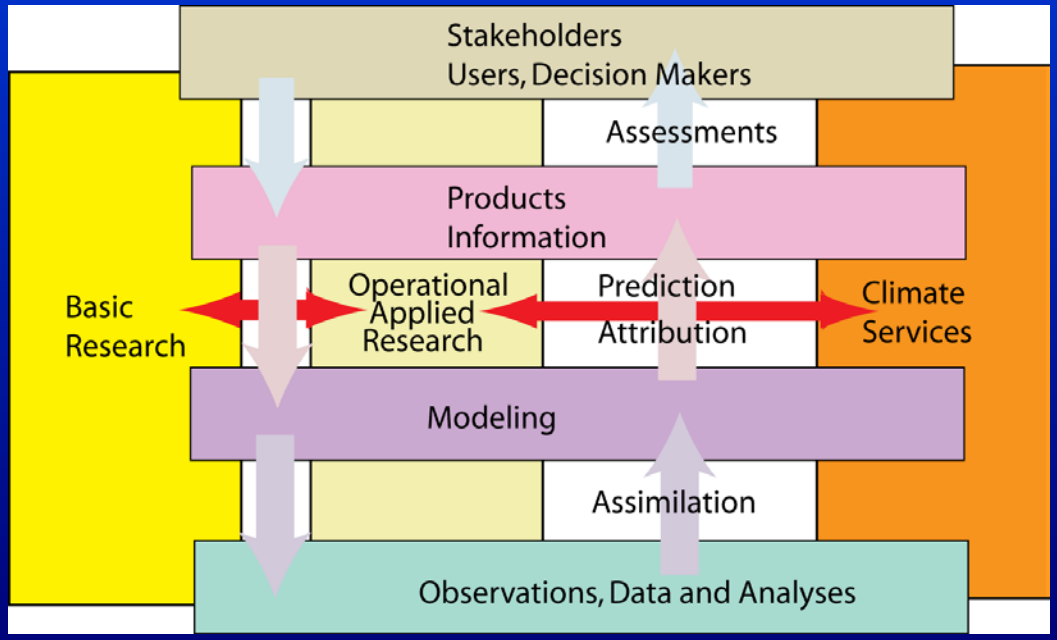
Aspects of a climate observing system: energy and water

Kevin E Trenberth
NCAR



Tracking Earth's Global Energy

Where has global warming from increased GHGs gone?

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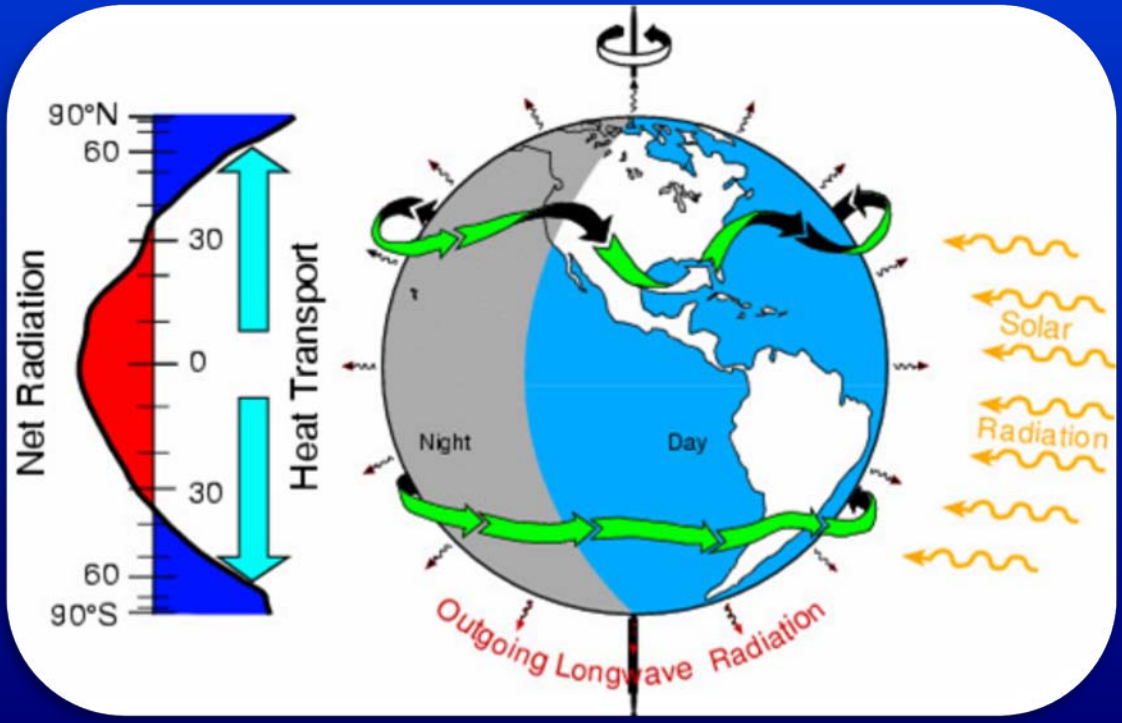
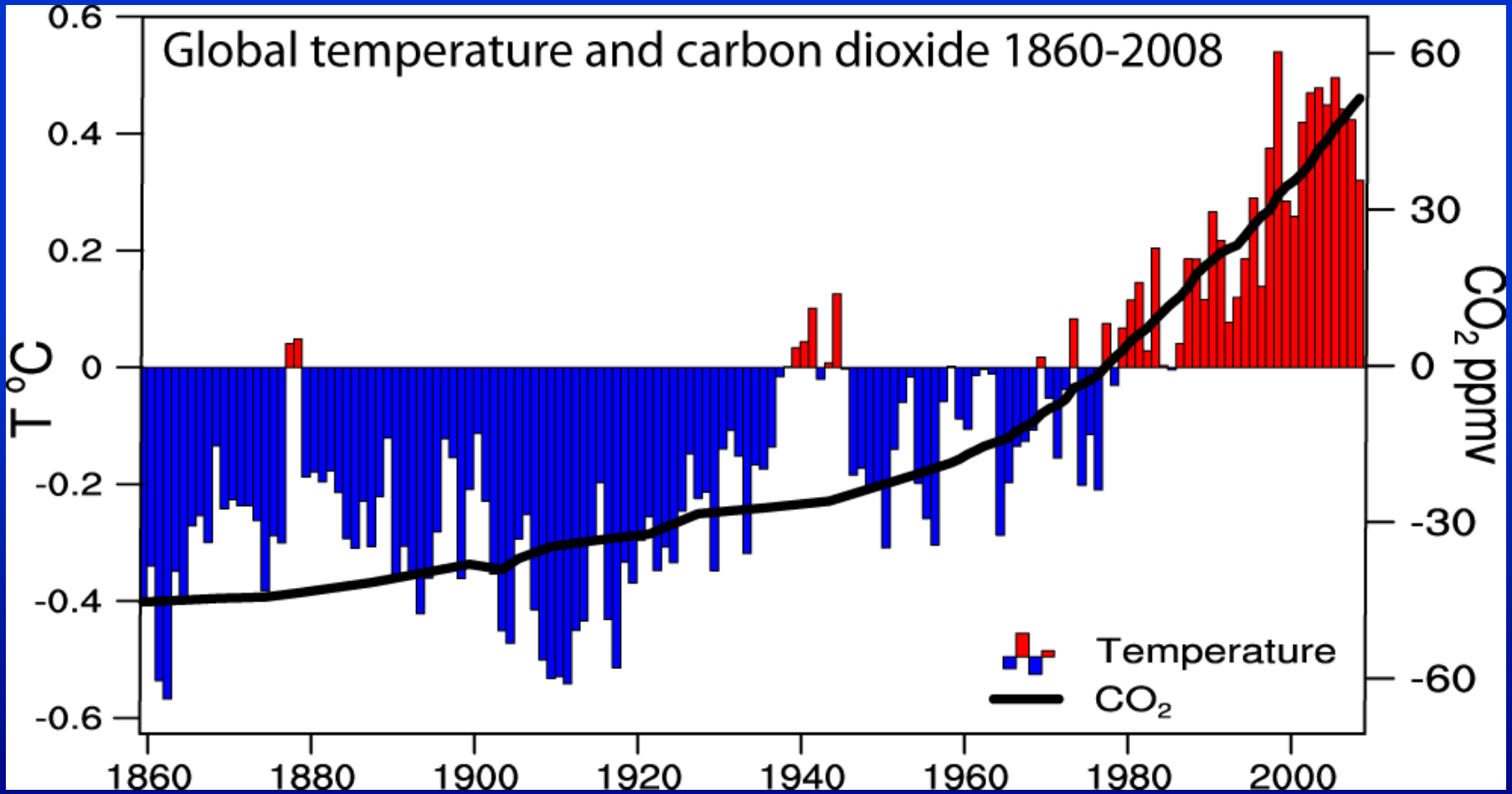


Where did the heat go?

