Review on Ocean Heat Content Variation and Ocean Warming

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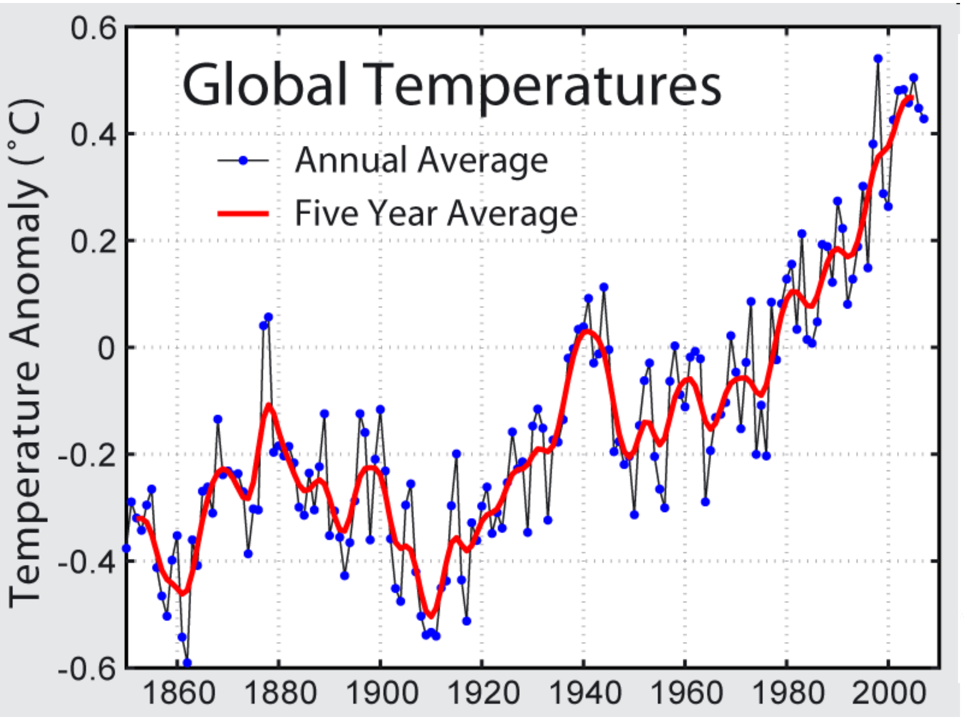
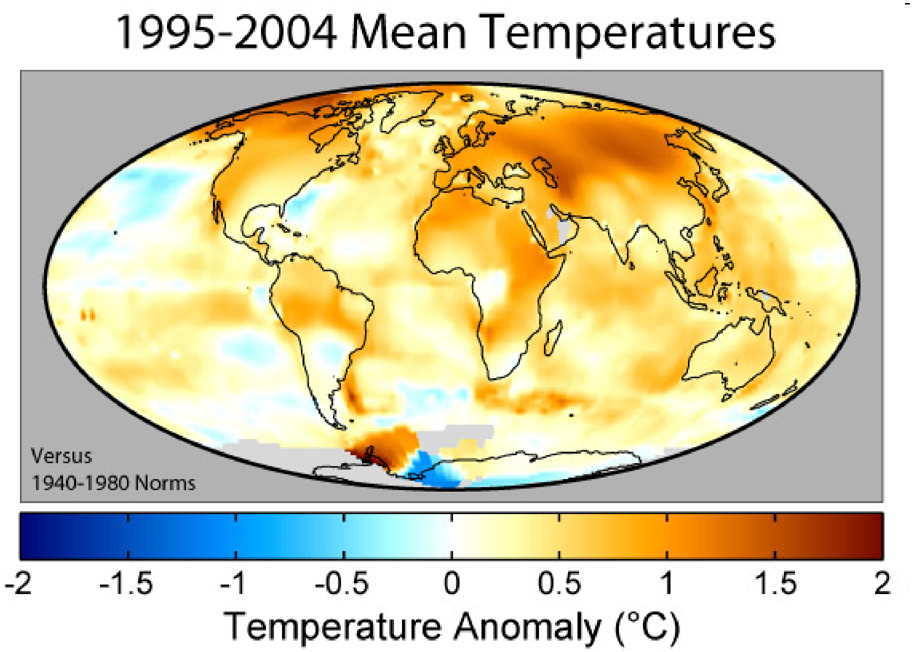
Outline

- Introduction
- Temporal and Spatial Variability
- GCM Model simulation results
- PCM Model simulation results
- Interannual variability
- Large-scale trends in salinity

Introduction



Global mean surface temperature anomaly relative to 1961–1990

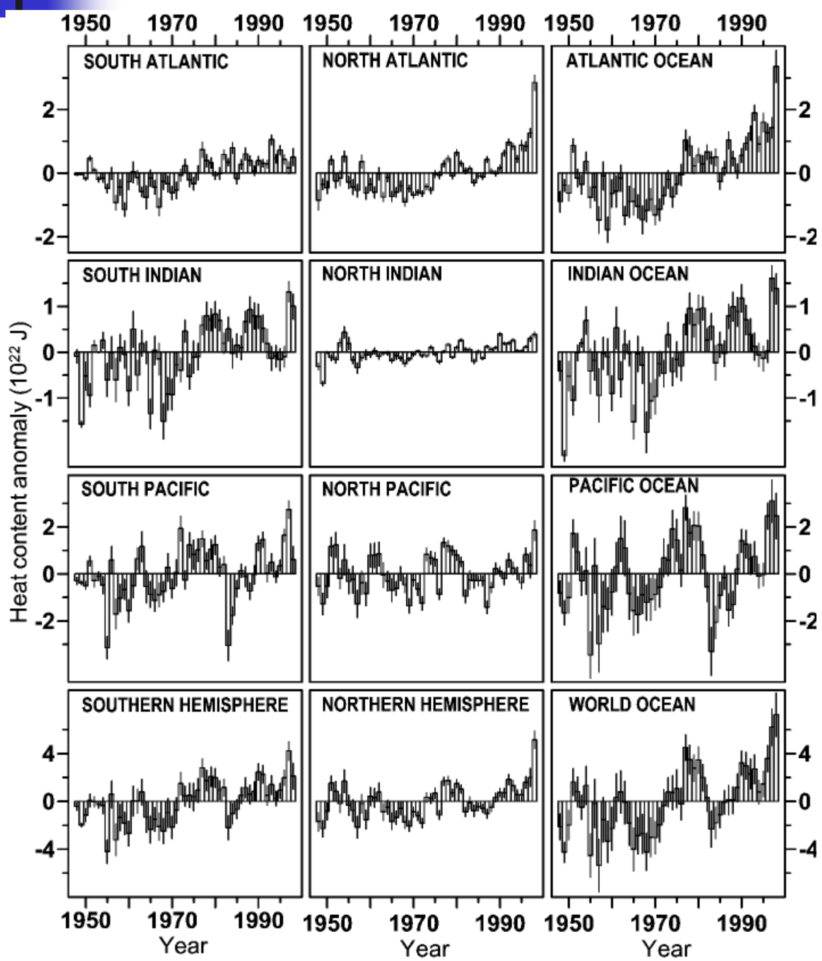


Mean surface temperature anomalies during the period 1995 to 2004 with respect to the average temperatures from 1940 to 1980

Introduction

- Understanding how ocean warming and the resulting thermal expansion contributes to rising sea levels is critically important to understanding climate change, and forecasting future temperature rises.
- Scientists found that from 1961 to 2003, ocean temperatures to a depth of 700 metres, contributed to an average rise in sea levels of 0.52 millimetre-per-year compared to a 0.32 millimetre rise reported by the IPCC 2007.
- “Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.” -----IPCC 2007

