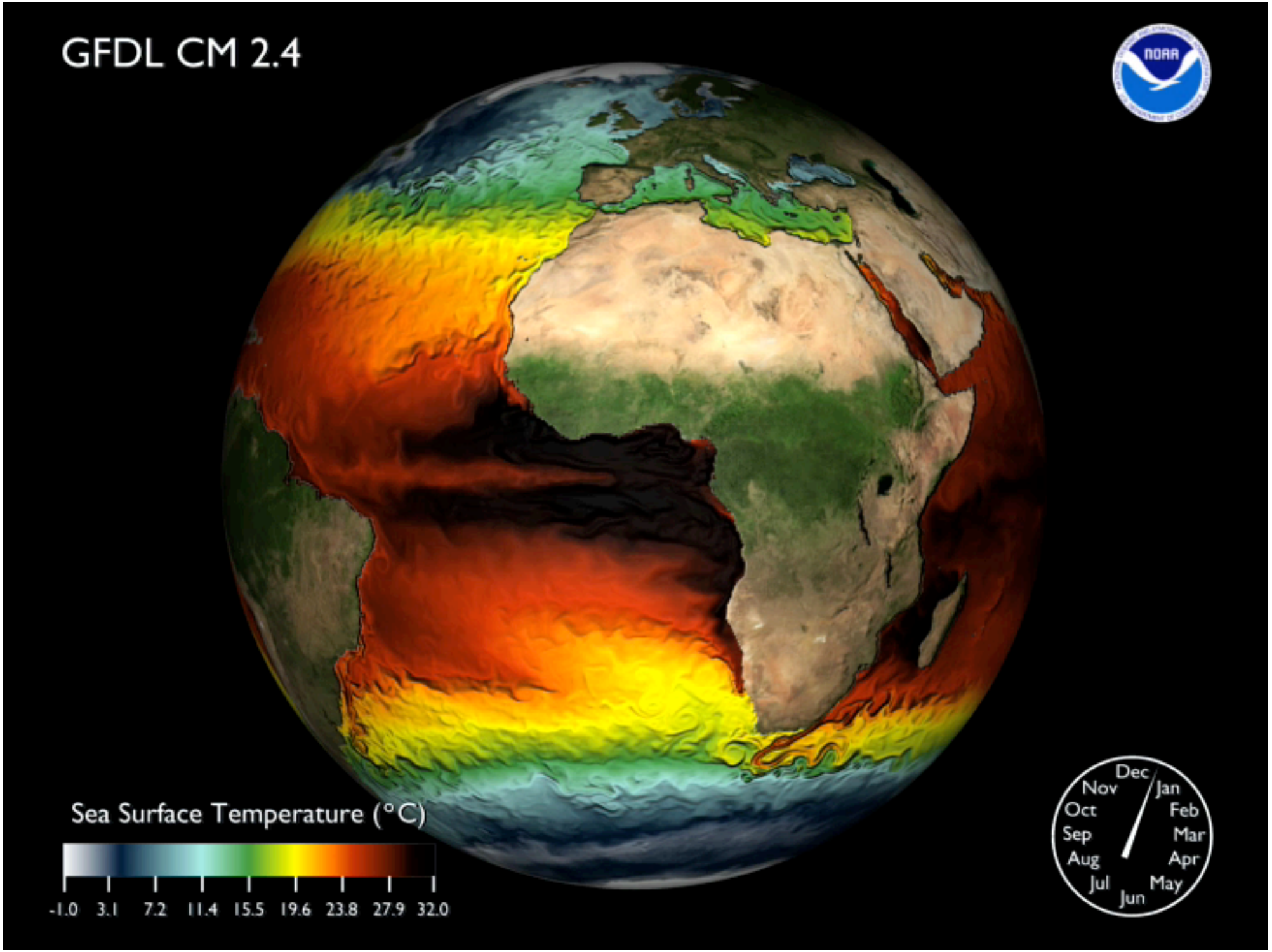
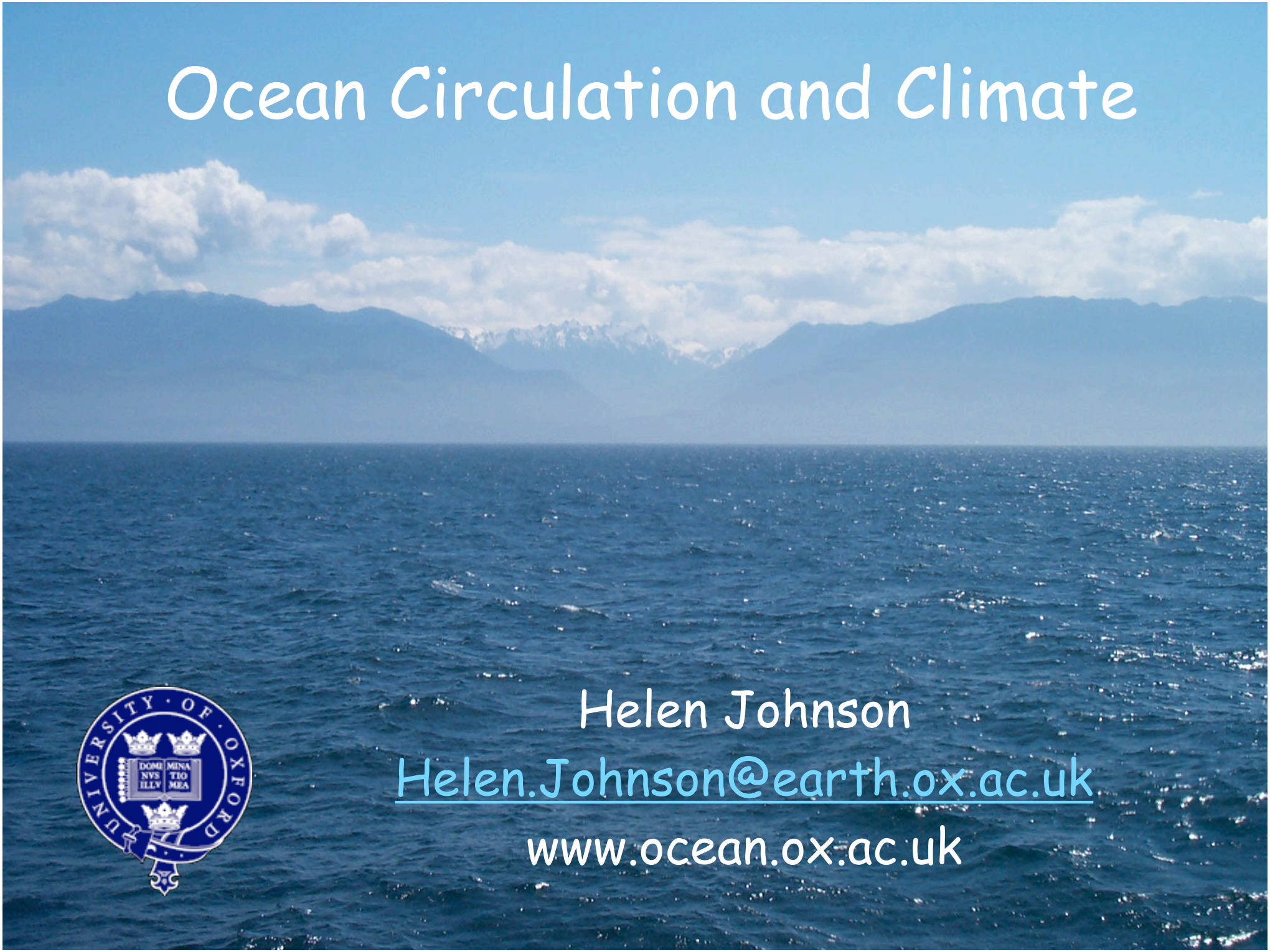
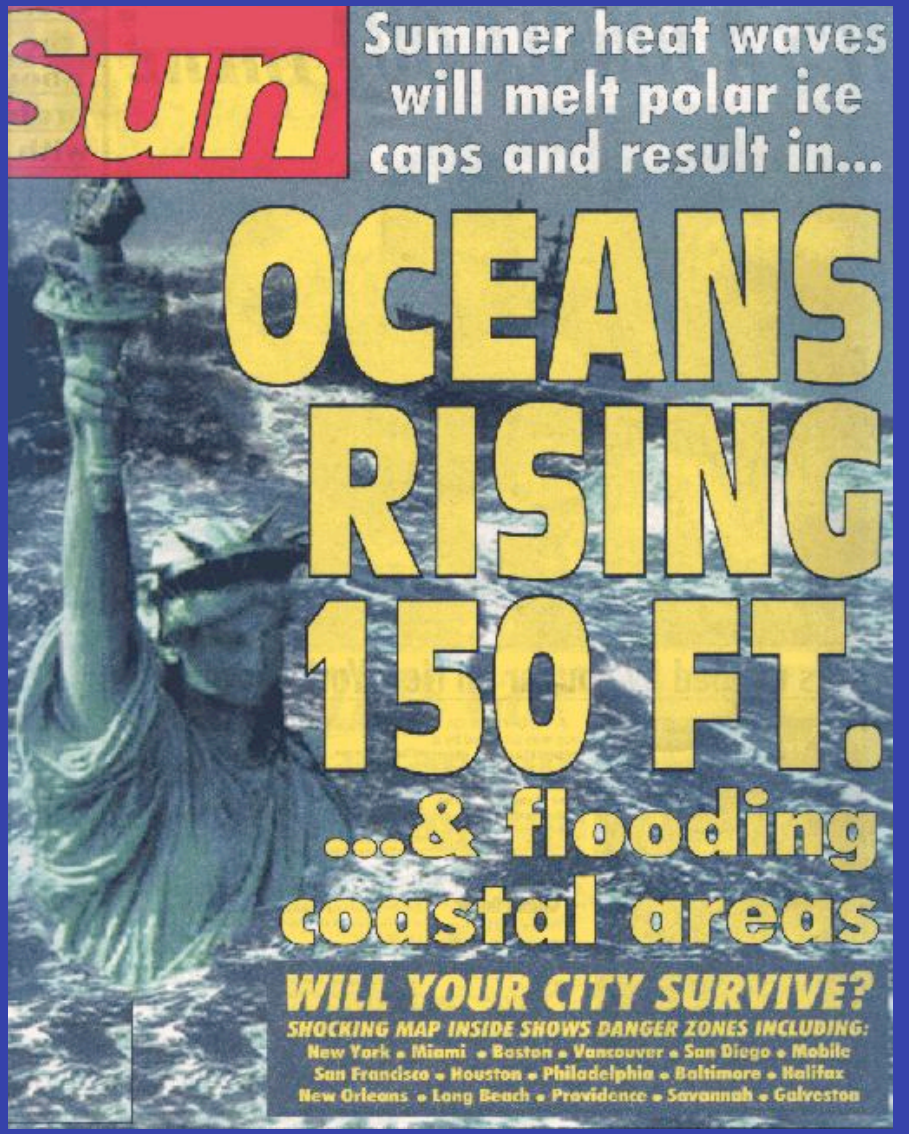

GFDL CM 2.4
NOAA
Sea Surface Temperature (°C)
-1.0 3.1 7.2 11.4 15.5 19.6 23.8 27.9 32.0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Ocean Circulation and Climate



Helen Johnson
Helen.Johnson@earth.ox.ac.uk
www.ocean.ox.ac.uk

The oceans implicated in climate change…!




THE DAY AFTER TOMORROW
AVAILABLE ON DVD
OCTOBER 12, 2004

Talk Outline

- Influence of the ocean on global and regional climate

- Global warming and the ocean

  - What changes might we expect as a result of increased greenhouse gases?

  - How will these feed back on to climate?

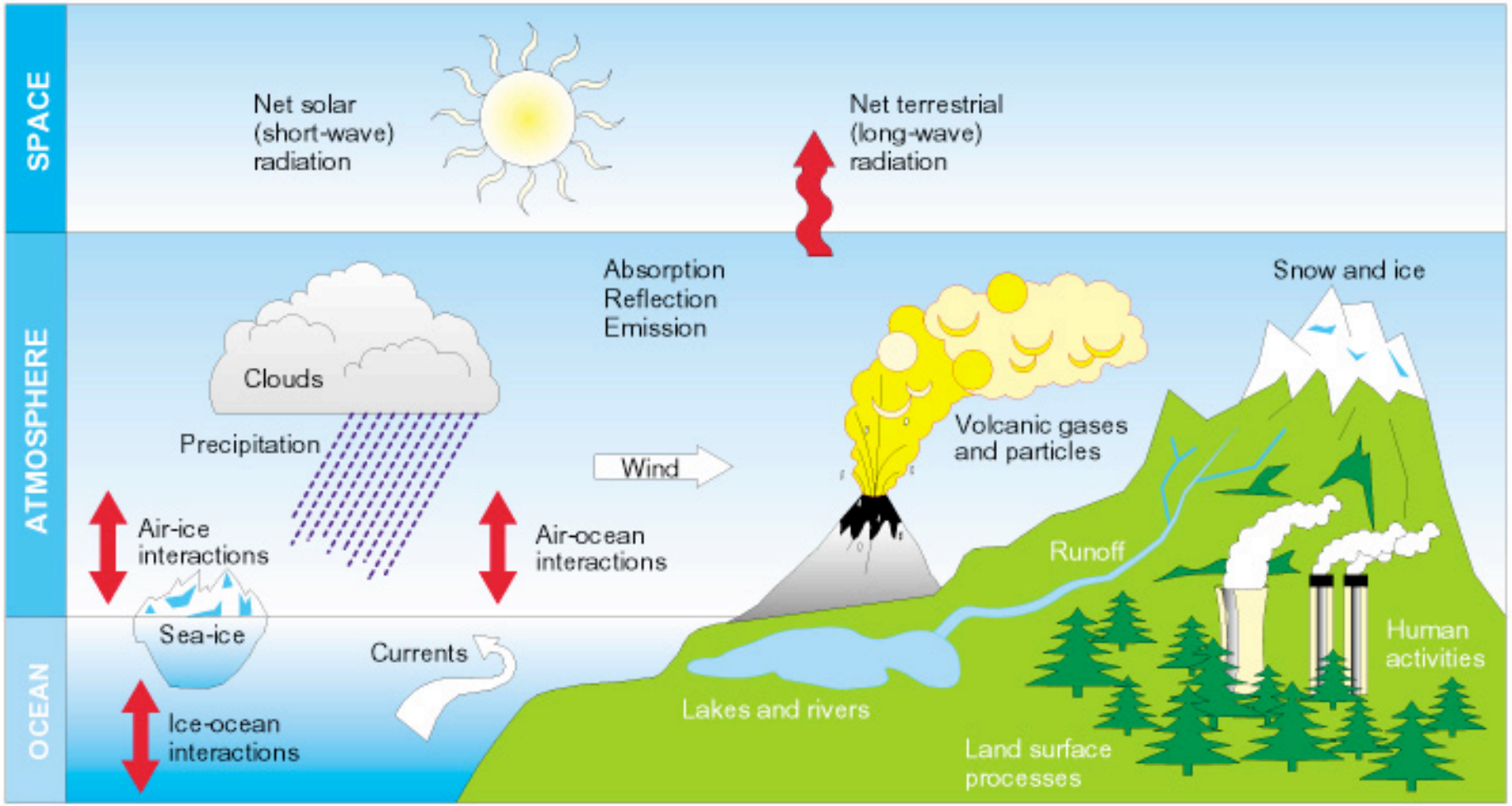
  - Open questions about the ocean's response to change

  - Oxford Physical Oceanography group research

- Limitations in our ability to predict the ocean's response to change.

- Summary and conclusions

The Climate System



courtesy N. Noreiks, L. Bengtsson, MPI

AV/Global/0101

The ocean plays a crucial role in determining global and regional climate:

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

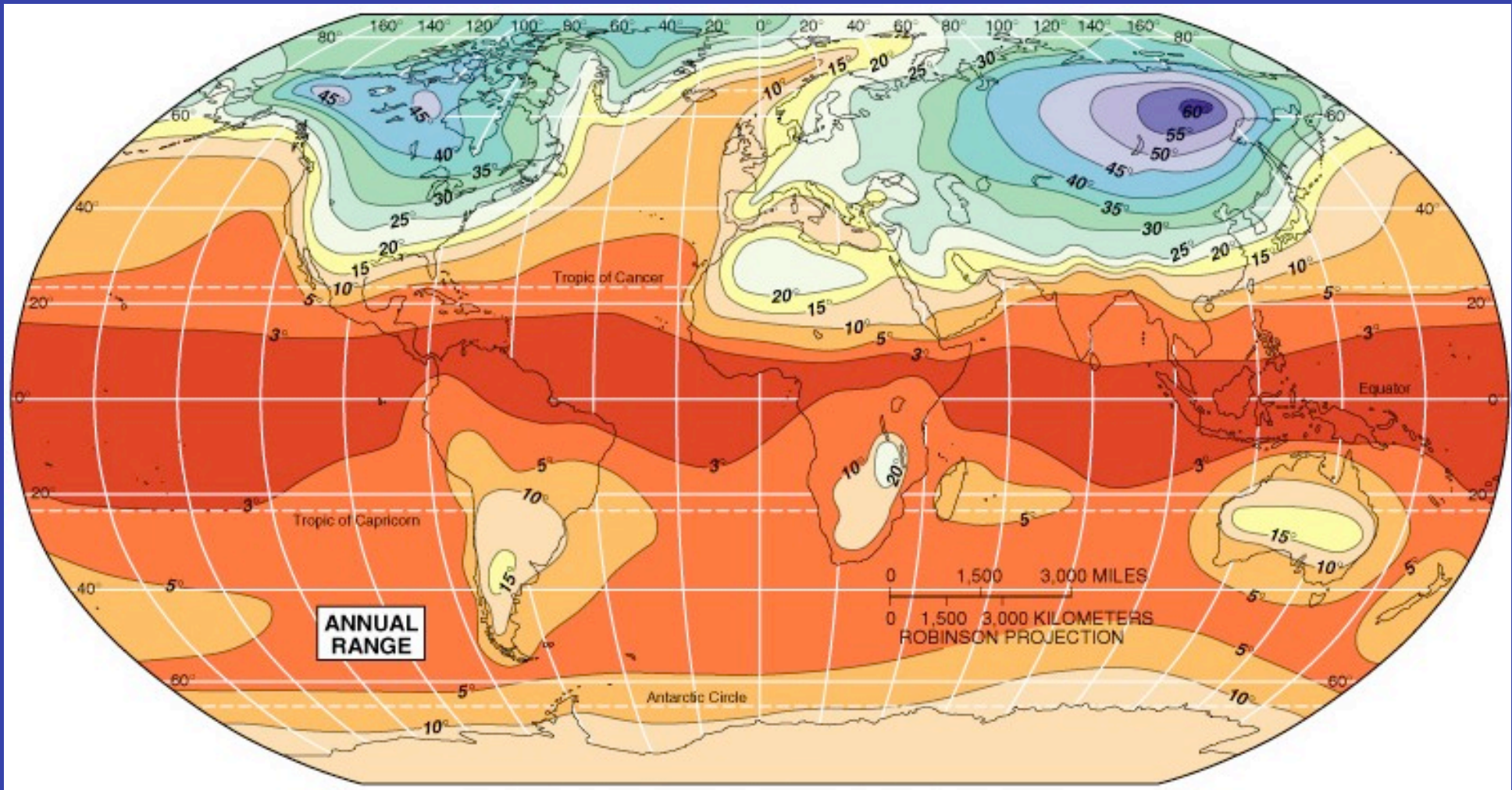
  e.g. El Nino, hurricanes

The ocean plays a crucial role in determining global and regional climate:

