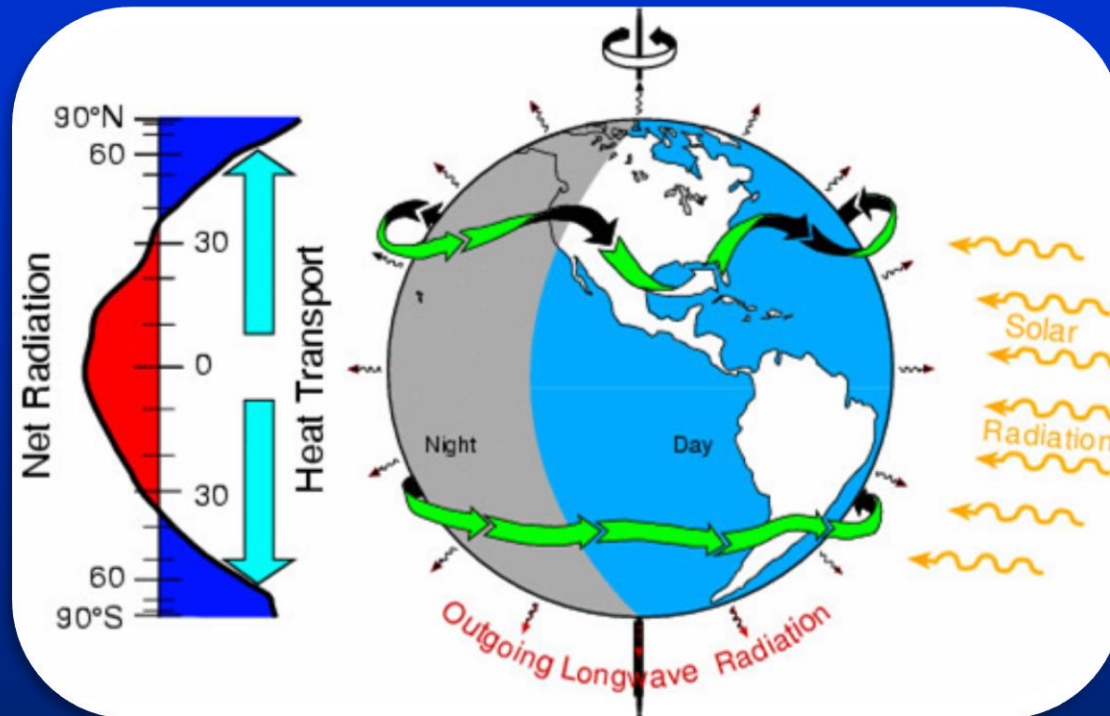


Tracking Earth's Energy: From El Niño to global warming

Kevin E Trenberth and John Fasullo

NCAR



Where has global warming from increased GHGs gone?

Stolen emails "climategate"

"The fact is that we can't account for the lack of warming at the moment and it is a travesty that we can't."

Kevin Trenberth

"It is quite clear from the paper that I was not questioning the link between anthropogenic greenhouse gas emissions and warming, or even suggesting that recent temperatures are unusual in the context of short-term natural variability."

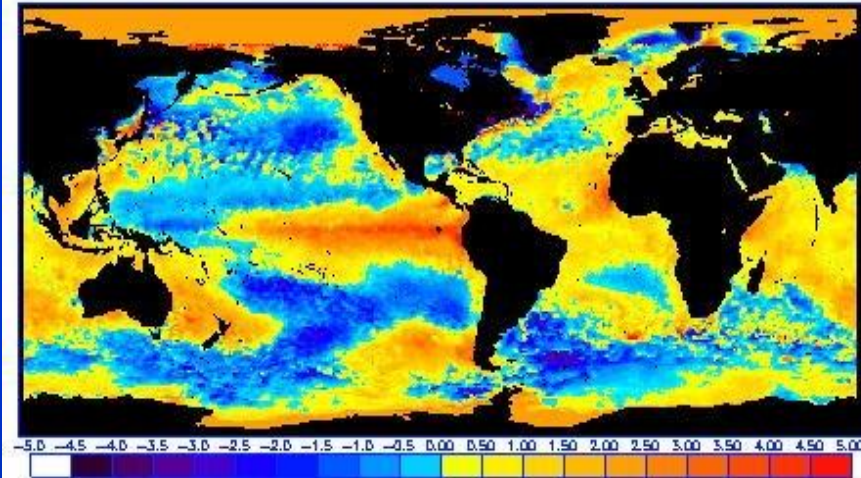
Kevin Trenberth

ENSO

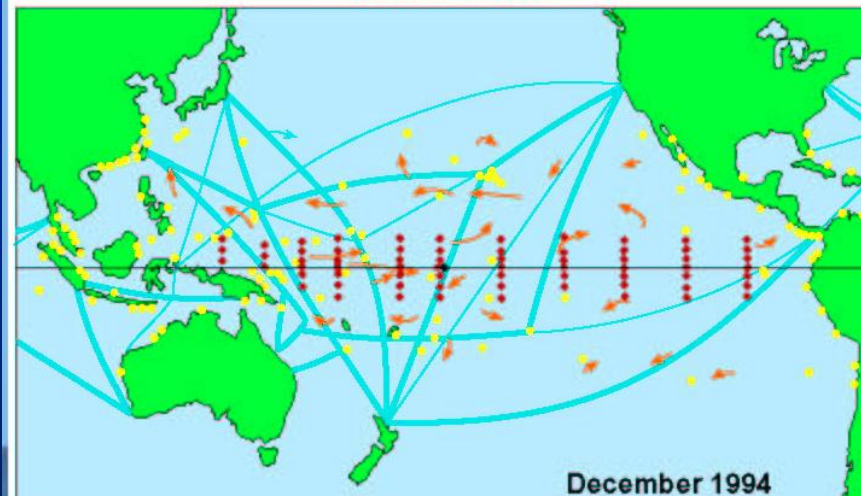
In 1997-98, successful warning of a massive El Niño were issued several months in advance.

These were made possible by the TAO moored buoys tracking the buildup of energy in the oceans and its redeployment during El Niño.

NOAA Current SST Anomalies, 2/24/1998



TOGA in Situ Ocean Observing System
Pacific Basin



Evolution of ENSO

Ocean heat content

1980-1998

Trenberth et al. 2002

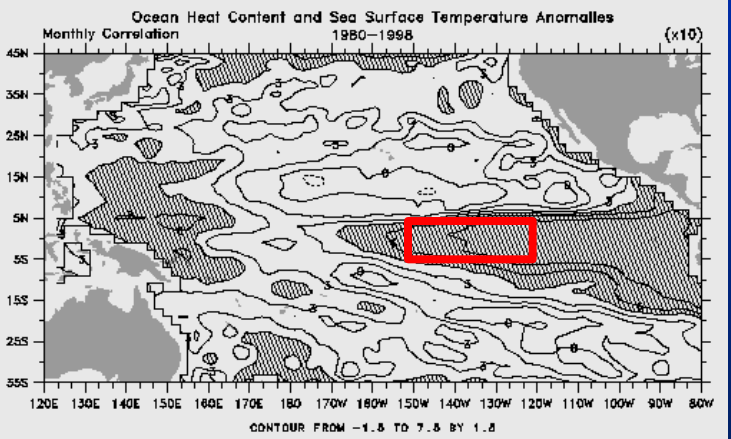
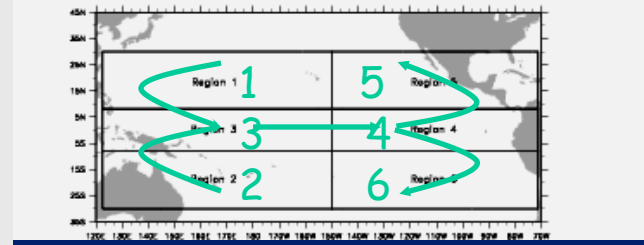
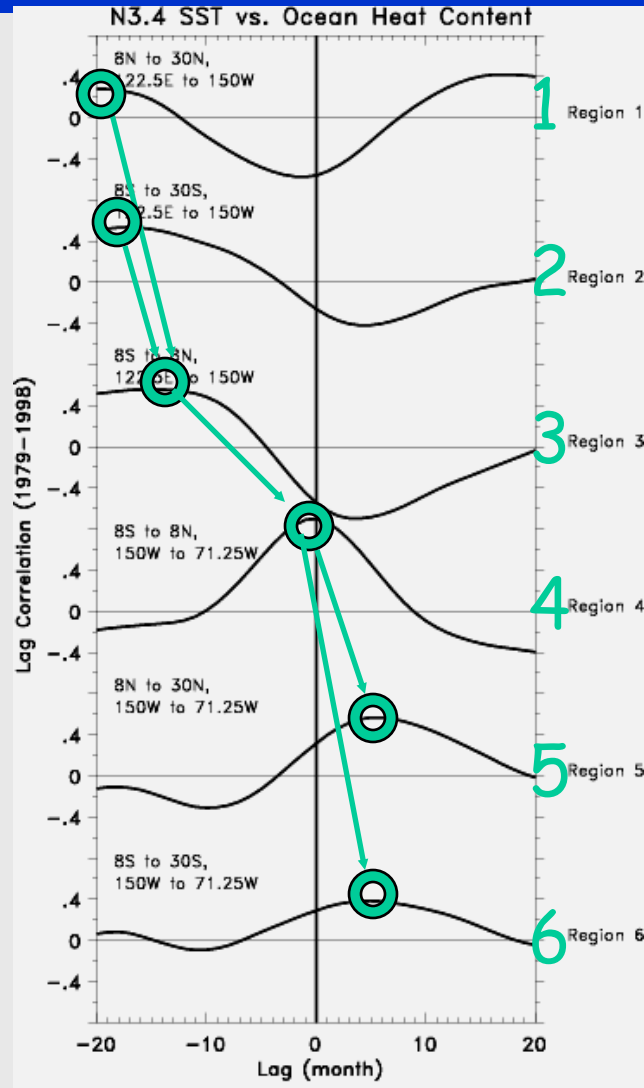
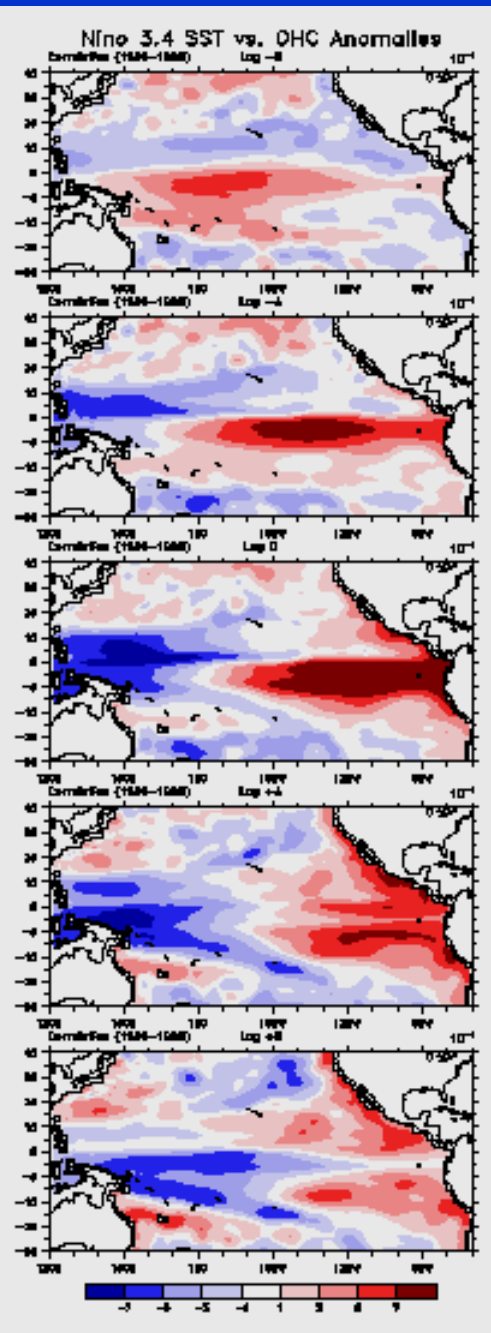
lag
-8

-4

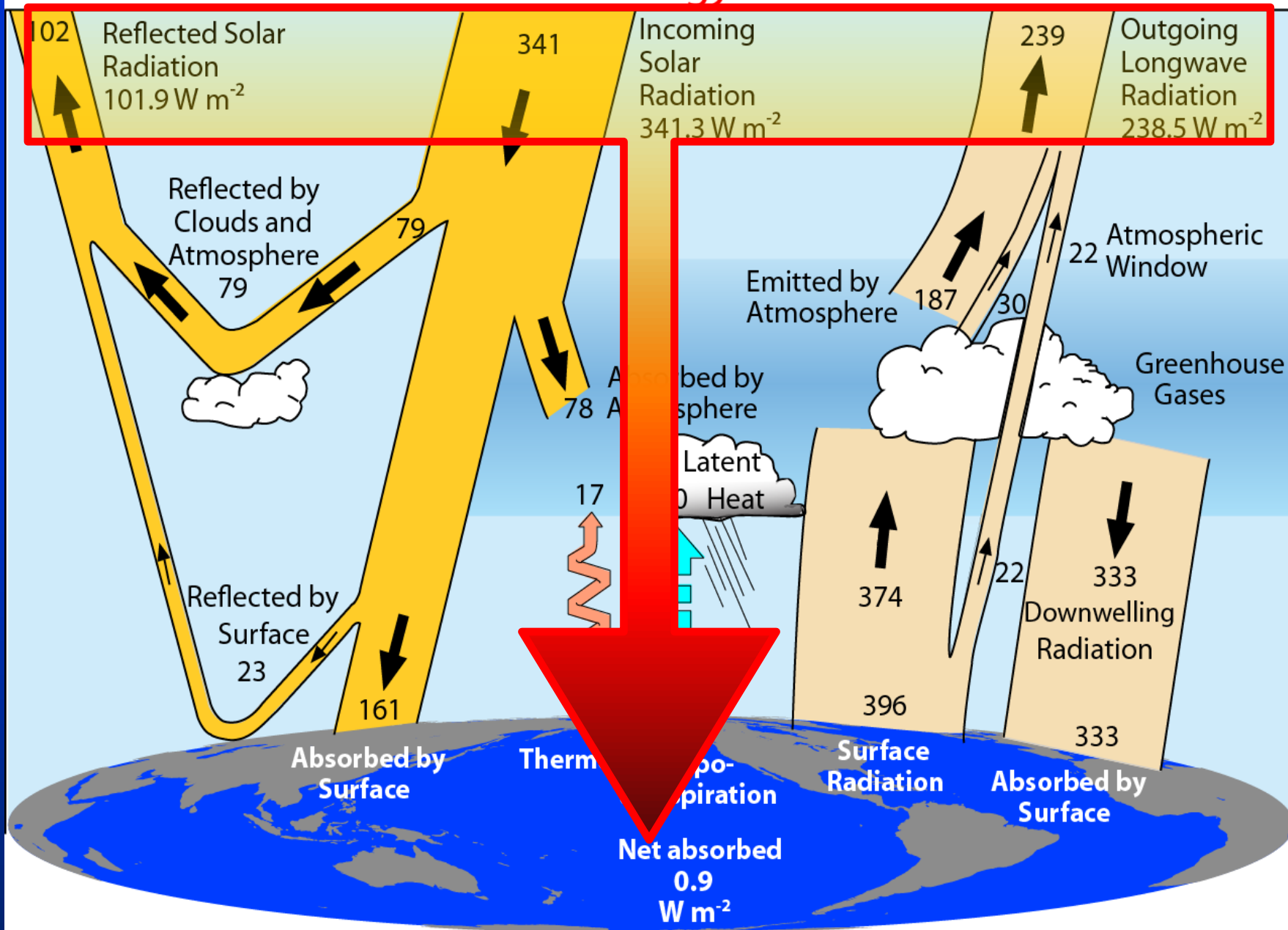
0

4

8



Global Energy Flows $W m^{-2}$



2000-2005

Adapted from Trenberth et al 2009

Ocean heat content and sea level

Global warming from increasing greenhouse gases creates an imbalance in radiation at the Top-Of-Atmosphere: now order $0.9 \pm 0.5 \text{ W m}^{-2}$.

Where does this heat go?

Main sink is ocean: thermosteric sea level rise associated with increasing ocean heat content.

