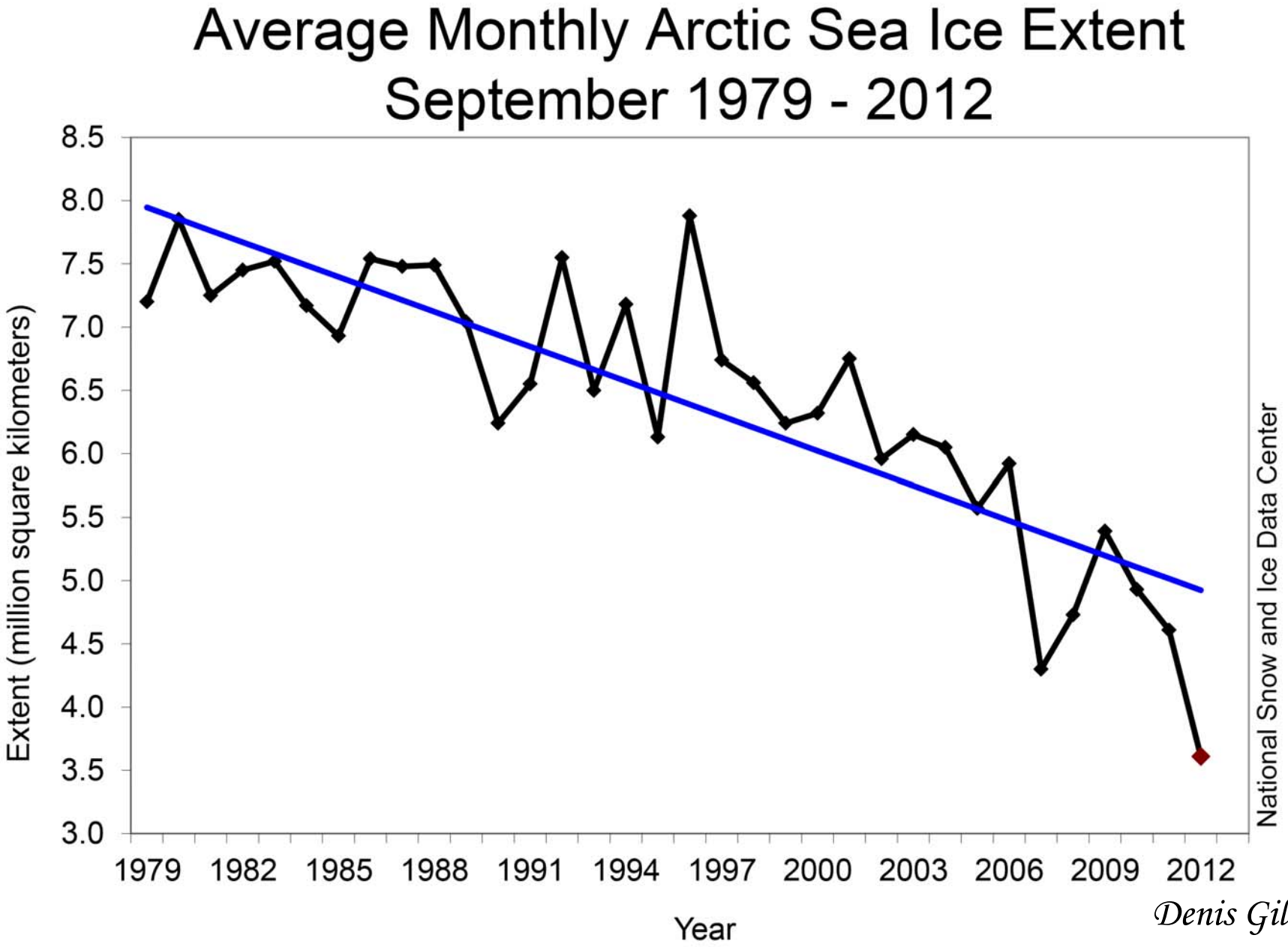
Outline

- Surface air temperature warming
- Upper ocean warming
- Thermohaline circulation
- Intensification of the hydrological cycle
- Dissolved oxygen decrease
- Ocean acidification (related to CO_2 uptake)
- Sea level rise and coastal erosion
- Arctic sea ice melting, opposite in Antarctic?