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

Amplitude of the seasonal cycle in temperature



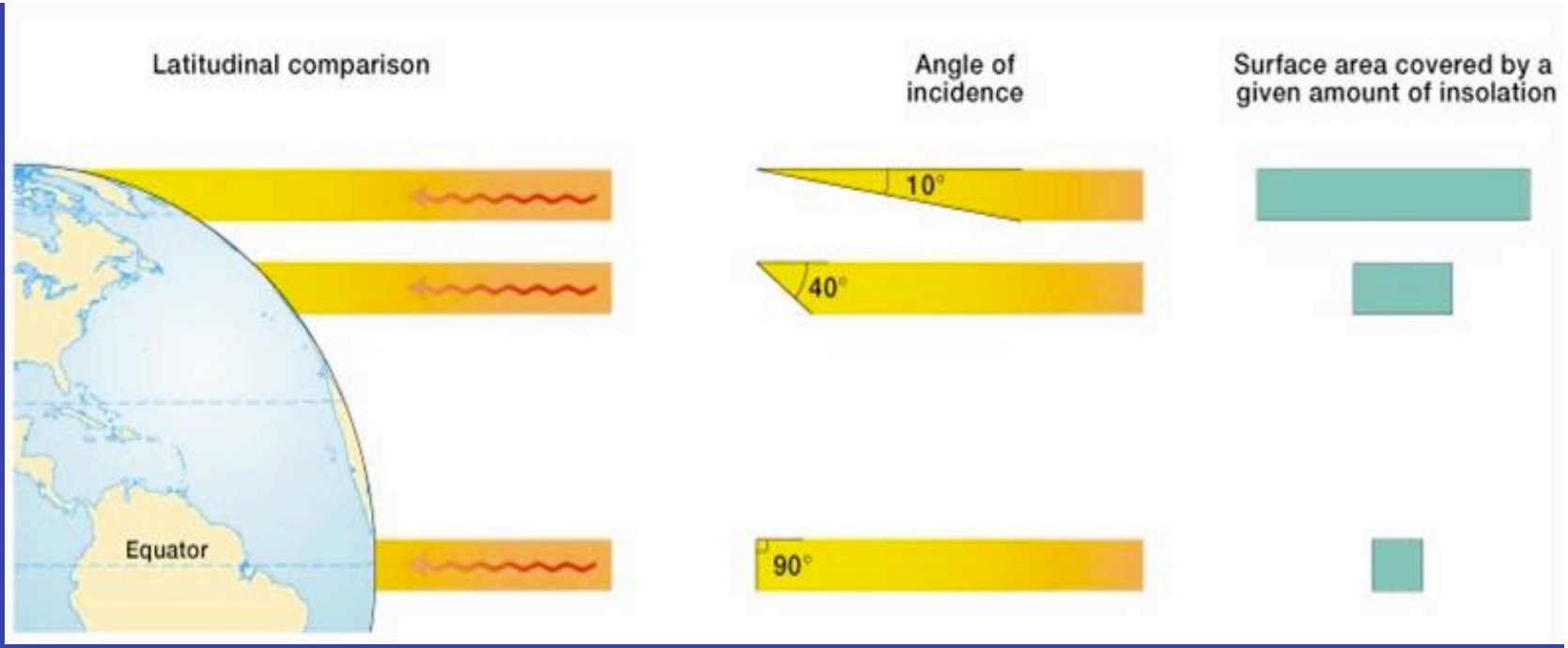
F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

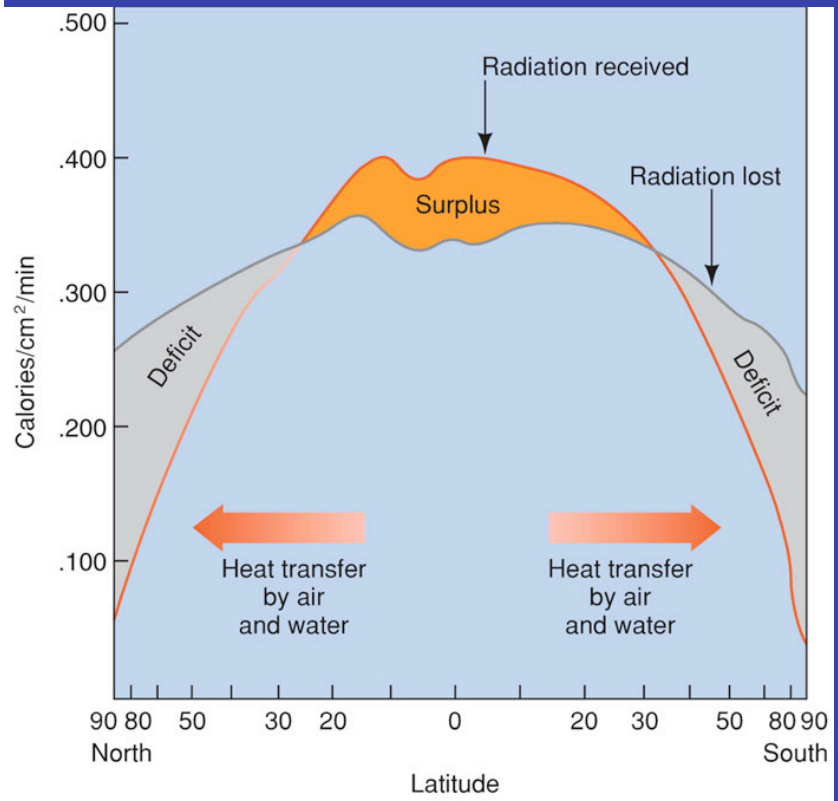
The ocean plays a crucial role in determining global and regional climate:

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

Earth's radiation balance



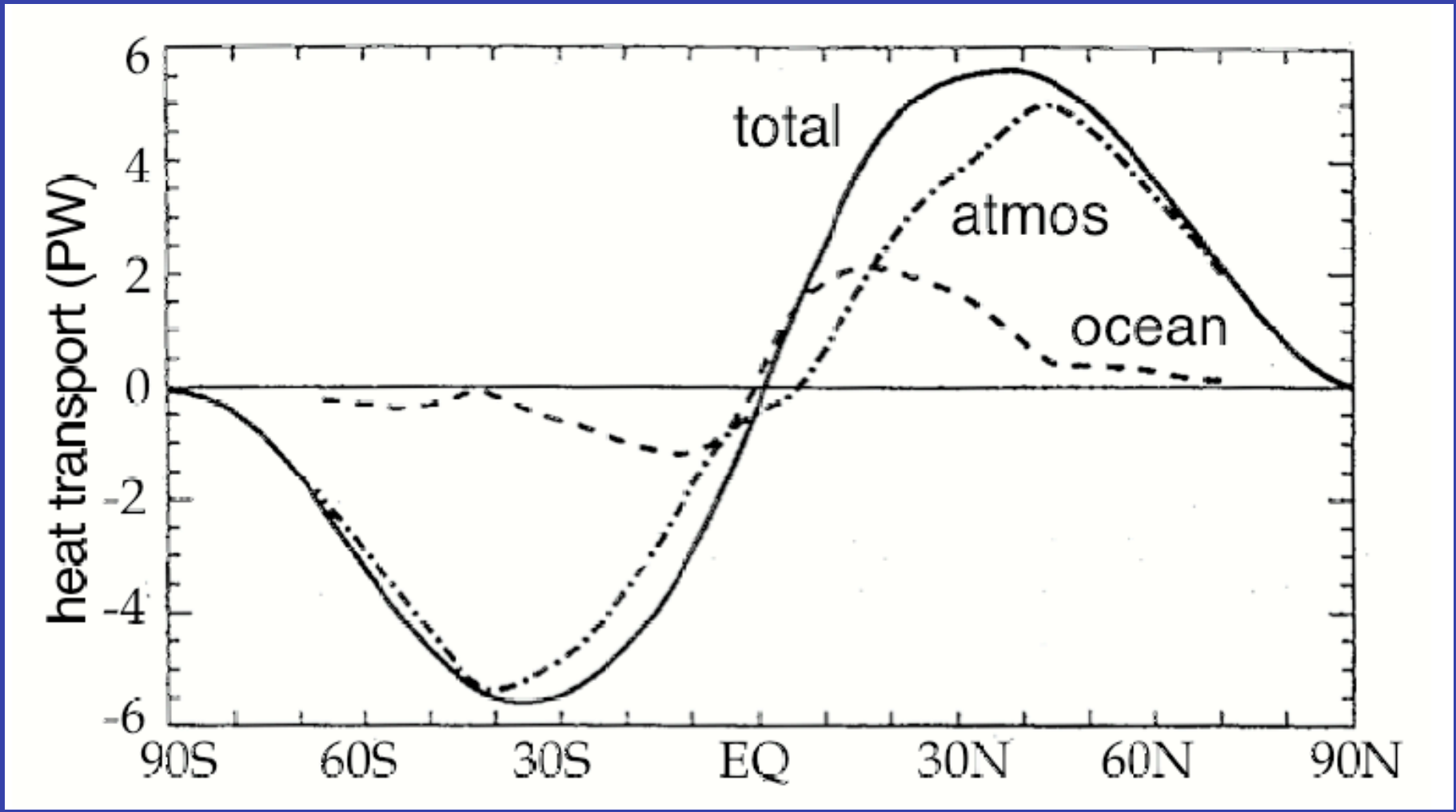


The Tropics receive more radiation per unit area than the poles.

Radiation lost from earth depends upon temperature and varies less strongly with latitude.

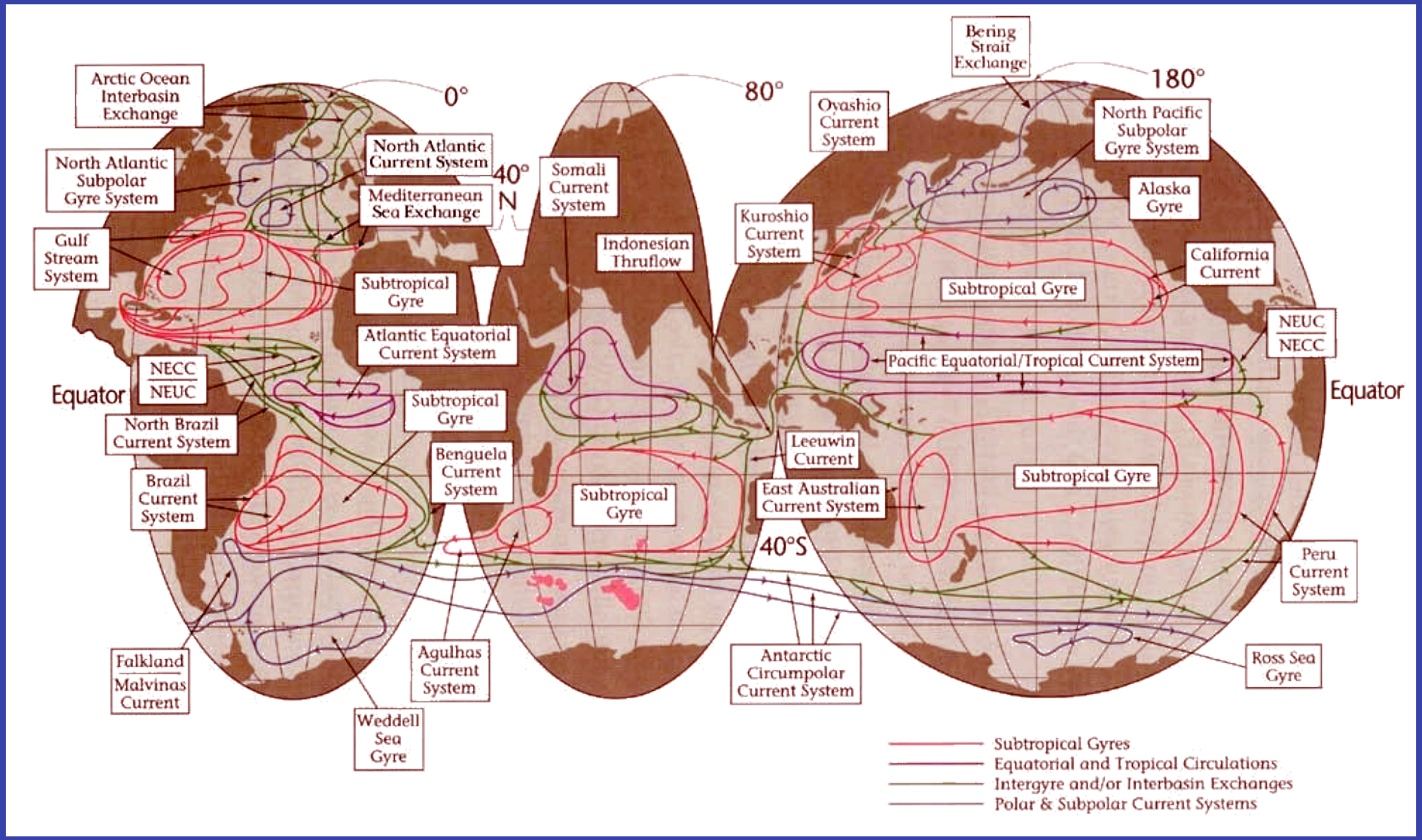
Therefore energy must be transported from the tropics (which have a surplus) to the polar regions (which have a deficit) by the atmosphere and ocean.

Atmosphere and ocean heat transport

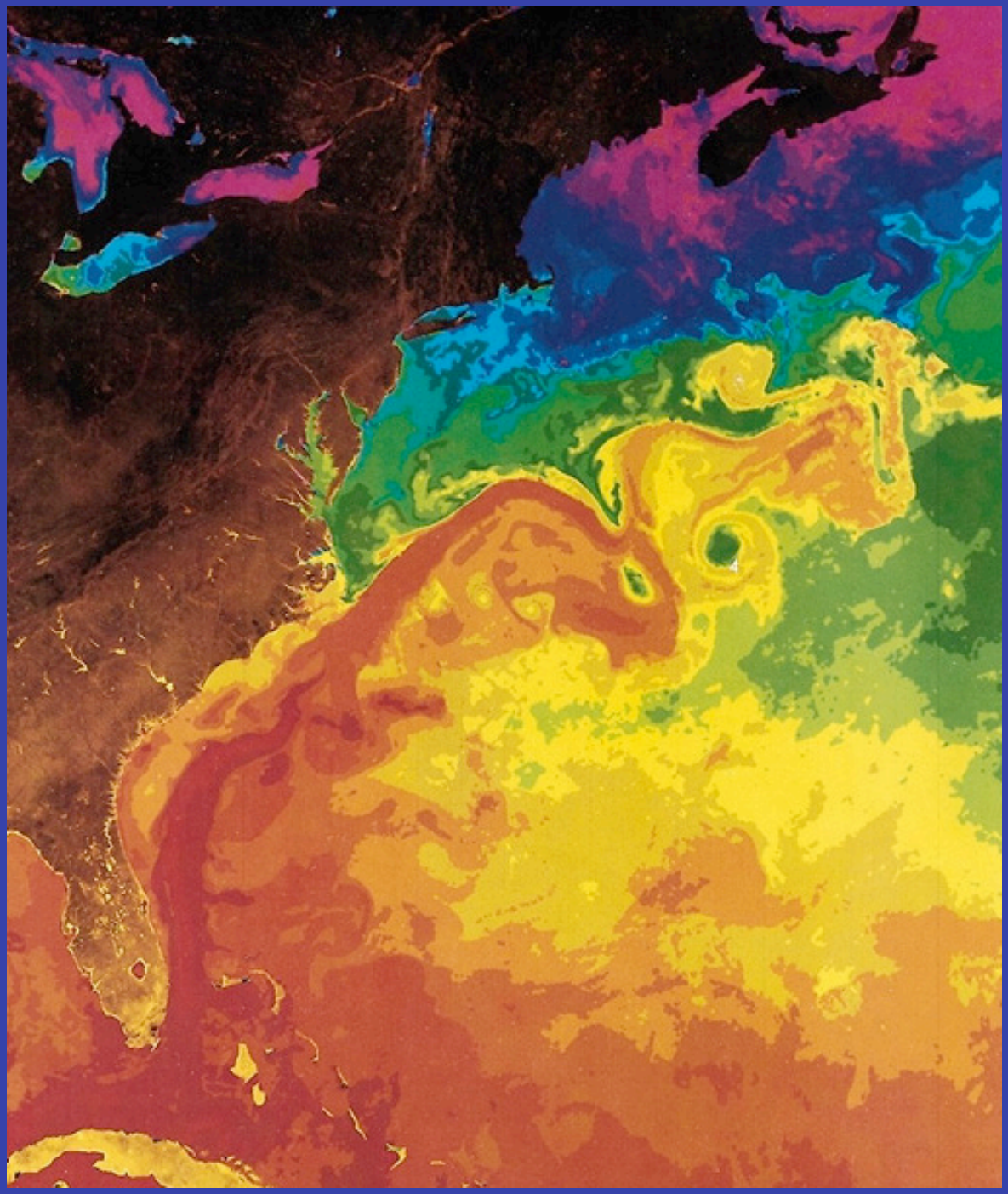


Trenberth and Caron (2001)