Temporal Variability of Upper Ocean Heat Content



-- Levitus et al., 2000

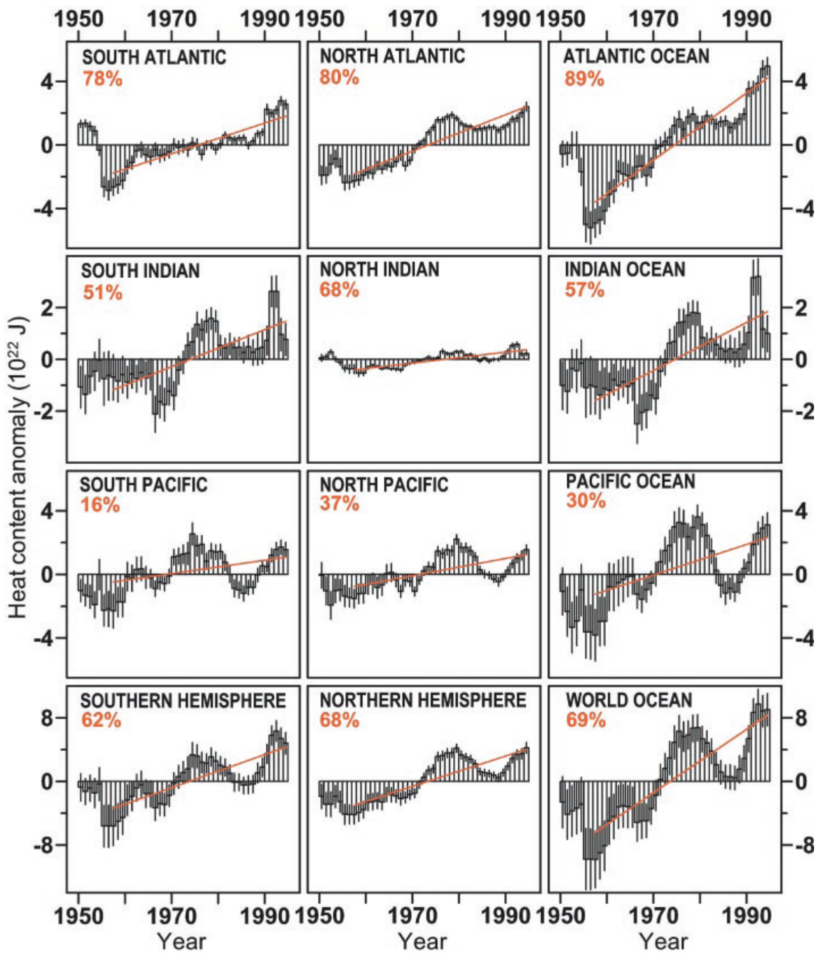
- The anomaly fields for the Atlantic and Indian oceans show a positive correlation.

- In each basin before the mid-1970s, temperatures relatively cool, whereas after the mid-1970s these oceans are in a warm state.

- Both Pacific Ocean basins exhibit quasi-bidecadal changes in upper ocean heat content, with the two basins positively correlated.

- A decadal-scale oscillation in North Pacific sea surface temperature (Pacific Decadal Oscillation) has been identified.

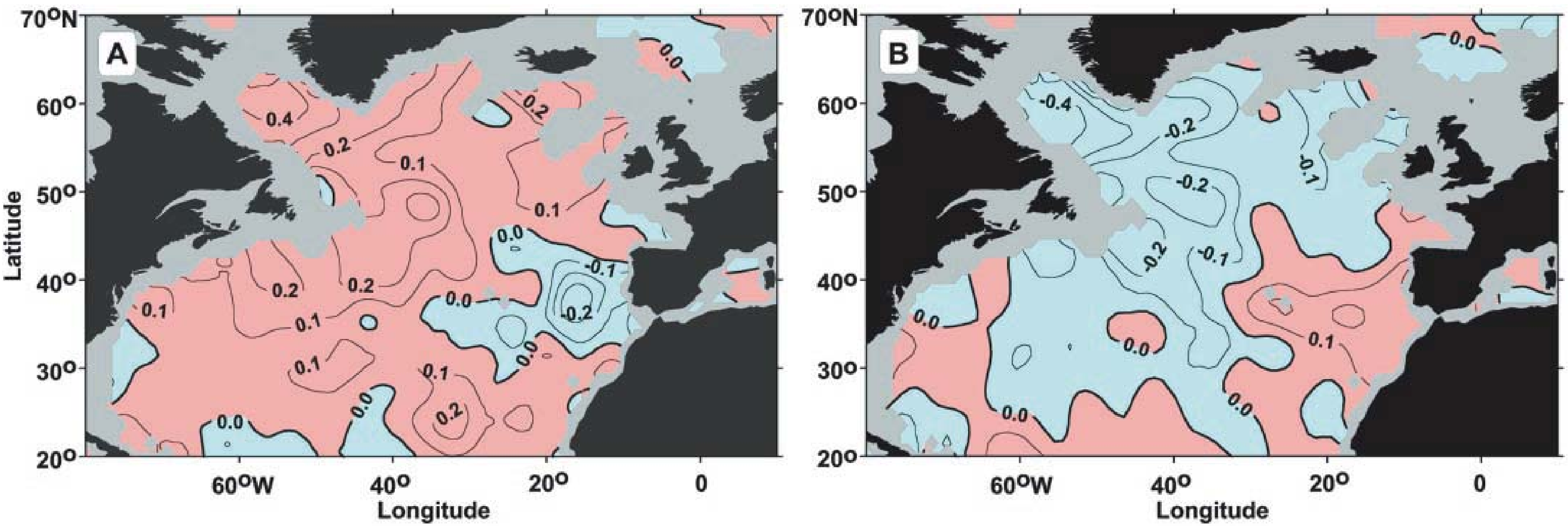
Temporal Variability of Upper Ocean Heat Content



-- Levitus et al., 2000

- Consistent warming signal in each ocean basin, not monotonic.
- North and south Pacific and Indian oceans are positively correlated, suggesting the same basin-scale forcings.
- The temporal variability of the South Atlantic differs significantly from the North Atlantic, due to the deep convective processes that occur in the North Atlantic.
- The delayed warming of the Indian Ocean may be due to the sparsity of data in the Indian Ocean before 1960.

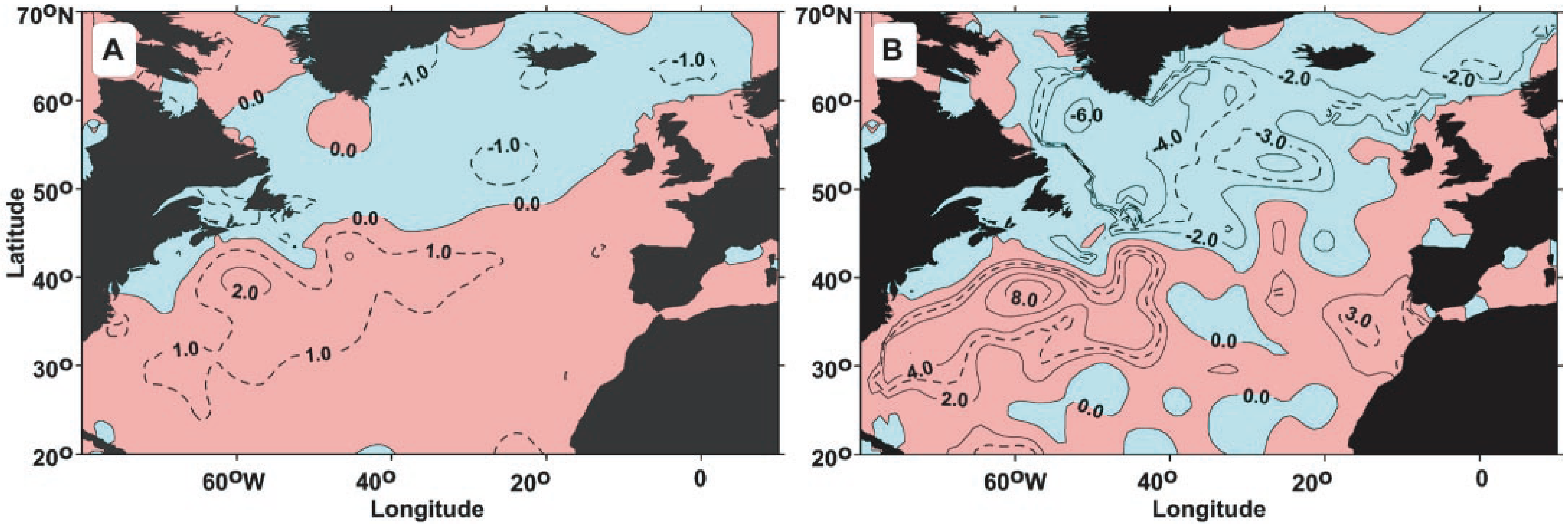
Temporal Variability of Upper Ocean Heat Content



Temperature difference (C) at 1750-m depth of the North Atlantic for (A) 1970-74 minus 1955-59 and (B) 1988-92 minus 1970-74.