Some melts sea ice: no change in SL

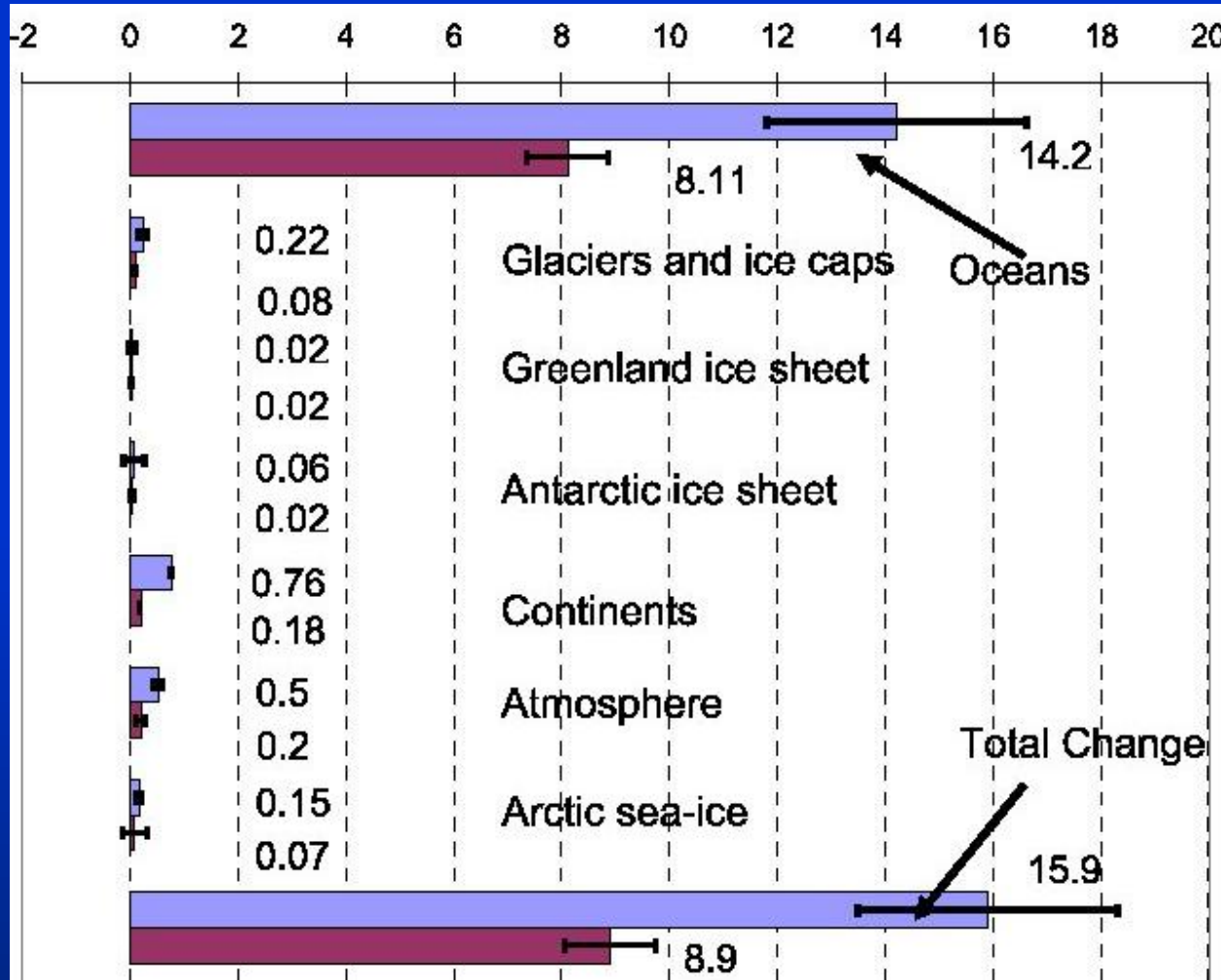
Some melts land ice.

SL increases much more per unit of energy from land-ice melt: ratio about 30 to 90 to 1.

Sea-ice melt does not change sea level.

Energy content change

10^{22} J



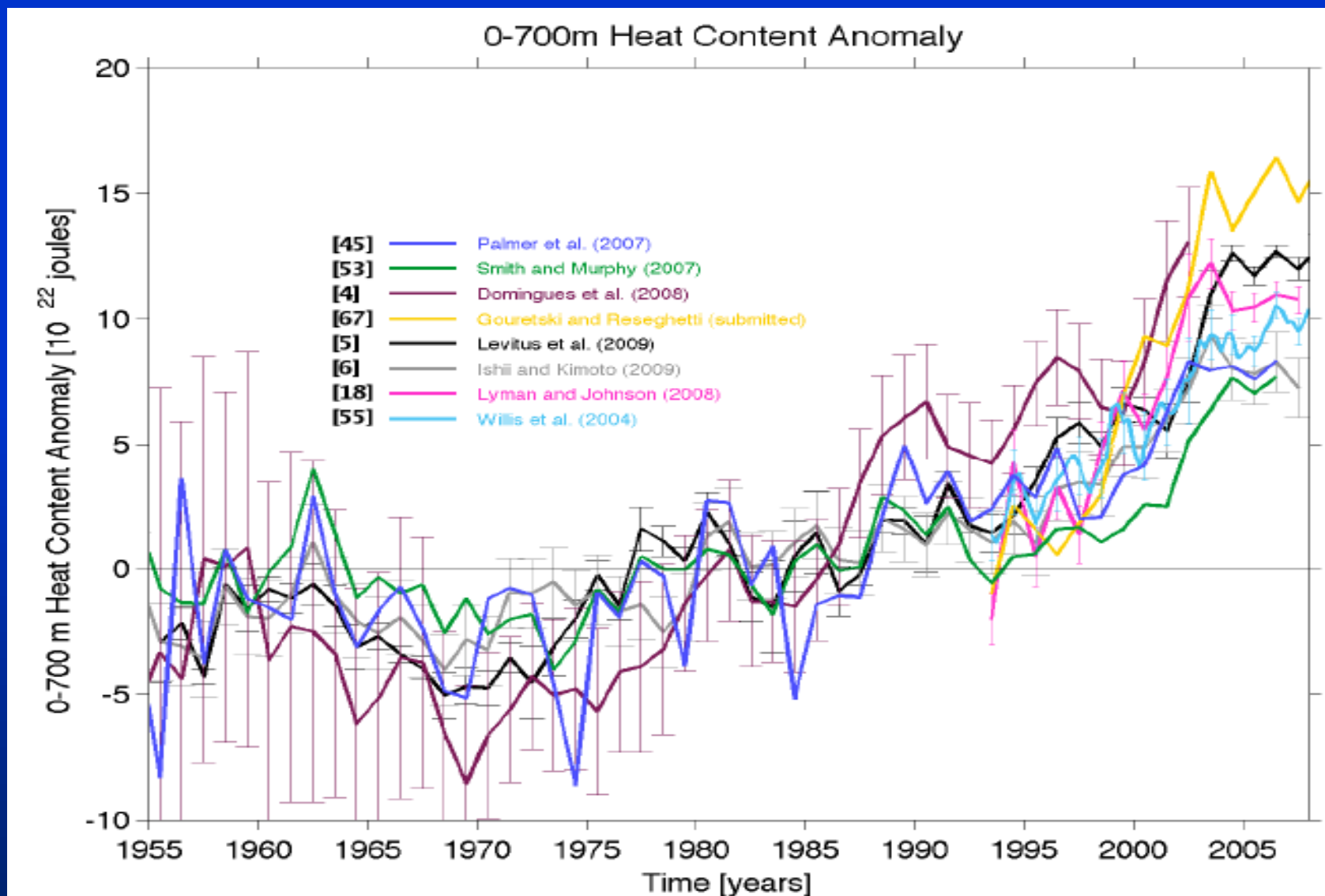
>90% oceans

1961-2003 (Blue bars)

1993-2003 (Burgundy bars)