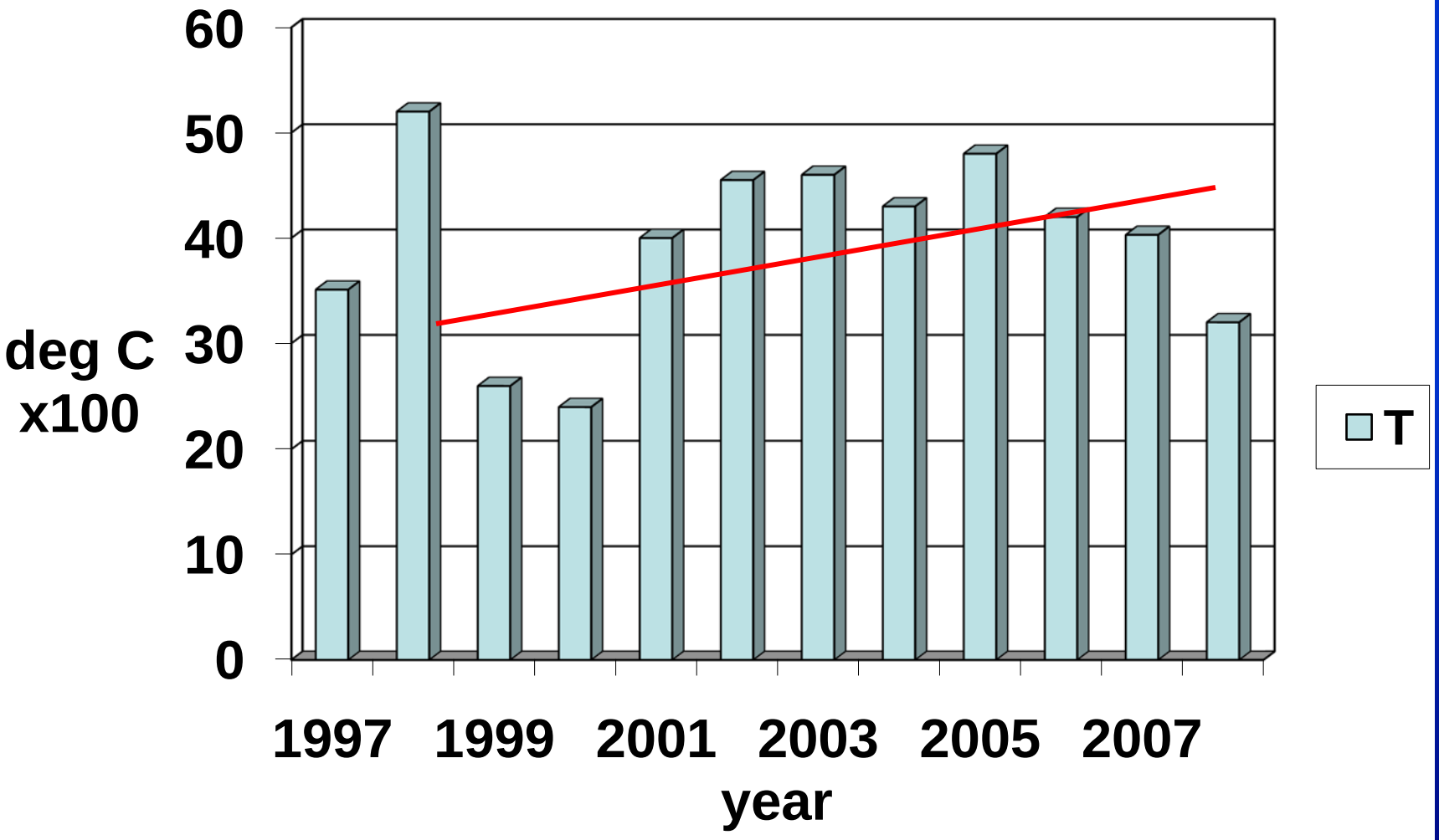
- 2008 is the coolest year since 2000
- Carbon dioxide continues to rise
- Radiative forcing continues apace
- Where did global warming go?

Global temperatures and carbon dioxide through 2008



Base period 1961-90

Global Temperature anomalies



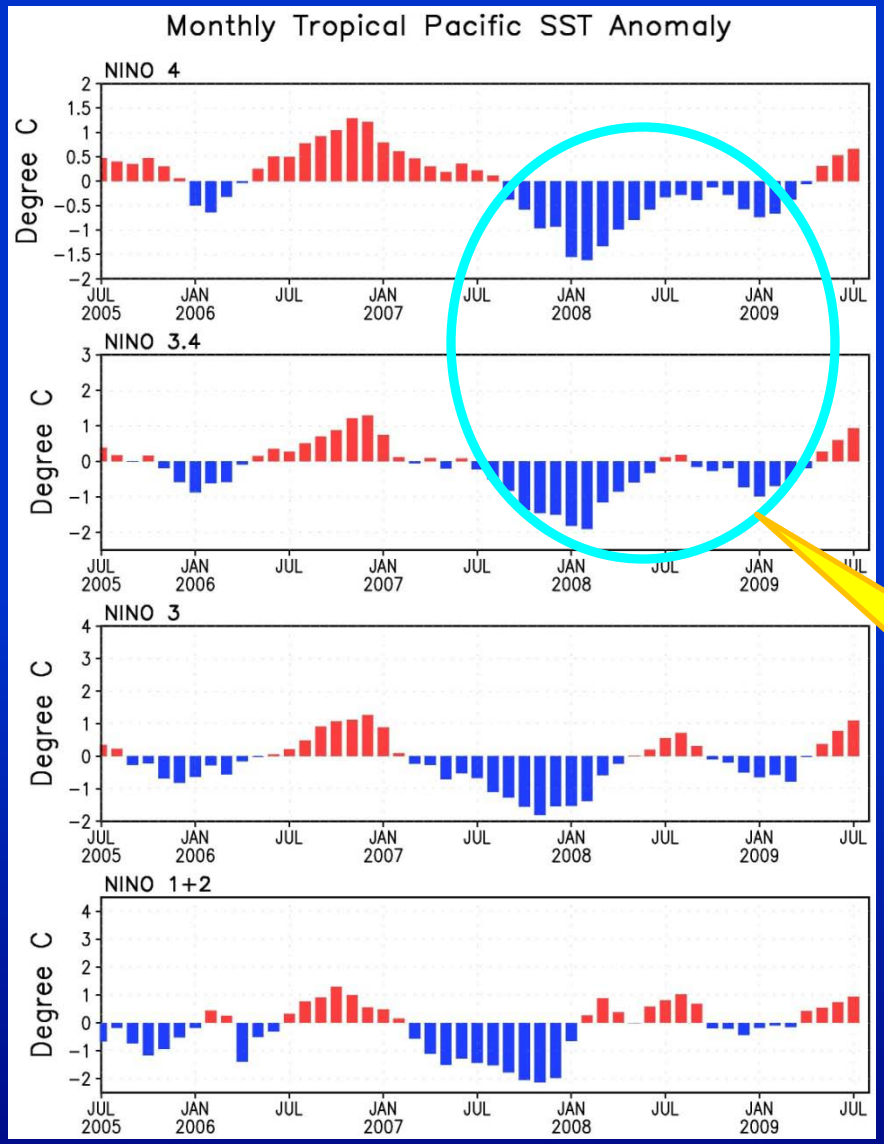
Trend 1998 to 2008 is slightly positive but not significant.

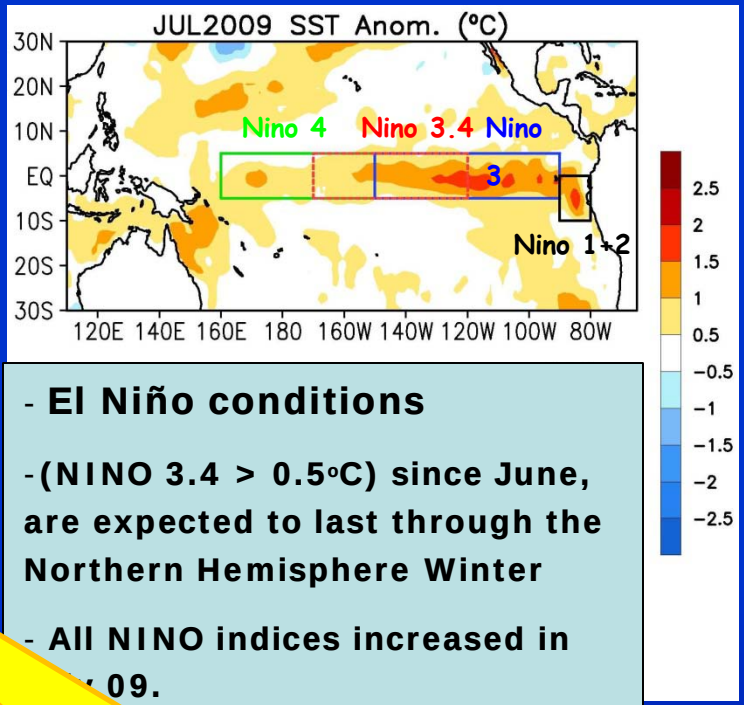
Hadley Centre and CRU

Natural variability

- We glibly answer that natural variability is the cause of the cooler year
- After-all we did have a La Niña in 2007-2008
- But where did the energy go?
- We should be able to trace it!

Evolution of Pacific NINO SST Indices





- **El Niño conditions**

- **(NINO 3.4 > 0.5°C) since June, are expected to last through the Northern Hemisphere Winter**

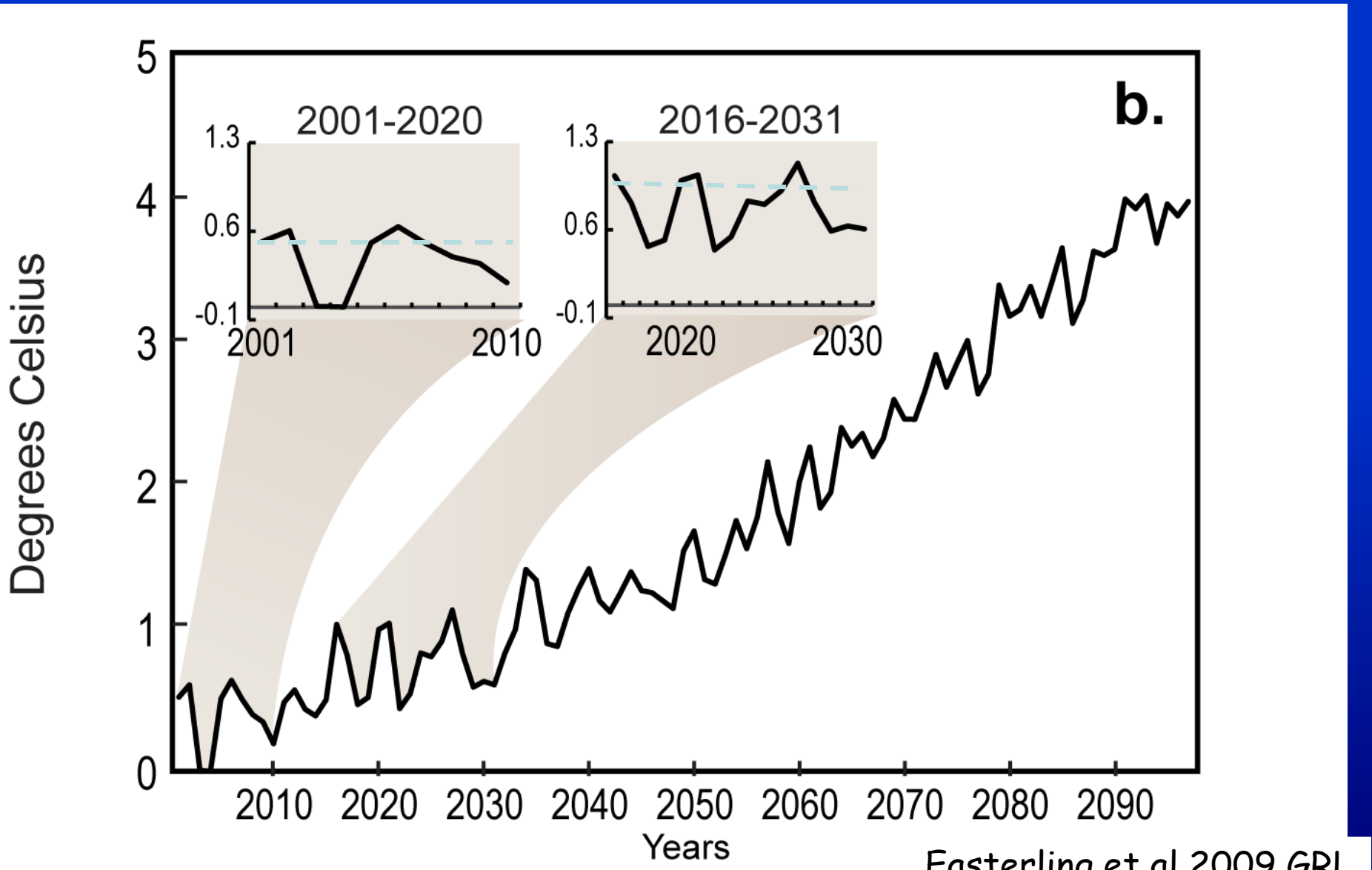
- **All NINO indices increased in 09.**

Strong La Niña 2007-08
Returns weakly in 2008-09
Jan 2008 coldest month
on land for long time
El Niño after June 2009