Wind-driven ocean gyres



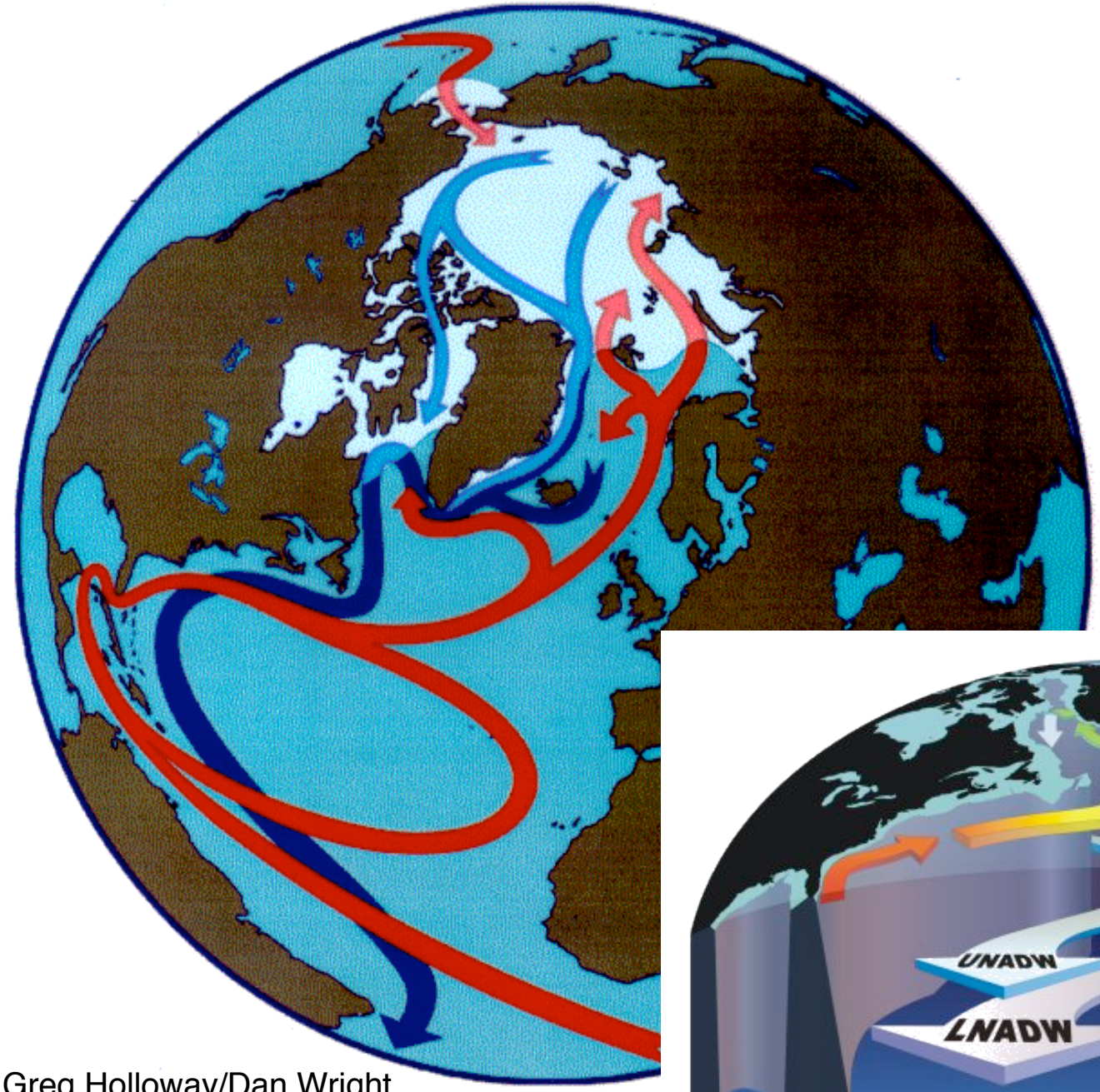
Schmitz (1996)



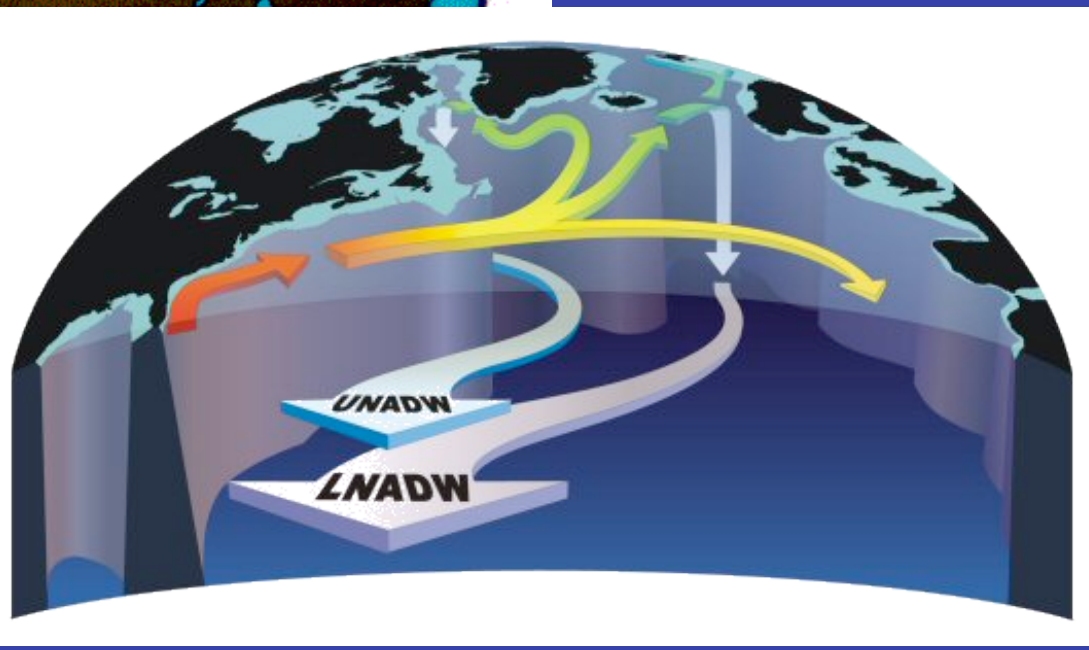
Heat transport
by ocean gyres

False-colour satellite
image of sea surface
temperature in the
Gulf Stream

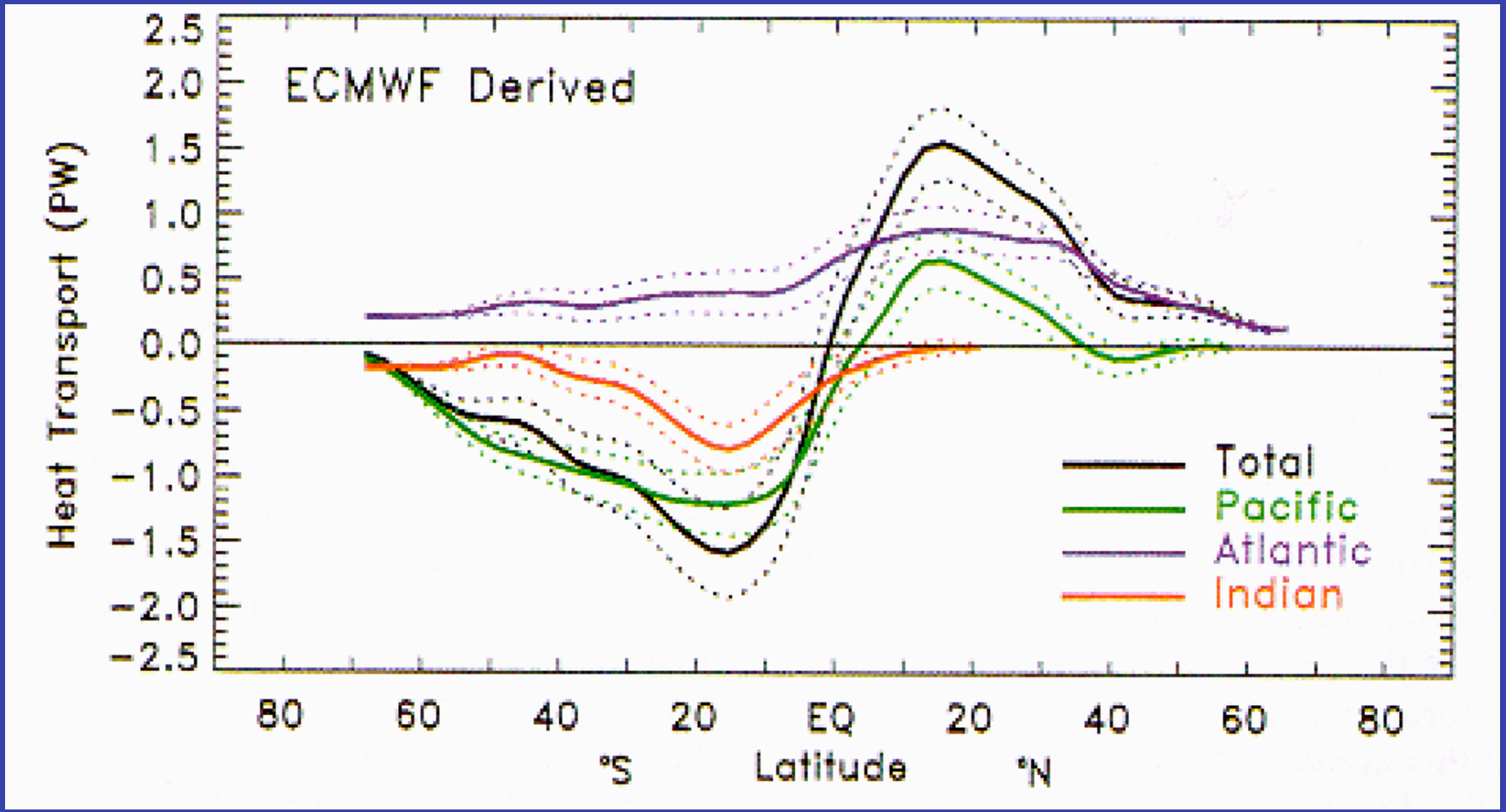
Thermohaline circulation



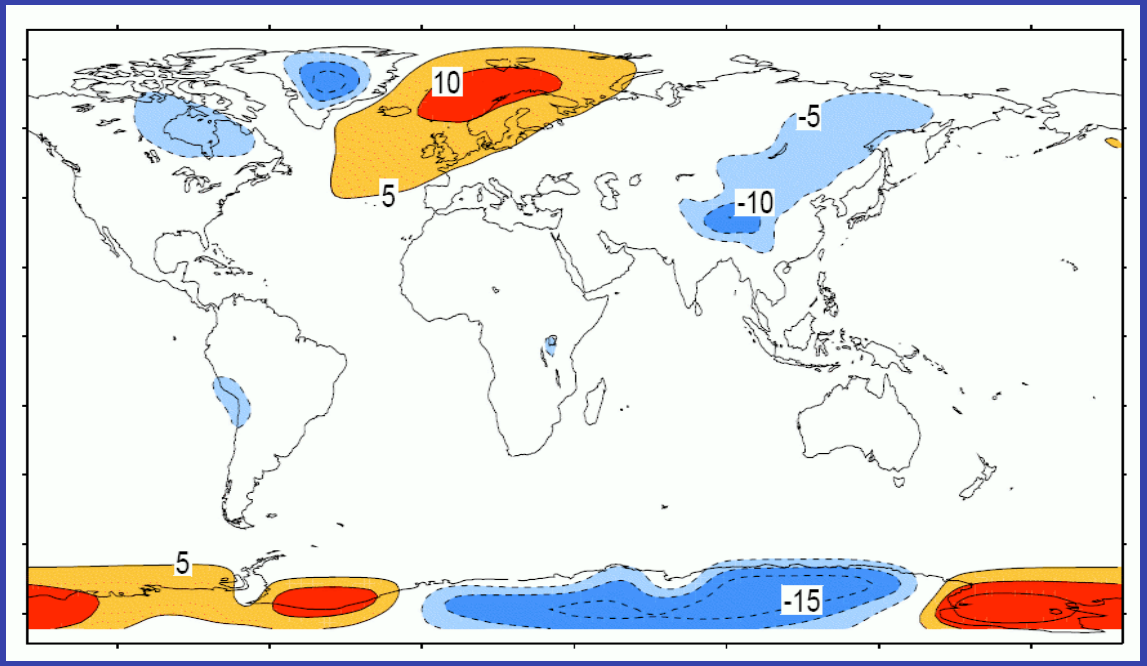
Greg Holloway/Dan Wright



Northward ocean heat transport in each basin



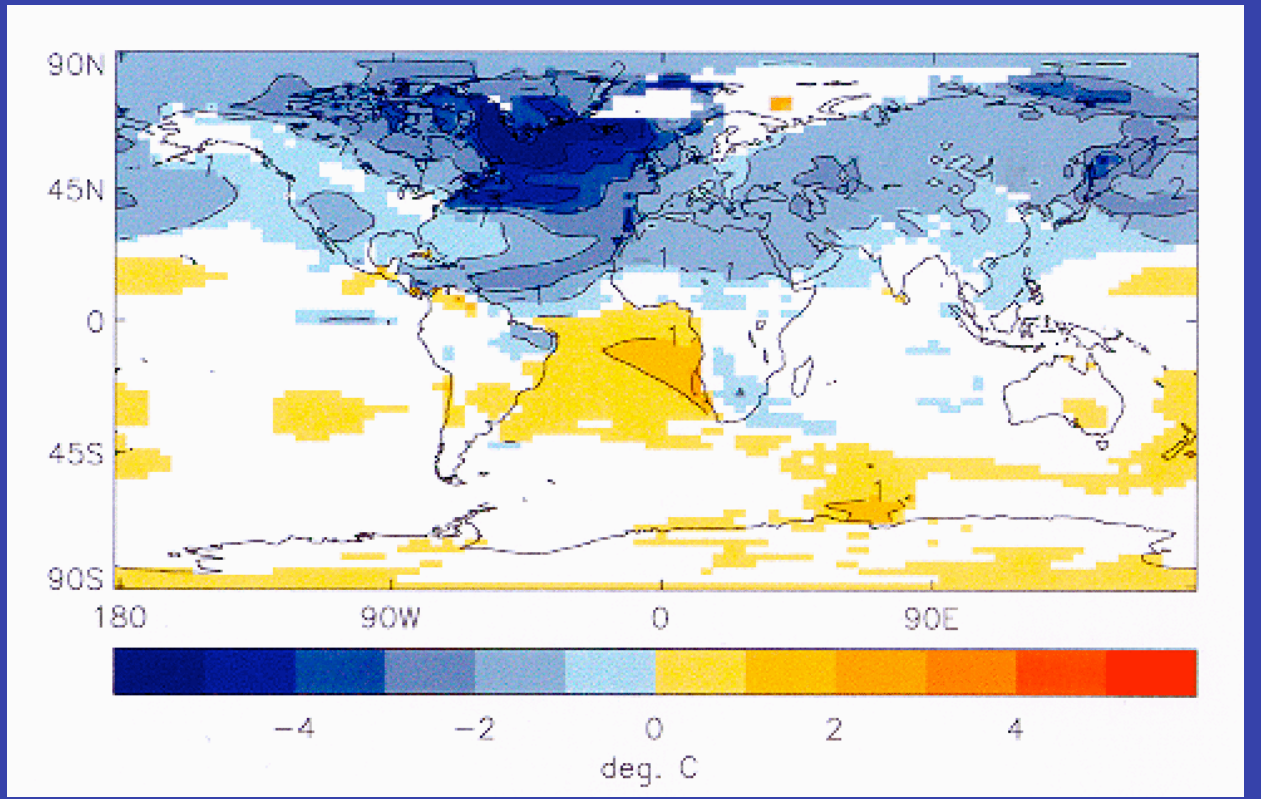
Trenberth and Caron (2001)



Deviation of the annual mean surface air temperature from its zonal average

Rahmstorf (2000)

Surface temperature anomalies 20-30 years after the thermohaline circulation is switched off in a climate model

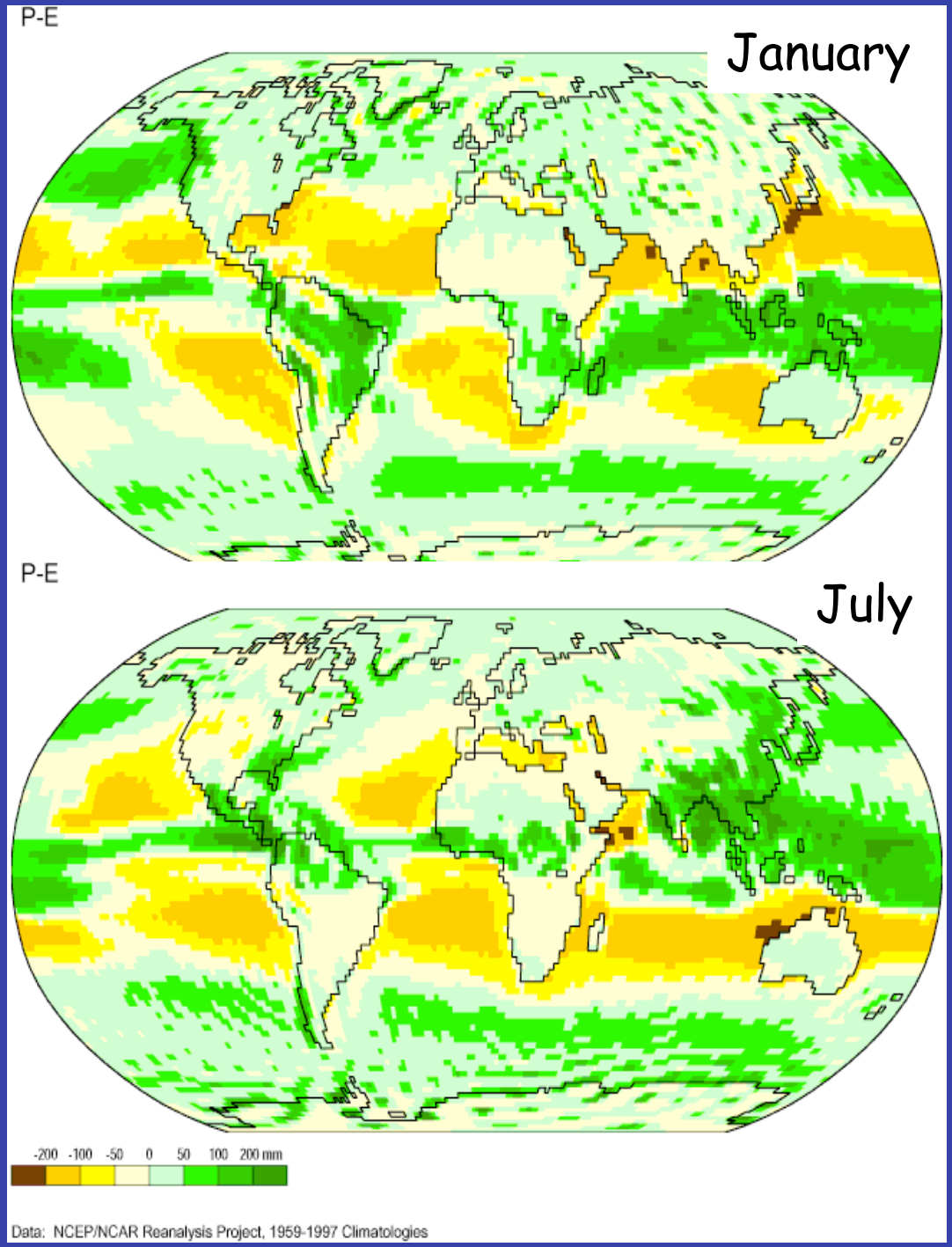


Vellinga and Wood (2001)

The ocean plays a crucial role in determining global and regional climate:

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes



Precipitation minus evaporation

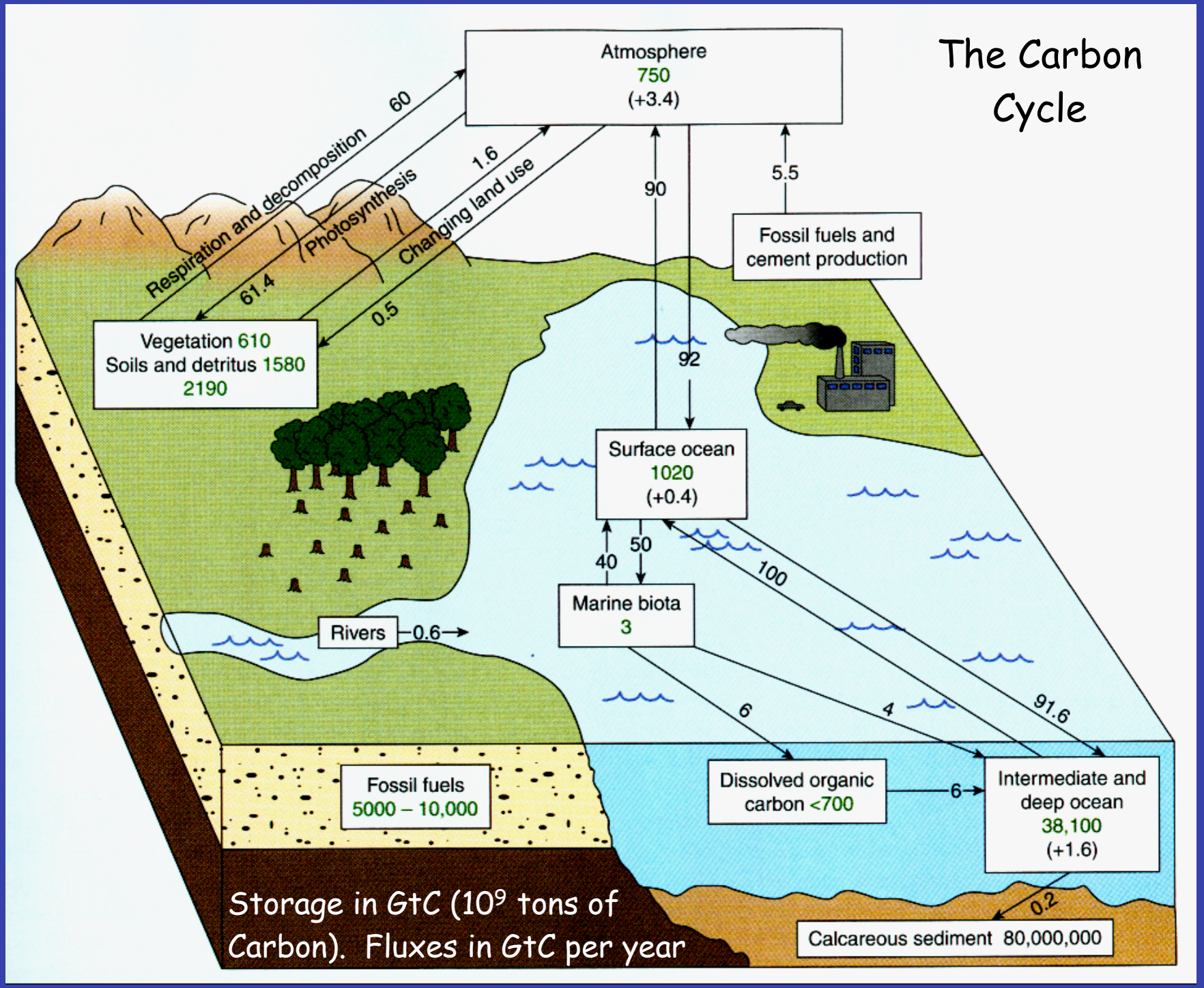
Oceans must transport fresh water!

The ocean plays a crucial role in determining global and regional climate:

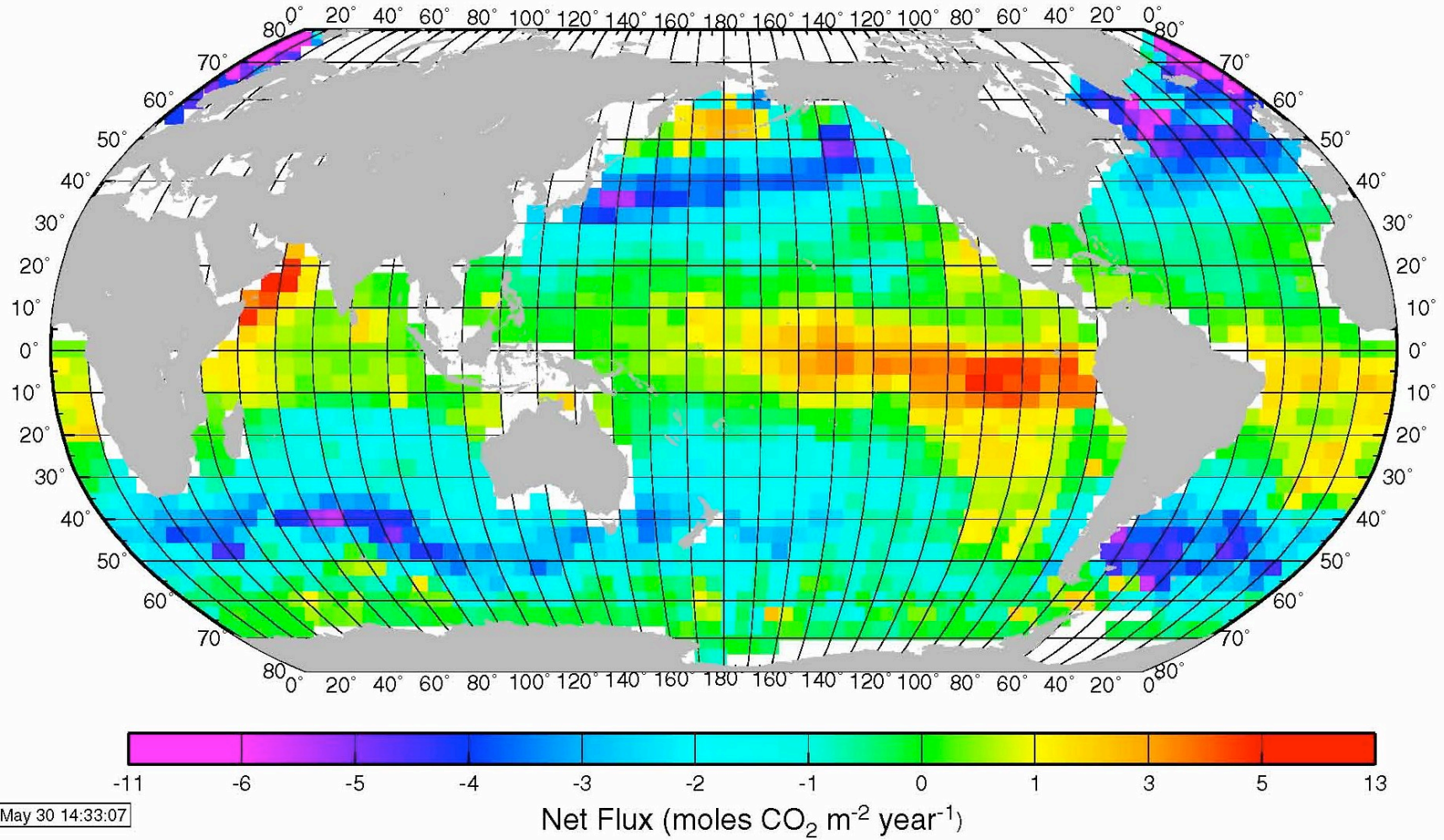
- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

The Carbon Cycle



Mean Annual Air-Sea Flux for 1995 (NCEP 41-Yr Wind, 1166K, W-92)

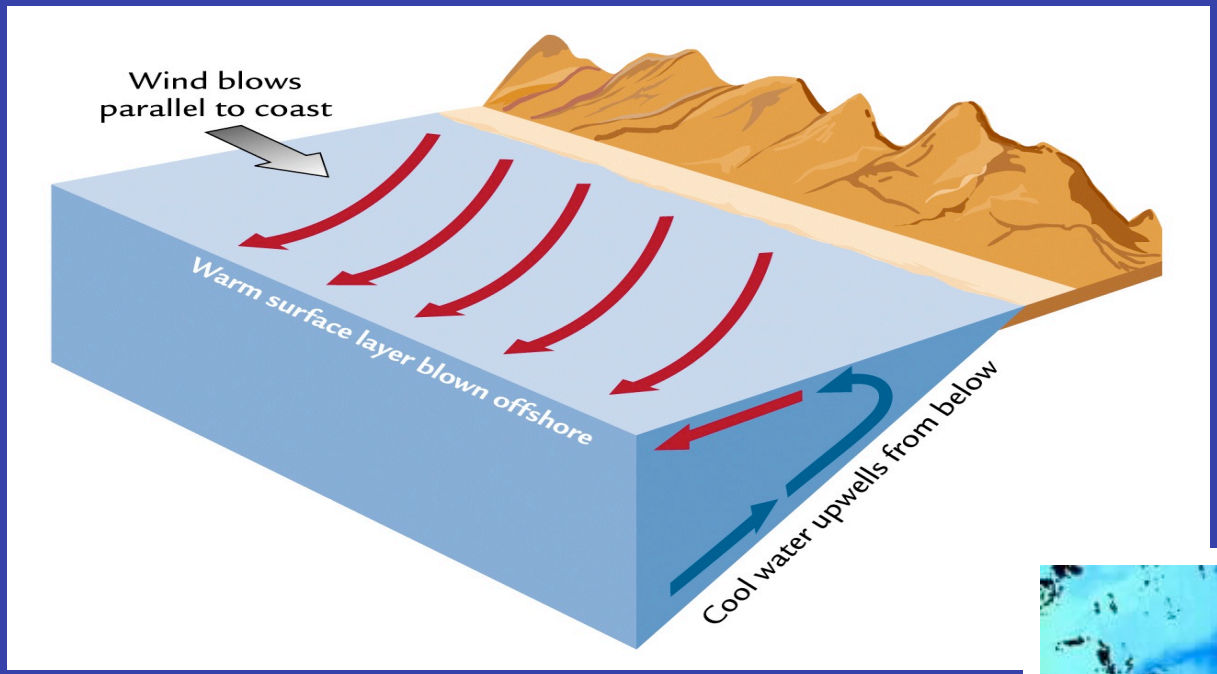


The ocean plays a crucial role in determining global and regional climate:

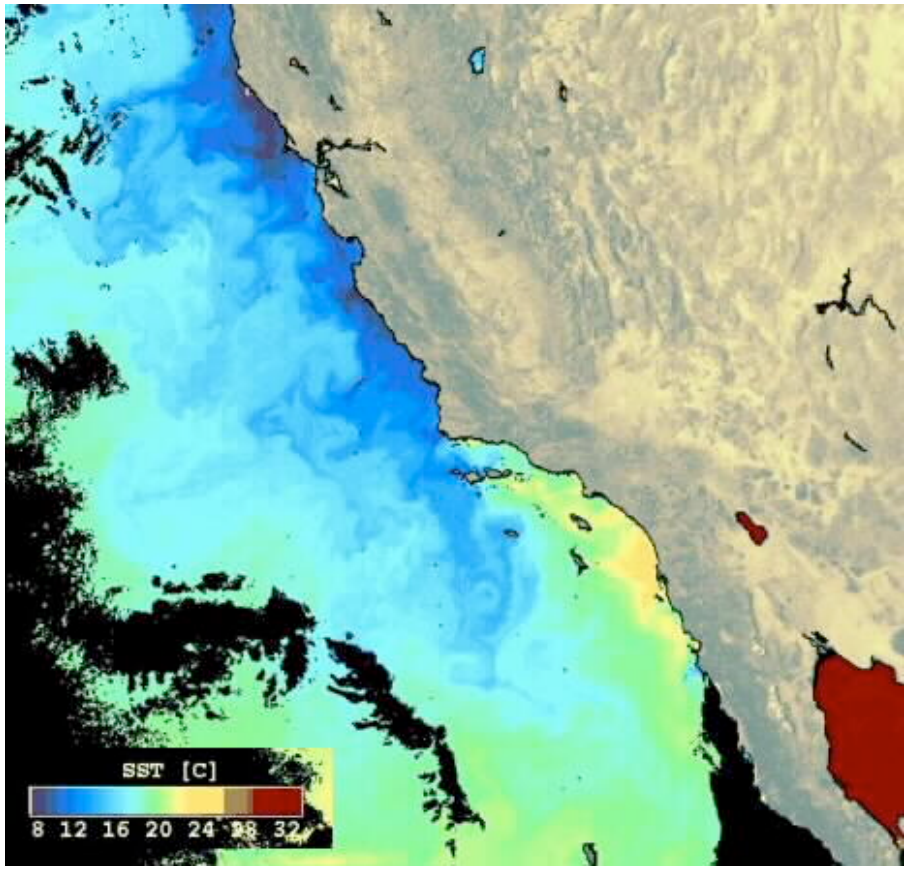
- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

Coastal upwelling

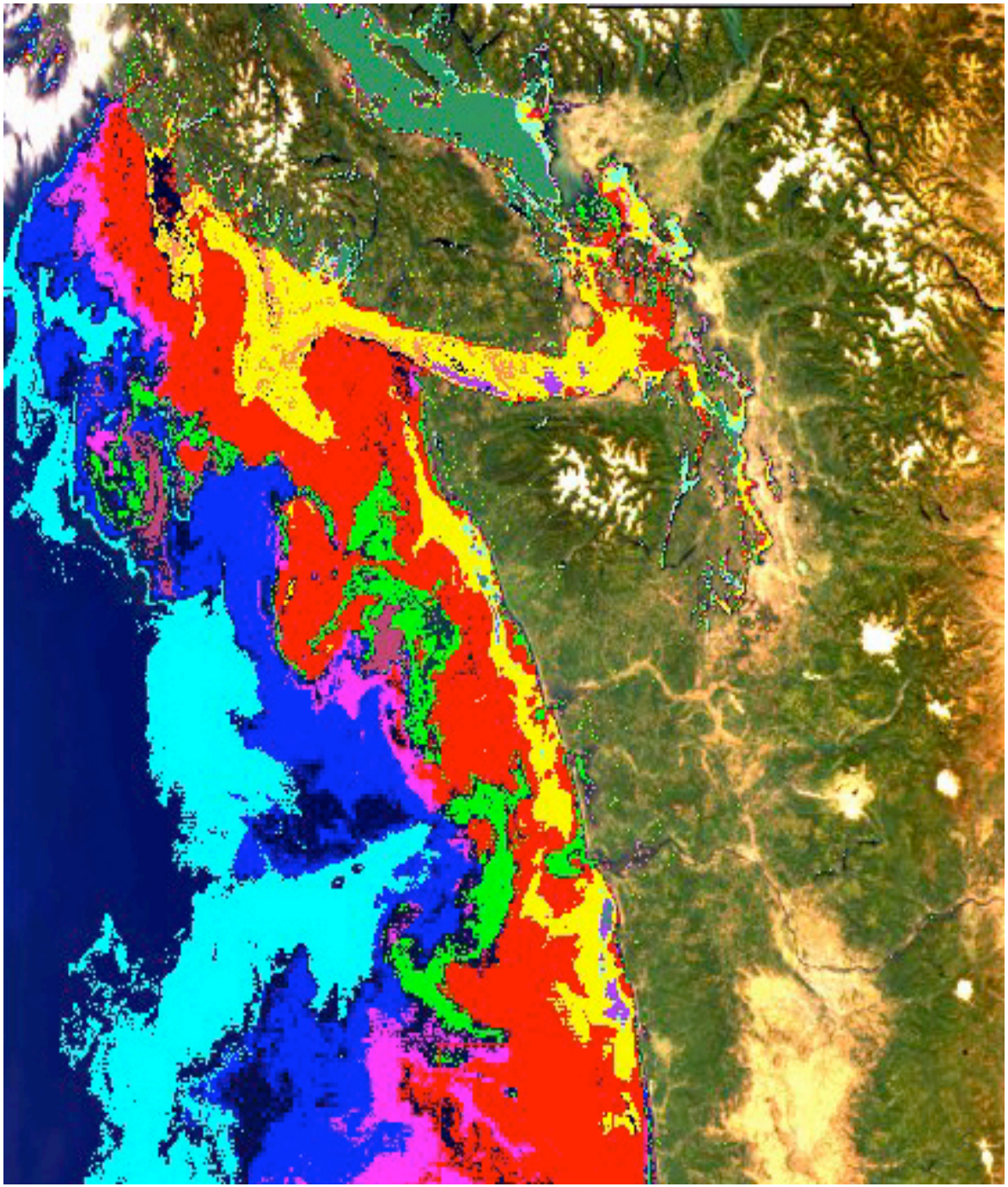


Water in surface layer moves offshore due to wind. Replaced by cold water which upwells from below.



Satellite-derived sea surface temperature off California

Upwelled water
is nutrient rich

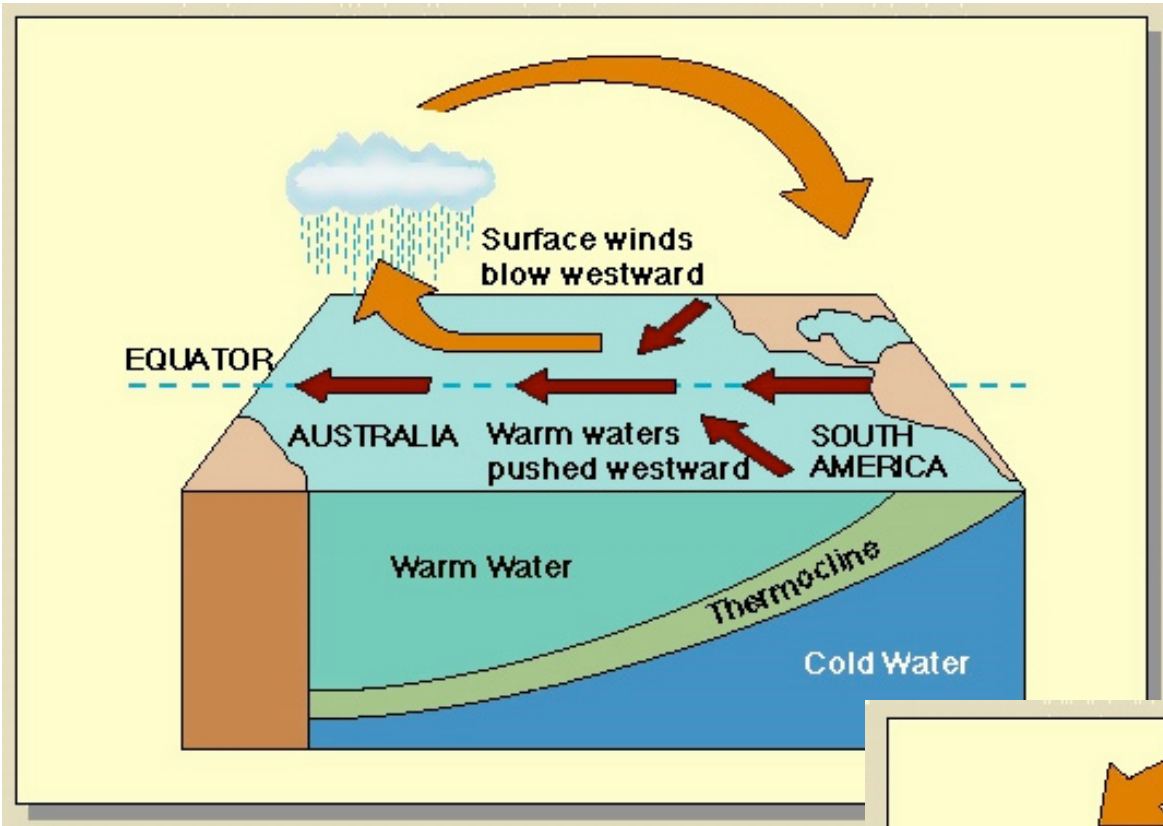


Coastal Zone Colour Scanner (CZCS) image showing phytoplankton abundance off the west coast of Vancouver Island and Washington.