-- Levitus et al., 2000

Temporal Variability of Upper Ocean Heat Content



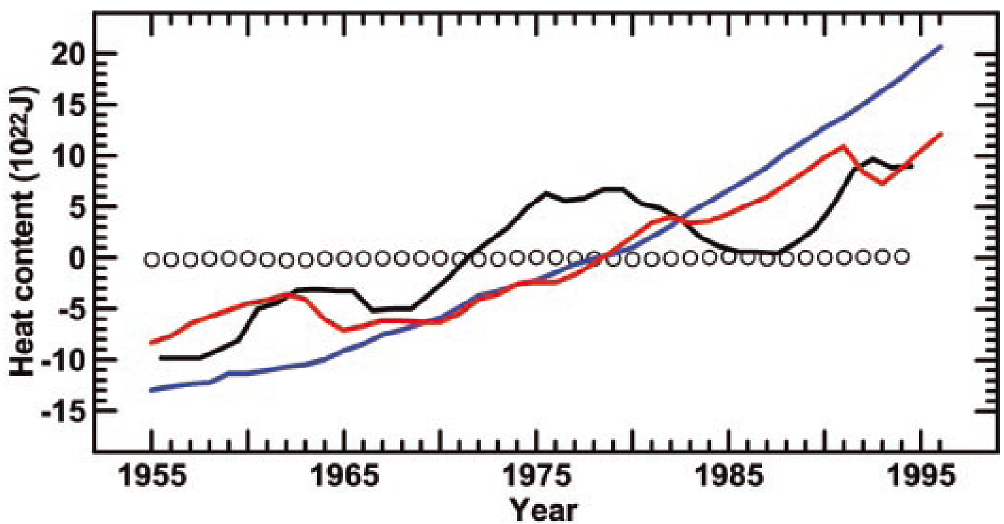
Heat storage for the North Atlantic for 1988-92 minus 1970-74. (A) Integral between the surface and 300-m depth; (B) integral between the surface and 3000-m depth.

-- Levitus et al., 2000

GCM Model simulation results

- coupled ocean-atmosphere-ice model
- global in domain and consists of GCMs of the atmosphere and ocean
- Atmosphere: 3.75° longitude by 2.25° latitude, with 14 vertical levels.
- Ocean: 1.875° longitude by 2.25° latitude, with 18 vertical levels.
- Over oceanic regions, a thermodynamic sea ice model is used that includes the advection of ice by surface ocean currents.

GCM Model simulation results



Time series of various components of the observed and simulated global heat content.

Two ensembles of integrations: the first ensemble includes the radiative effects of the observed temporal variations in GHGs, sulfate aerosols, solar irradiance, and volcanic aerosols over the past century;

the second ensemble omits the radiative effects of changes in solar irradiance and volcanic aerosols.

First ensemble, linear trend, excellent agreement with the observed estimate

Second ensemble, 70% larger than in first one or than the observed estimate.

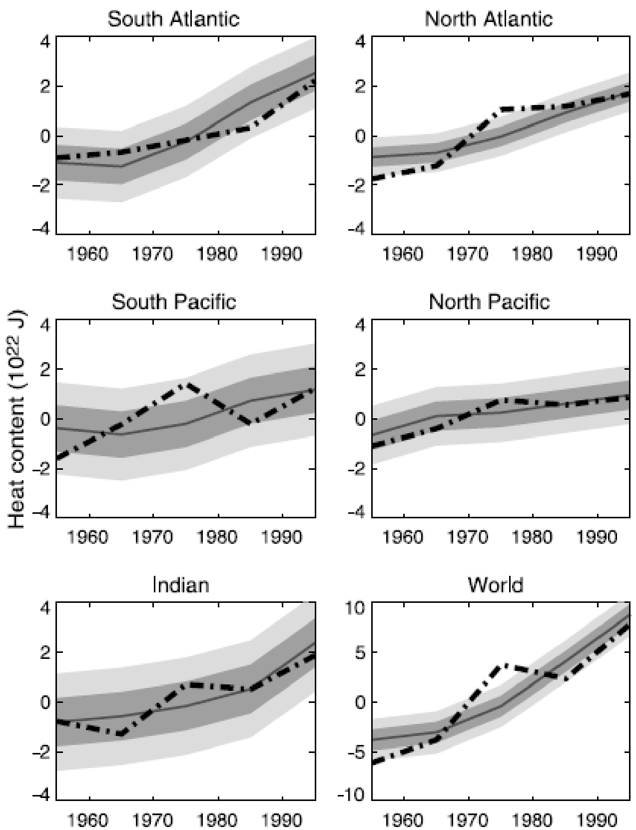
The difference is primarily due to the radiative effects of volcanic activity.

-- Levitus et al., 2001

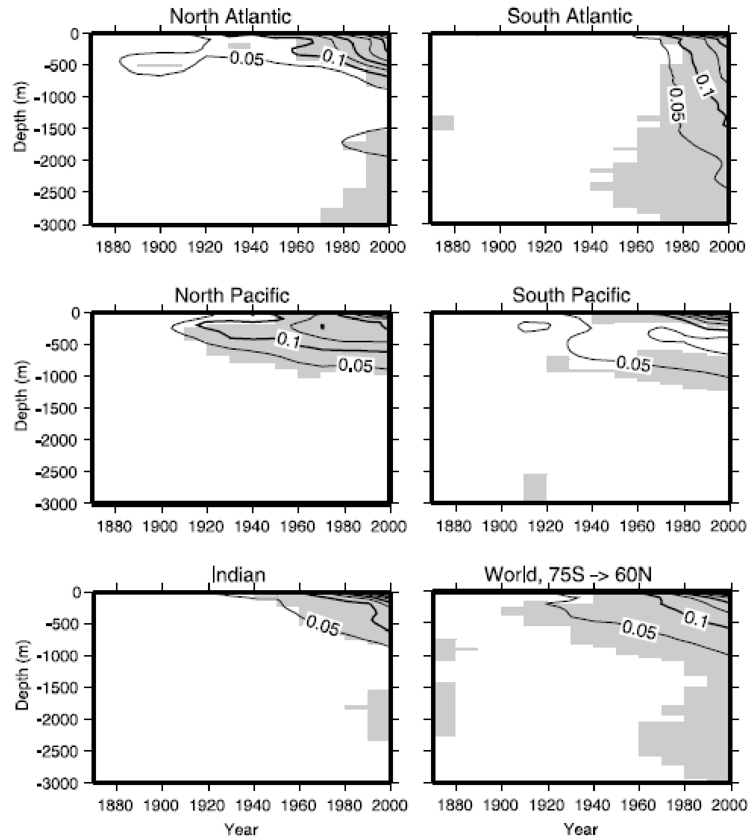
PCM Model simulation results

- Parallel Climate Model (PCM): a state-of-the-art global climate model.
- Using no flux-correction scheme, forced by observed and estimated concentrations of greenhouse gases and the direct effect of sulfate aerosols on the atmosphere.