Nino region indices, as area-averaged monthly SST anomalies (°C) as departures from 1971-2000
Climate Prediction Center

Cooling can easily happen for a decade or so

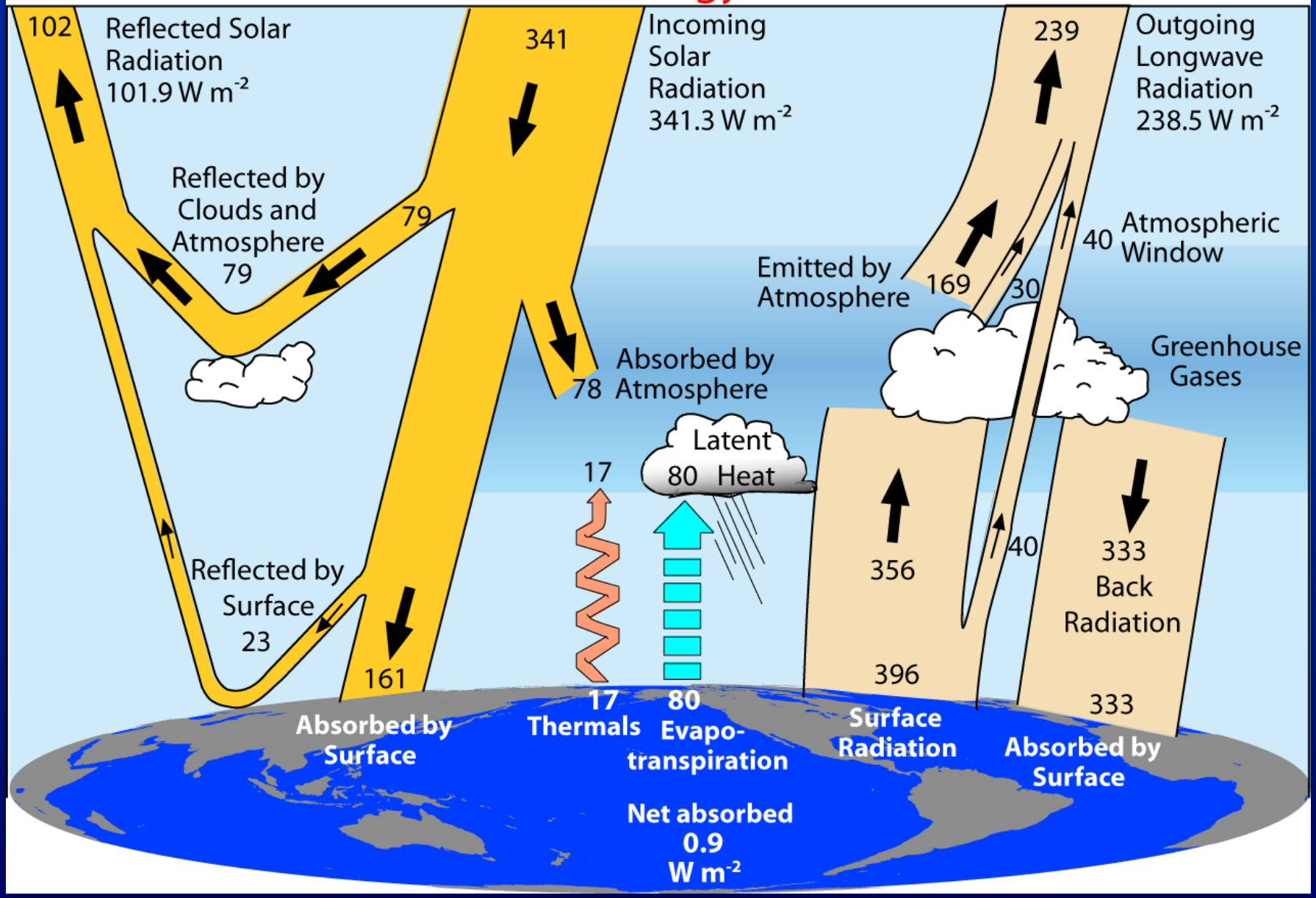
Global Annual Surface Air Temperature,
MPI-ECHAM CGCM: A2 Forcing



Easterling et al 2009 GRL

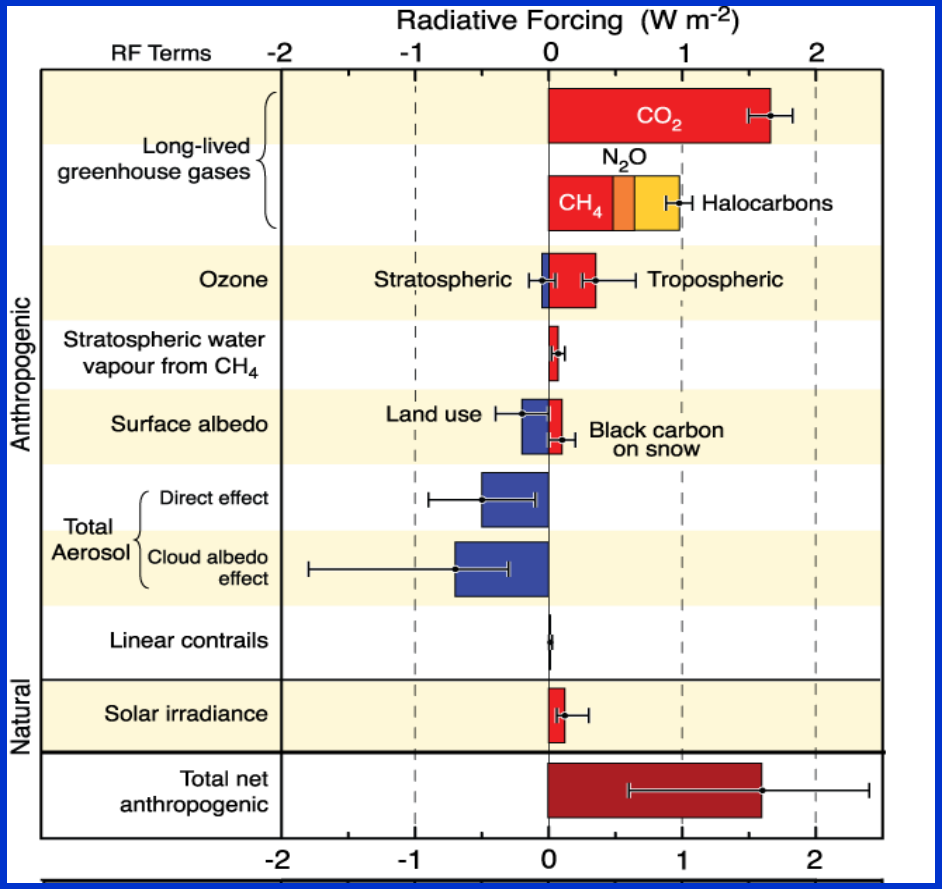
2000-2005 (CERES Period)

Global Energy Flows W m^{-2}



Trenberth et al 2009

A warming climate has a cause:
Radiative Forcing and Response of Climate



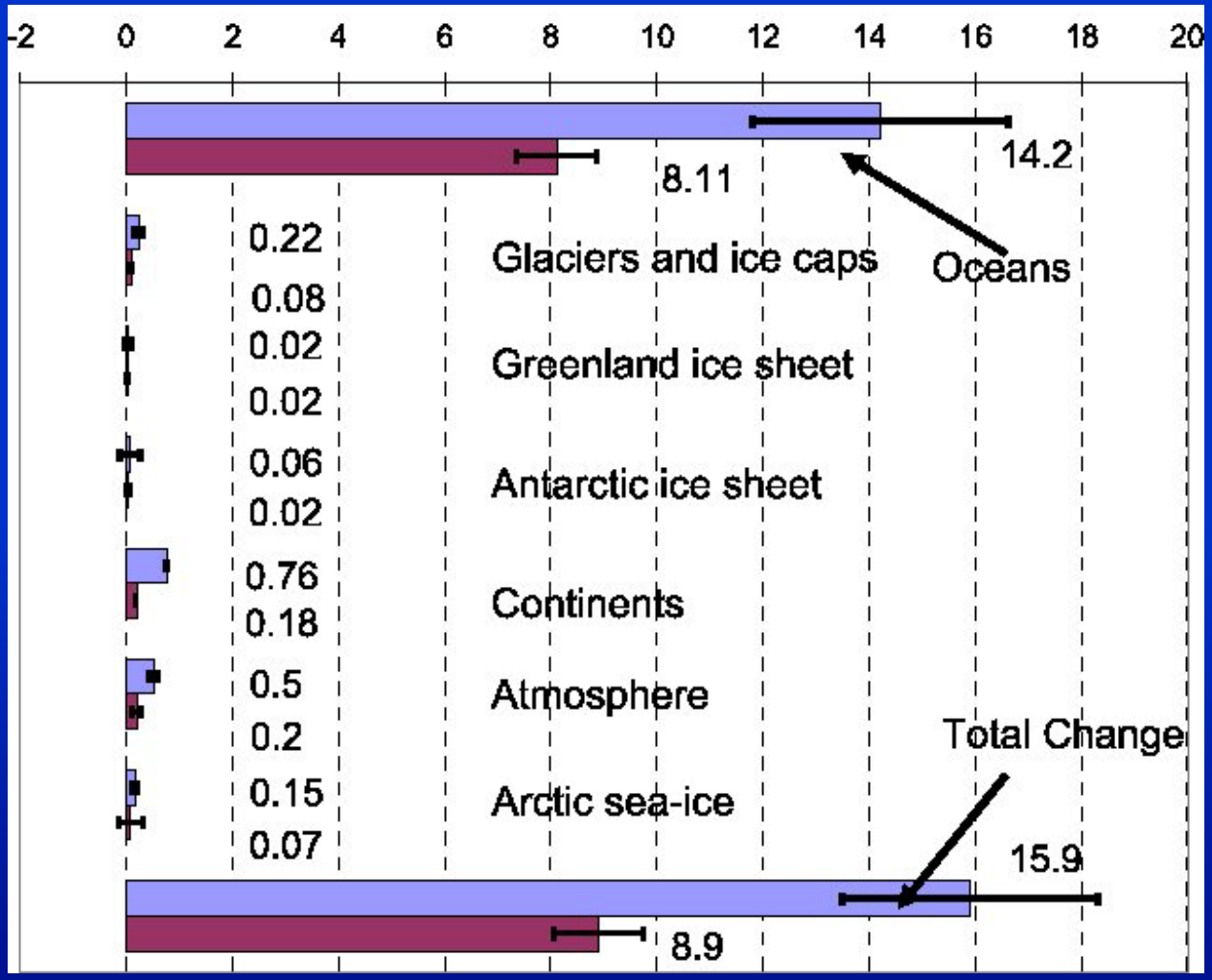
Forcings	W m^{-2}
CO_2:	1.6
GHGs:	3.0
Aerosols:	-1.4
Net:	1.6

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?