The ocean plays a crucial role in determining global and regional climate:

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes



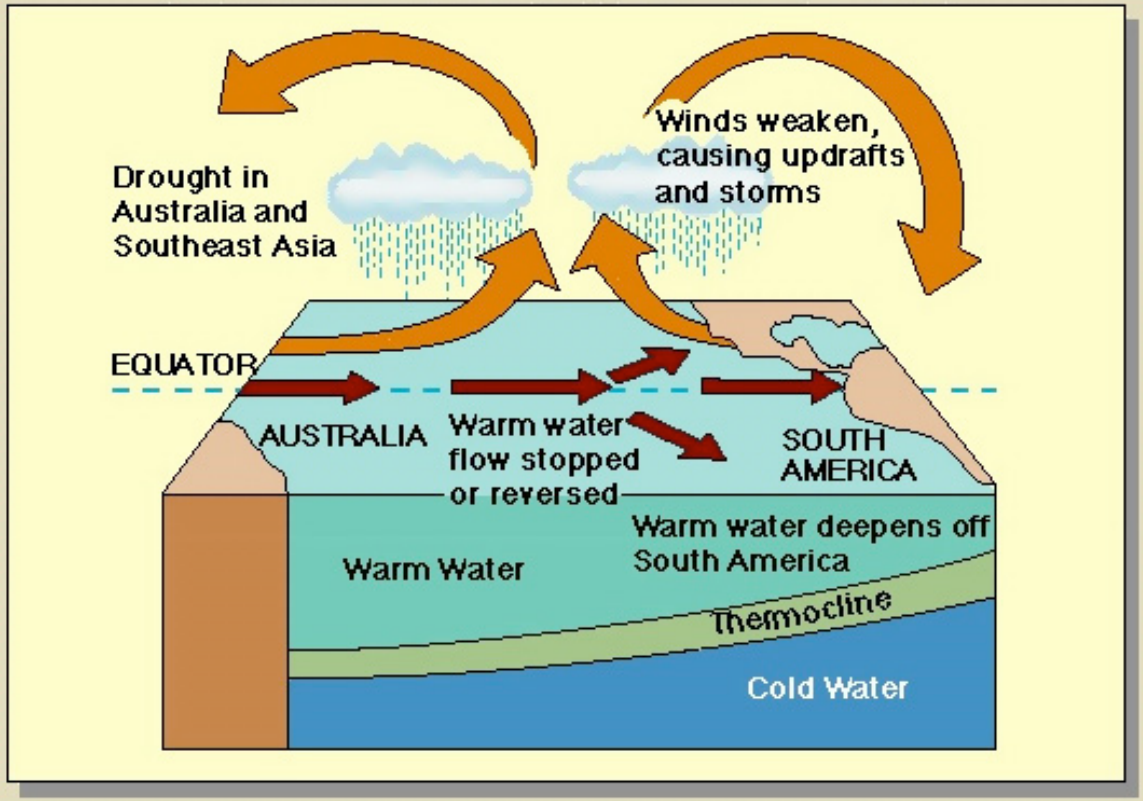
El Nino

Trade winds weaken

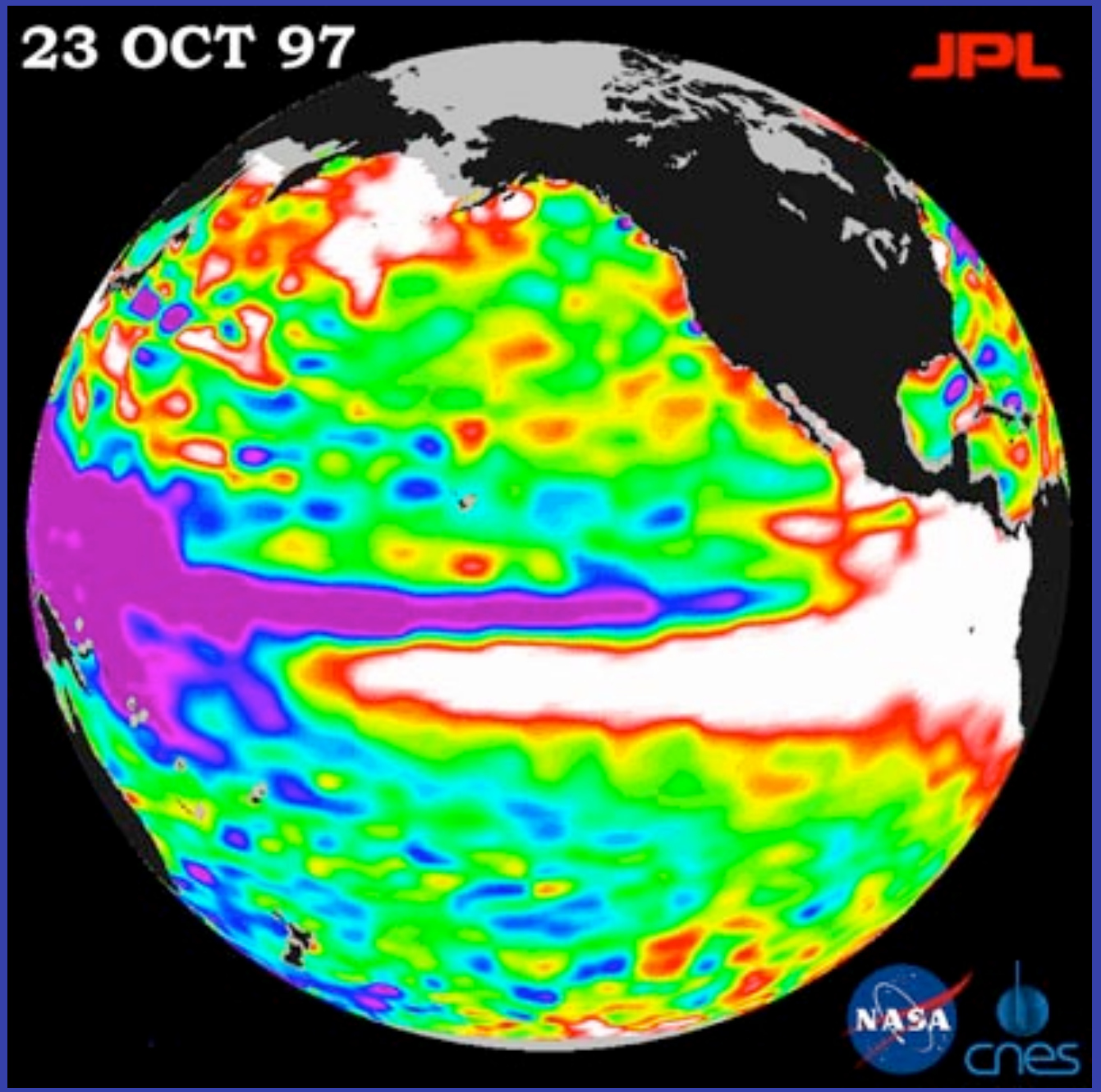
Coastal upwelling suppressed

Anomalously warm water in Eastern Pacific

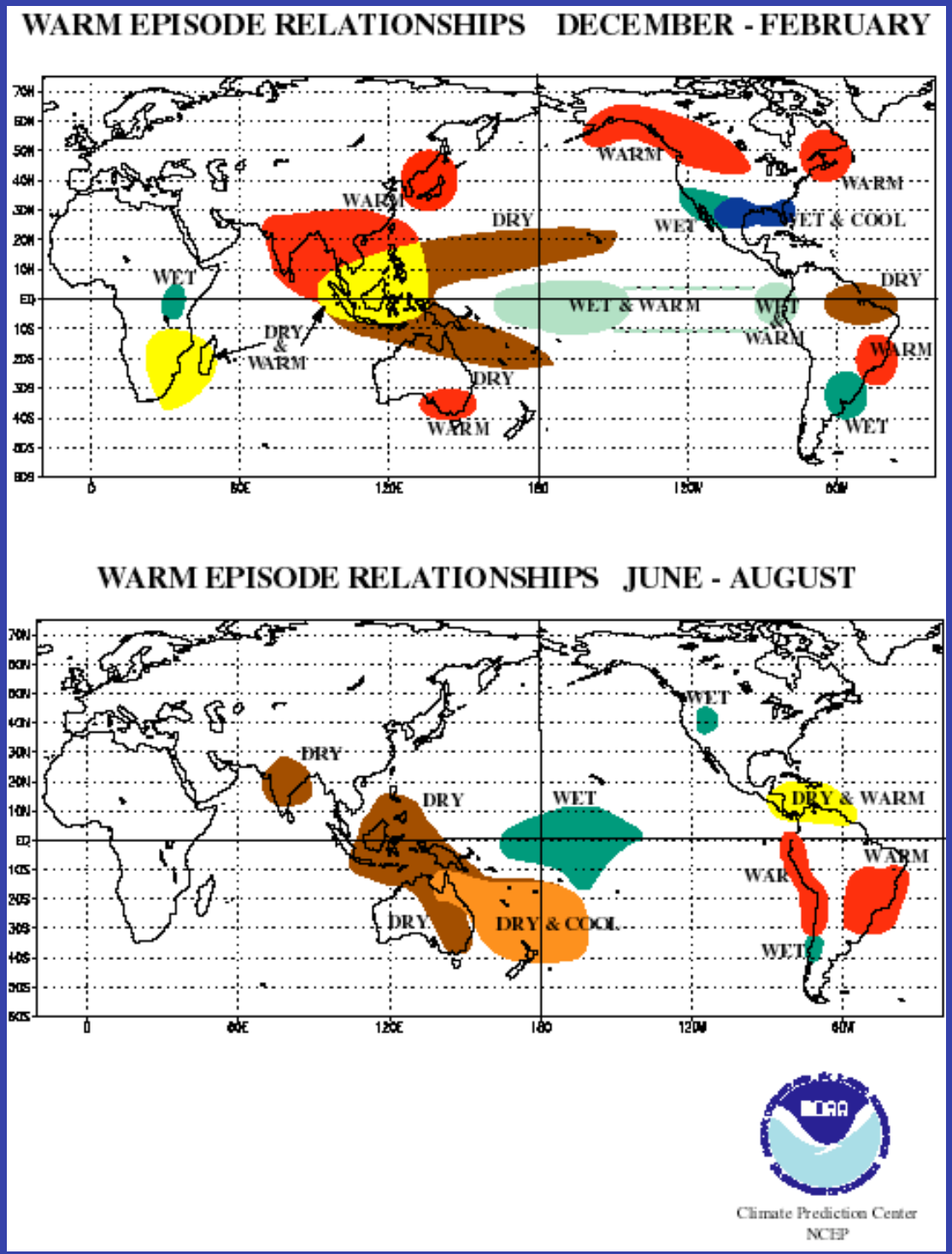
Entire global atmosphere affected



Anomalies in sea surface elevation during the 1997 El Nino



Measured by satellite altimetry



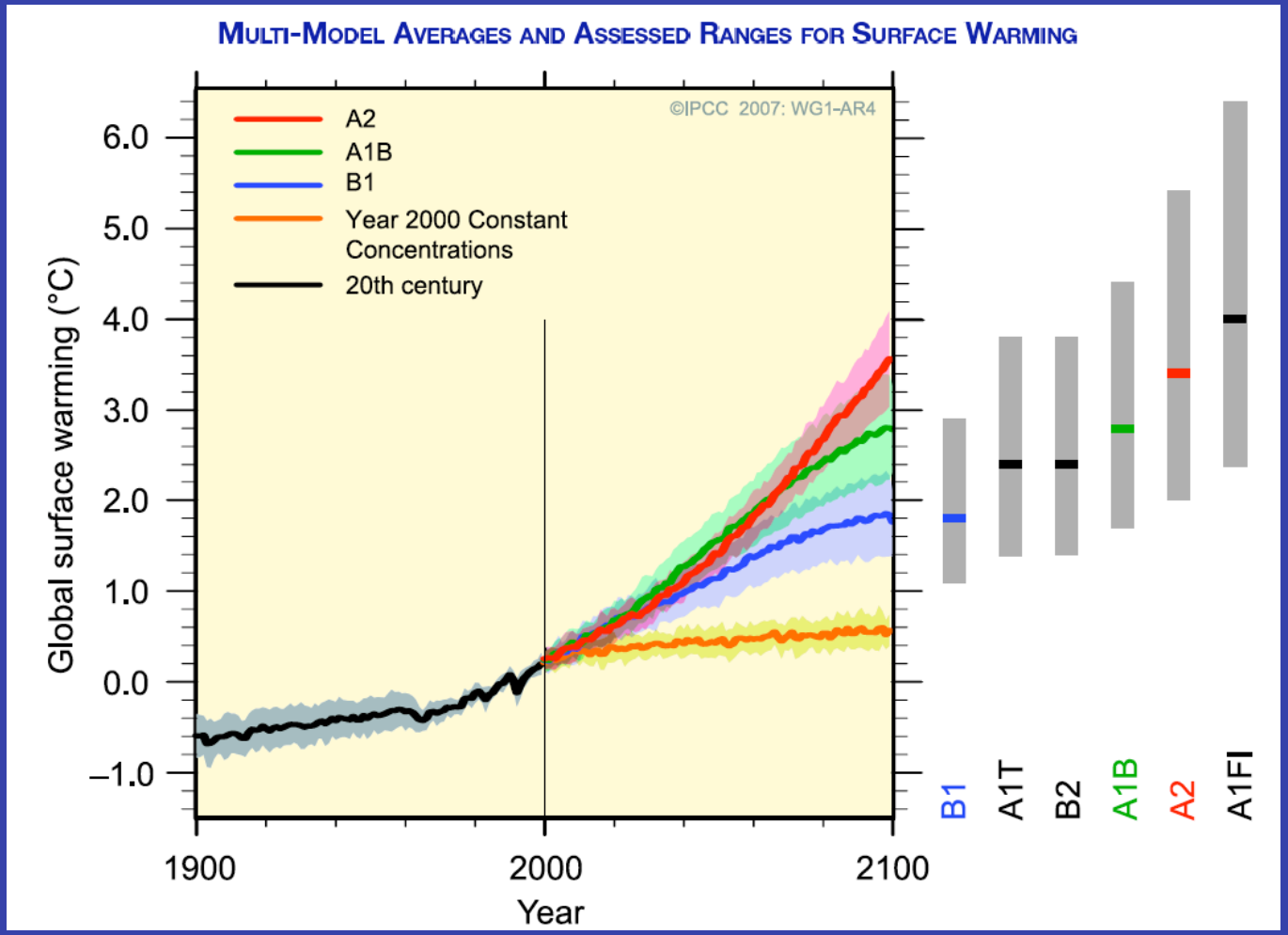
El Nino has an influence over much of the globe…

Ocean change in response to greenhouse gas emissions

- Heat storage
  - delay in climate system response
  - sea level rise
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

Projections of global mean surface temperature

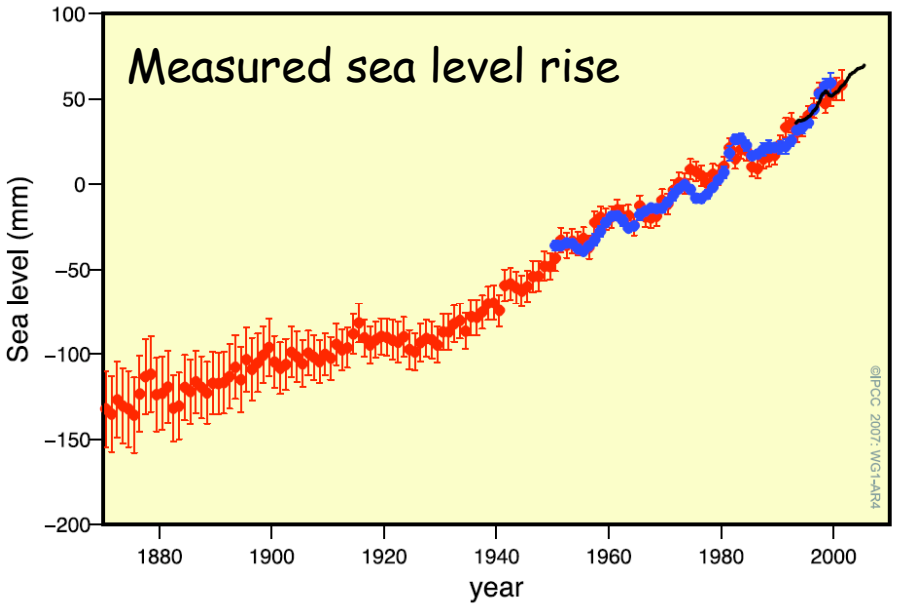


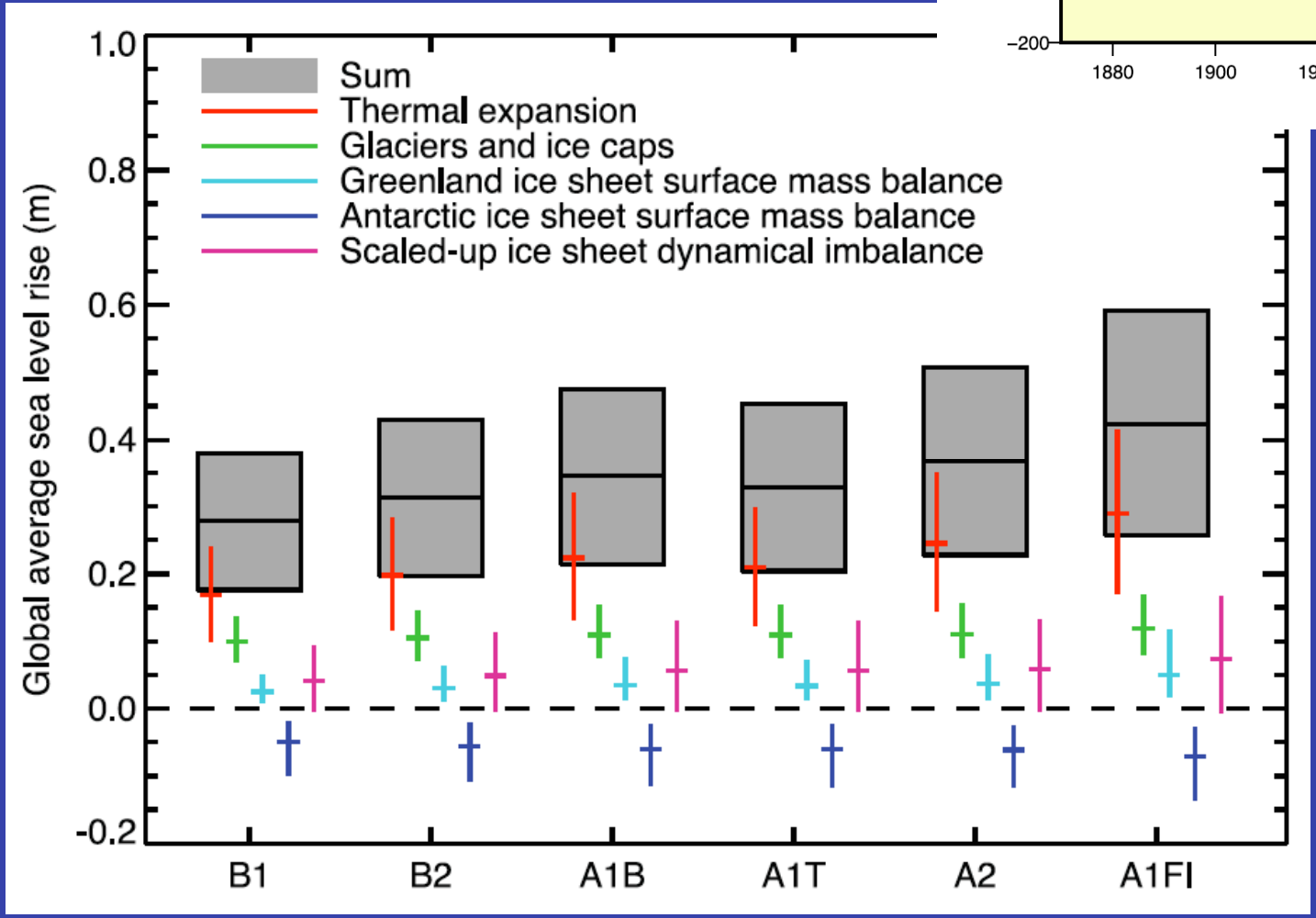
Likely ranges (over 66% probability)

"Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were stabilised."