PCM Model simulation results



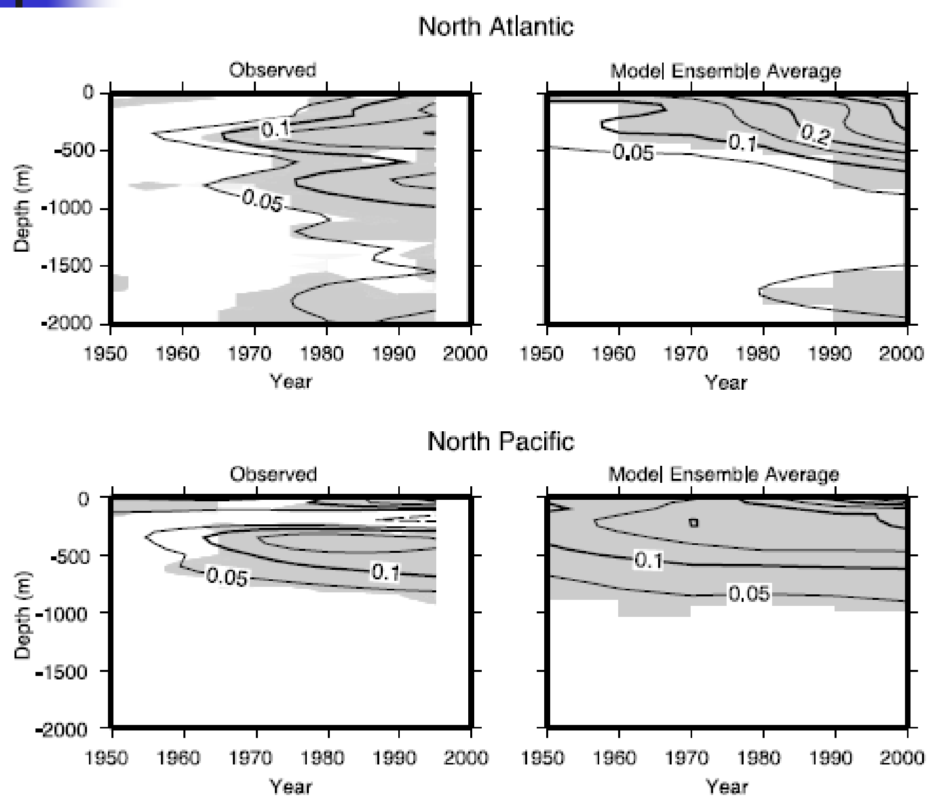
Decadal values of anomalous heat content in various ocean basins.



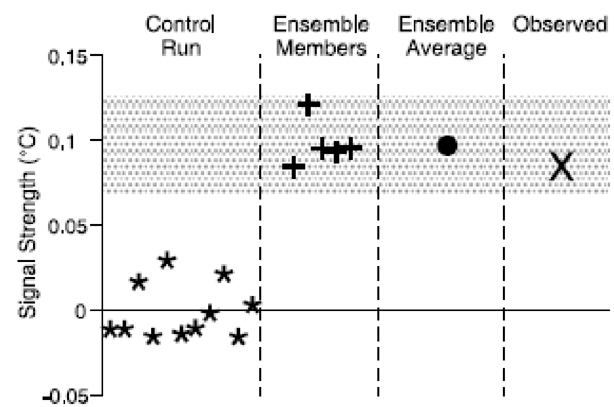
Decadal temperature anomalies (° C) in various ocean basins since 1870 from the PCM

-- Barnett et al., 2001

PCM Model simulation results



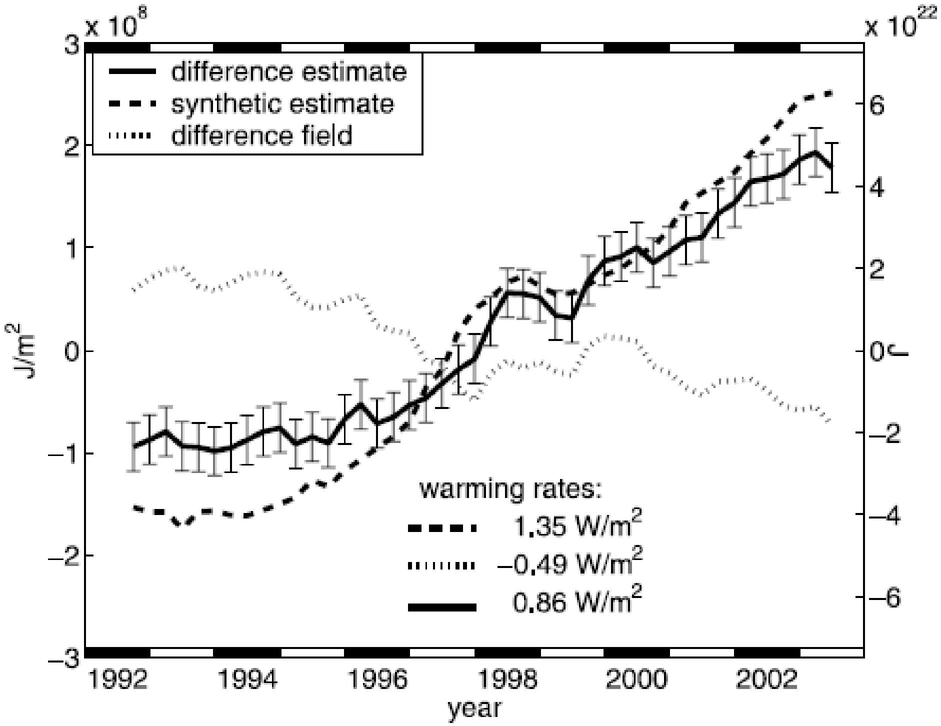
Modeled and observed temporal and vertical changes in the temperature in the upper 2000 m of the data-rich North Pacific and North Atlantic Oceans.