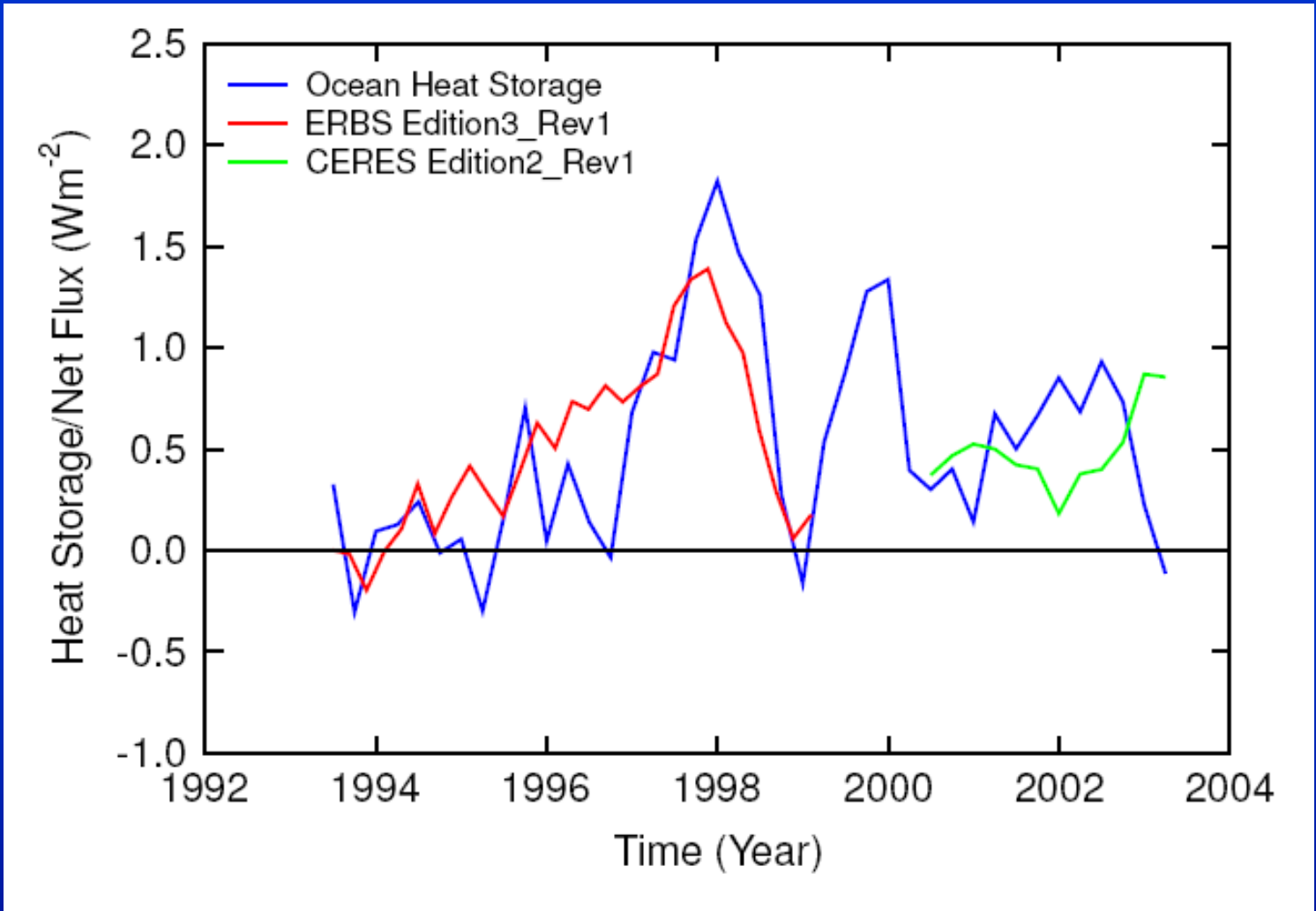
Energy content change 10^{22} J



1961-2003 (Blue bars)

1993-2003 (Burgundy bars)

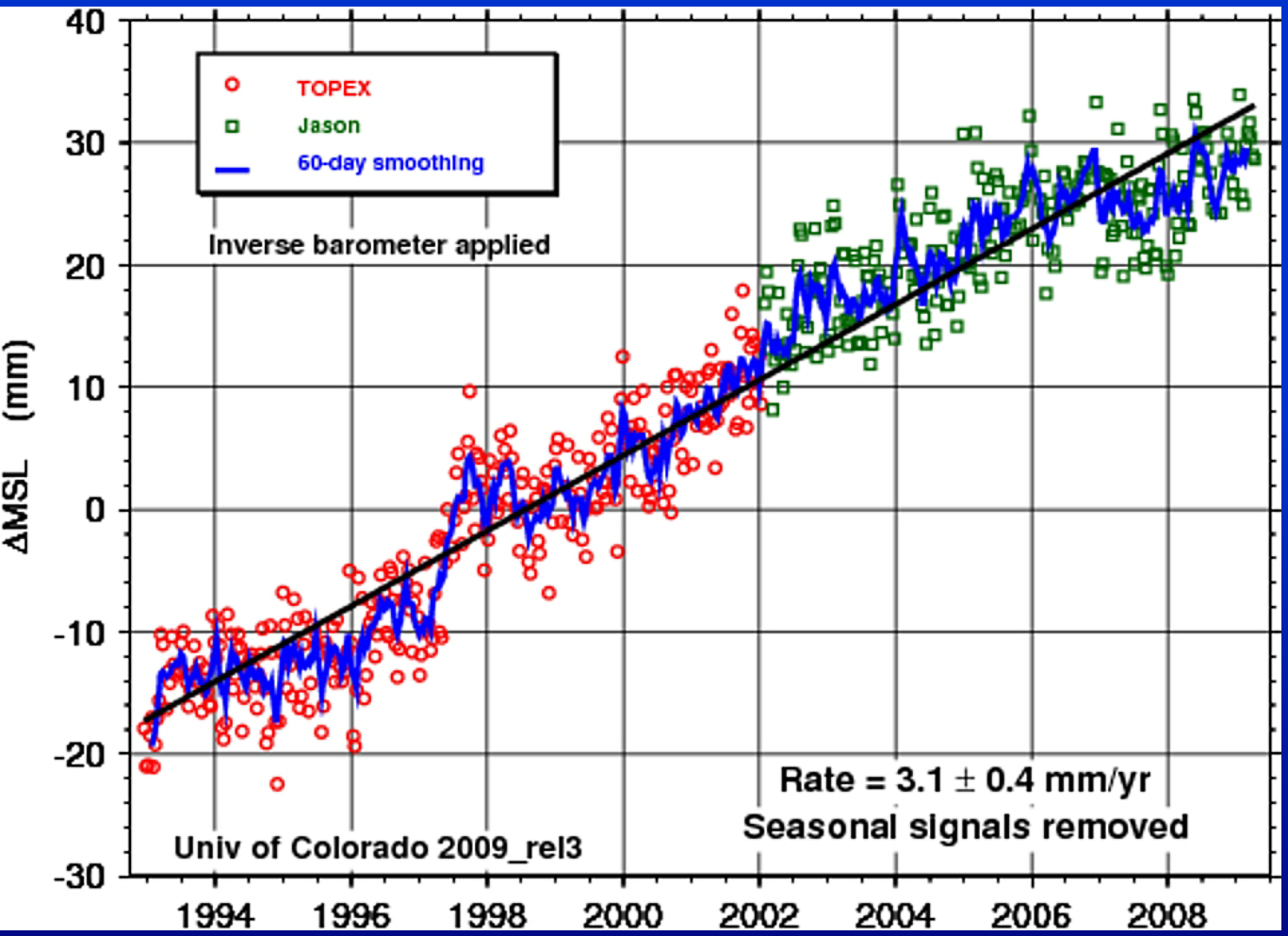
Figure 5.4 IPCC AR4



Matching ocean heat storage (Willis et al 04) and TOA radiation (Wong et al 06)