IPCC (2007)

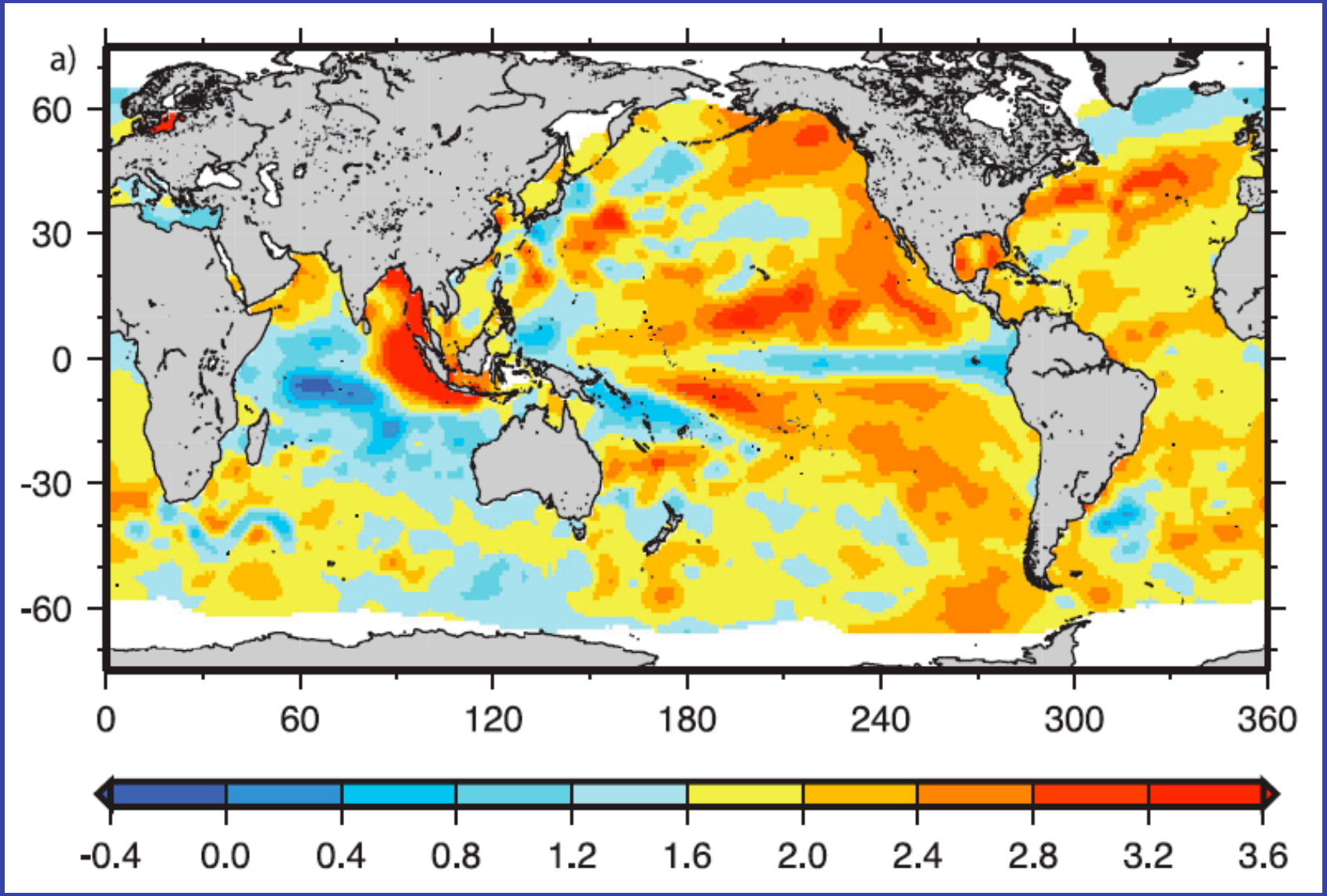
Sea level rise is mostly due to thermal expansion of the ocean





Projected sea level rise for 2090-2099 compared with 1980-1999 (IPCC 2007).

Regional patterns of sea level change



Linear trend in mean sea level (1955-2003)

IPCC (2007)

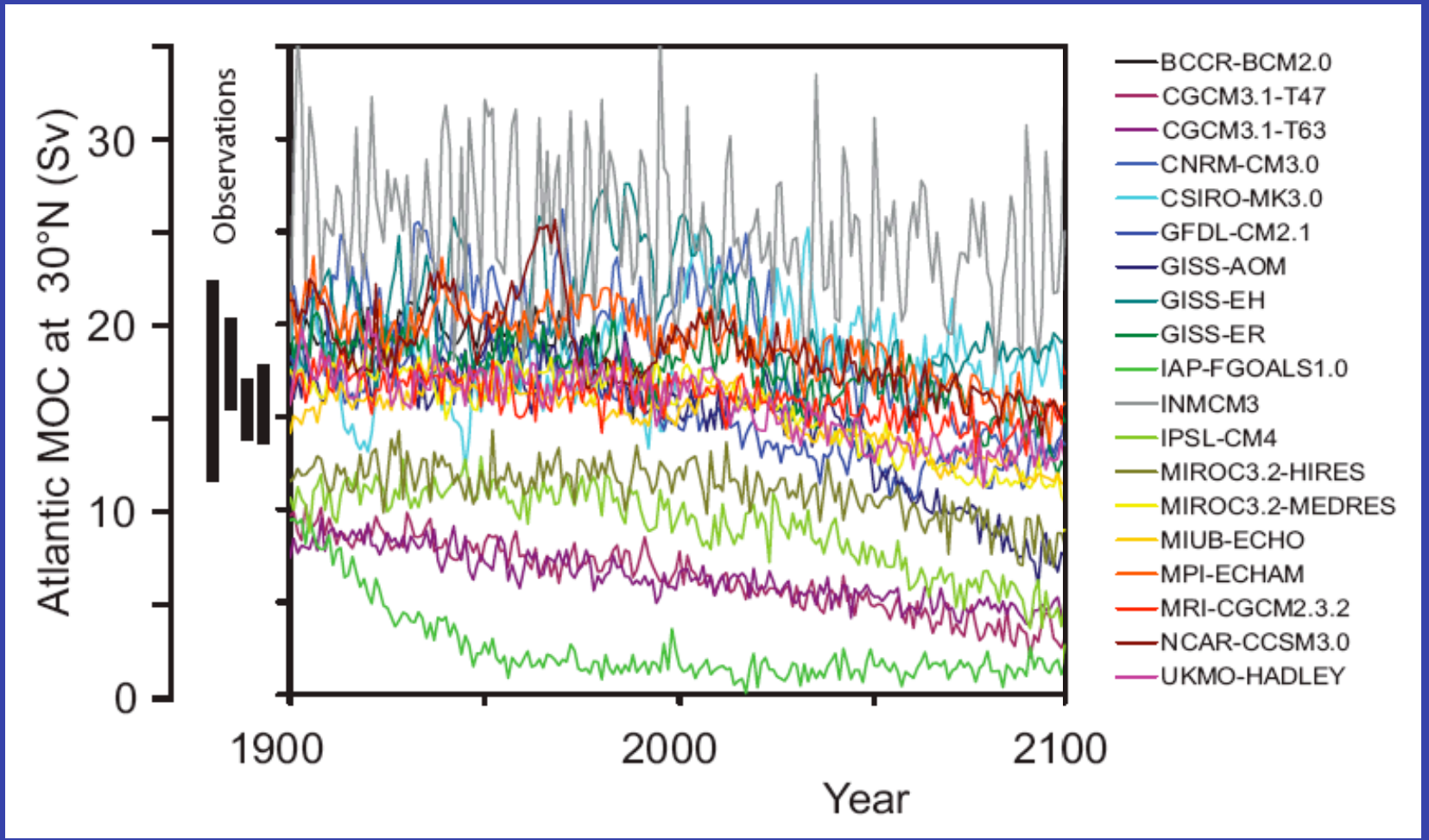
Ocean change in response to greenhouse gas emissions

- Heat storage
- Heat transport
  - thermohaline circulation change
  - sea-ice
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical processes

  e.g. El Nino, hurricanes

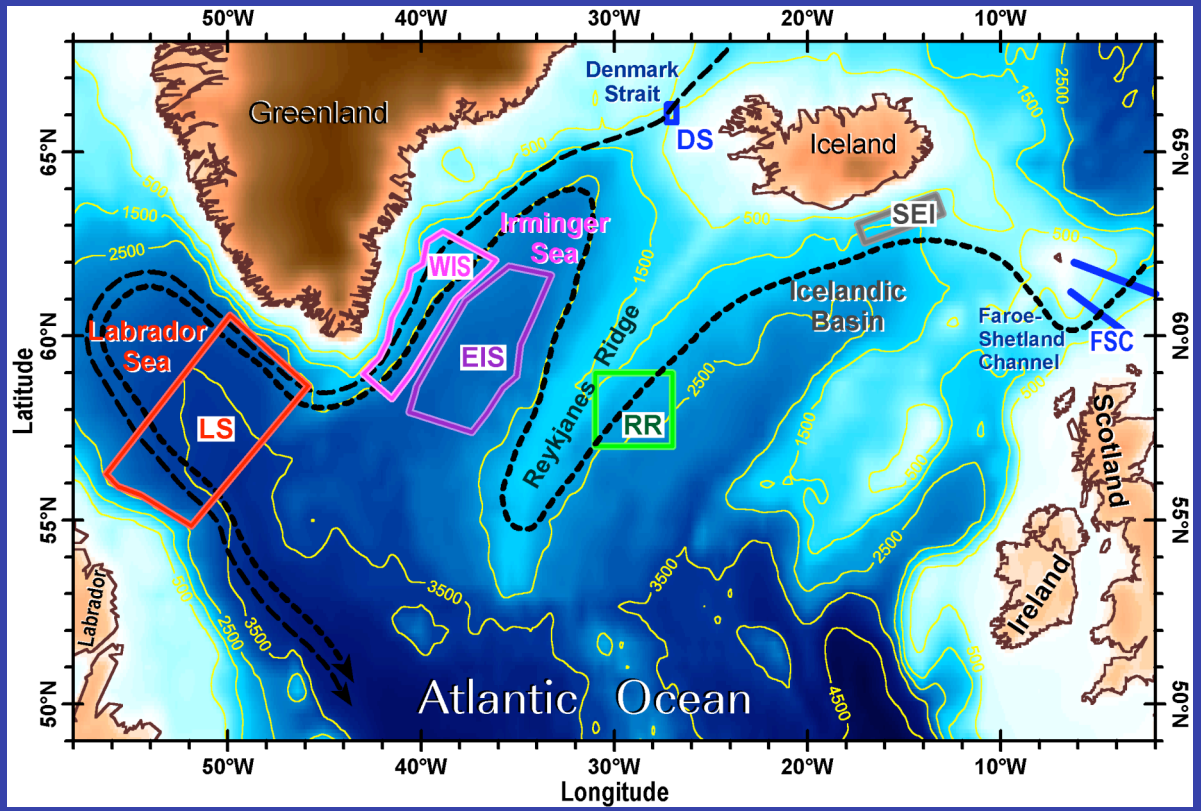
Increased fresh water fluxes at high latitudes (due to increased rain and ice-melt) may inhibit ocean convection and the formation of dense water.

Most models predict a weakening of the thermohaline circulation over the next century…

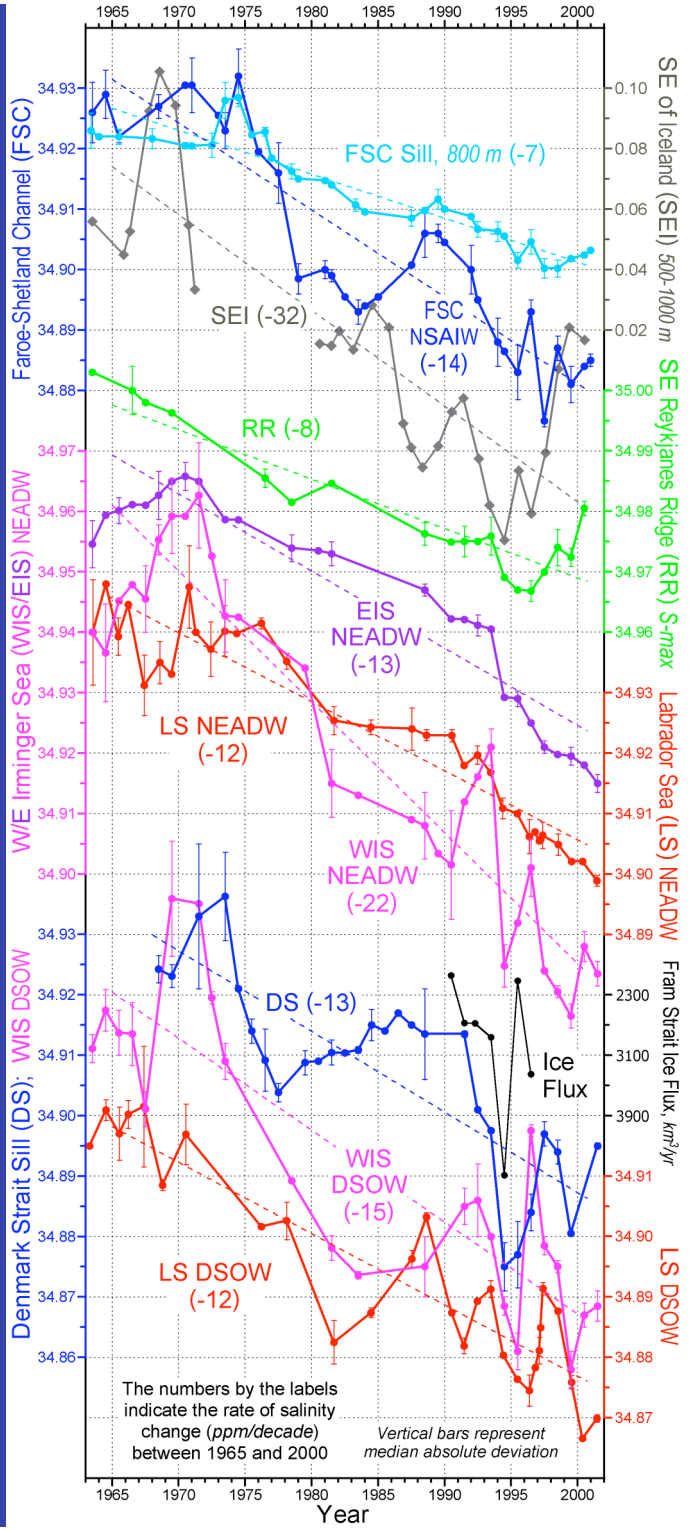


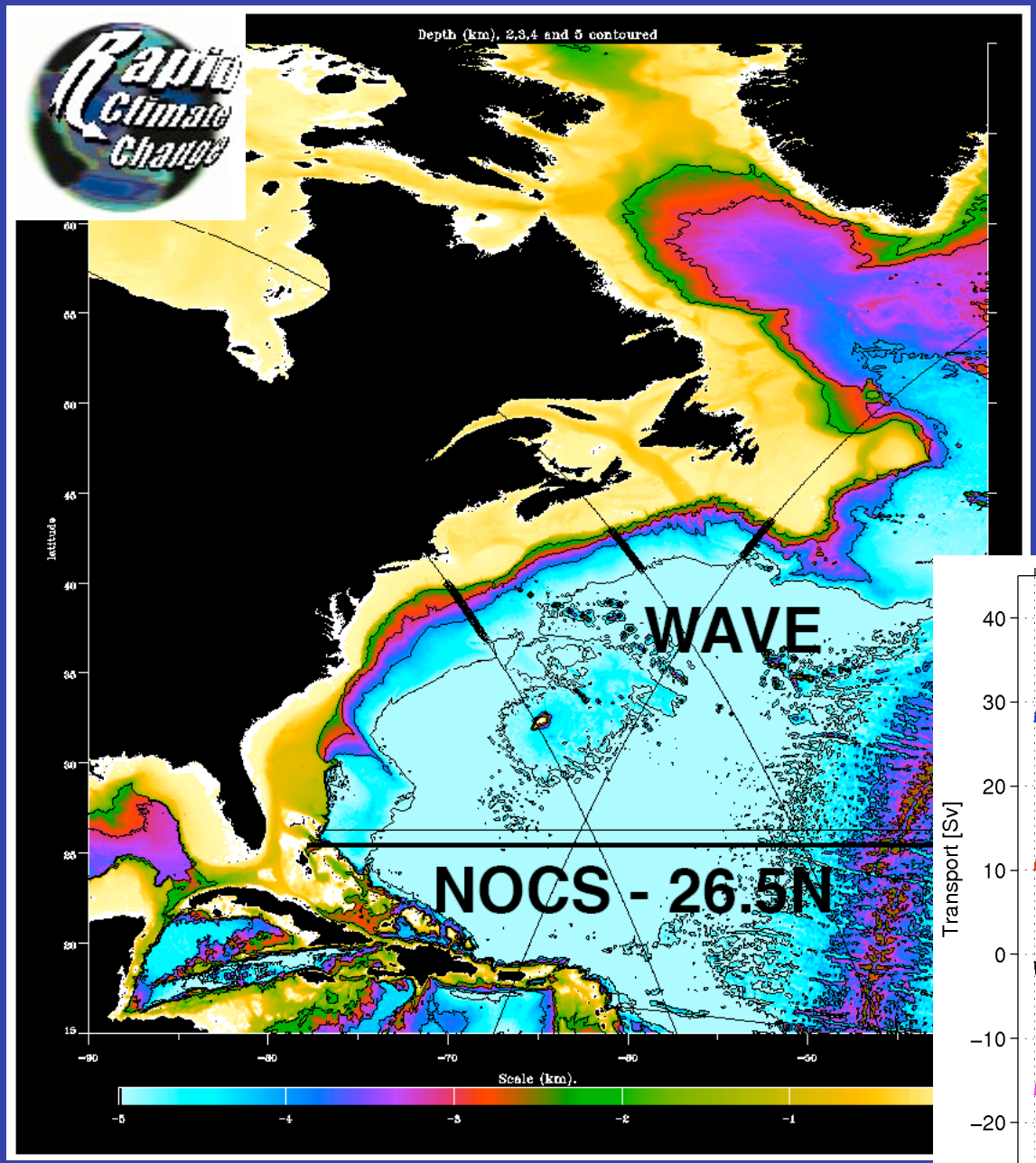
adapted from IPCC (2007)

Some evidence of rapid and steady freshening over the past four decades in the North Atlantic….