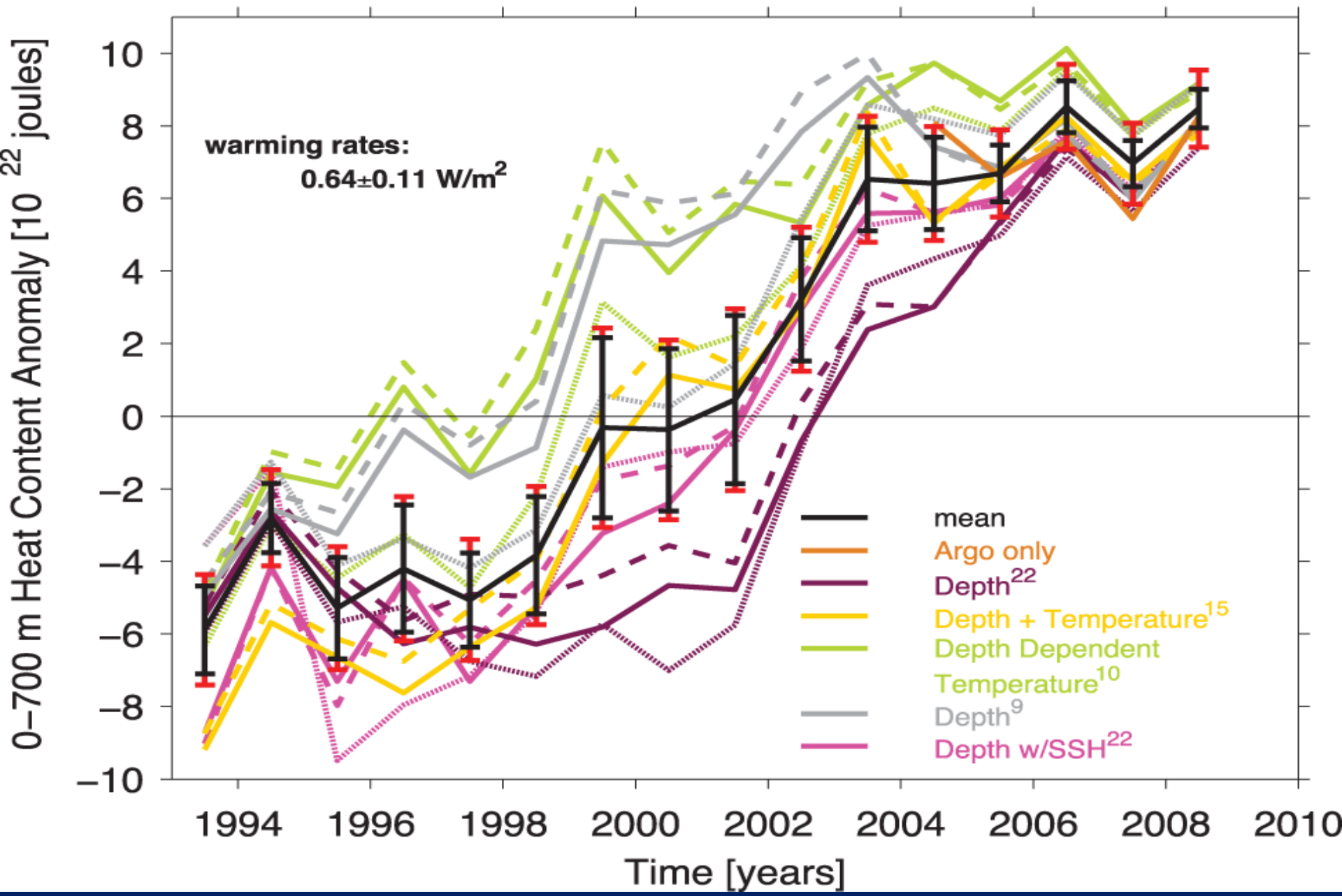
Figure 5.4
IPCC AR4

Ocean heat content to 700 m

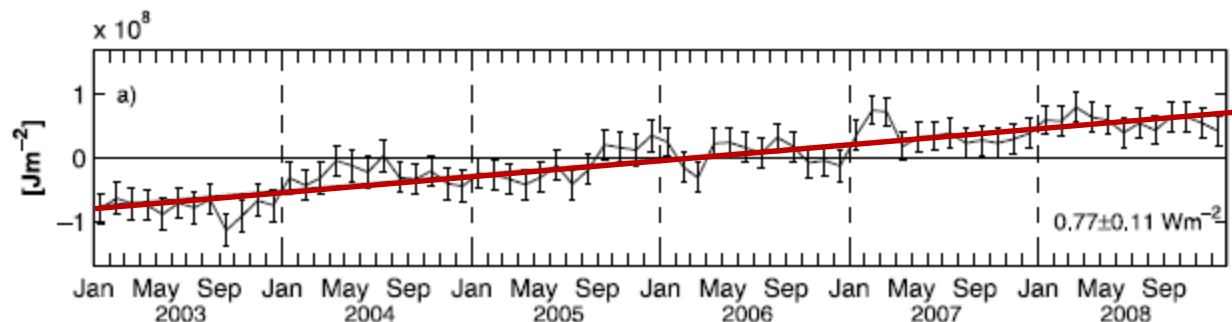


Lyman et al 2010 Nature

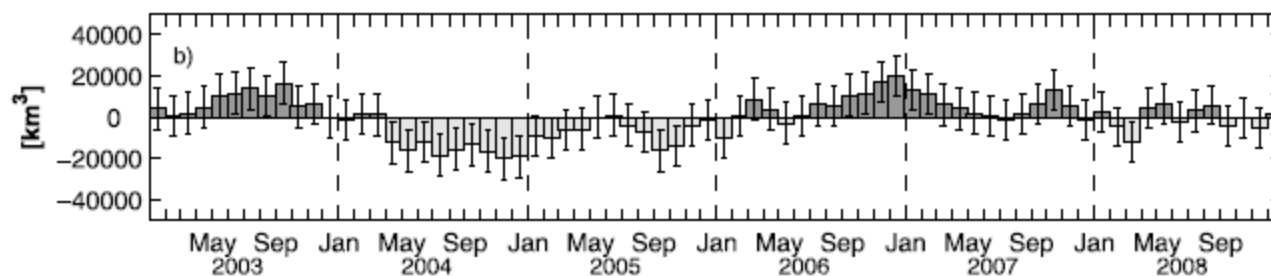
0-700 m Heat Content Anomaly



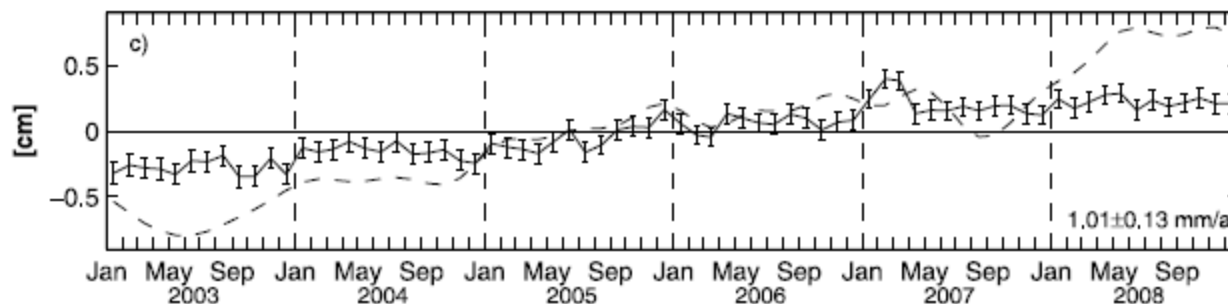
Ocean heat content 0-2000m



OHC
0.77 W m⁻²
gl ocean
0.54 W m⁻²
Global

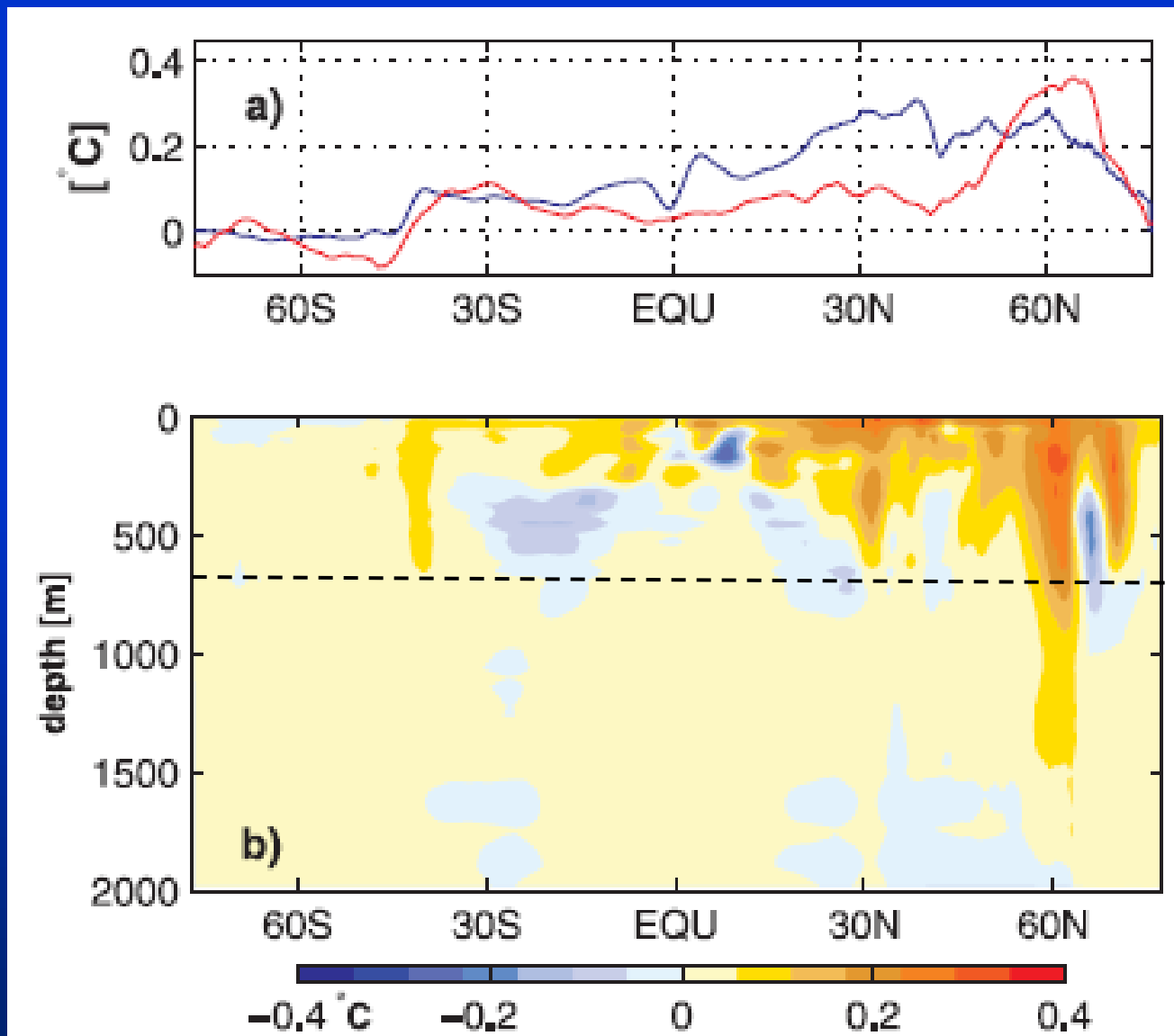


Fresh water



Sea level and
thermosteric
OHC

Ocean heat content 0-2000m



SST (red)
2003-2008 -
1990-2008
10 m depth
ARIVO -
WOA05

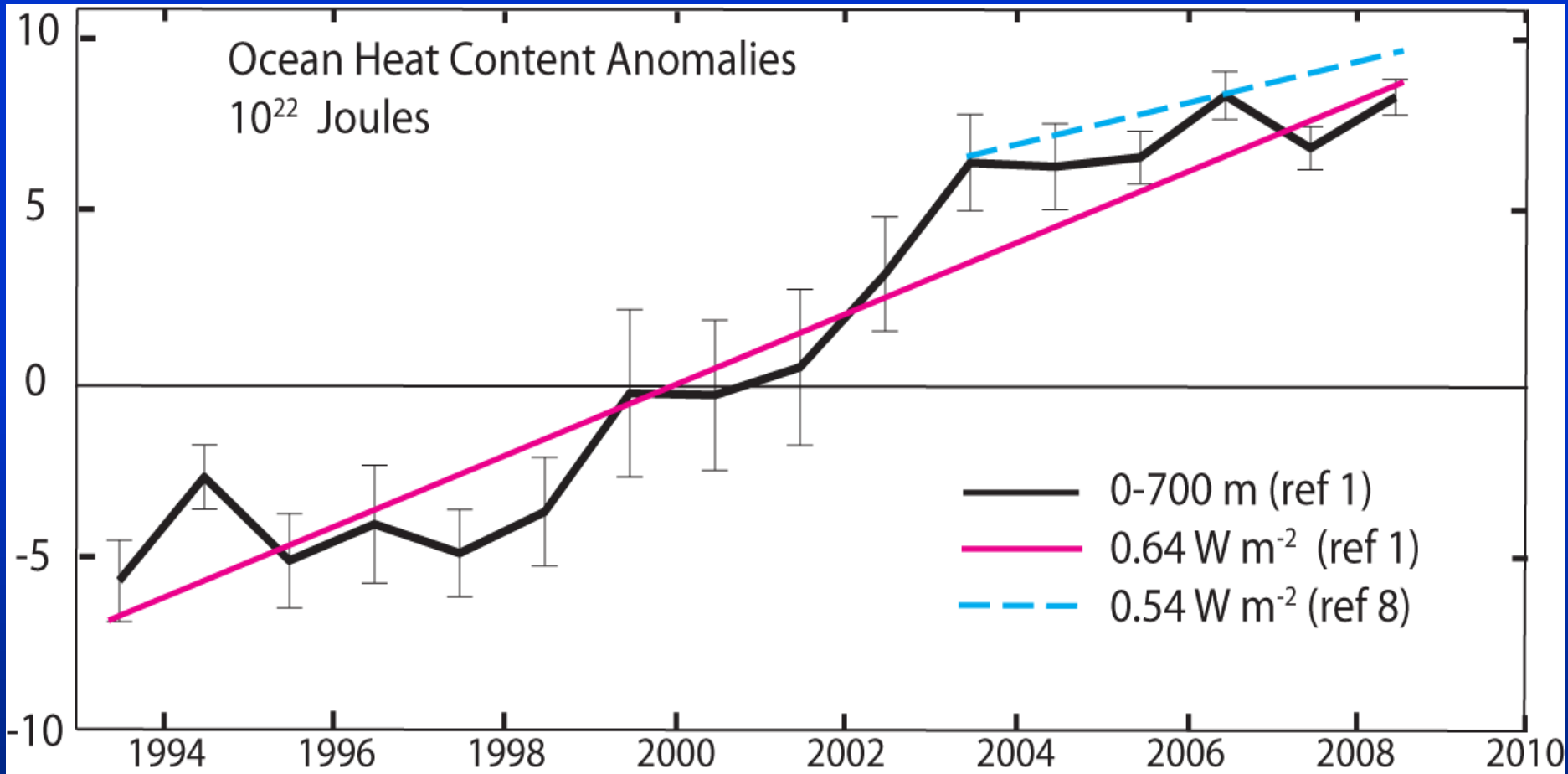
Temps

Difference for
2003-2008
From WOA05
Levitus et al

Comments on Von Schuckmann

- VS did not provide 0-700 m OHC vs 0 to 2000m
- Some floats are programmed to go only to 1000 m and do not go to 2000 m, so that coverage decreases with depth
- How come all the error bars are the same even though coverage is increasing?
- How good is the quality of the sensors over this time? Up to 30% report negative pressures at the surface.

Ocean heat content is increasing



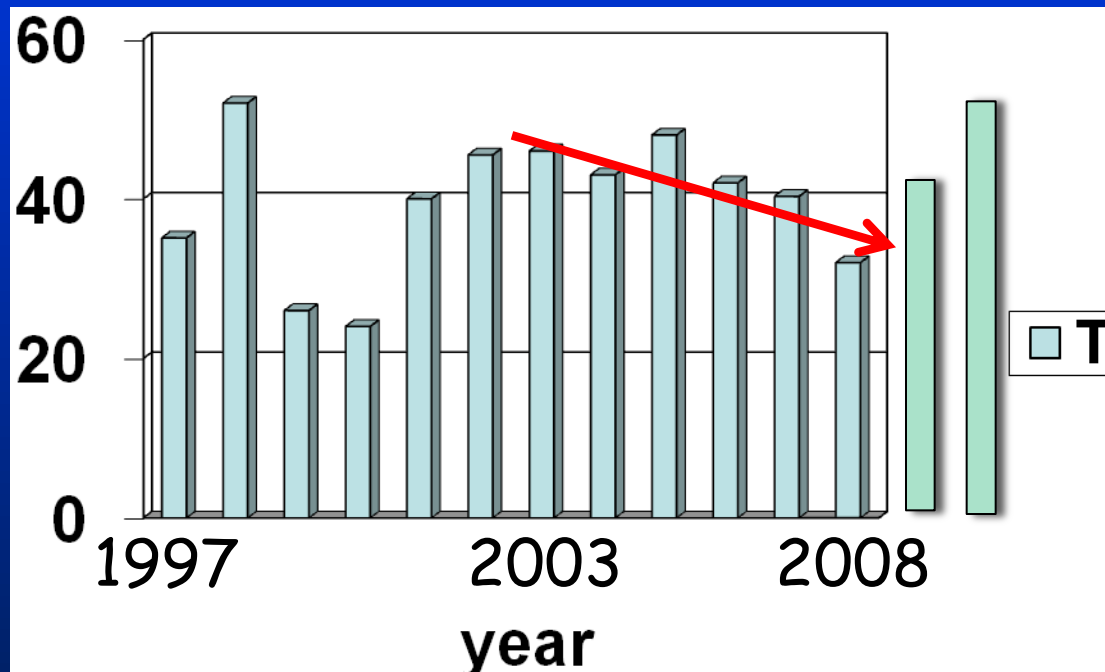
1. Lyman et al 2010 : to 700m

8. von Schuckmann et al 2009 :to 2000m

From Trenberth 2010 *Nature*

Where did the heat go?

- 2008 is the coolest year since 2000
- Carbon dioxide continues to rise
- Radiative forcing continues apace
- Where did global warming go?

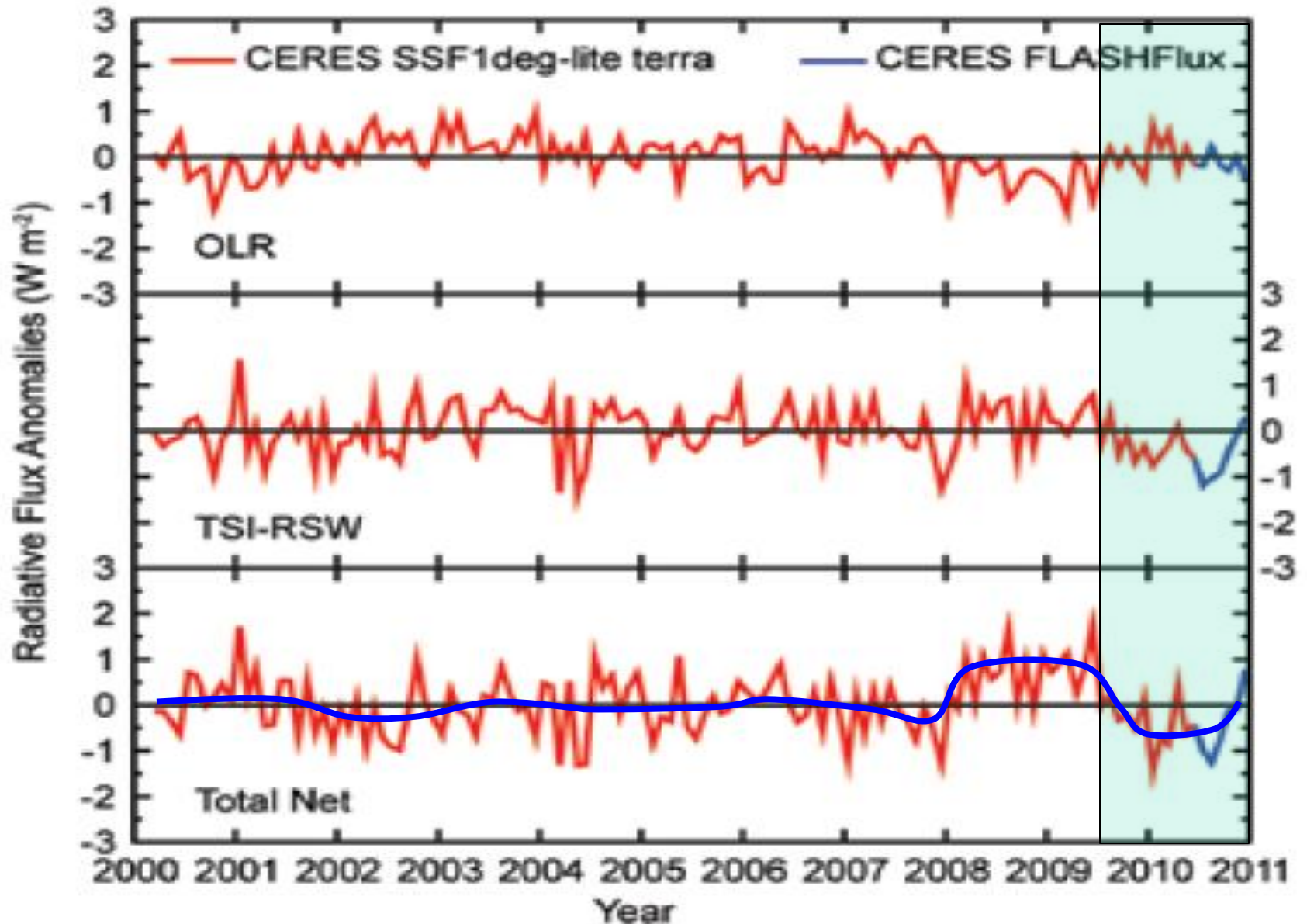


Where does energy go?

1. Warms land and atmosphere
2. Heat storage in the ocean (sea level)
3. Melts land ice (sea level)
4. Melts sea ice and warms melted water
5. Evaporates moisture \Rightarrow cloud \Rightarrow reflection
= lost to space

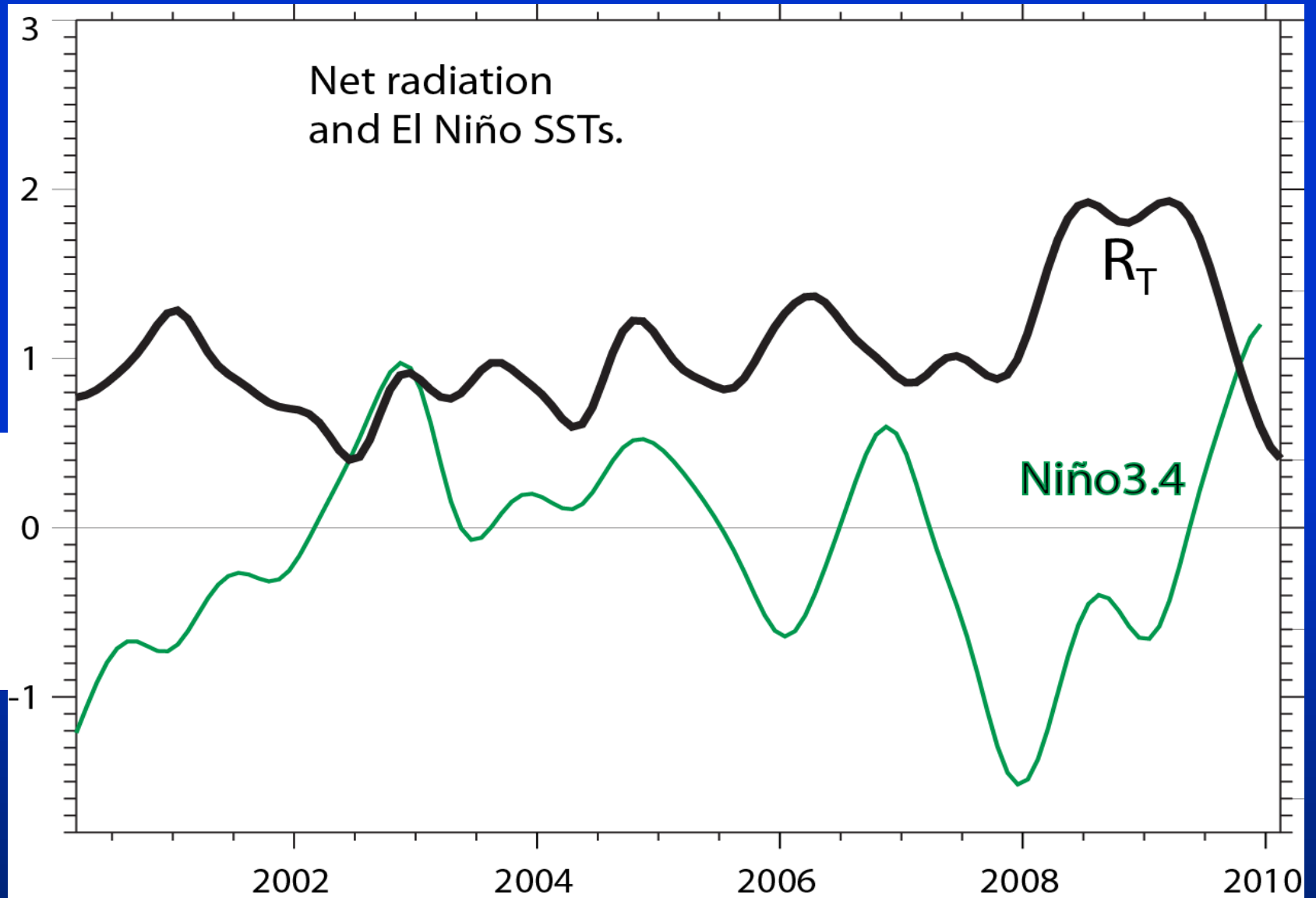
Can we track it?