Sea level is rising:

from ocean expansion and melting glaciers

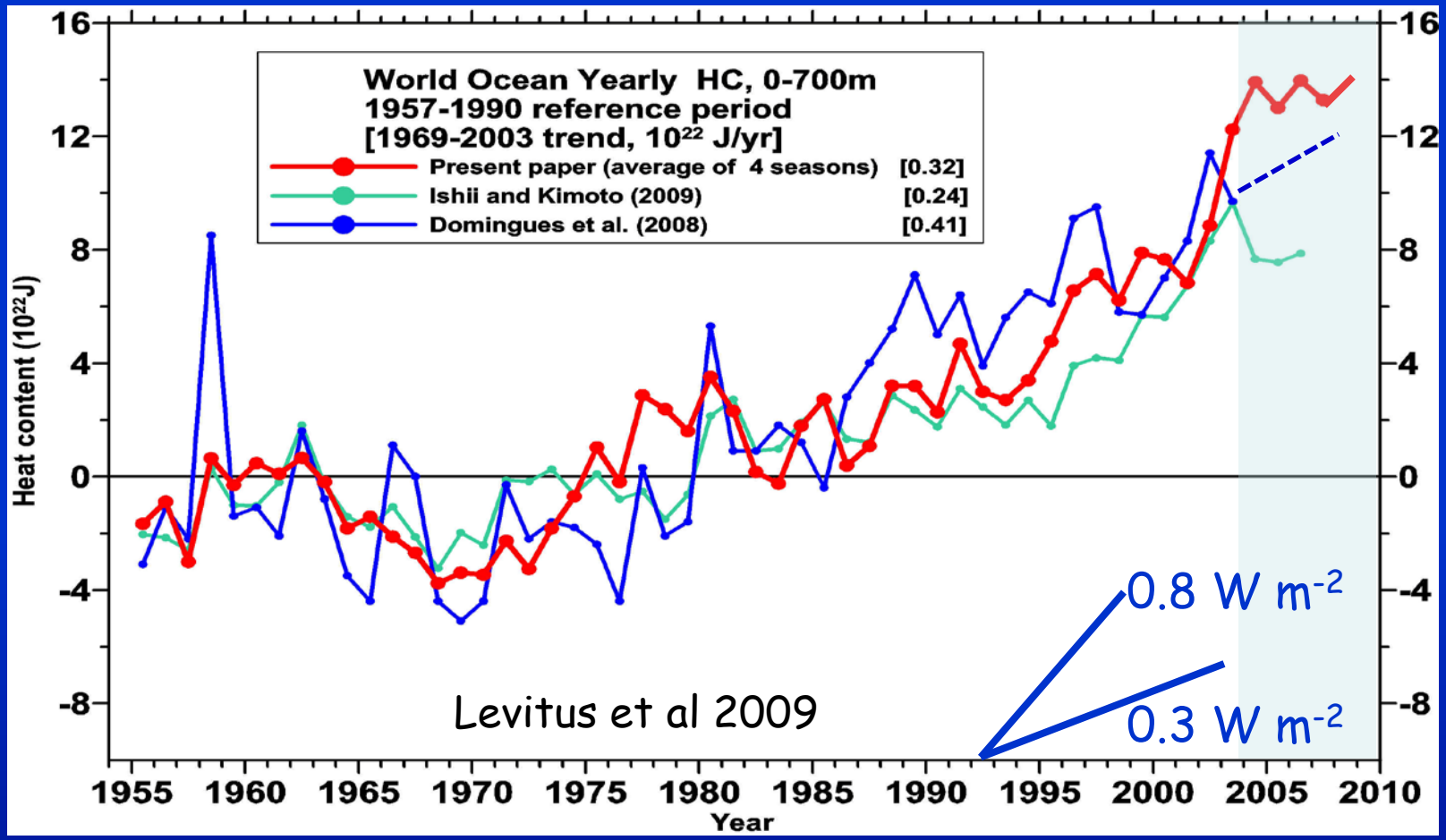


Since 1992
Global sea level has risen 48 mm (1.9 inches)

To 2003:
- 60% from expansion as ocean temperatures rise,
- 40% from melting glaciers

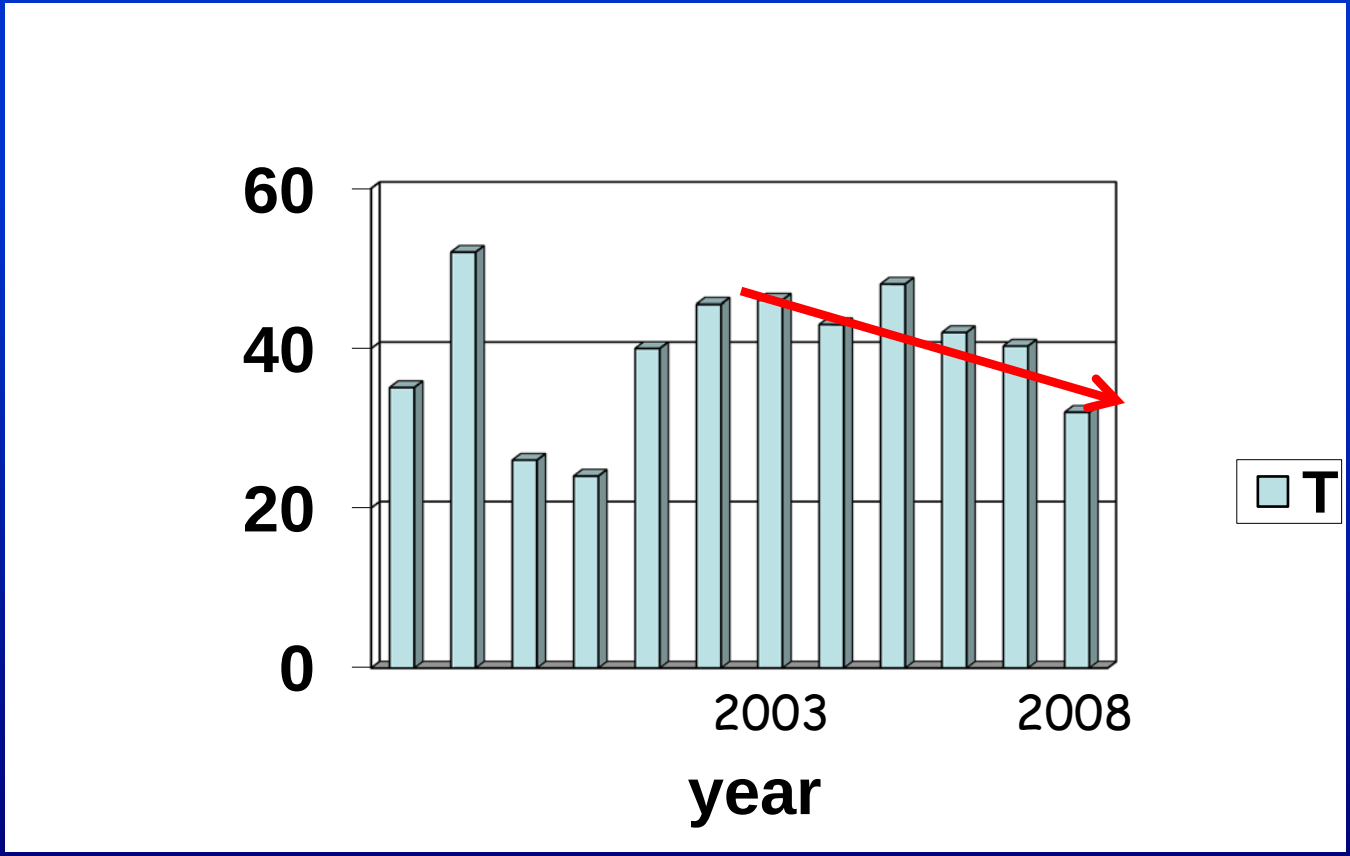
Courtesy Steve Nerem
U Colo

Revised ocean heat content

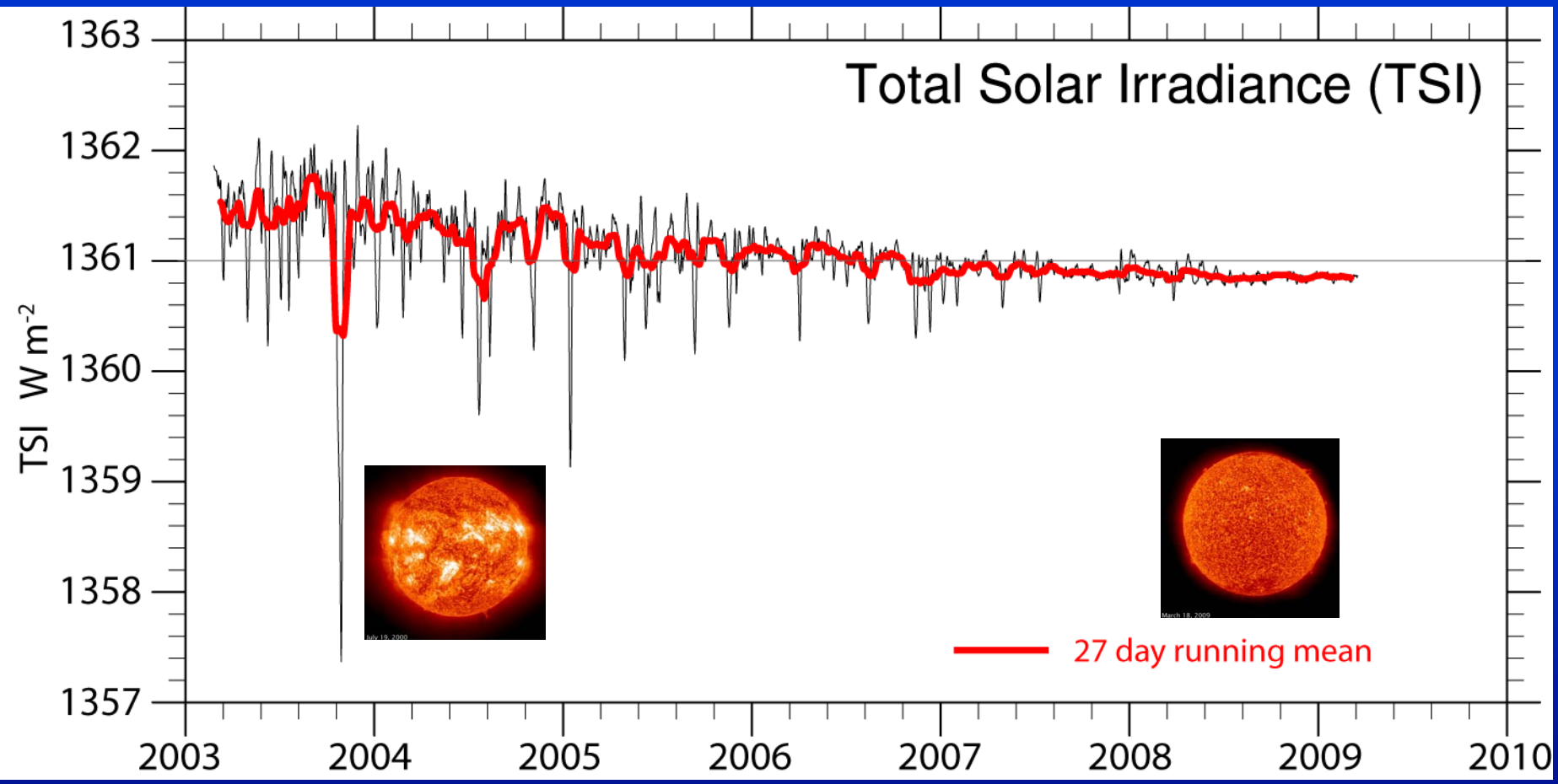


Yearly time series of ocean heat content (10^{22} J) for the 0-700 m layer from Levitus et al (2009), Domingues et al. (2008) and Ishii and Kimoto (2009) with a base period of 1957-1990. Linear trends for each series for 1969-2007 given in the upper portion of the figure.