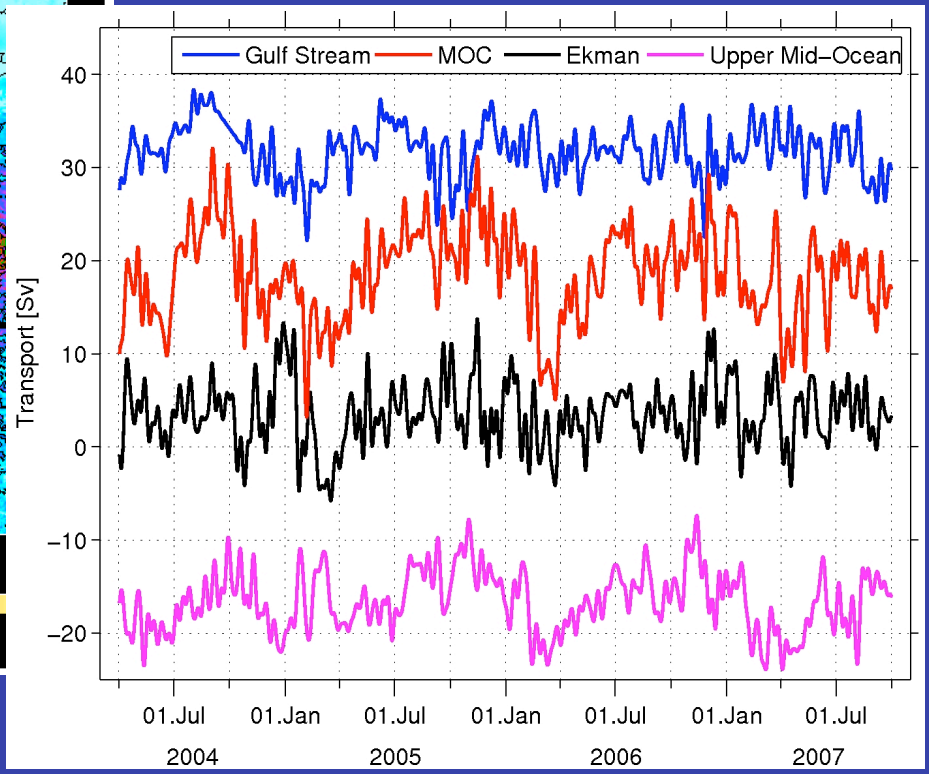
Dickson et al. (2002)





The RAPID observational array

- a prototype for monitoring the Atlantic thermohaline circulation

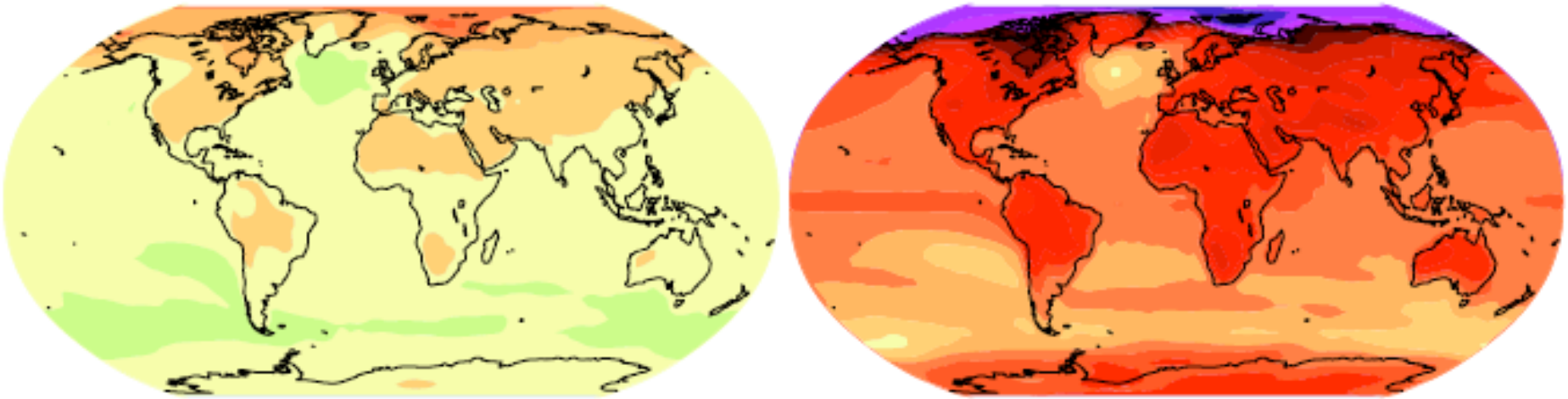


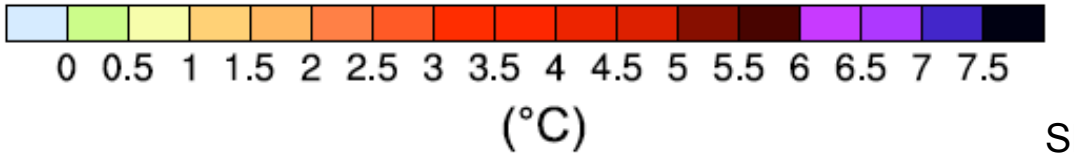
Kanzow et al. (2009)

Surface temperature projections

2020-2029

2090-2099





Multi-model mean

SRES A1B Scenario

IPCC (2007)

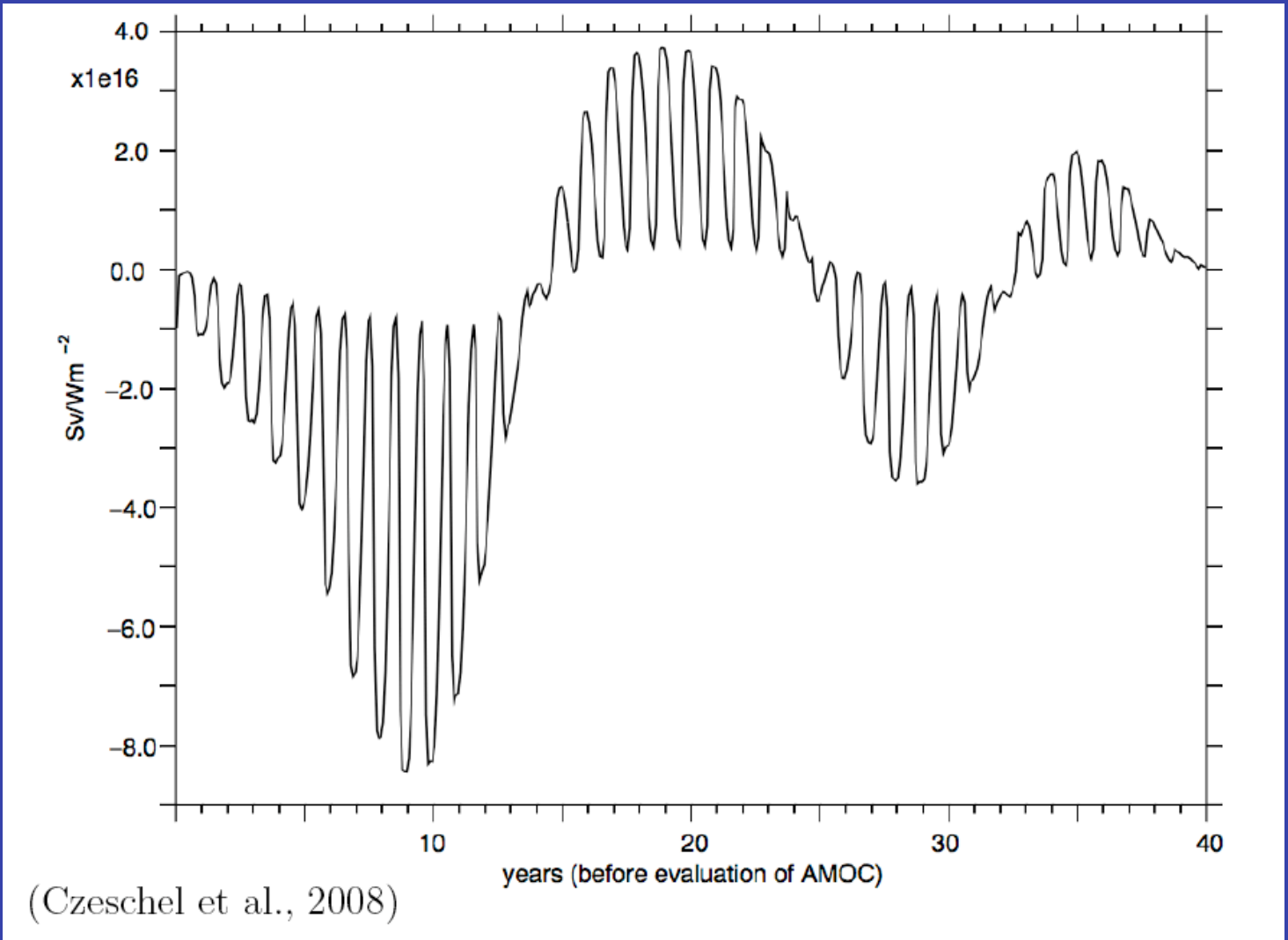
The Oxford Physical Oceanography group is currently working on many thermohaline circulation projects!

Observations of propagation along boundaries and of flow through key gateways…

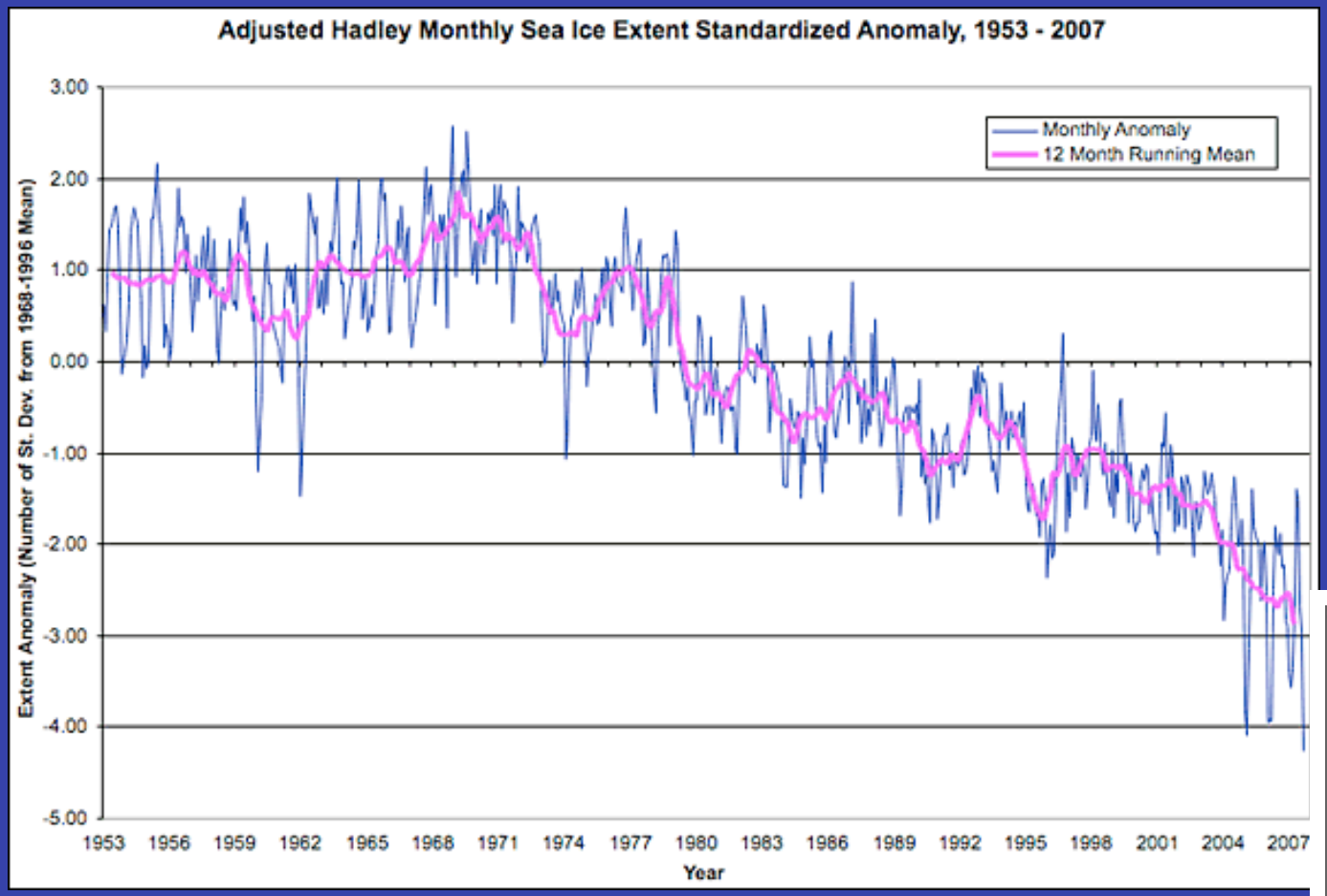
Canadian Archipelago Throughflow Study (CATS)

Theoretical studies investigating how the 3D thermohaline circulation adjusts to change, what sets its strength, whether it is able to change abruptly, how best to monitor, etc…

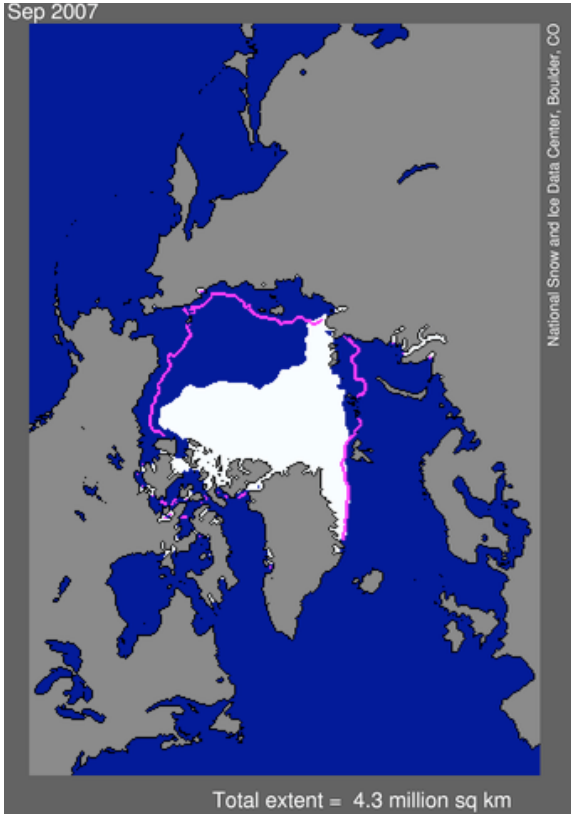
…and modelling studies to determine the sensitivity of the thermohaline circulation to heat and fresh water fluxes from the atmosphere.



Sensitivity of the overturning circulation at 27°N to heat flux over subpolar region (Czeschel et al. 2008)



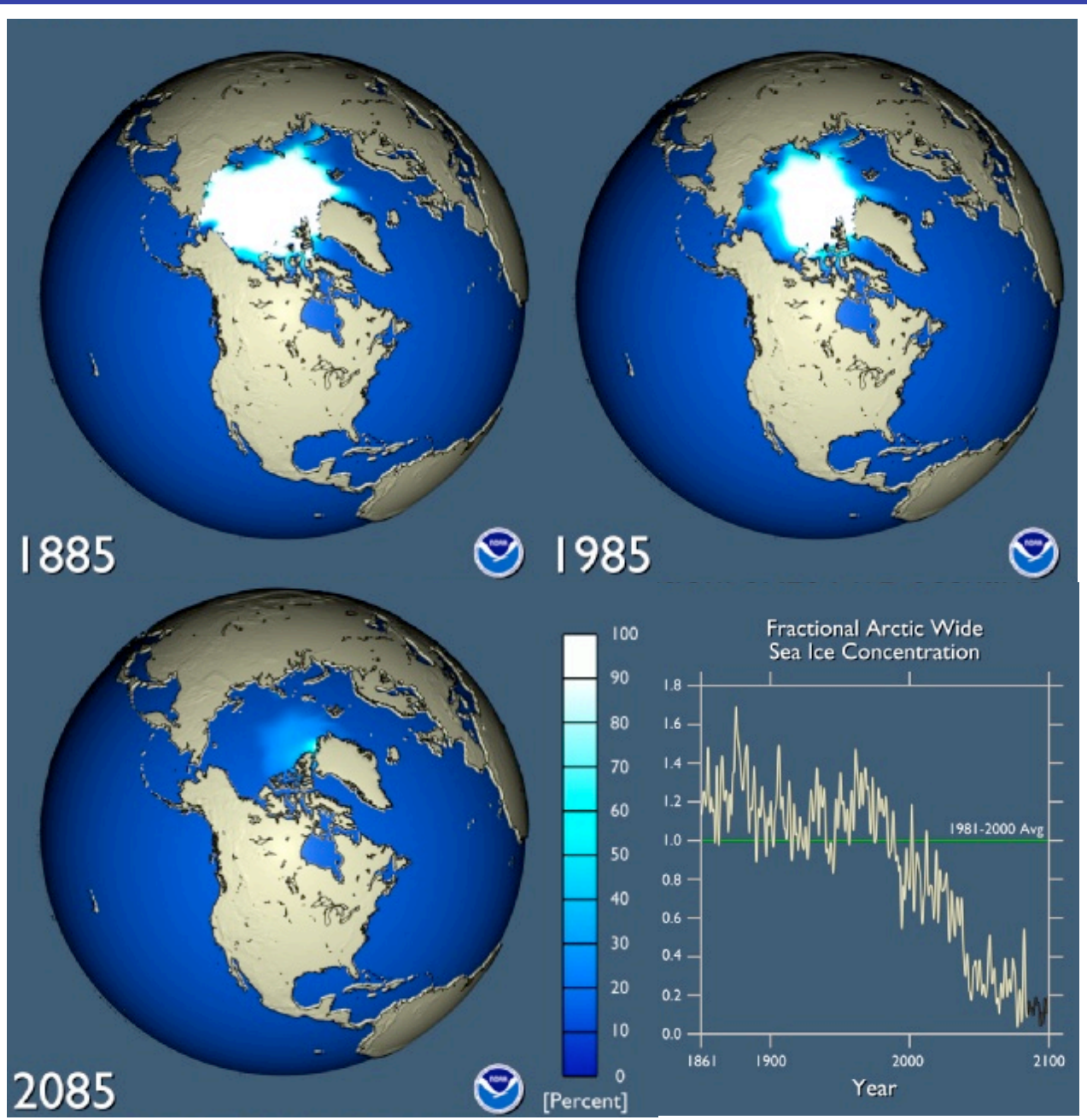
Change in sea-ice extent



September 2007 compared with median ice-edge 1979-2000

(National Snow and Ice Data Centre, Colorado)

Projected changes in sea-ice concentration



Aug/Sep/Oct average sea-ice concentration

NOAA GFDCL CM2.1 Model Simulation: SRES A1B Scenario.