Detection and attribution diagram

-- Barnett et al., 2001

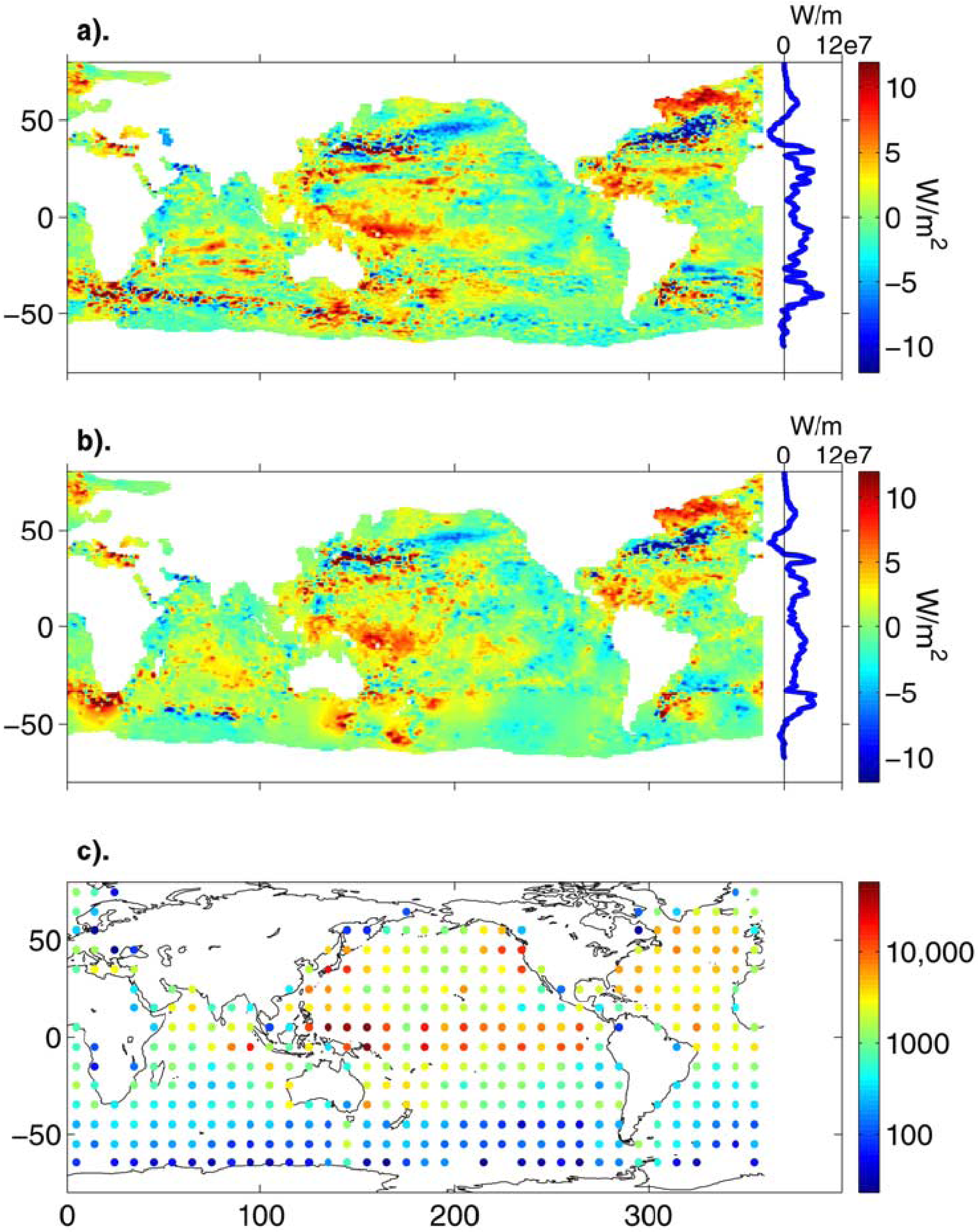
Interannual variability of upper ocean heat content



Globally averaged heat content variability.

- A considerable warming trend
- The 10-year heat increase from mid-1993 to mid-2003 implied an average warming rate of 0.86 $\pm$0.12 watts per square meter of ocean
- A significant amount of interannual variability is present in the time series of the difference field

-- Willis et al., 2004



Maps of 10-year change in heat content.

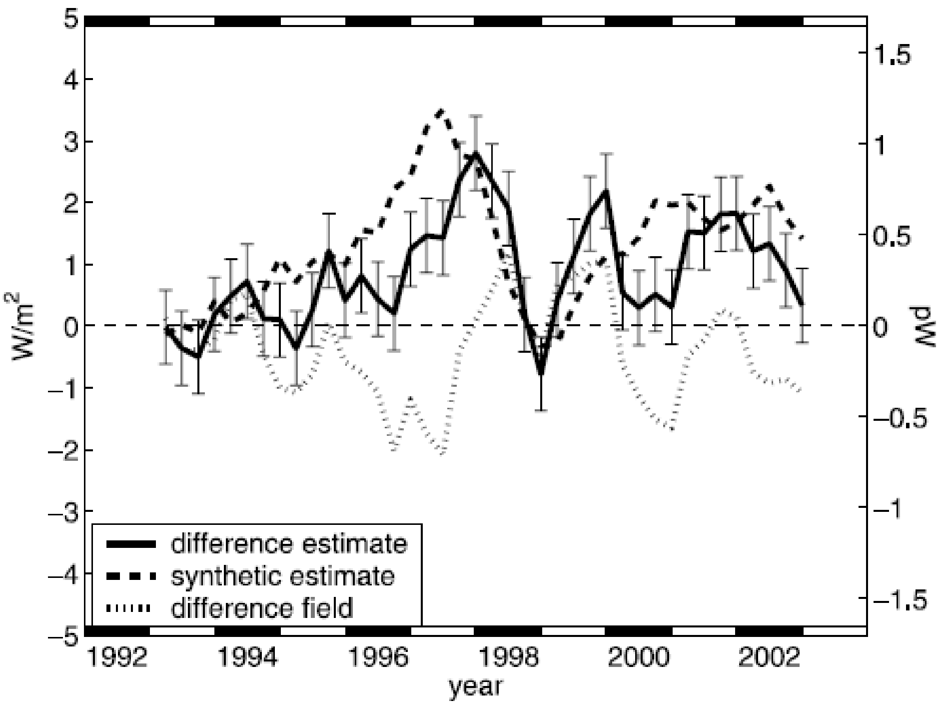
(a) Difference estimate (combined altimeter and in situ data);

(b) Estimate from in situ data alone. The curves on the right-hand side show the zonal integral of the maps in watts per meter of latitude;

(c) Number of in situ profile per 10° box.

-- Willis et al., 2004

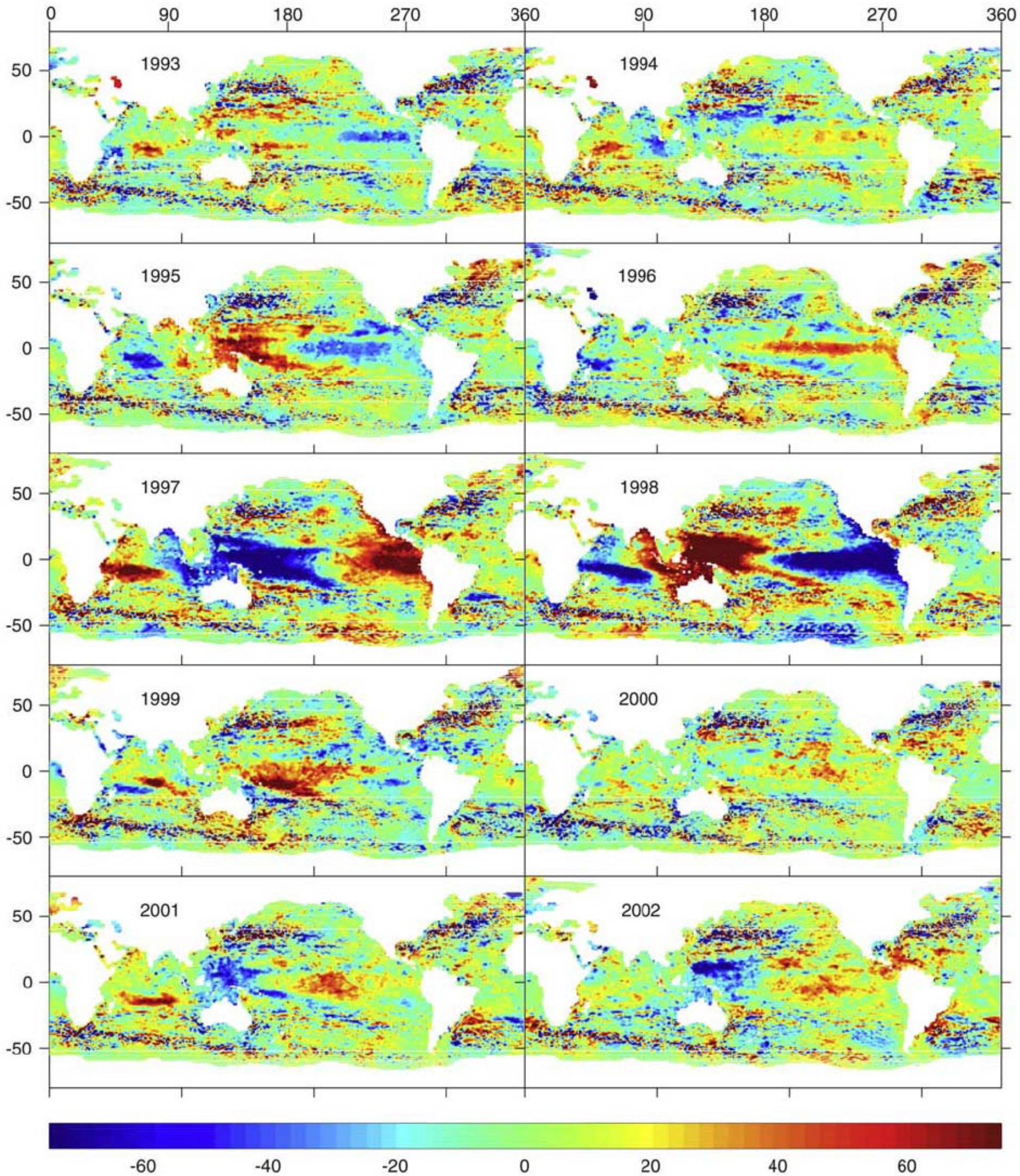
Interannual variability of upper ocean heat content



Globally averaged heat storage variability.