What about 2003 to 2008?



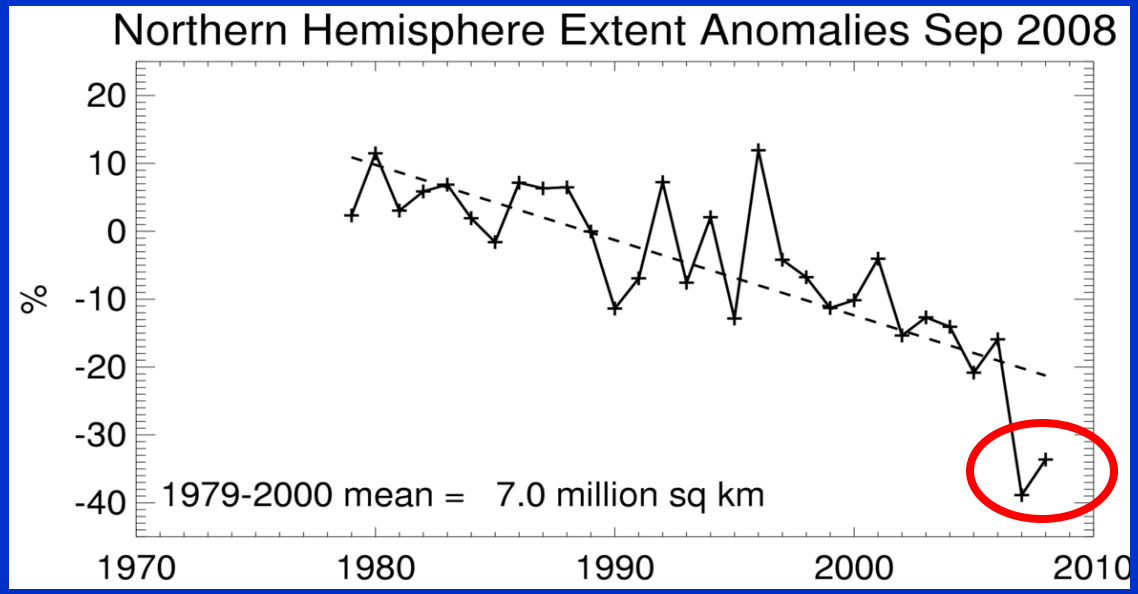
Solar irradiance



Drop of about 0.5 W m^{-2} or
0.1 W m^{-2} for radiative forcing

Total Irradiance Monitor (TIM) on the Solar Radiation and Climate Experiment (SORCE), U Colorado

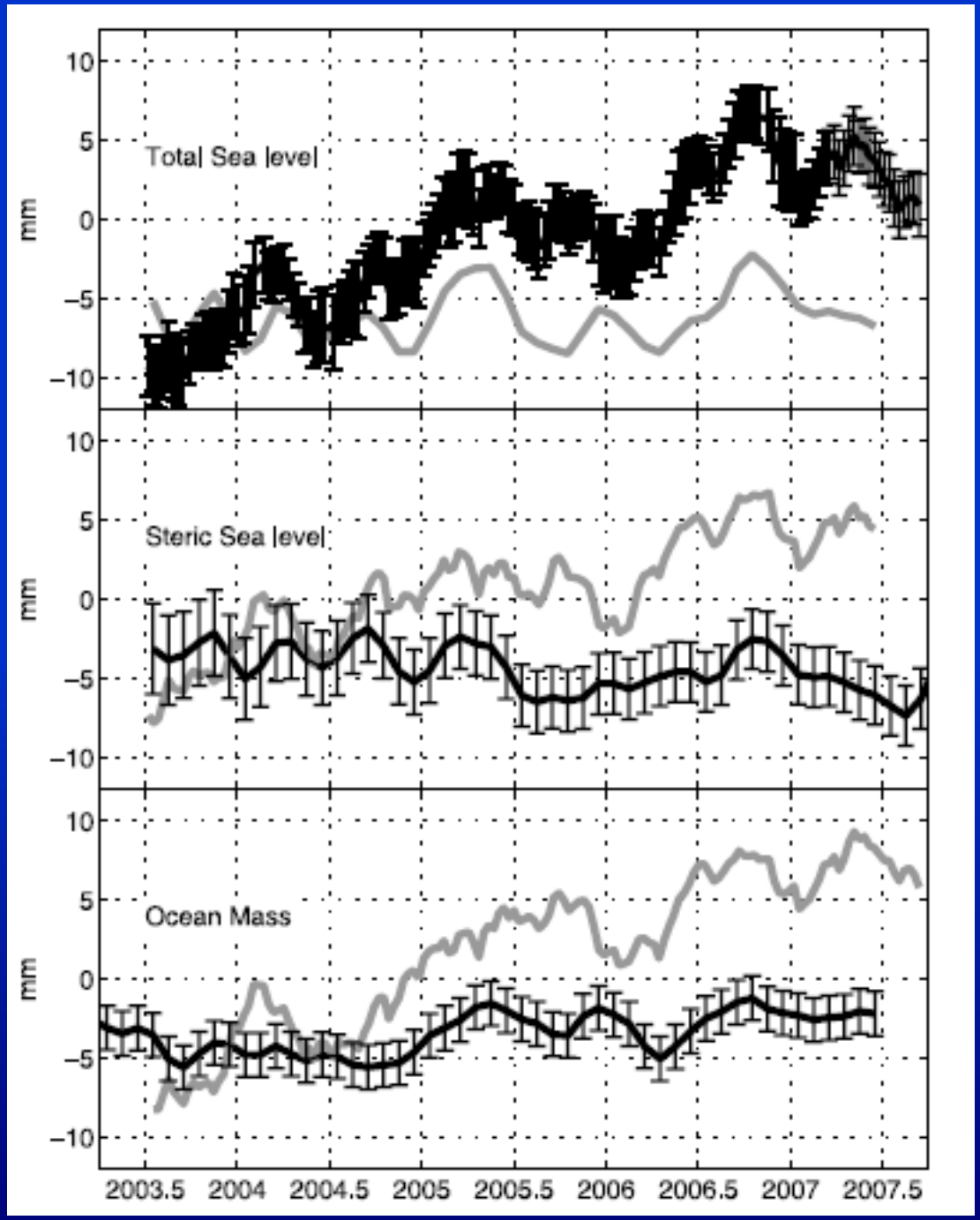
Snow cover and Arctic sea ice are decreasing



Arctic sea ice area decreased by 2.7% per decade (Summer: -7.4%/decade) up to:
2007: 22% (10^6 km^2) lower than 2005
2008, second lowest

- To melt 10^6 km^2 ice 1 m thick (2007) to 10°C = 3.4×10^{20} J
- Globally per year since 2004 this is 0.02 W m^{-2}.

IPCC



Sea level

Anomalies
Altimeter

Argo
Ocean heat content = Thermosteric

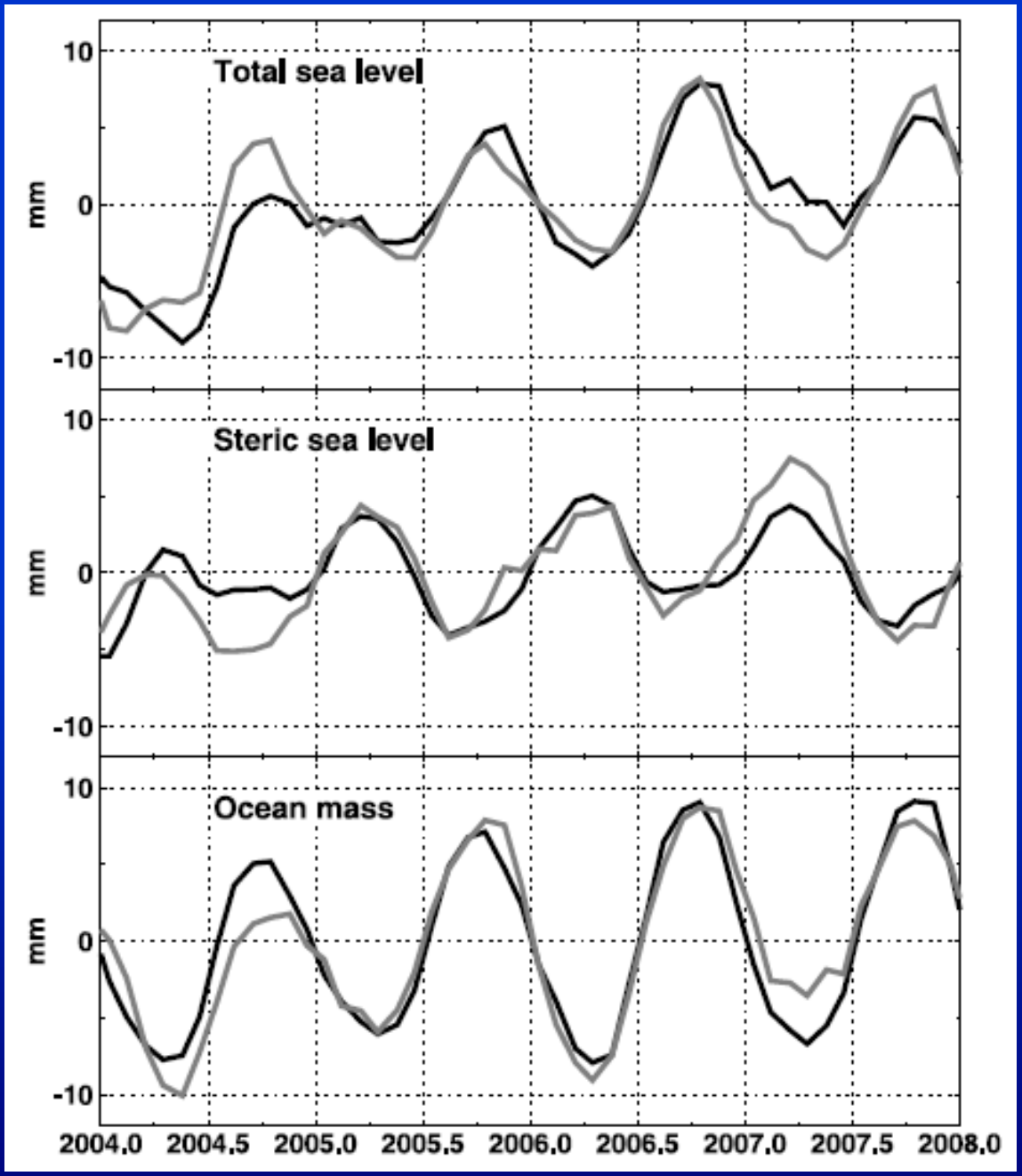
GRACE
Ocean mass sea level

Willis, Chambers, Nerem JGR 2008

Sea level 2003-2008

Sea level (altimetry)	**2.5 ±0.4**
Ice sheets (GRACE)	1 ± 0.15
Glaciers and ice caps (Meier et al., 2007)	1.1 ± 0.24
Terrestrial waters	0.17 ± 0.1
Sum of ice and waters	**2.2 ± 0.28**
Sea level (altimetry minus GRACE)	0.31 ± 0.15
Steric sea level (Argo; 04–08)	**0.37 ± 0.1**

mm/yr Cazenave et al 2009 GPC.



