Earth's Energy Imbalance

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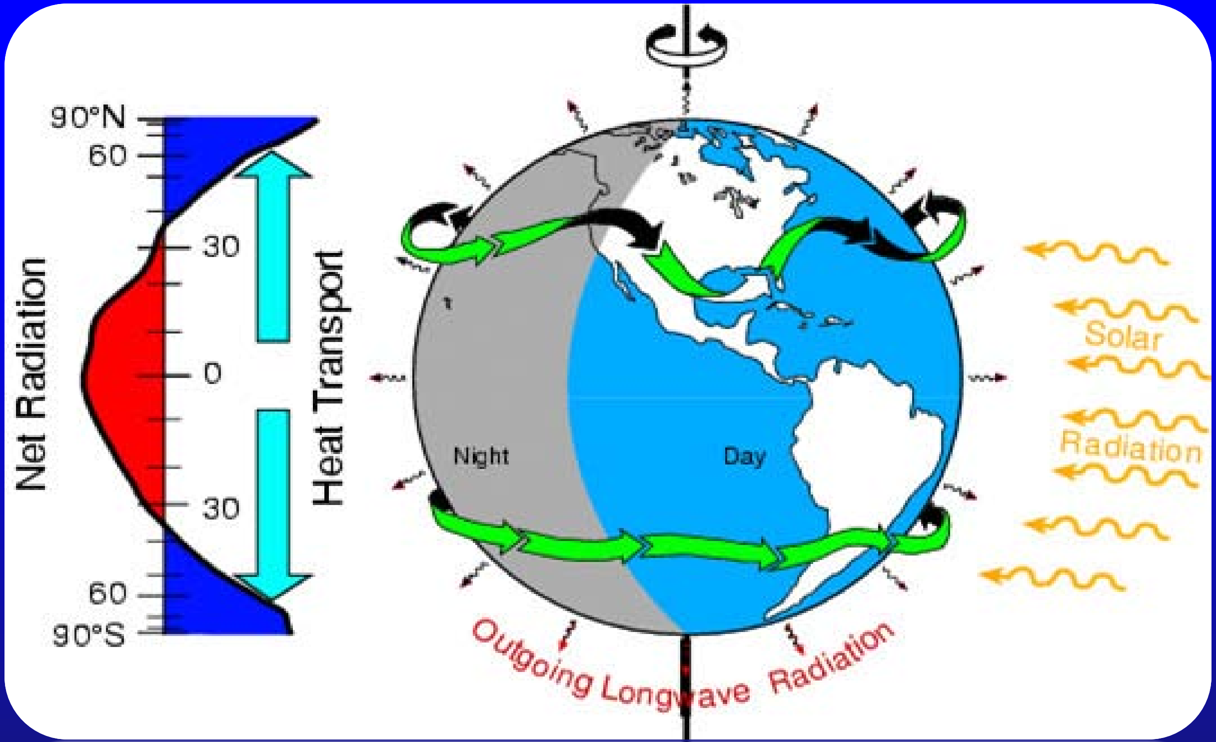
NCAR

with John Fasullo



NCAR Earth System Laboratory

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Earth's Energy Imbalance: How do we measure it?

1. Direct measurements from space of ASR, OLR, Net
   Net = ASR-OLR
2. Take inventory of where all the energy has gone
3. Use climate models with specified forcings

1. Not accurate enough, but good for relative changes
2. Best, but not consistent over time: some energy missing?
3. Depends on how good the model and the forcings are.

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Global warming means more heat: Where does the heat go?

1. Warms land and atmosphere
2. Heat storage in the ocean (raises sea level) — >90%
3. Melts land ice (raises sea level)
4. Melts sea ice and warms melted water
5. Evaporates moisture ⇒ rain storms, cloud
   ⇒ possibly reflection to space

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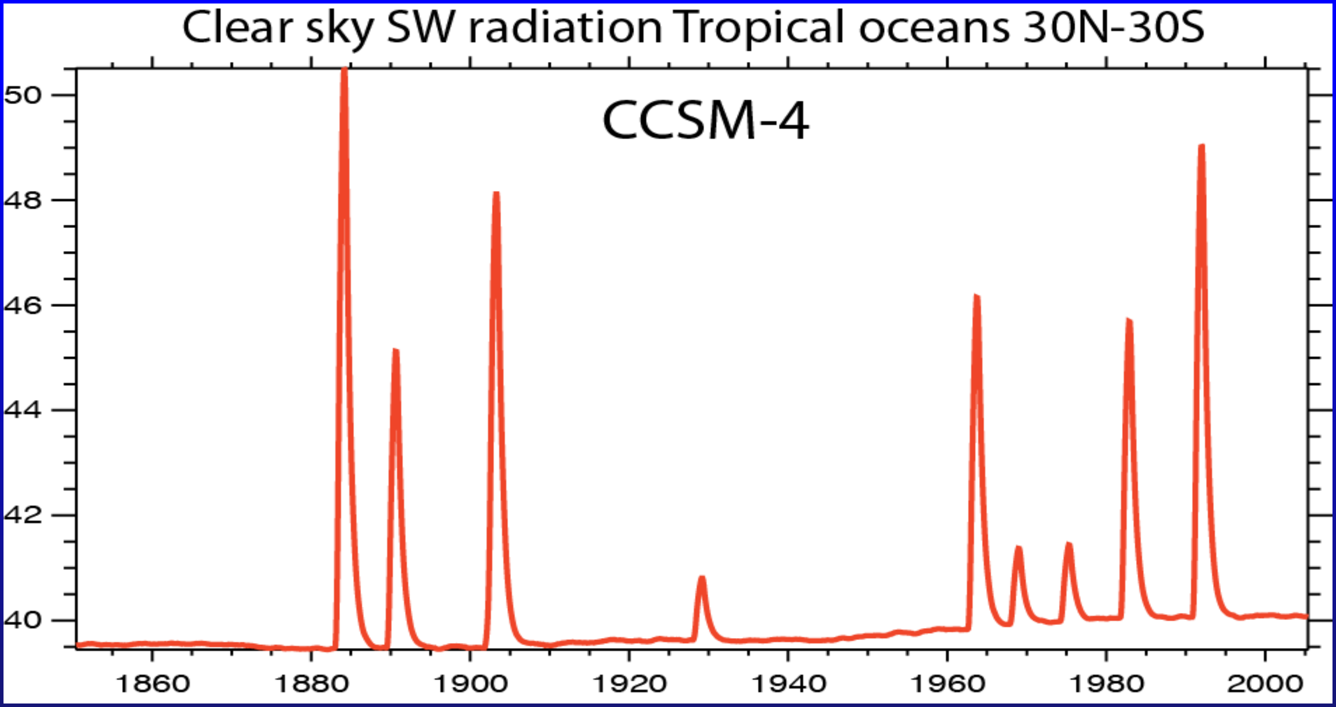
TOA energy imbalance from CCSM4