- A rapid warming during the onset of the 1997–1998 El Nino, followed by a slight cooling in the latter part of 1998.
- Significant inter-annual variability.
- An error bar of 0.6 W/m^2 for the time series of the difference estimate.

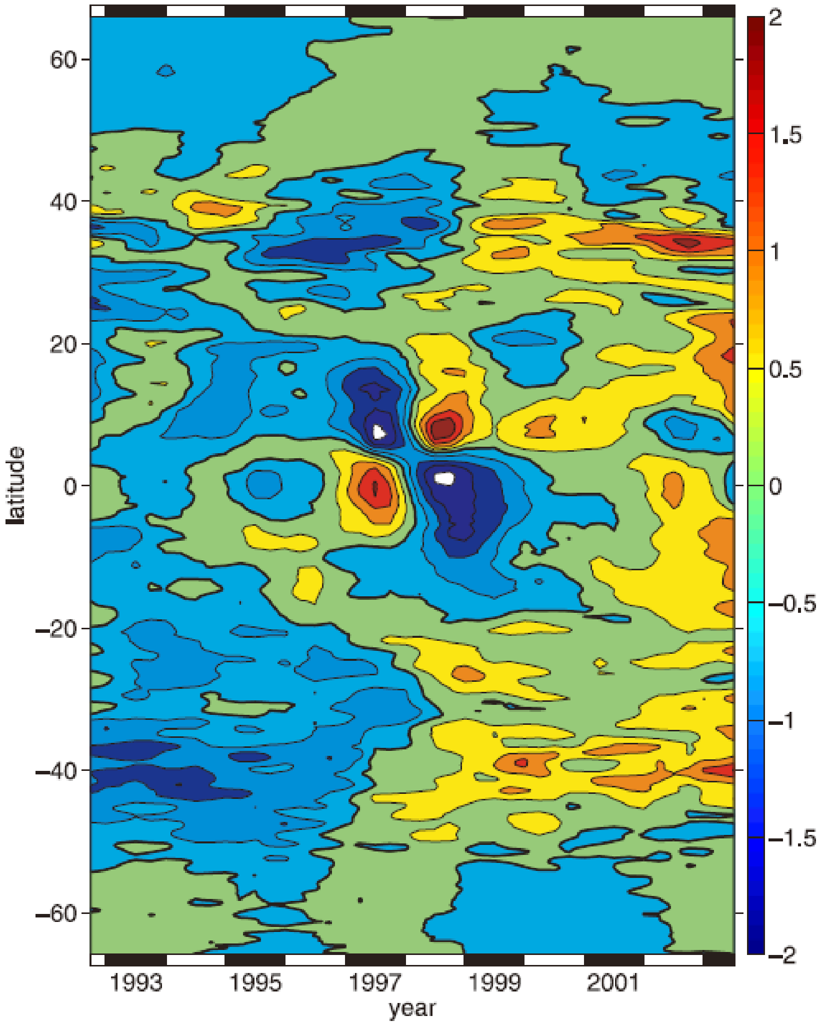
-- Willis et al., 2004



Maps of heat storage variability. Each map is a 1-year average centered on the year shown.

-- Willis et al., 2004

Interannual variability of upper ocean heat content



✓ Time-latitude plot of zonally integrated heat content.

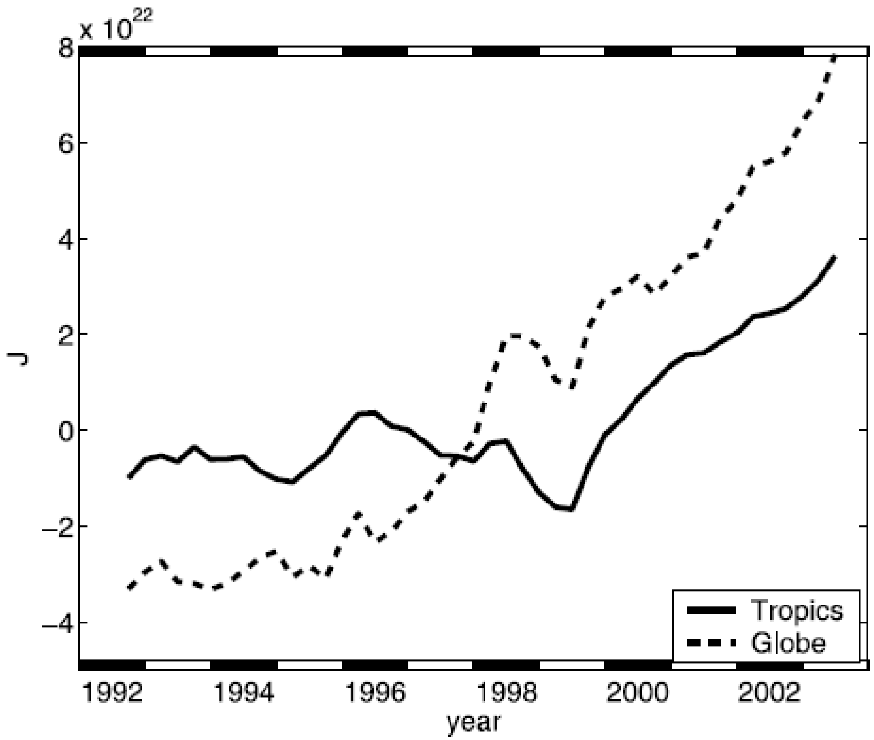
✓ The most prominent feature is the 1997–1998 El Nino.

✓ Poleward propagation of a positive heat content anomaly, beginning in mid-1997 at about 20° S and continuing to 30° S by the beginning of 2000.

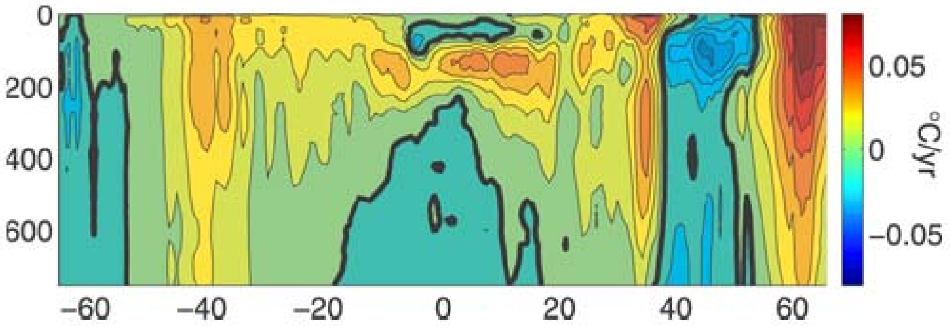
✓ Heat from the tropics propagated poleward into mid-latitudes subsequent to the large 1997–1998 El Nino event.