Sea level

Anomalies
Altimeter

Argo
Ocean heat content = Thermosteric

GRACE
Ocean mass sea level

Leuliette and Miller 2009

ARGO
Sea level

Anomalies

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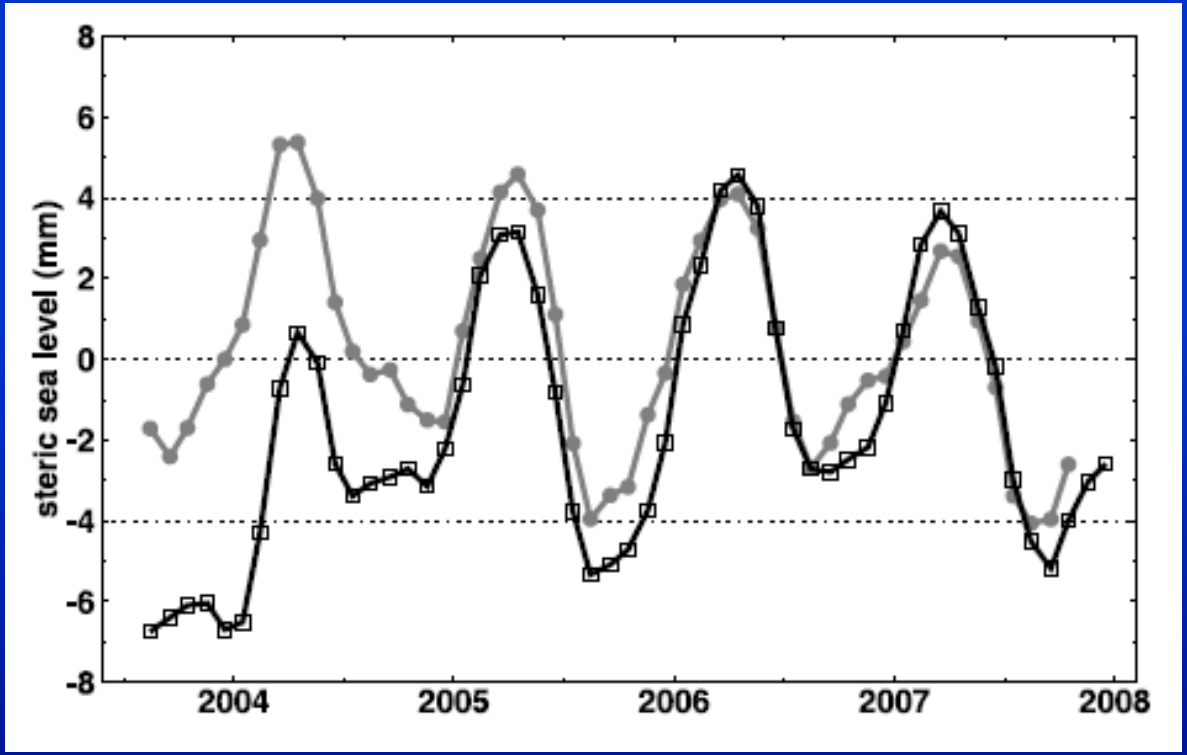


Differences between Leuliette and Miller 2009 and Willis et al 2008

-0.5± 0.5 mm/yr vs
+0.8± 0.8 mm.yr

Commentary

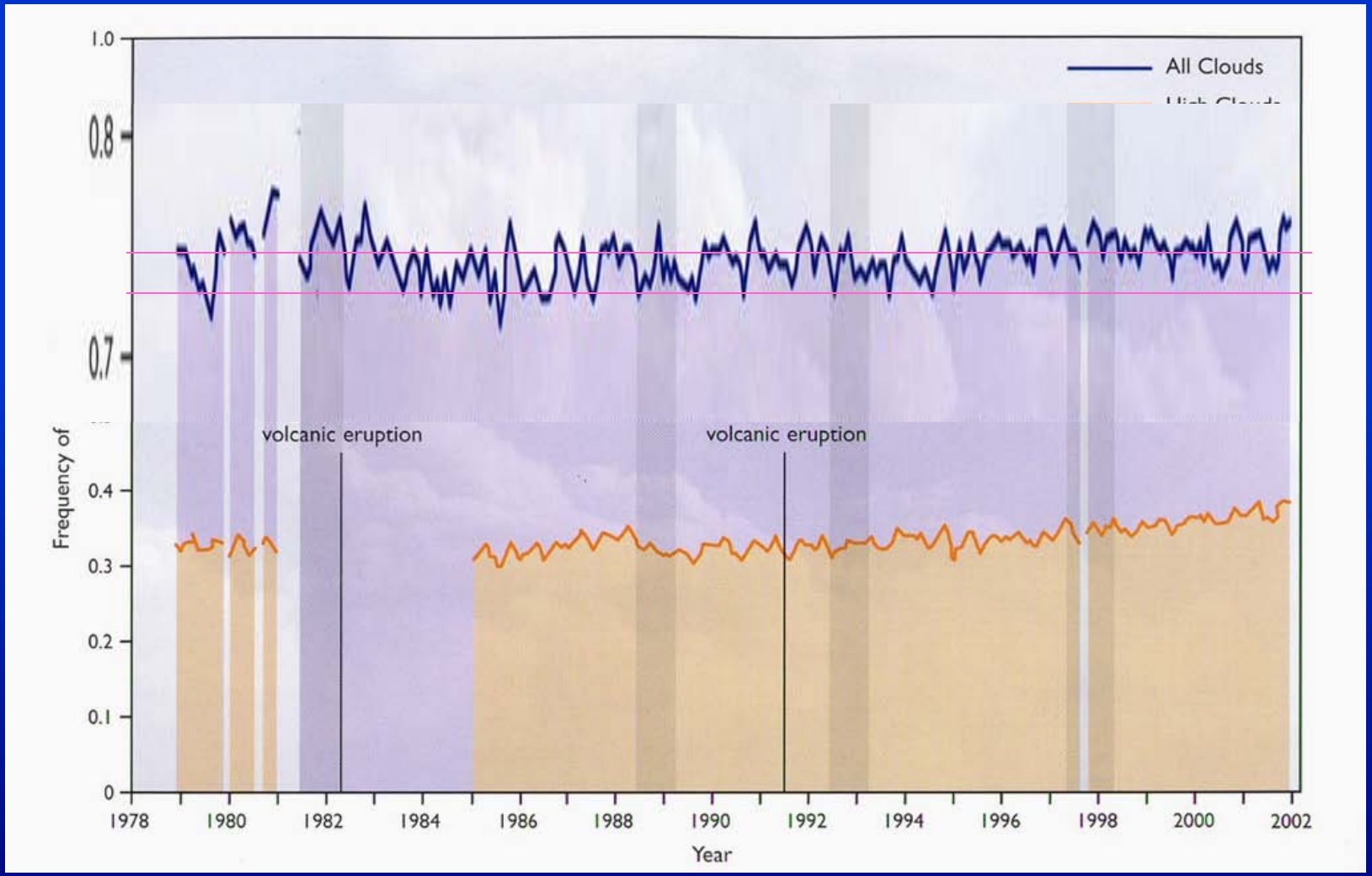
- It is possible to reconcile recent changes in sea level.
- Depends a lot (uncomfortably so) on Glacial Isostatic Adjustment in GRACE
- Implication is that since 2003, main source of sea level rise is melting of Greenland and Antarctica, and glaciers.
- These require about a **factor of 50 less heat to produce same sea level rise as expansion**
- If correct, implies a slow down in ocean heat uptake and reduced TOA energy imbalance in past 4 years.
- Does NOT solve energy imbalance problem.

Need to know energy balance What about clouds?

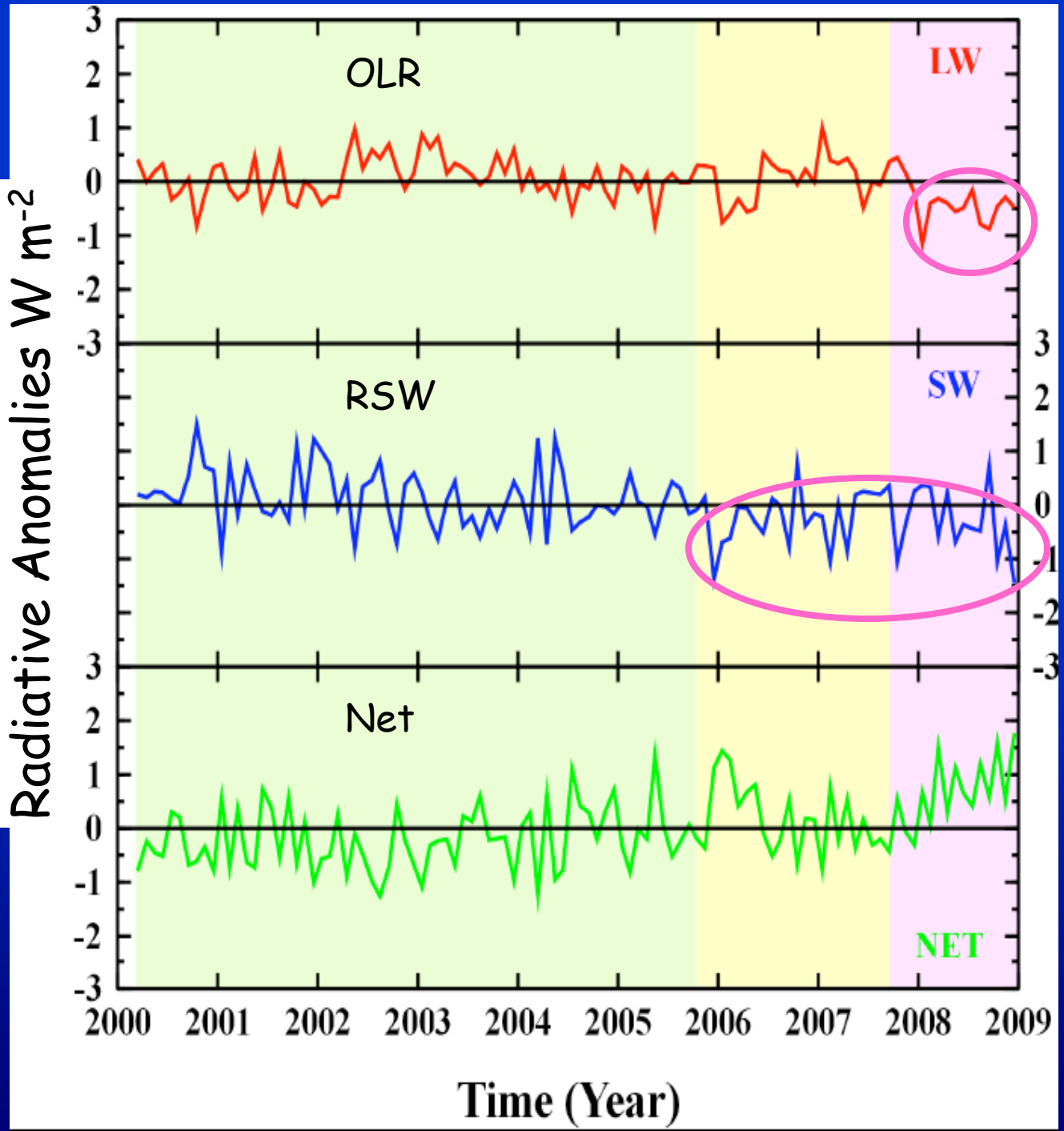
- Cloud data (ISCCP, HIRS, Modis, etc)???
  - ISCCP into 2007, but not homogeneous
- CERES data on TOA radiation???
- Some stuff available: Flashflux: CERES plus MODIS clouds