CERES SSF 1Deg Lite Ed2.5 Anomalies



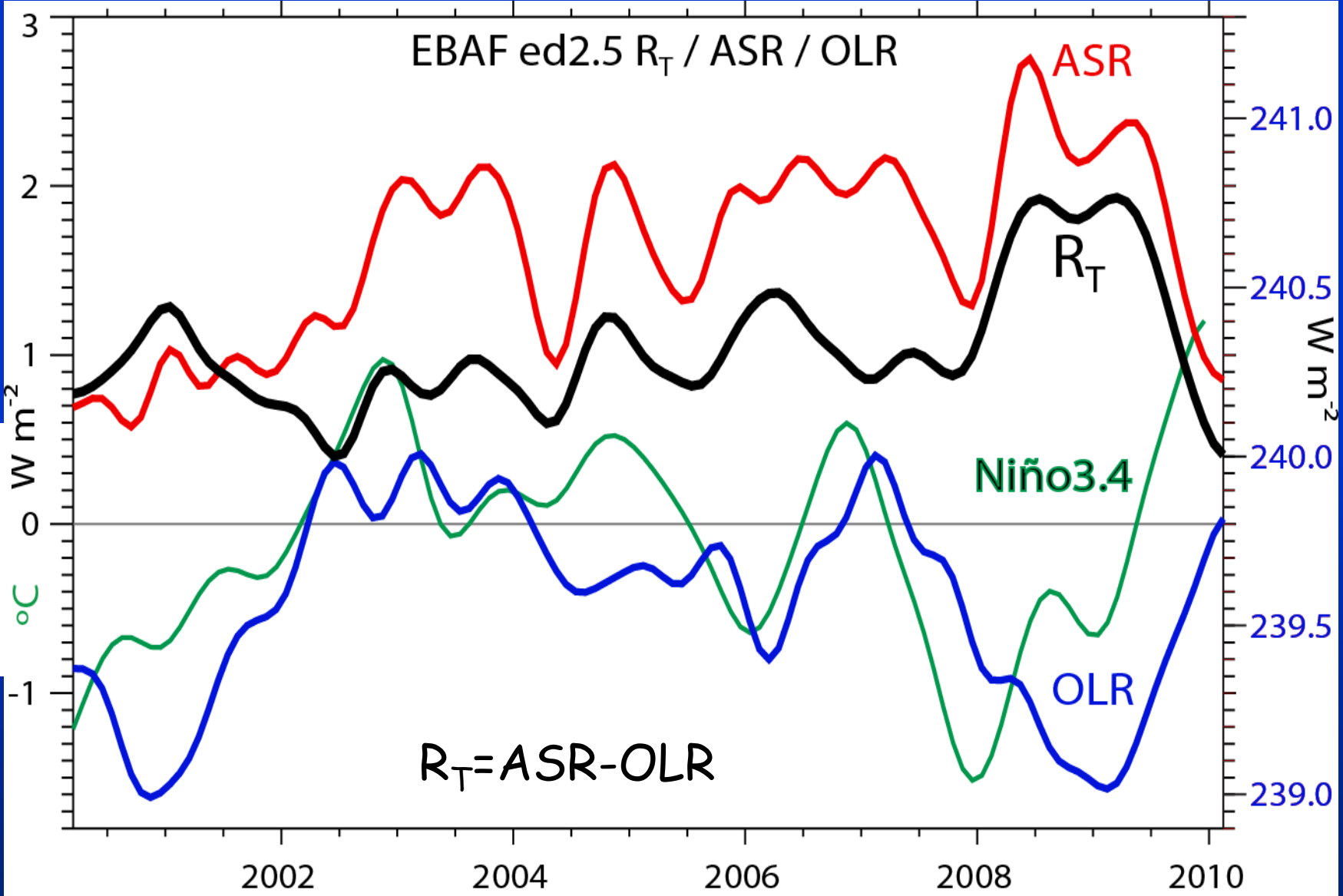
Kratz et al 2011 BAMS

CERES EBAF adjusted product

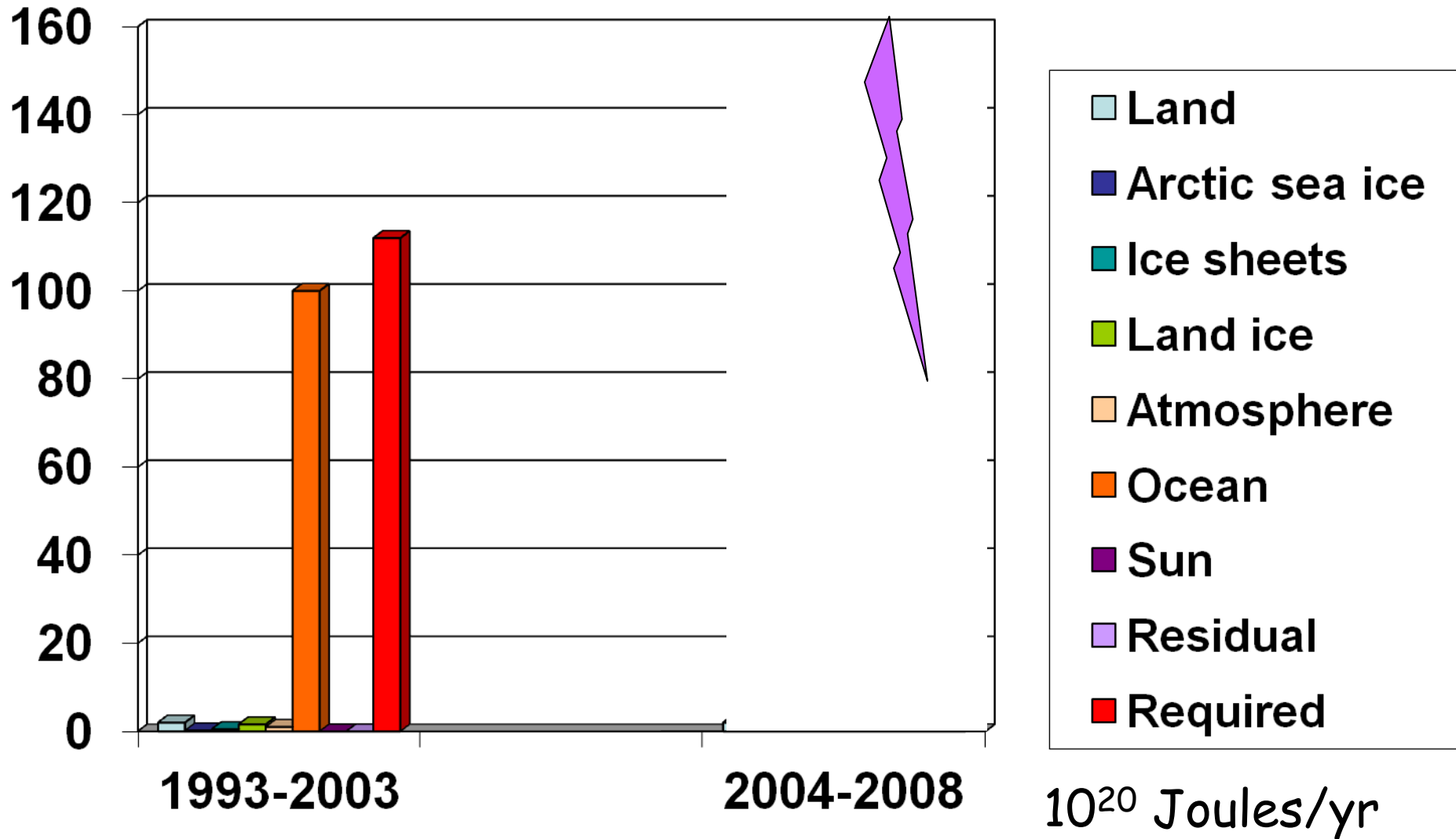


R_T

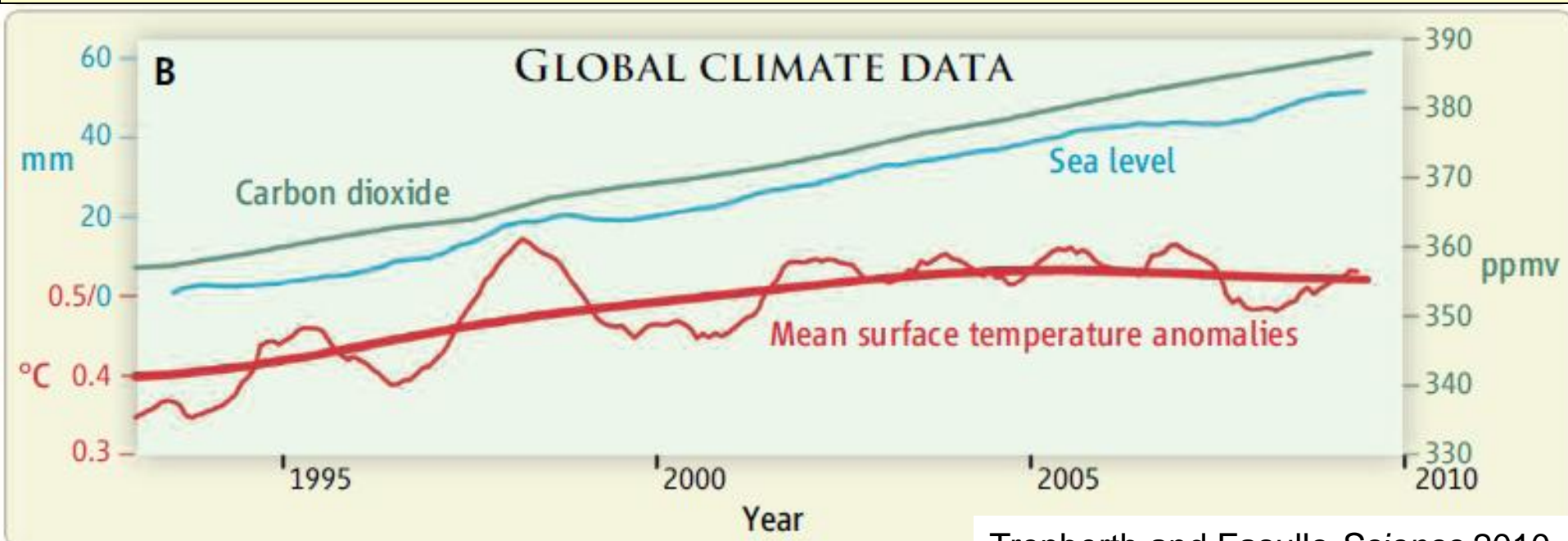
Niño 3.4

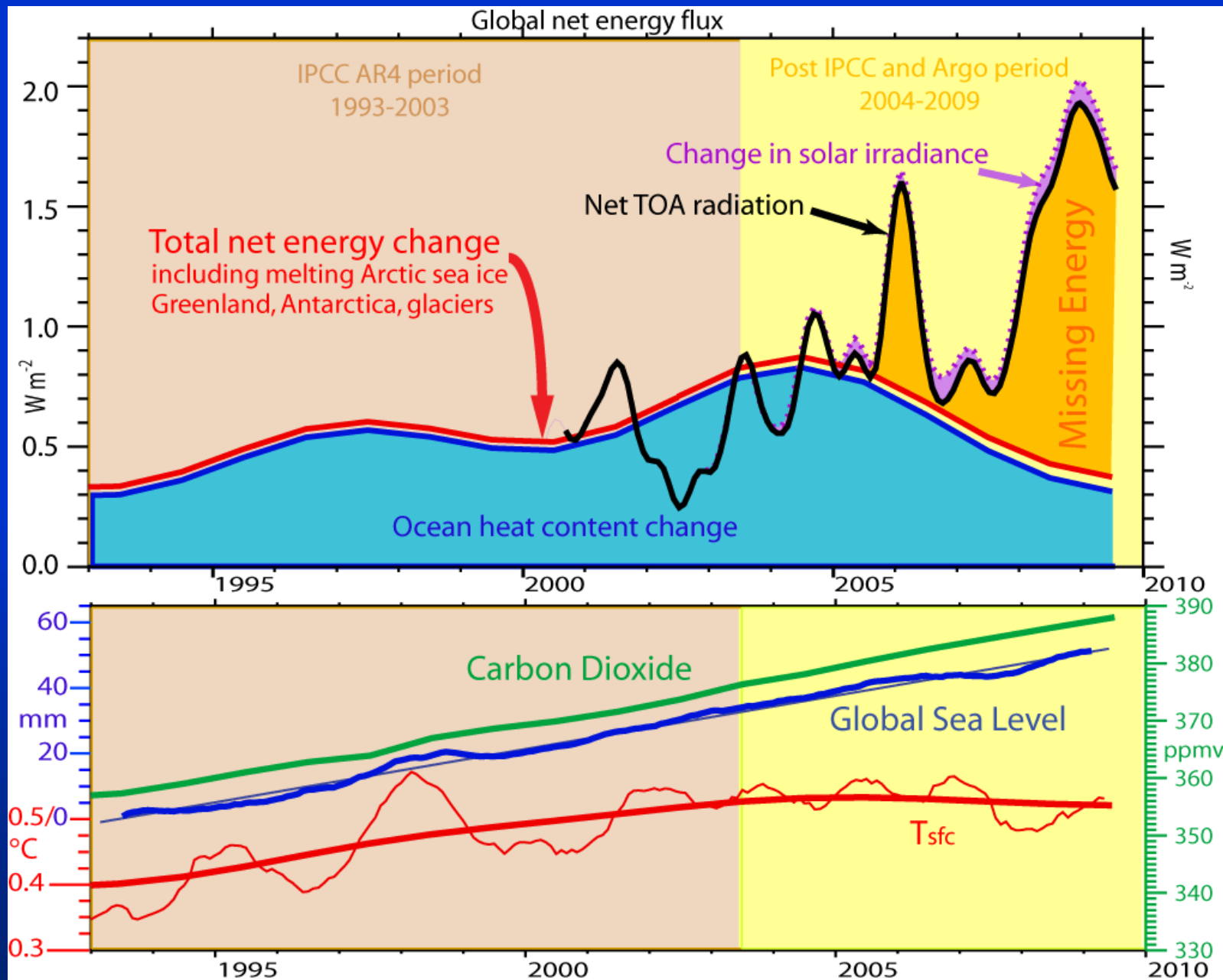


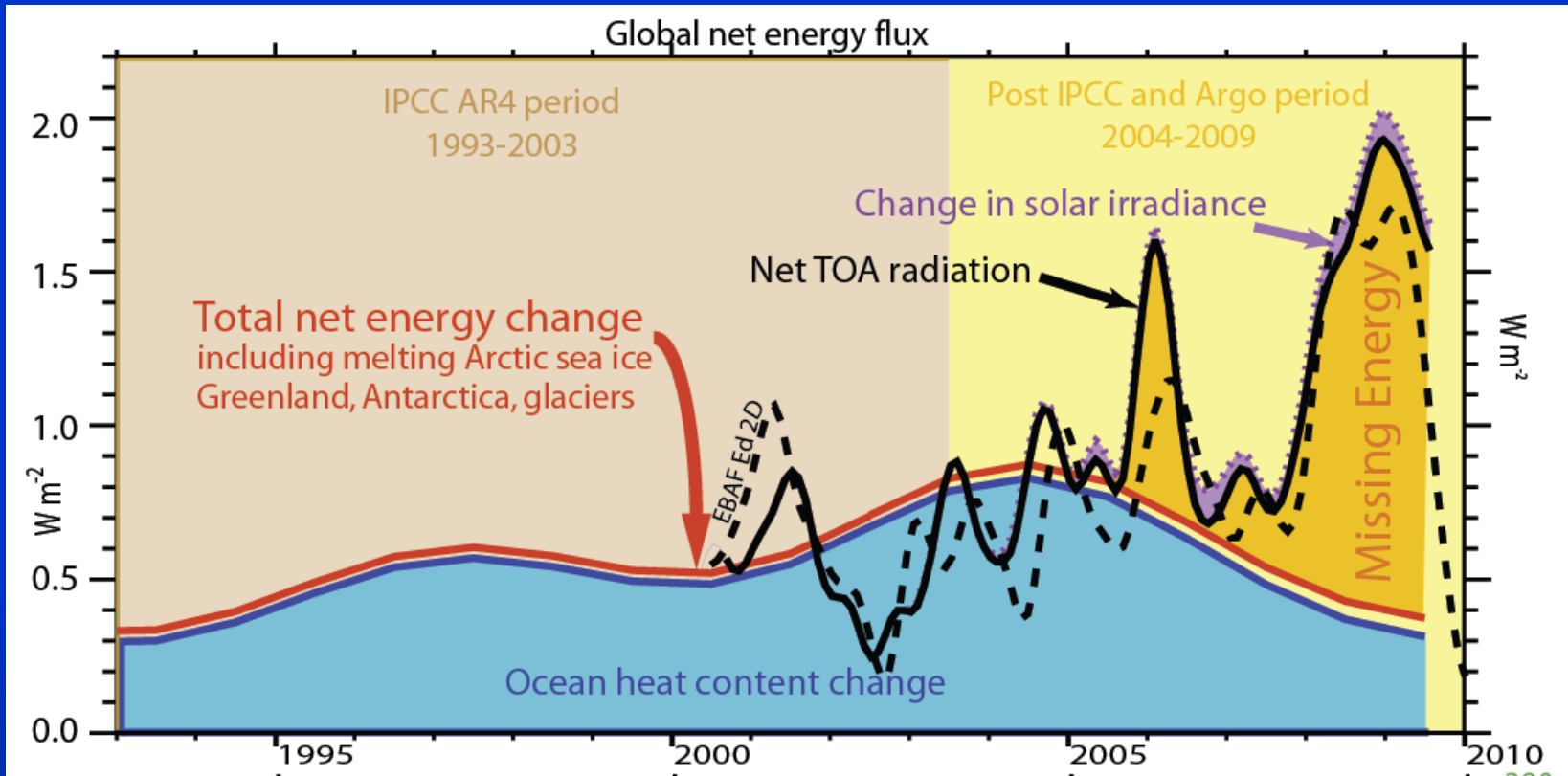
Where does energy go?