-- Willis et al., 2004

Interannual variability of upper ocean heat content



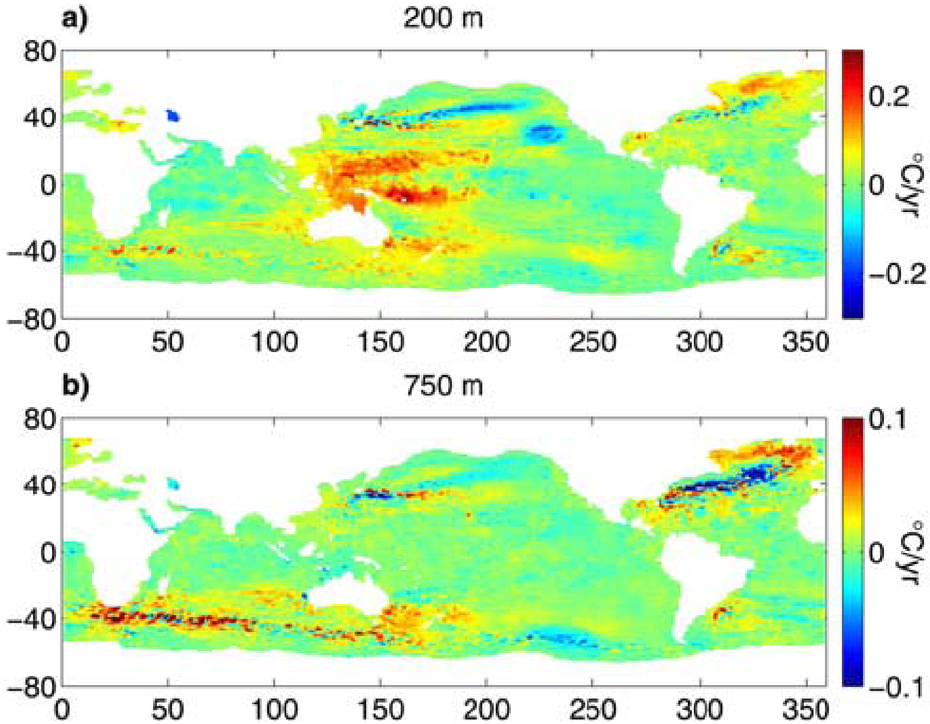
Interannual variability in heat content integrated over the region from 20° N to 20° S (solid line) and over the entire globe (dashed line).



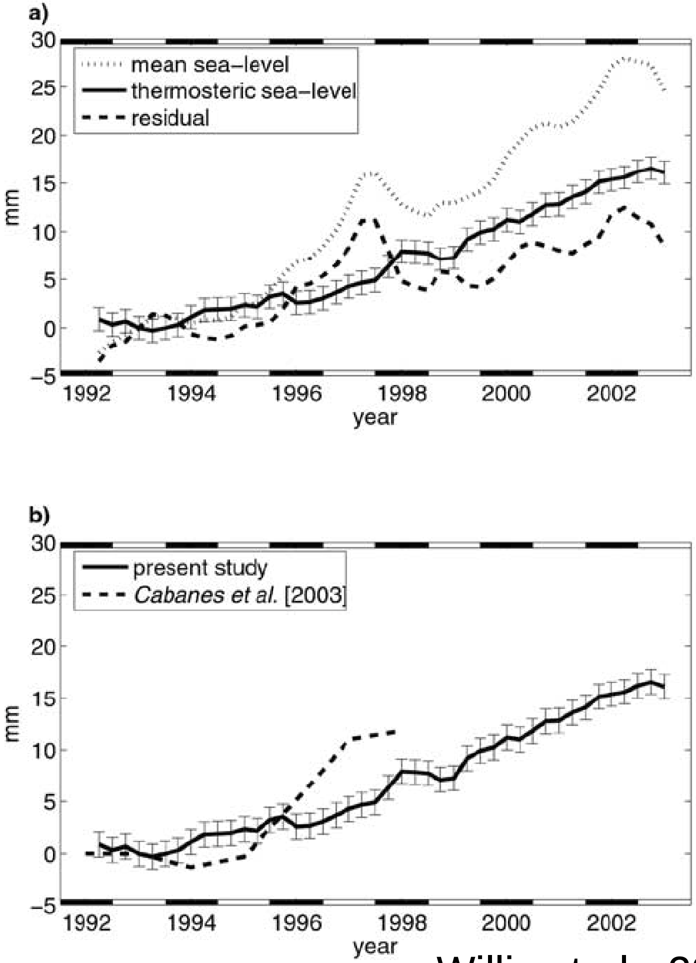
Ten-year trend in zonally averaged temperature versus depth and latitude.

-- Willis et al., 2004

Interannual variability of upper ocean heat content

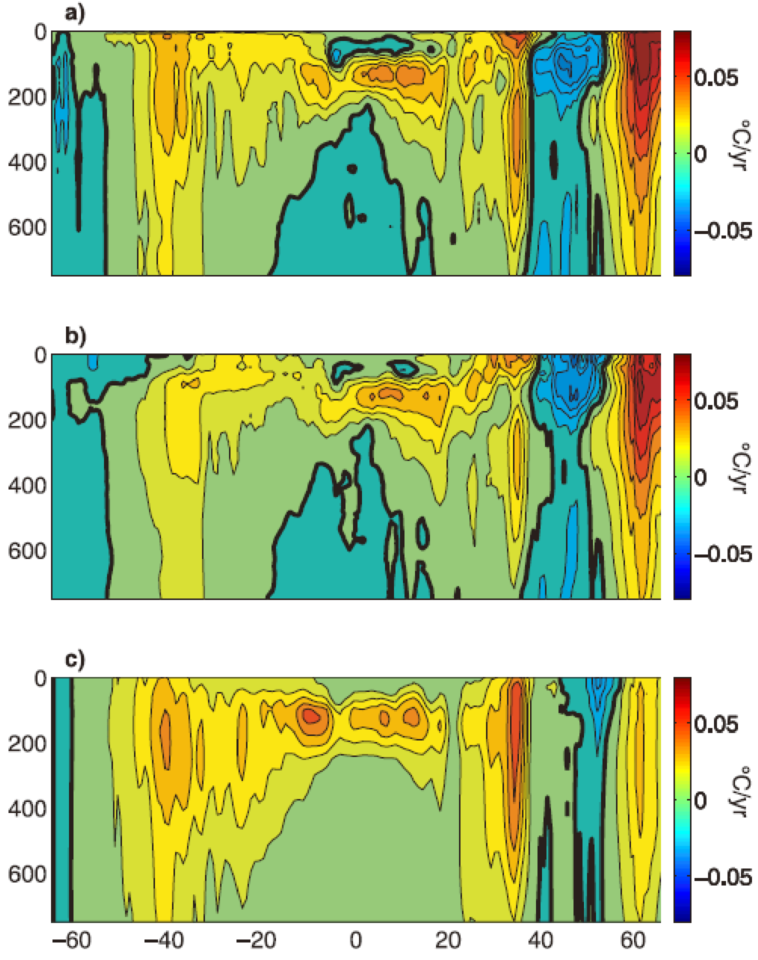


Ten-year trend in temperature at (a) 200 m; (b) 750 m.



-- Willis et al., 2004

Interannual variability of upper ocean heat content



Zonally integrated, 10-year temperature trend in ° C/yr calculated using a least squares fit.