http://eosweb.larc.nasa.gov/PRODOCS/flashflux/table_flashflux.html

HIRS cloud amount trends



Wylie et al 2005



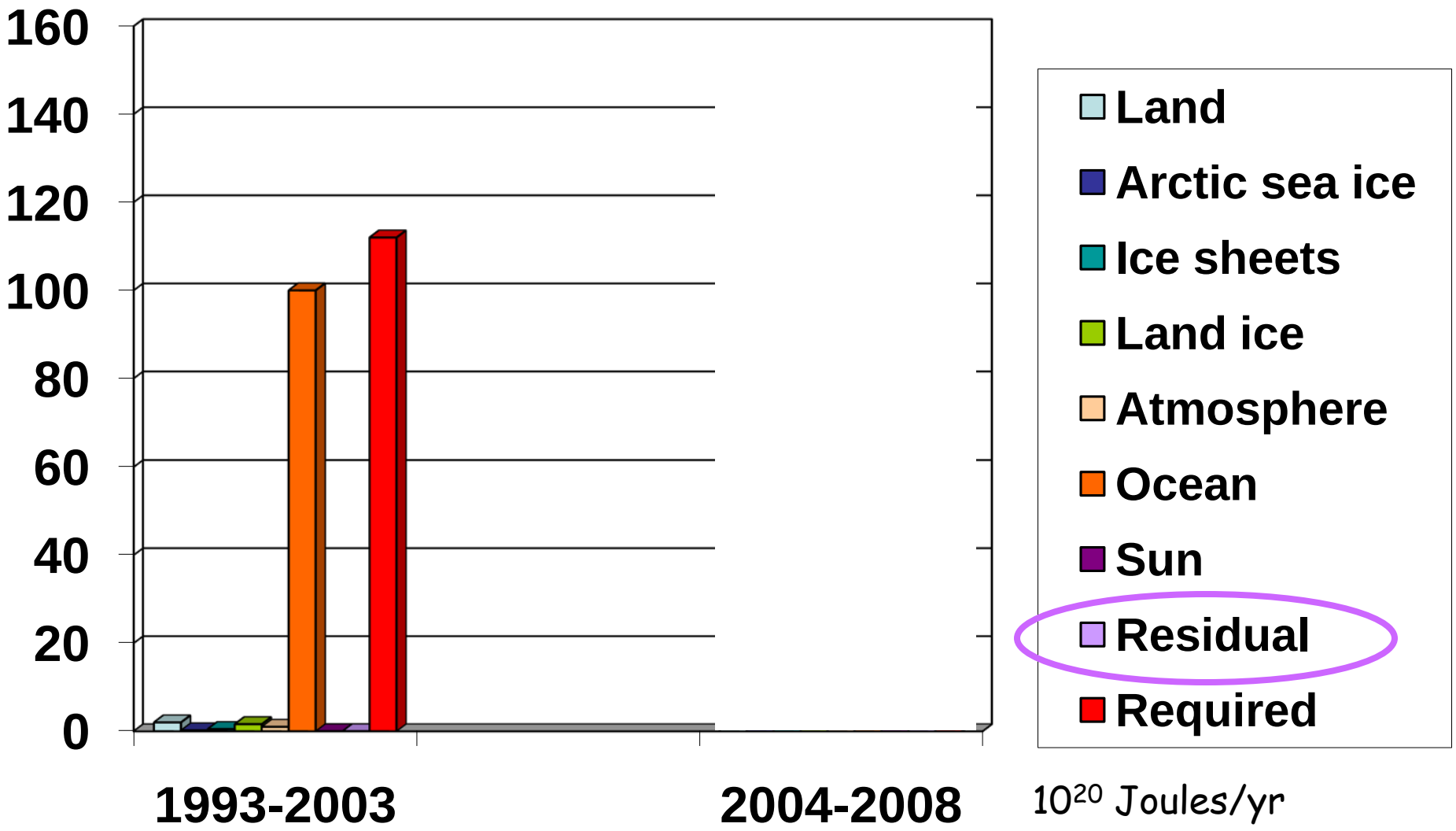
CERES data

1. QC official product to Oct 2005 (green)

2. CERES preliminary (yellow): MTSAT (Japan) problem begins Nov 2005

3. Flashflux data (pink); discon Jan 2008 in OLR

Where does energy go?



Need to know energy balance

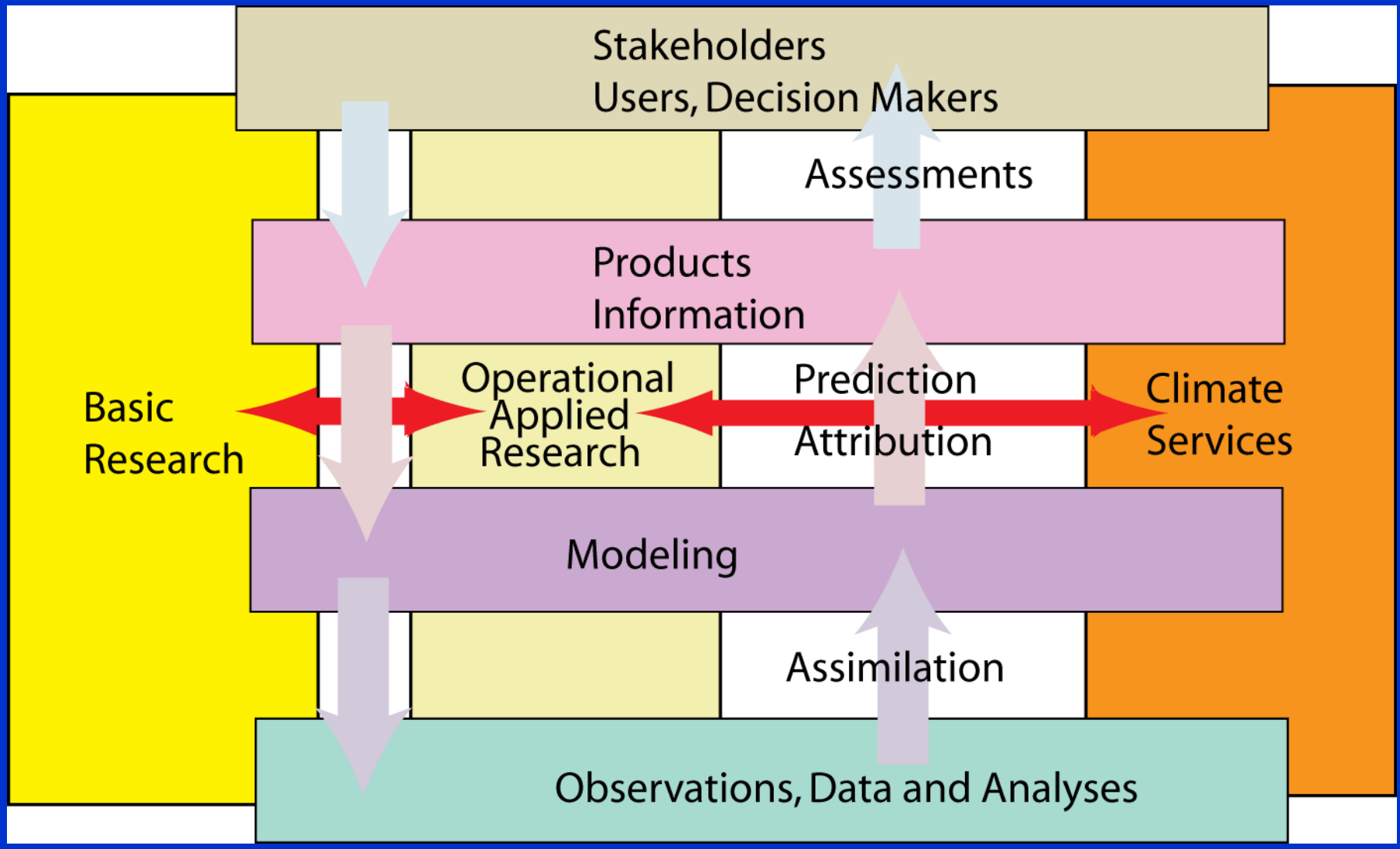
- A 1% increase in clouds is about $-0.5\ W\ m^{-2}$
- Need reliable clouds and radiation data in closer to real time.

Is global warming continuing?

Geoengineering

- Given that we can not adequately track what is going on now, what business have we even considering geoengineering?
  - The intentional modification of climate
  - Risk of serious side effects is real

Climate Information System



Trenberth 2008

Imperative
A climate information system

- Observations: forcings, atmosphere, ocean, land
- Analysis: comprehensive, integrated, products
- Assimilation: model based, initialization
- Attribution: understanding, causes
- Assessment: global, regions, impacts, planning
- Predictions: multiple time scales
- Decision Making: impacts, adaptation

An Integrated Earth System Information System