Can we track energy since 1993 when we have had good sea level measurements?



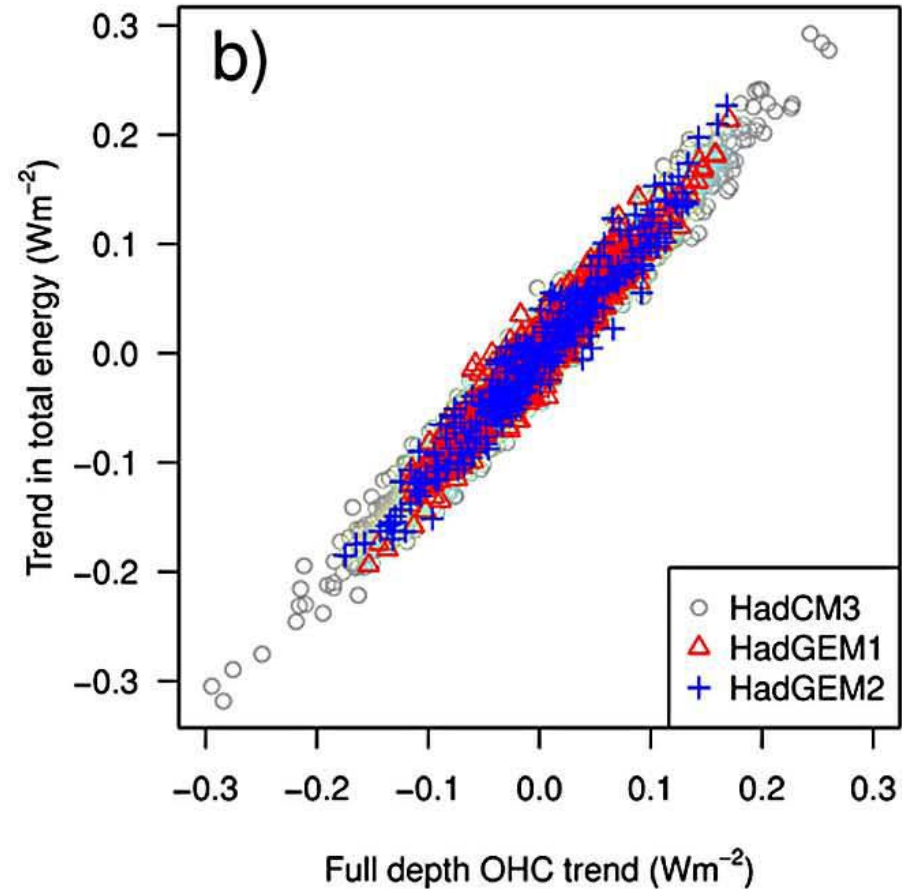
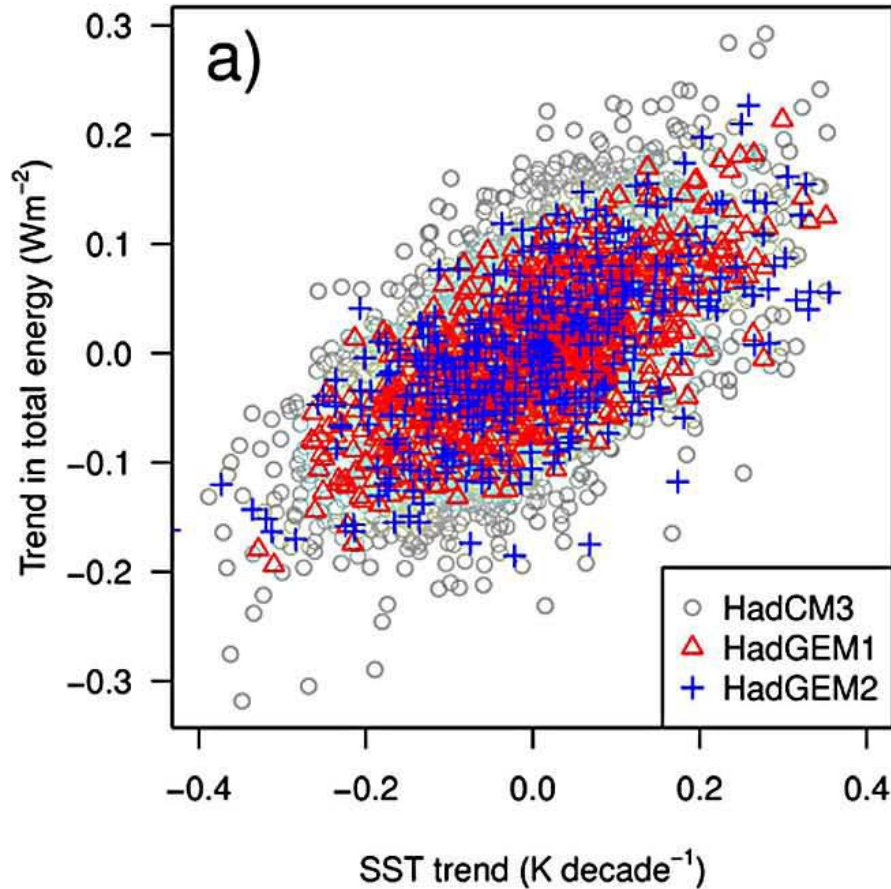




Where does the heat go?

At present this is difficult to do from observations/ocean reanalyses,
so what about models?

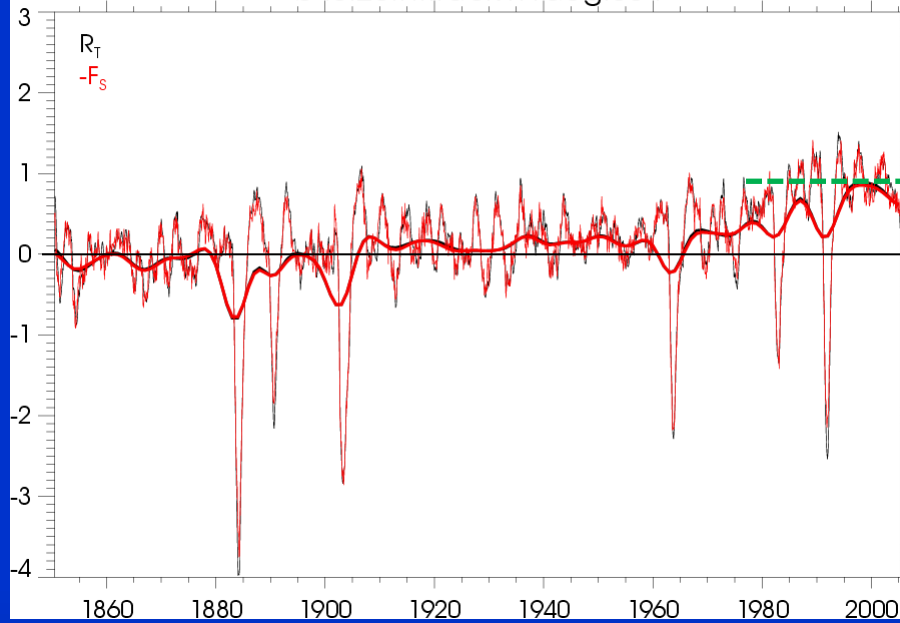
SST vs OHC vs TOA



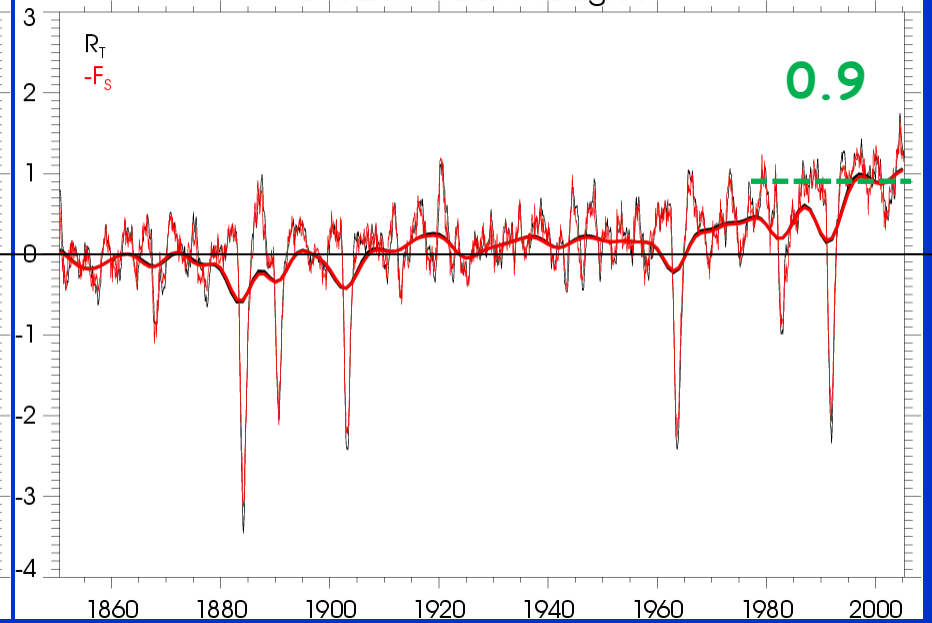
Linear decadal trends in total energy (W m^{-2}) regressed against decadal trends in : a) globally SST (K dec^{-1}); b) full-depth OHC (W m^{-2}). The trend in total energy is equivalent to the average TOA radiation balance.