Arctic Ocean



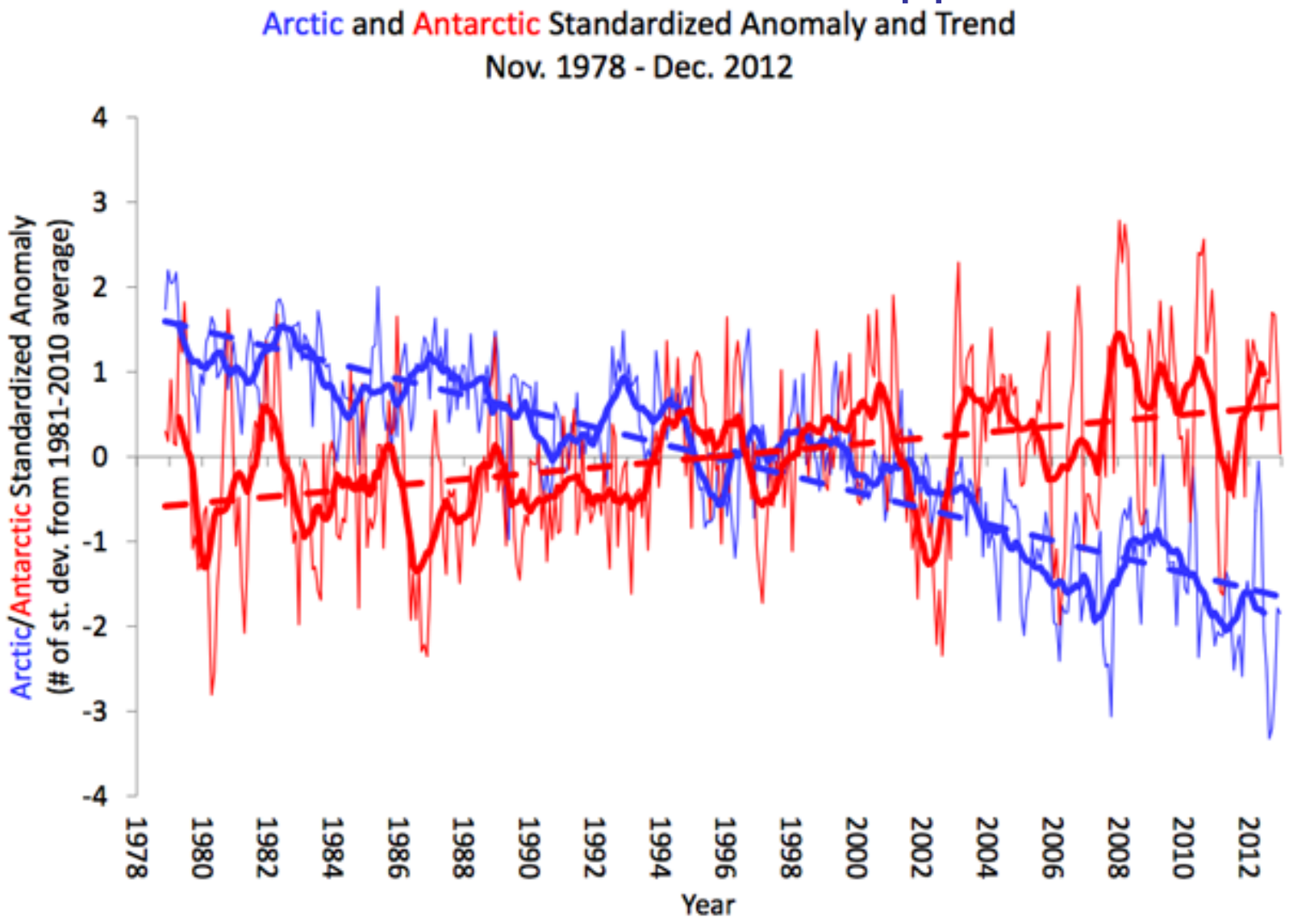
Arctic Sea Ice Cover



http://nsidc.org/arcticseaicenews/files/2000/09/Figure3.png

Denis Gilbert
2013-01-15

Arctic versus Antarctic sea ice: opposite trends



http://nsidc.org/cryosphere/sotc/sea_ice.html

Summary

- Upper ocean warming – Argo profiling floats help us monitor this with greater confidence
- Thermohaline circulation – no evidence of reduction yet
- Intensification of the hydrological cycle – yes based on observed sea surface salinity changes
- Dissolved oxygen decrease
- Ocean acidification – observed, impacts largely unknown
- Sea level rise and coastal erosion – large impacts on human infrastructures
- Arctic sea ice melting – large positive feedbacks
- Antarctic sea ice expansion – due to increased westerlies pushing ice north?