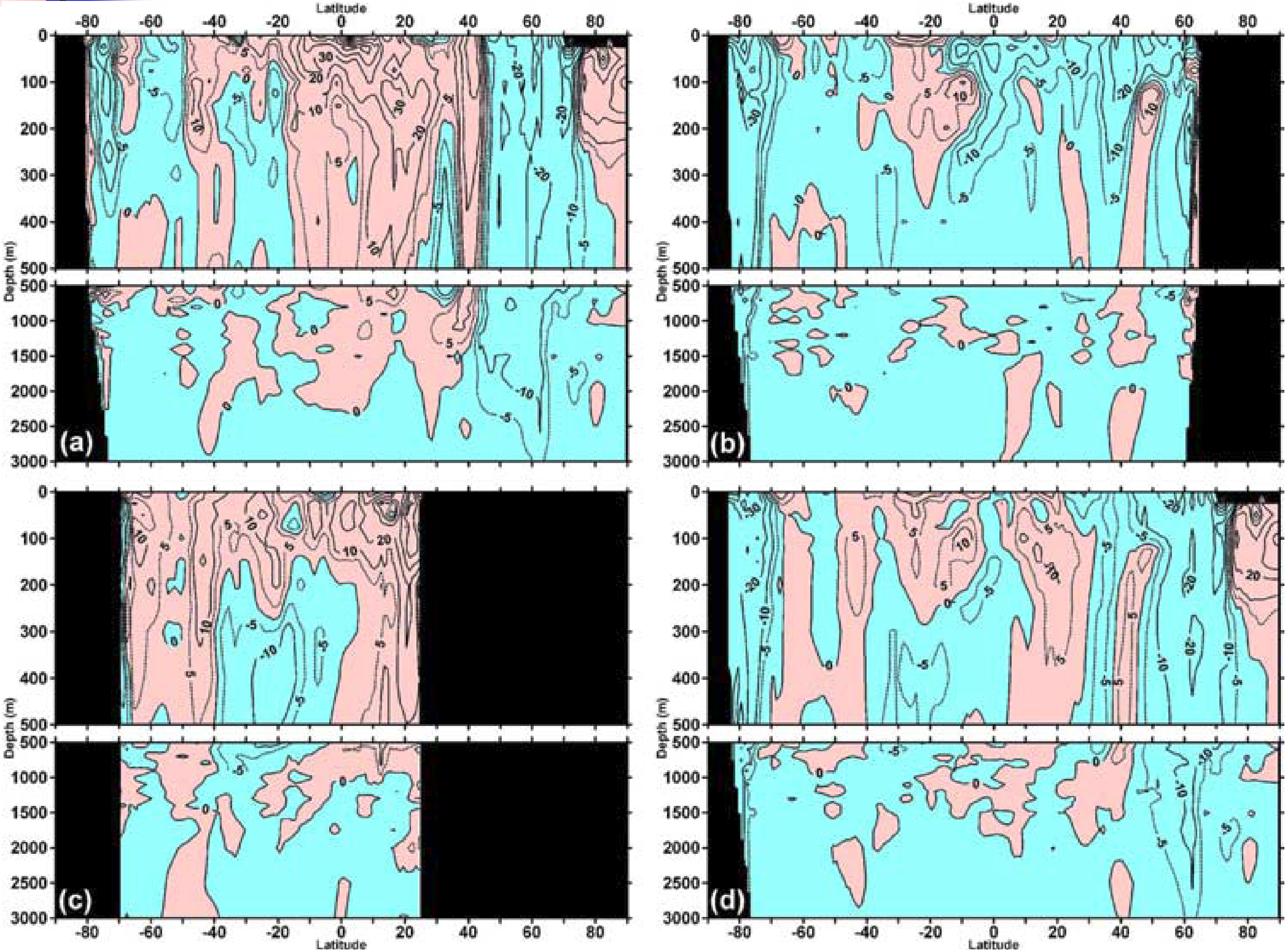
(a) Difference estimate;

(b) Estimate made using in situ data alone;

(c) Synthetic estimate (altimeter only).

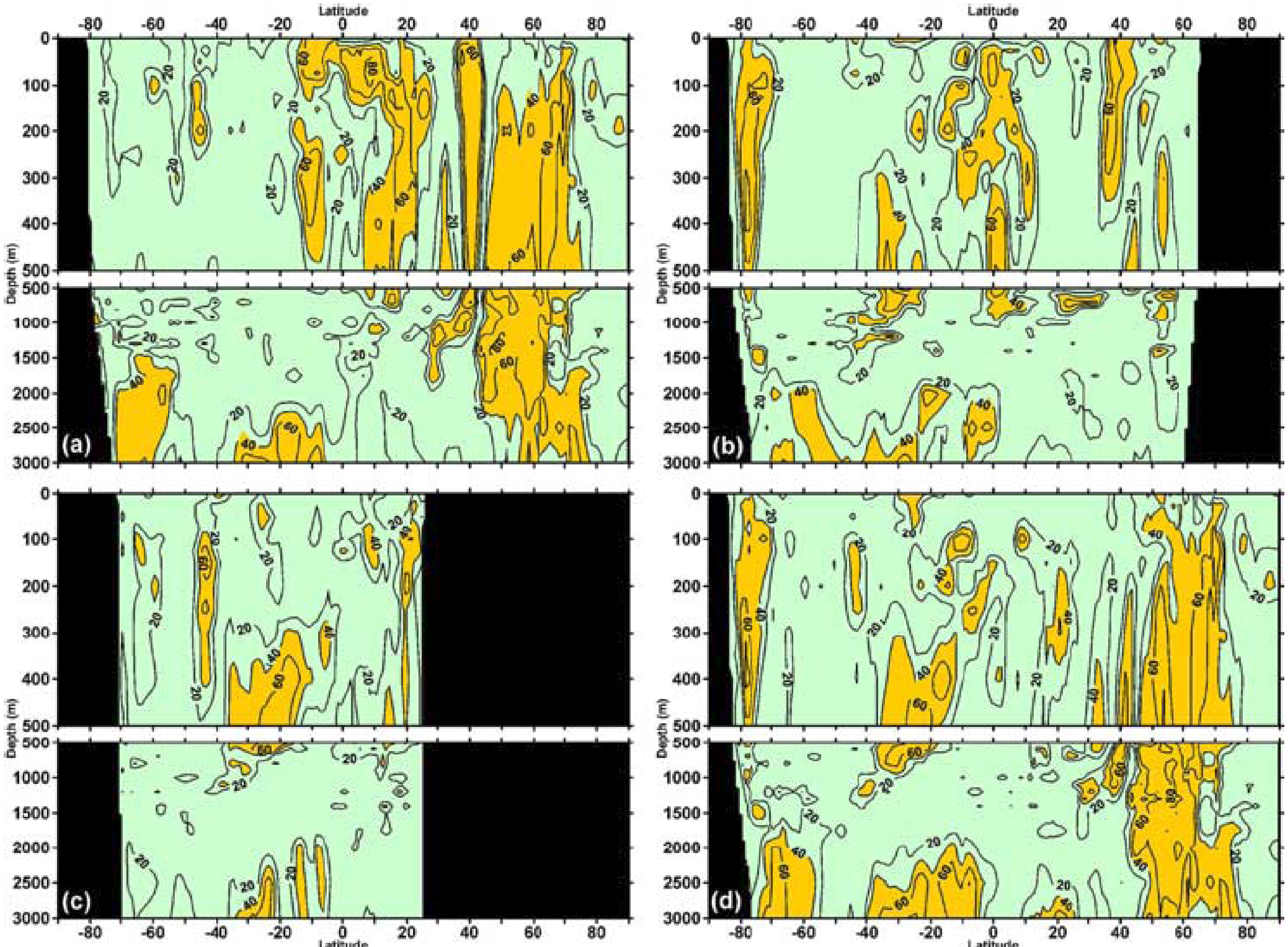
-- Willis et al., 2004

Large-scale trends in salinity



--Boyer et al., 2005

Large-scale trends in salinity



--Boyer et al., 2005

Summary

- A large part of the world ocean has exhibited coherent changes of ocean heat content during the past 50 years, with the world ocean exhibiting a net warming.
- The agreement between model results and observational estimates of ocean heat content supports the hypothesis that increases in radiative forcing are the source of the warming observed between 1955 and 1996.
- Because most of the increase in radiative forcing in the latter half of the 20th century is anthropogenic, this suggests a possible human influence on observed changes in climate system heat content.