TOA Radiation and F_s from CCSM4

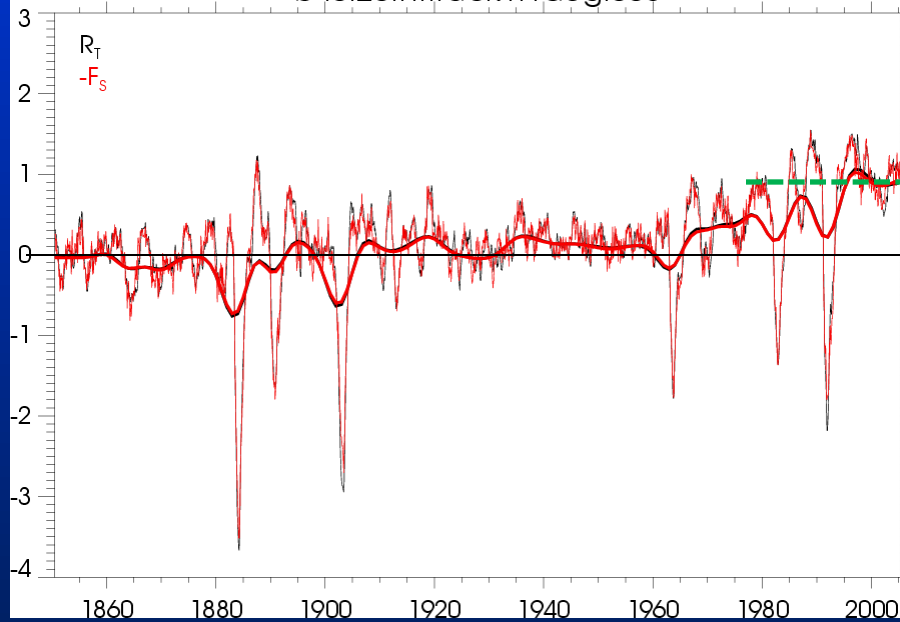
b40.20th.track1.1deg.004



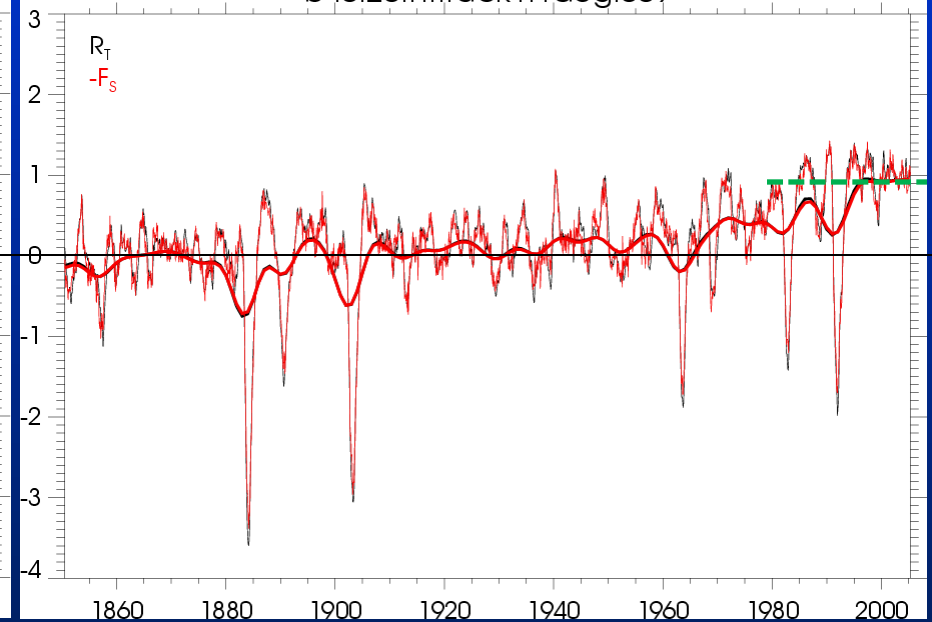
b40.20th.track1.1deg.005

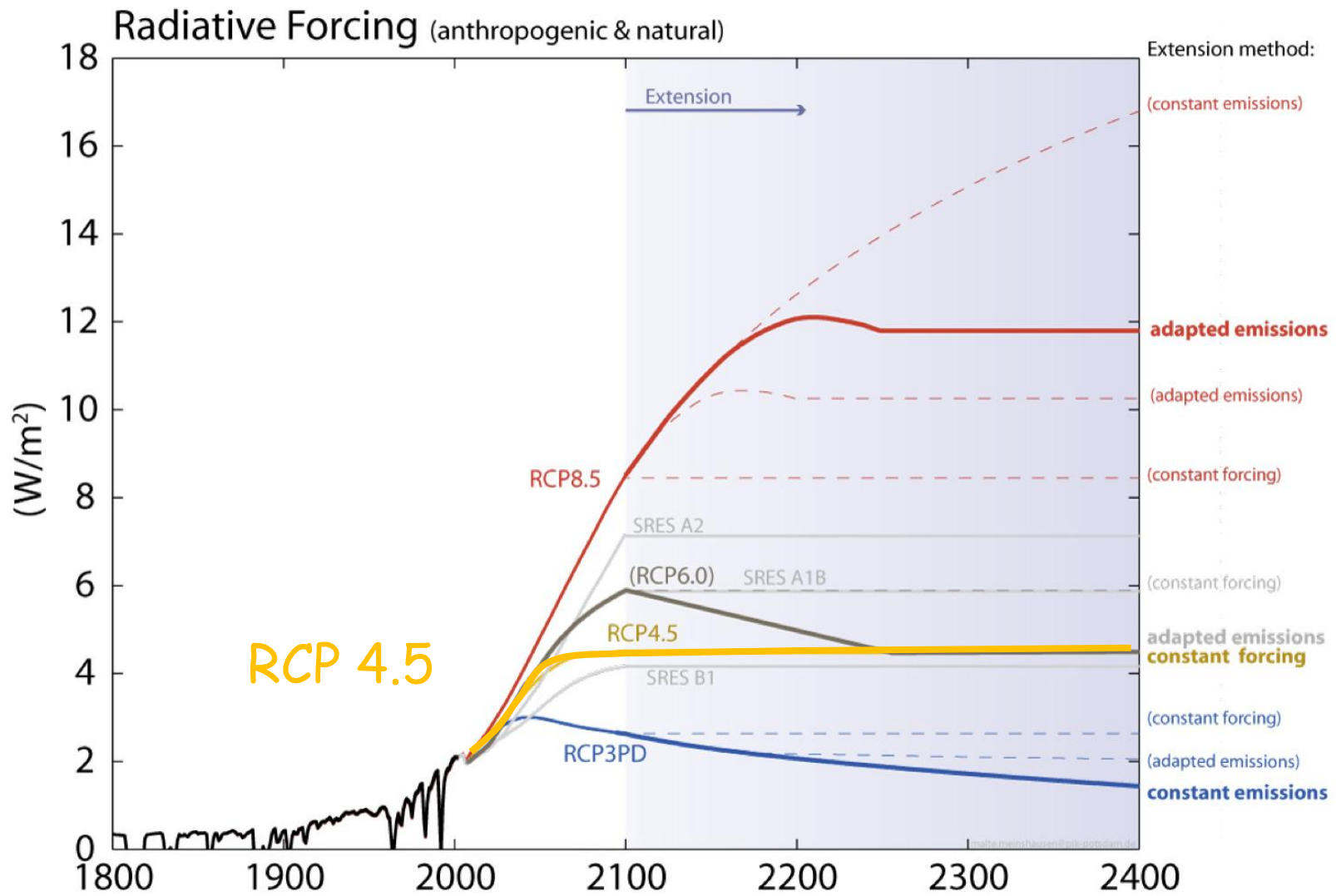


b40.20th.track1.1deg.008



b40.20th.track1.1deg.009

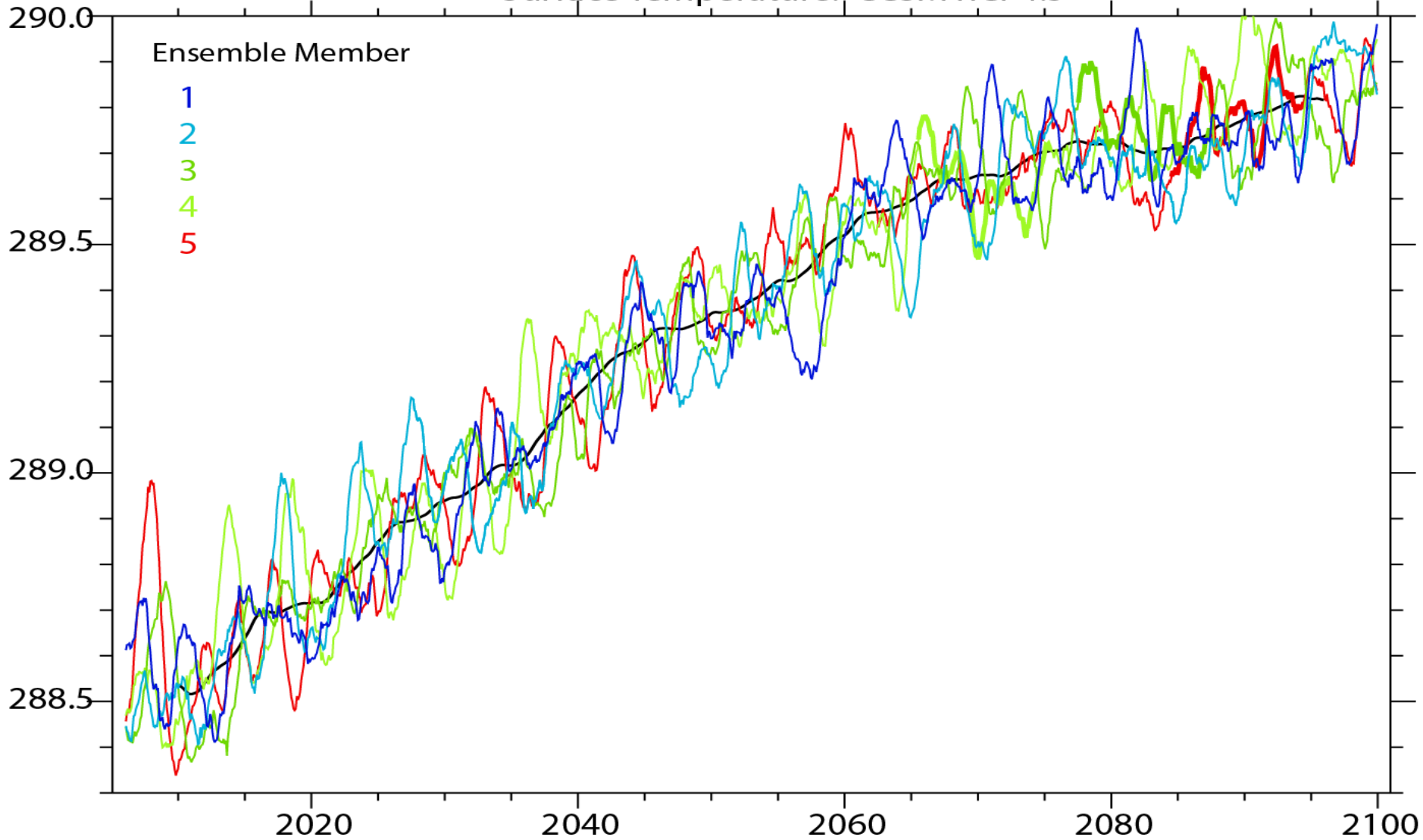




Representative Concentration Pathways (RCPs) for use in AR5

Missing energy in CCSM4?

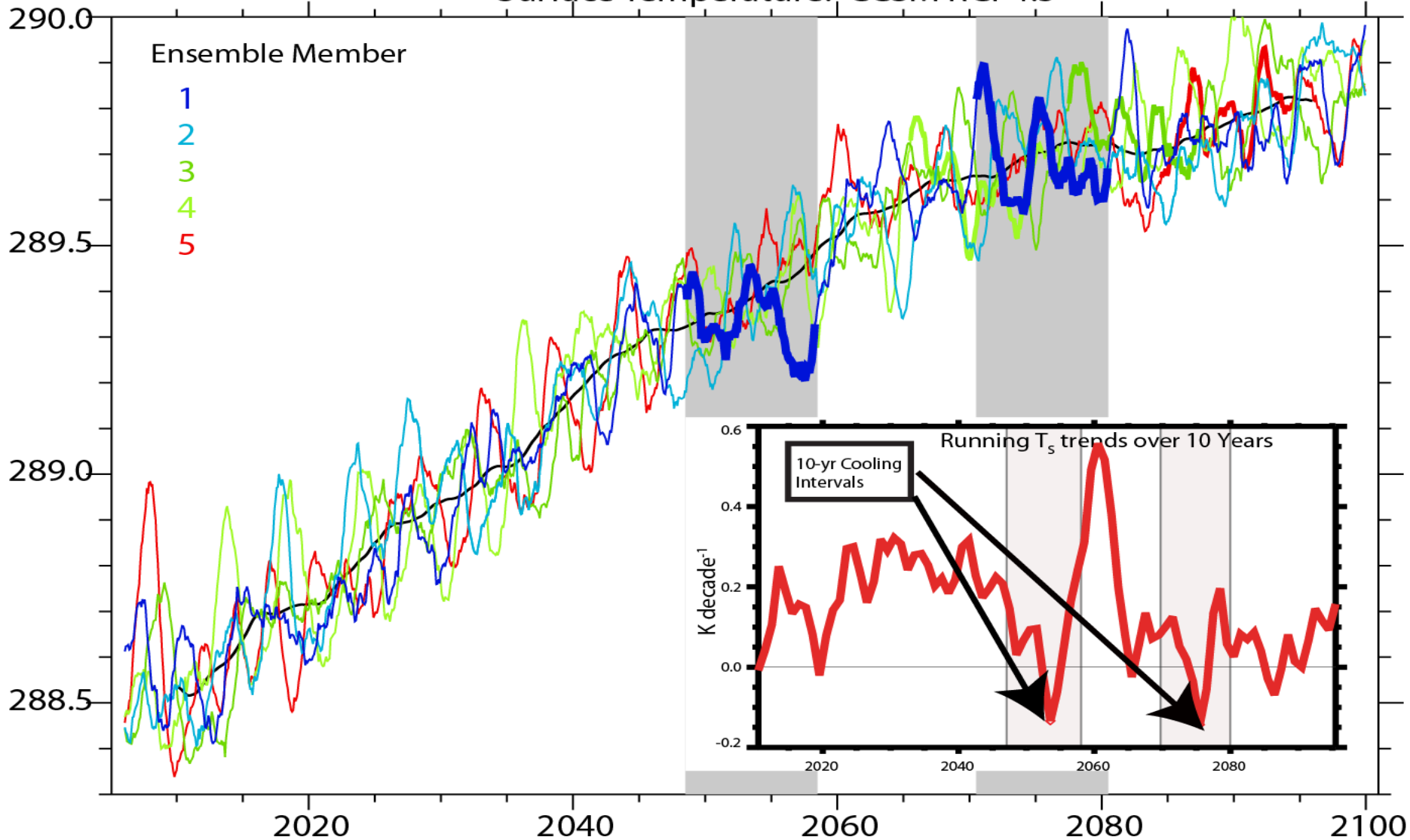
Surface Temperature: CCSM RCP4.5



In CCSM4, sfc T rises in 5 ensemble members.

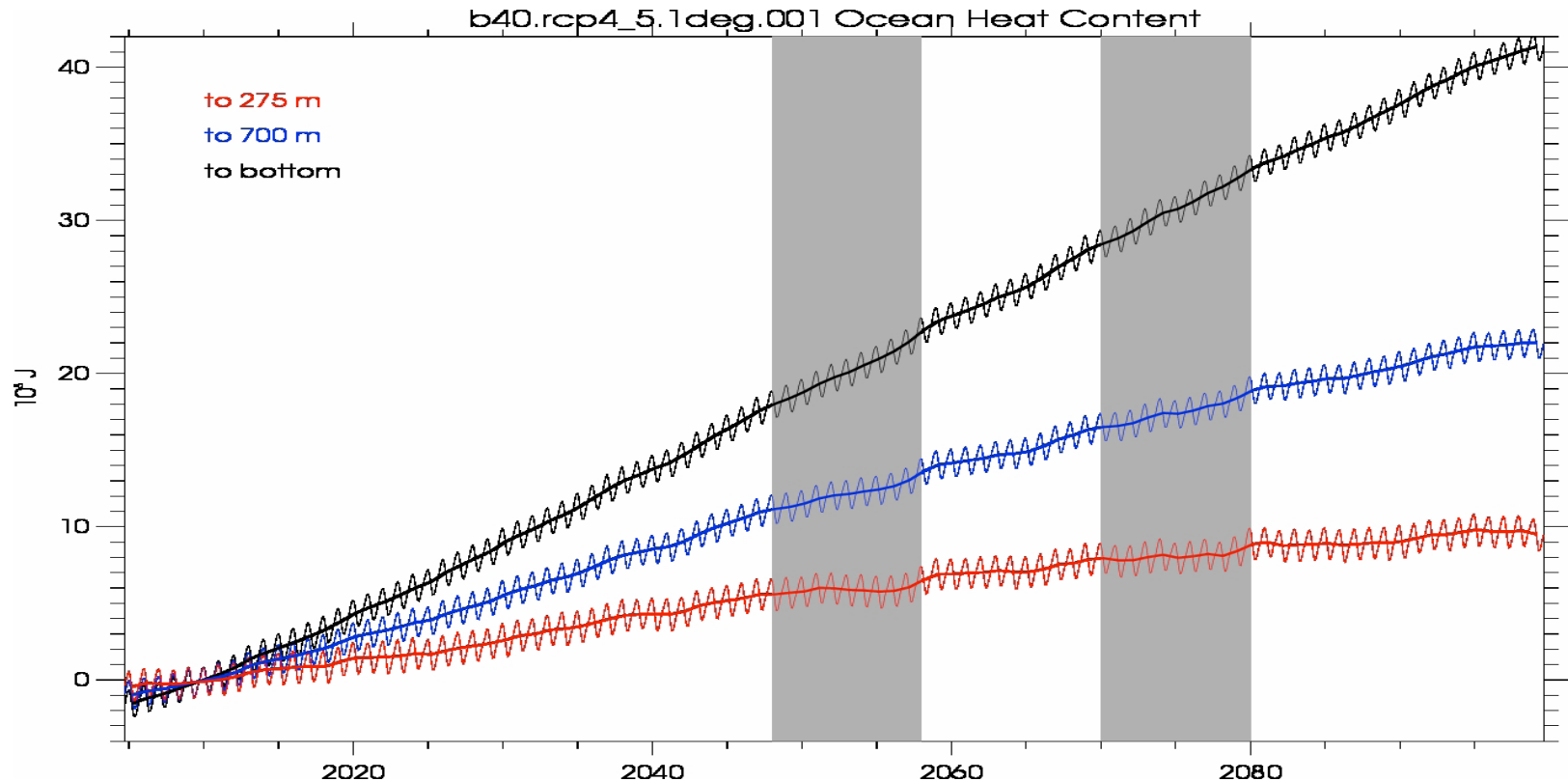
Missing energy in CCSM4?

Surface Temperature: CCSM RCP4.5



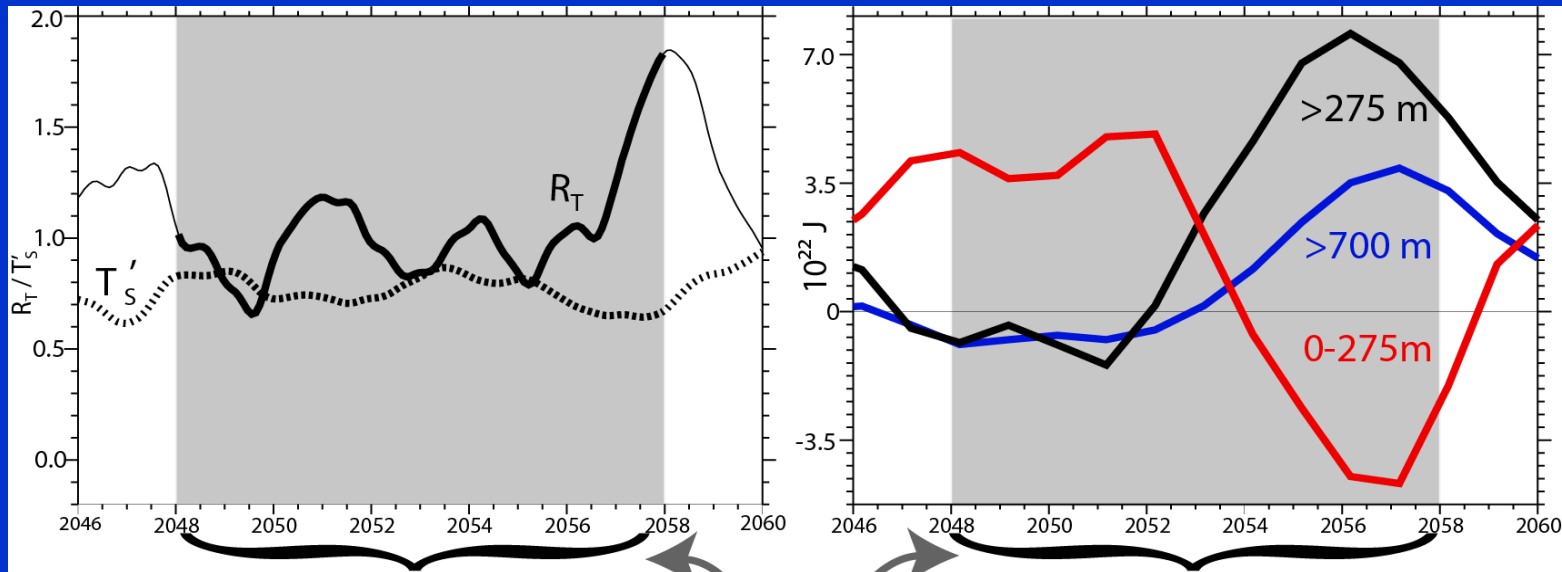
In CCSM4, during periods with no sfc T rise, the energy imbalance at TOA remains about 1 W m^{-2} warming. So where does the heat go?

Missing energy in CCSM4?