Ocean change in response to greenhouse gas emissions

- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
  - e.g. if the thermohaline circulation slows down, transfer of carbon to the deep ocean will be reduced
- Coastal upwelling
- Tropical processes

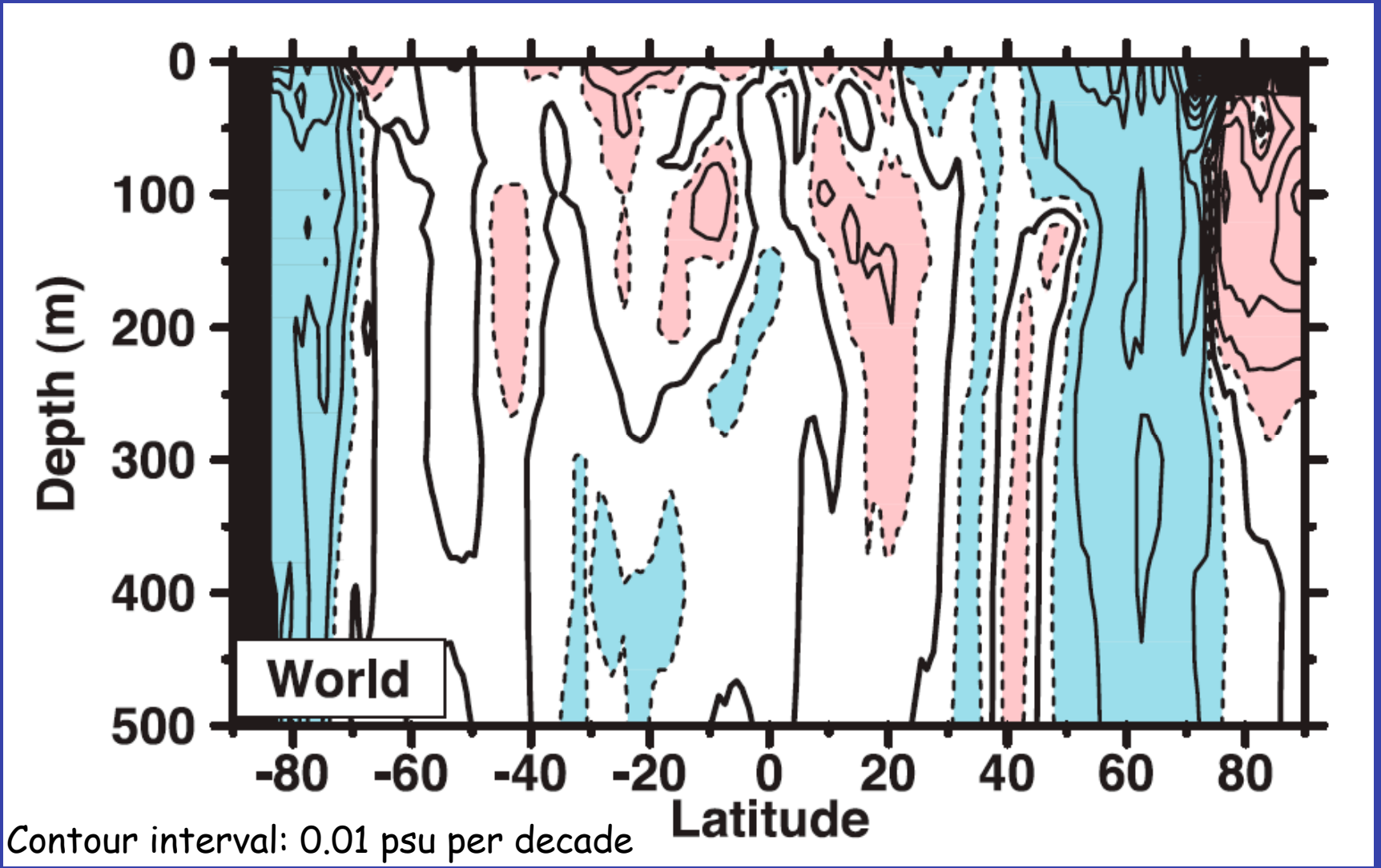
  e.g. El Nino, hurricanes

Ocean change in response to greenhouse gas emissions

- Heat storage
- Heat transport
- Hydrological cycle intensified
- Carbon cycle
- Coastal upwelling
- Tropical processes

    e.g. El Nino, hurricanes

Evidence of intensified hydrological cycle…?



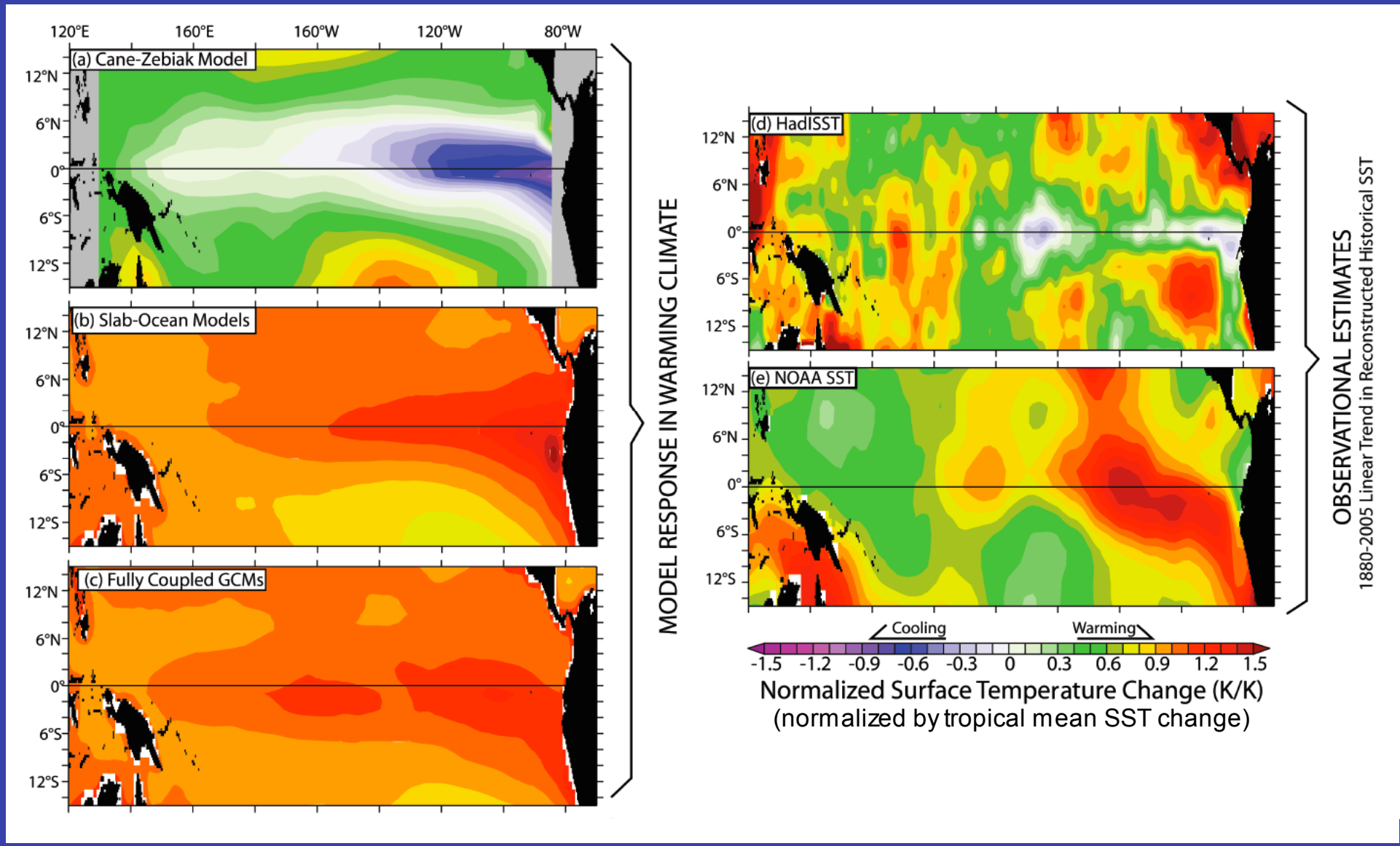
Change in zonal mean salinity 1955-1998

IPCC (2007)

Ocean change in response to greenhouse gas emissions

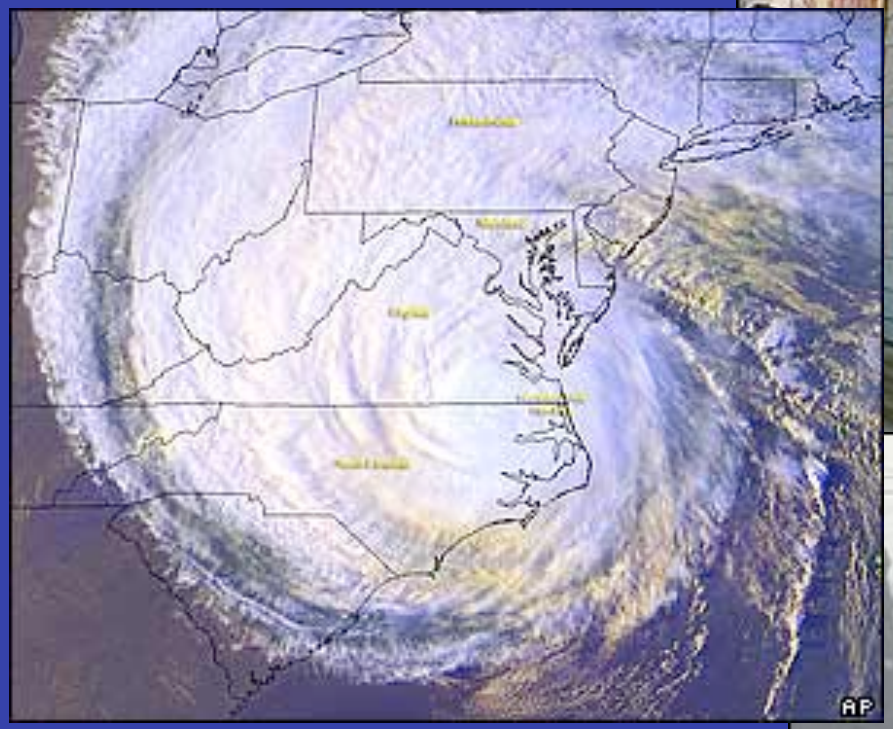
- Heat storage
- Heat transport
- Hydrological cycle
- Carbon cycle
- Coastal upwelling
- Tropical coupled ocean-atmosphere processes
    - frequency of El Nino?
    - hurricanes and tropical cyclones

Temperature change in the Tropical Pacific



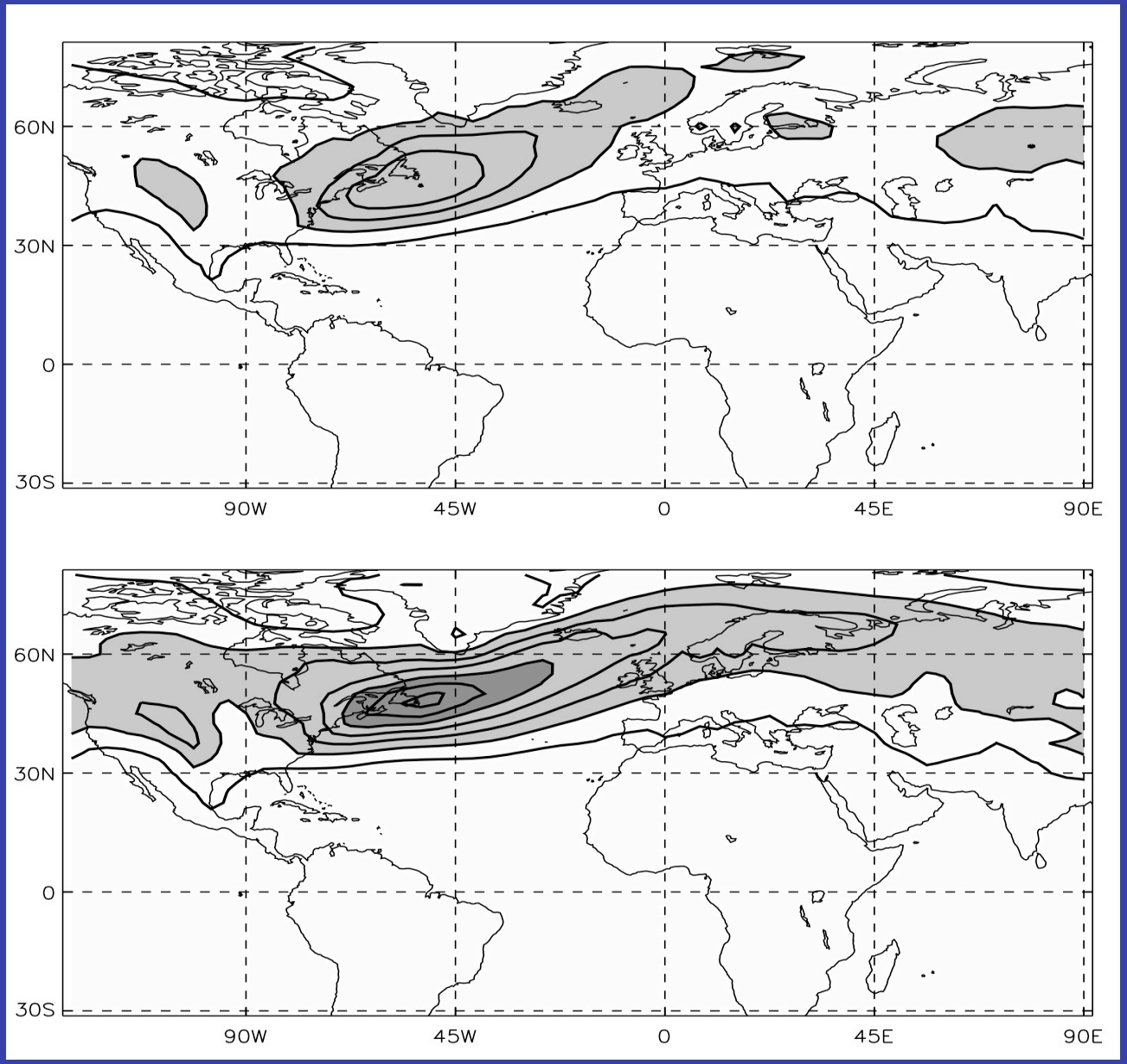
Vecci et al. (2008)

Hurricane formation depends on sea surface temperature



26.5 °C threshold

Effect of ocean change on mid-latitude storms



2-6 day mean sea-level pressure variance

Control run

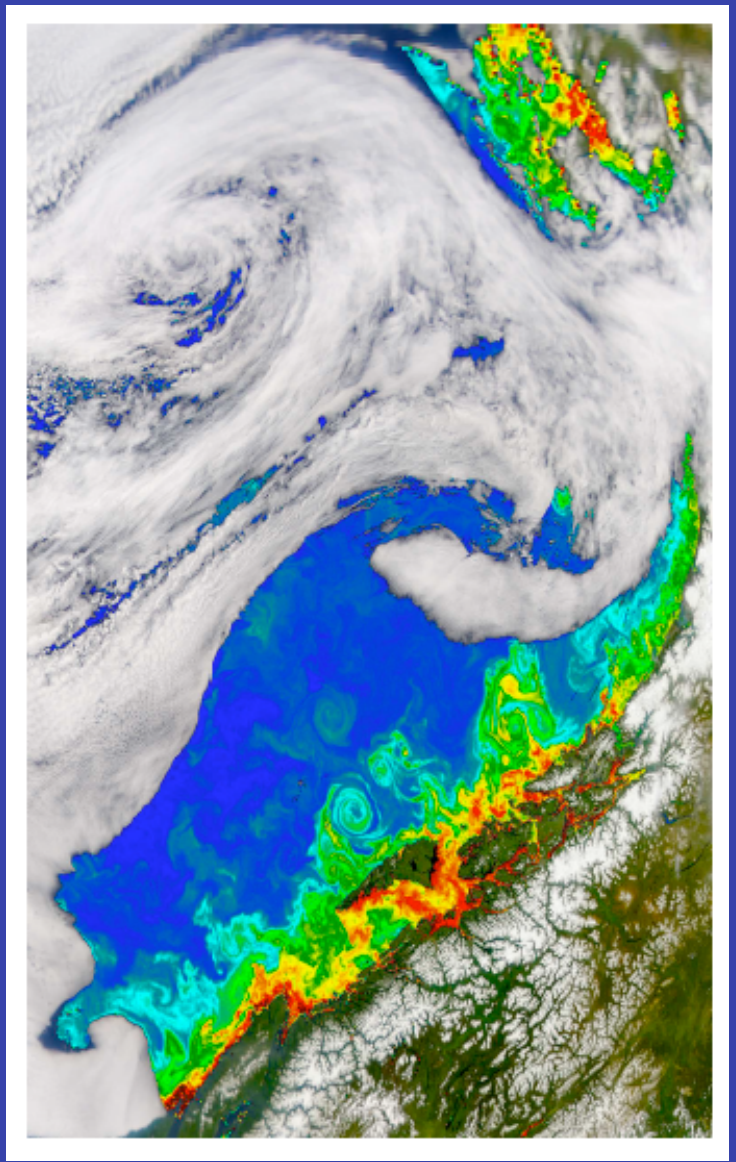
Experiment with thermohaline circn switched off

Brayshaw, Woollings and Vellinga (2008)

Why are there so many open questions??!

Challenges for modelling and observing climate change in the ocean:

- Large range of spatial scales
- Natural variability c.f. climate change?
- Physical processes not fully understood
- Links between the physical, chemical and biological parts of the system only just beginning to be investigated!



Summary

The ocean plays a crucial role in determining global and regional climate.

Therefore, global warming induced changes in the ocean have the potential to significantly feed back on climate.

Some ocean changes may offset the direct effects of global warming, while others may accentuate them.

Significant change has already occurred, and we are committed to more as a result of the long timescales involved.

Our ability to predict the ocean's response to change and its consequences for climate is still limited.


Questions?