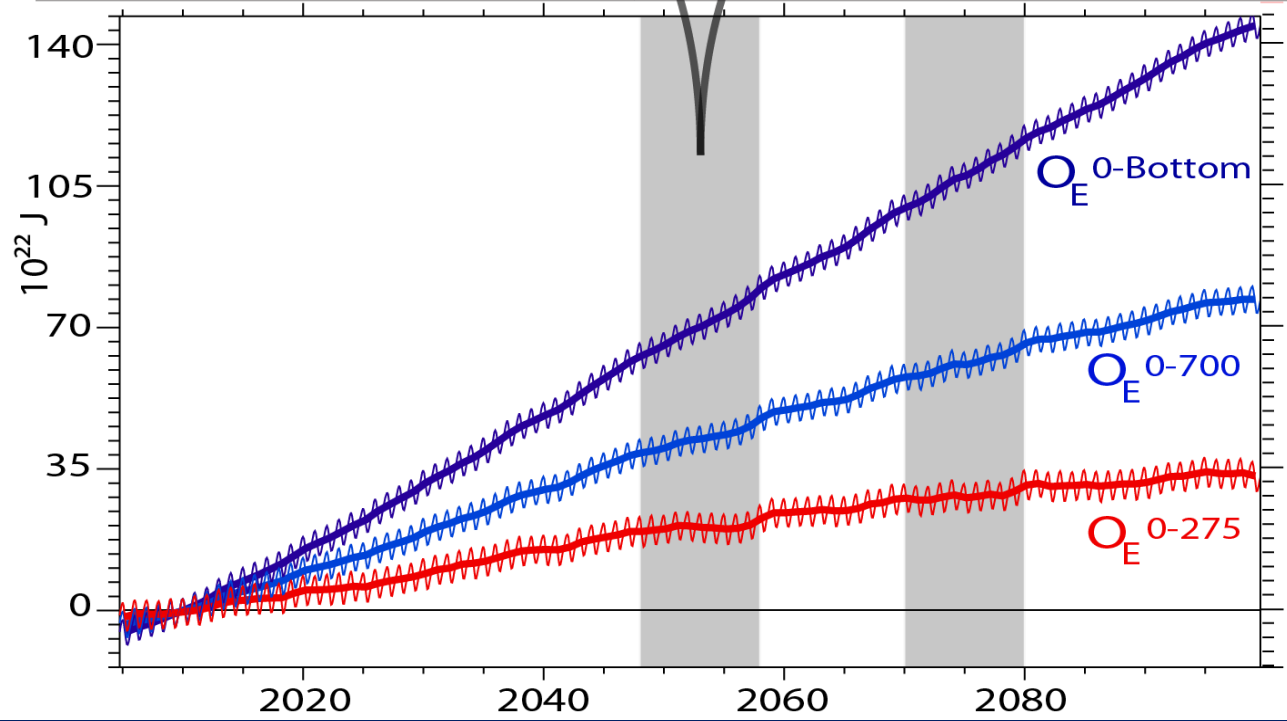
Ocean heat content for those two periods shows no warming trend in the upper 275 meters, little trend down to 700 meters, but an ongoing warming trend in the deep ocean; the heat is going into the deep ocean, but where and how?

In CCSM4, during periods with no sfc T rise, the energy goes into the deep ocean, somehow.

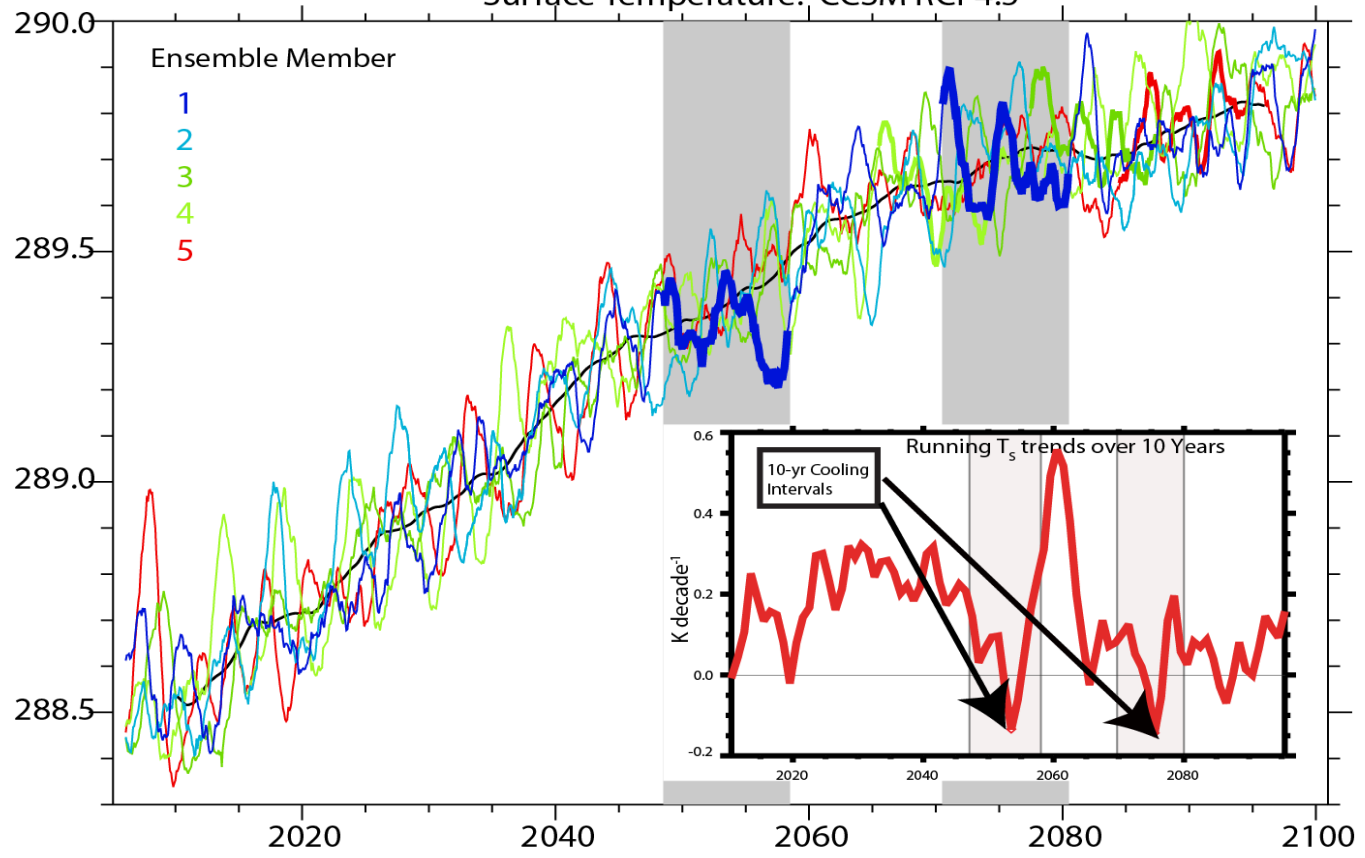


TOA and Surface Anomalies RCP4.5 - 1 21st Century Ocean Heat Content Heat Content Anom by Depth

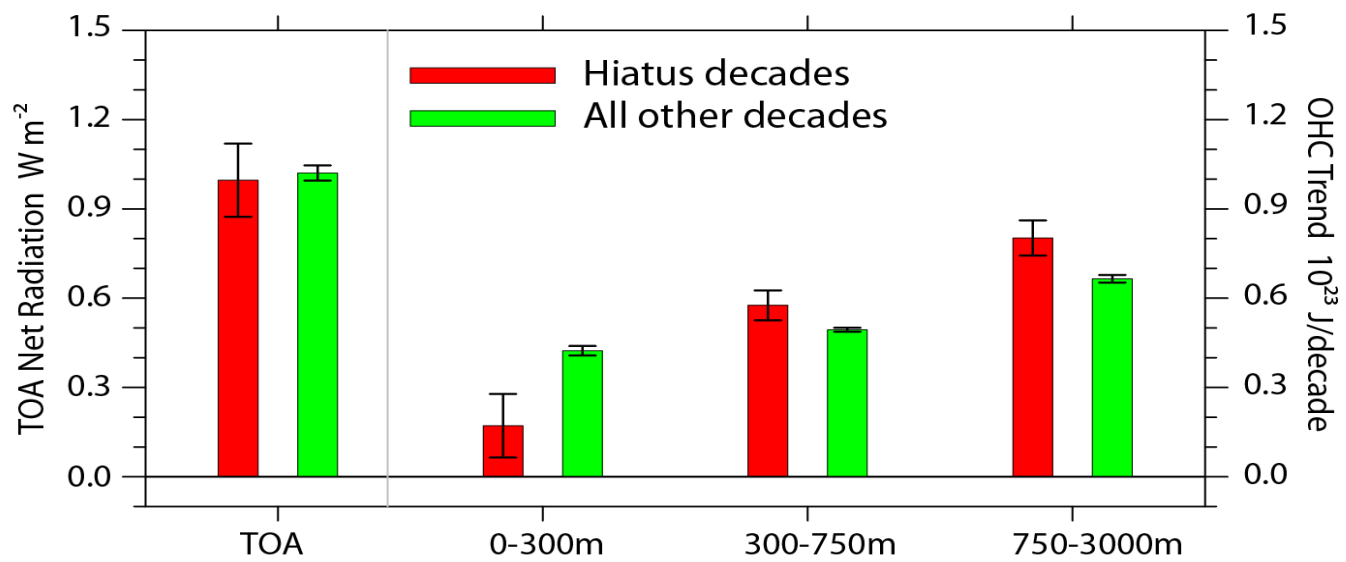
Dep. From 20 yr running mean

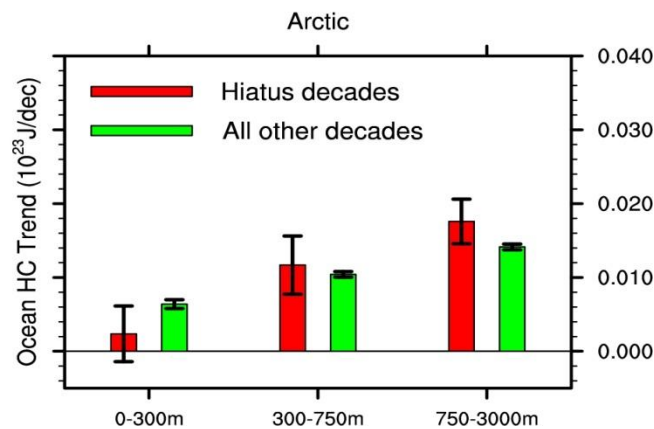
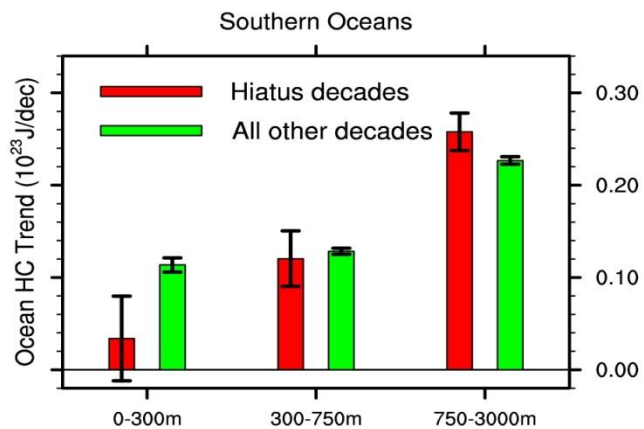
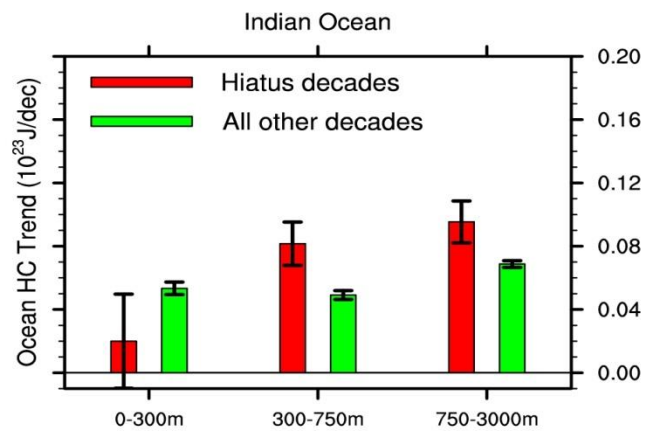
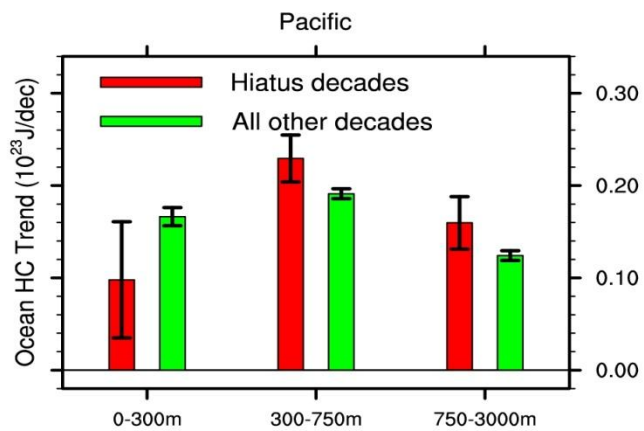
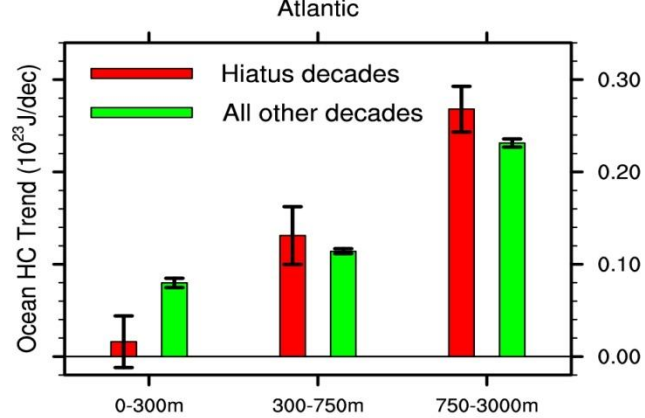
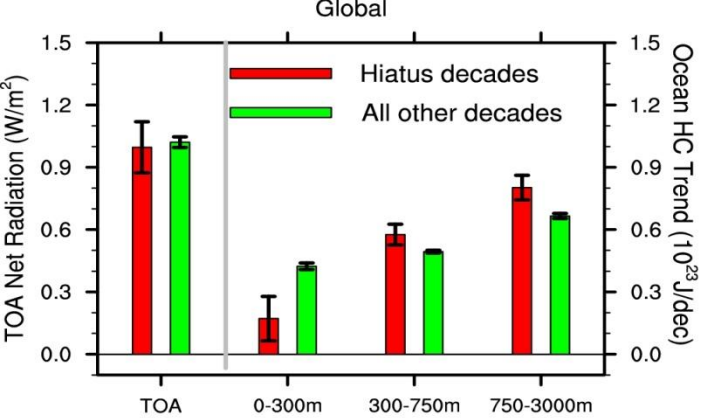


Surface Temperature: CCSM RCP4.5

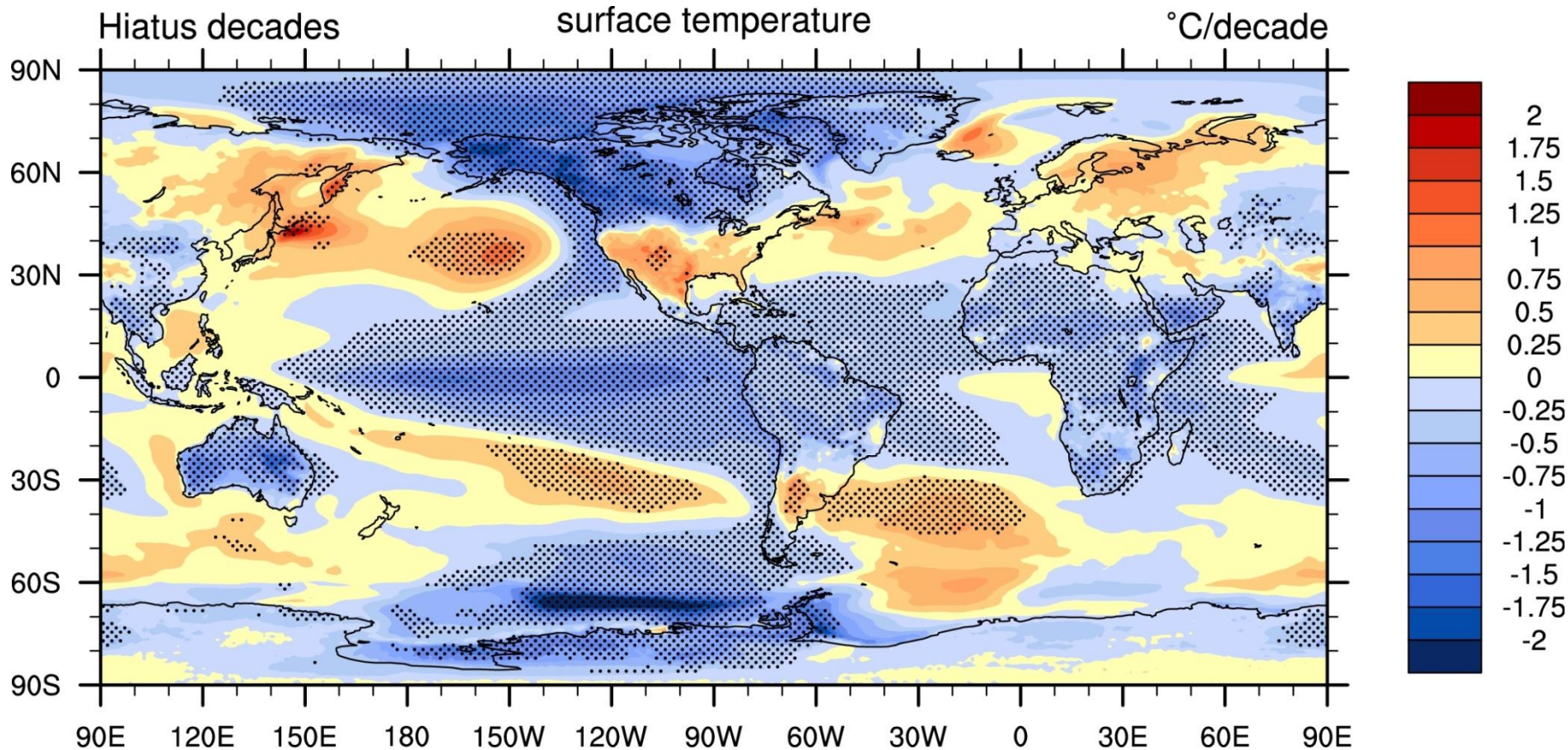


RCP4.5
Composites
from 5
ensemble
members 10
distinct 10-year
periods with
either zero or
slightly
negative
globally
averaged
temperature
trend.





750 to 3000m
Is the same
as for 750 to
bottom.

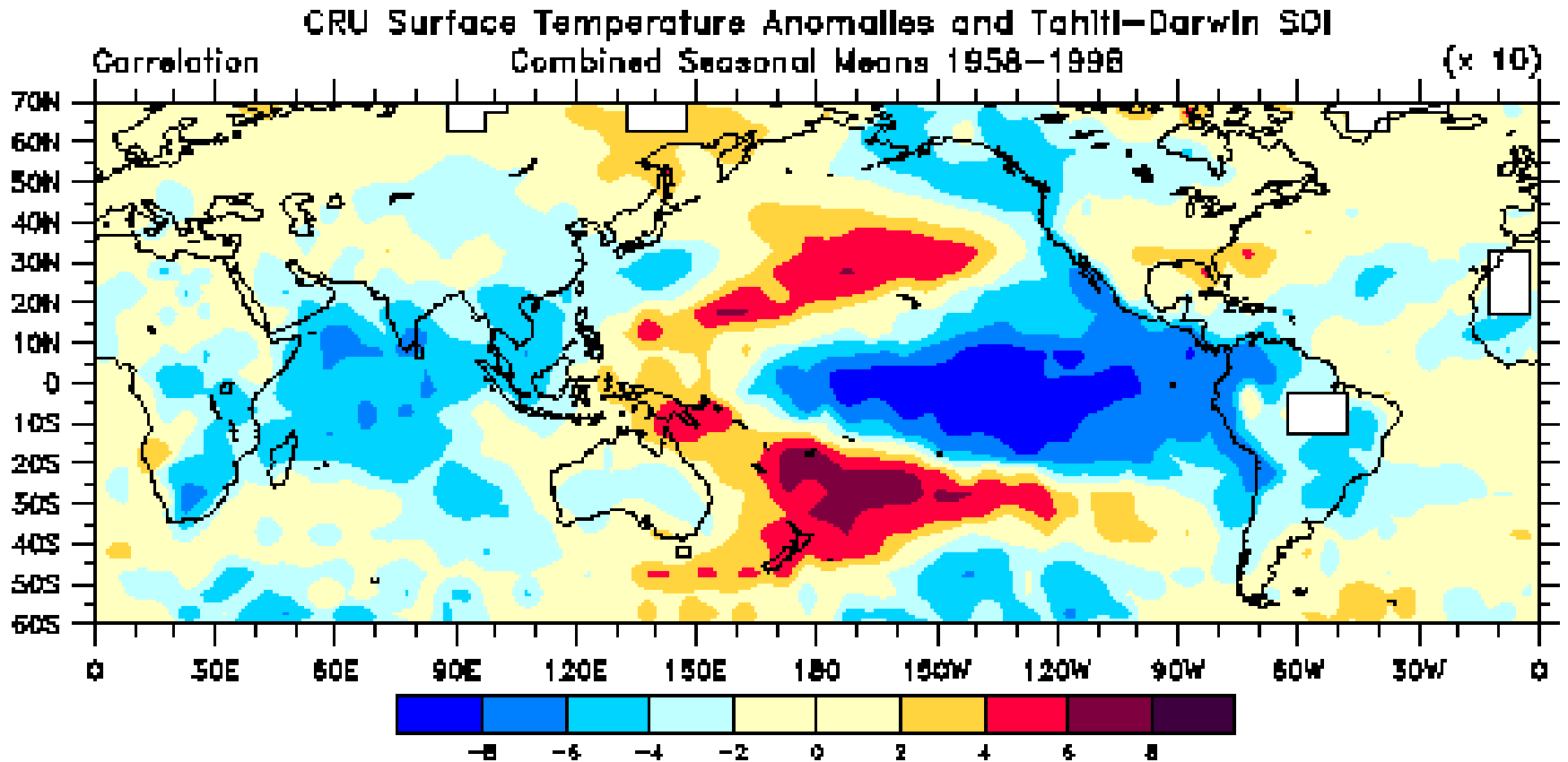


Taking five ensemble members of RCP4.5 and compositing 10 distinct 10-year periods with either zero or slightly negative globally averaged temperature trend shows these time periods are characterized by a negative phase of the Interdecadal Pacific Oscillation (IPO) or La Niña.

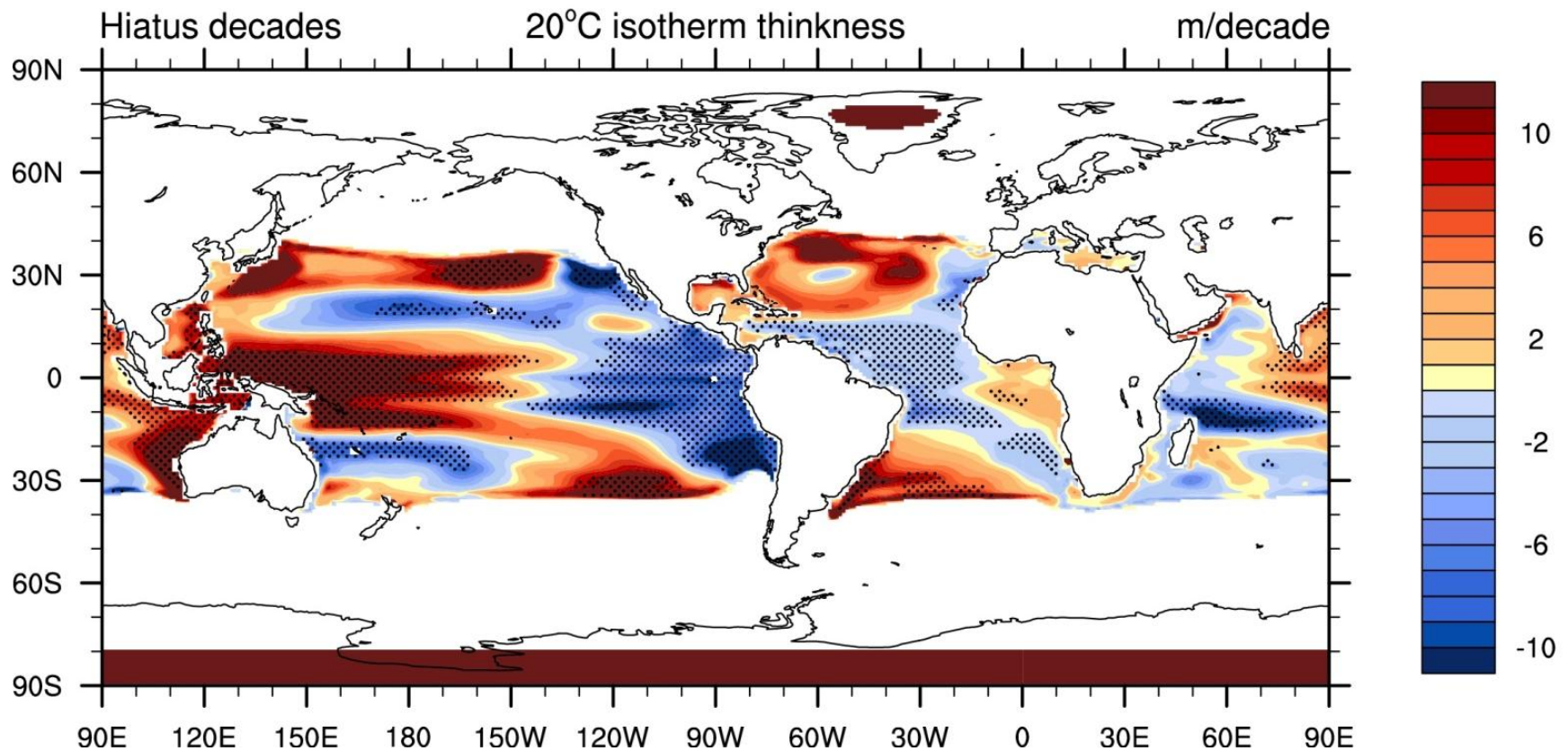
(the t-test was based on the variance across the 5 year differences in these 7 periods compared to the 5 year differences from the entire run.)

La Nina temperatures

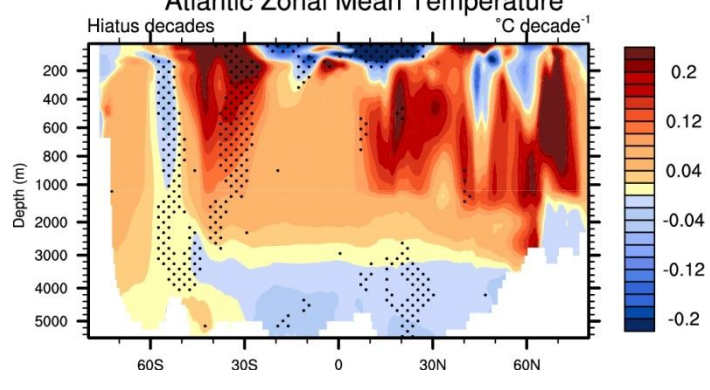
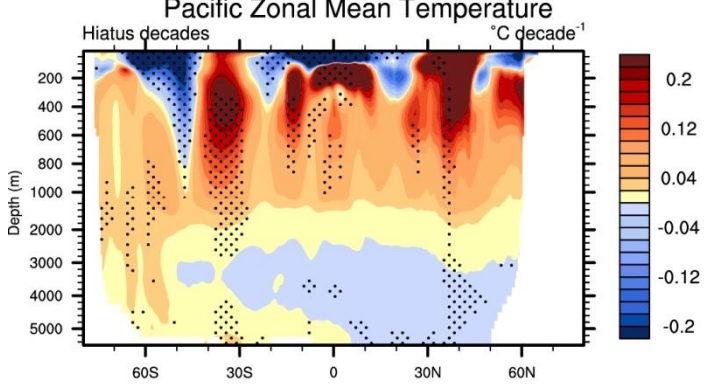
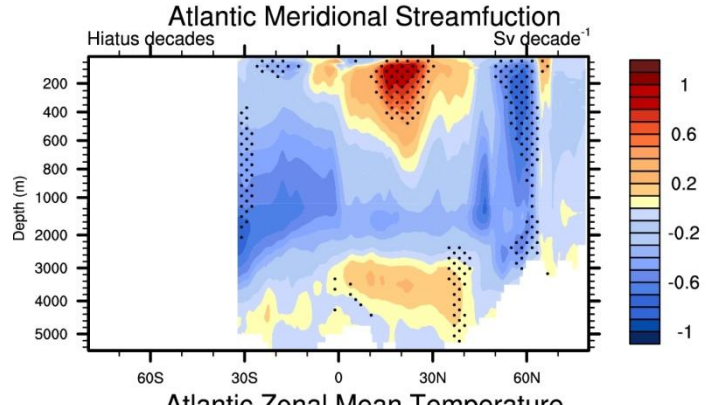
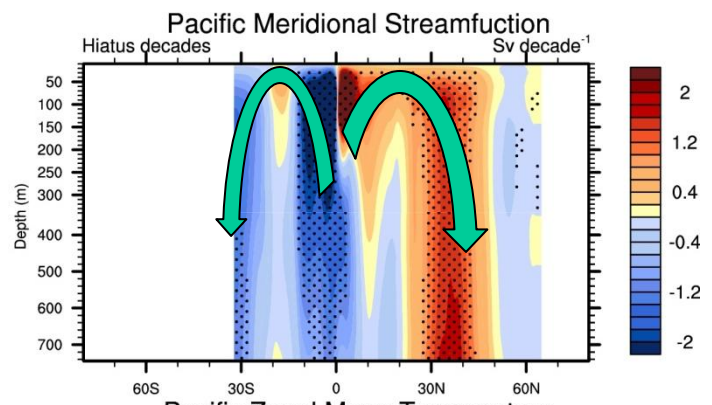
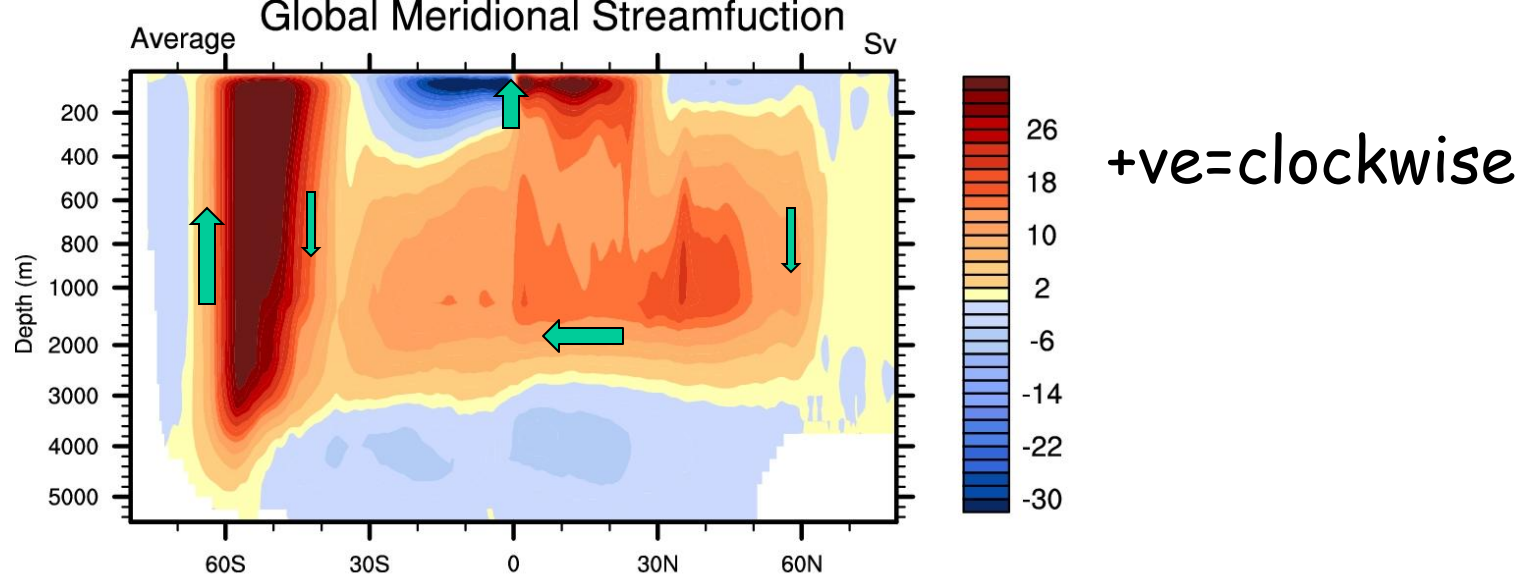
(correlation with SOI)



Trenberth and Caron 2000



Changes in the depth of the 20°C isotherm for the hiatus decades relate to OHC changes. Positive (the 20°C isotherm is deeper) suggest regions where heat is taken down into the subsurface ocean. Relates especially to subtropical overturning cells.



Conclusions

In the model, it is easy to get a decade of no surface temperature rise: relates to La Nina/ -ve PDO.

Recent experience indicate the same behavior in observations of the real world.

The energy imbalance at TOA remains the same: about 1 W m^{-2} .

The heat imbalance does not go into top 300 m of the ocean; in fact that region loses heat.

Instead heat penetrates below there and some below 700m.

The mechanism appears to relate to subtropical meridional overturning cells.

Where does the heat go?

Questions remain. Both the CCSM4 and observations suggest that ENSO plays a necessary, if not sufficient, role. Strong recent ENSO events, including the El Niño of 1997/98 and the La Niña of 2007/08 exert a strong influence on trends in global temperature computed across this period.

Similarly, cooling decades from the CCSM4 are bounded by El Niño events at their initiation and La Niña events are their termination. Yet other intervals bounded by El Niño and La Niña are not accompanied by significant cooling.

Our current work focuses on understanding this variable association between ENSO and global temperature trends.