Specified radiative forcings from

- increased GHGs,
- solar,
- volcanoes,
- aerosols

idealized



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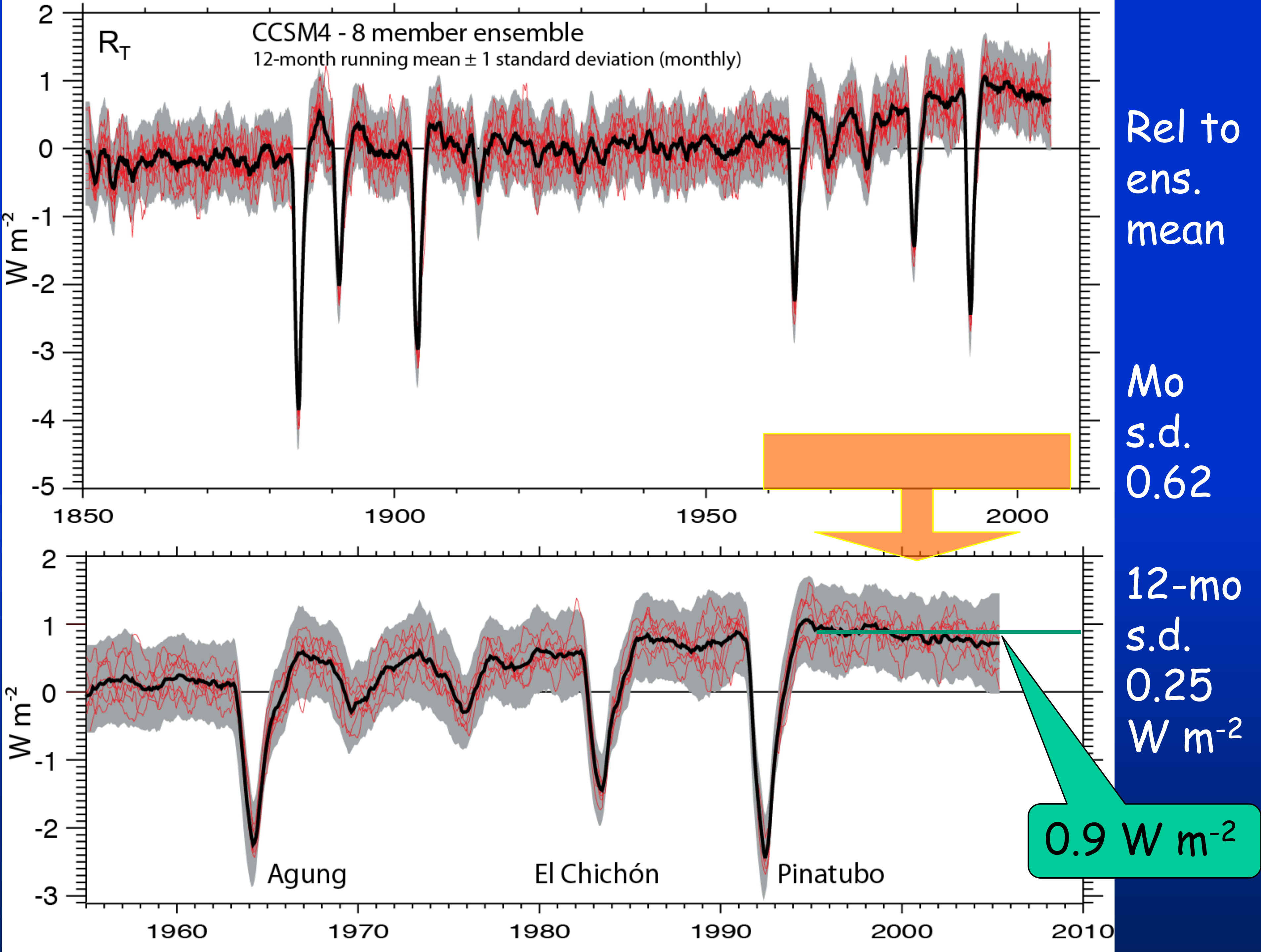
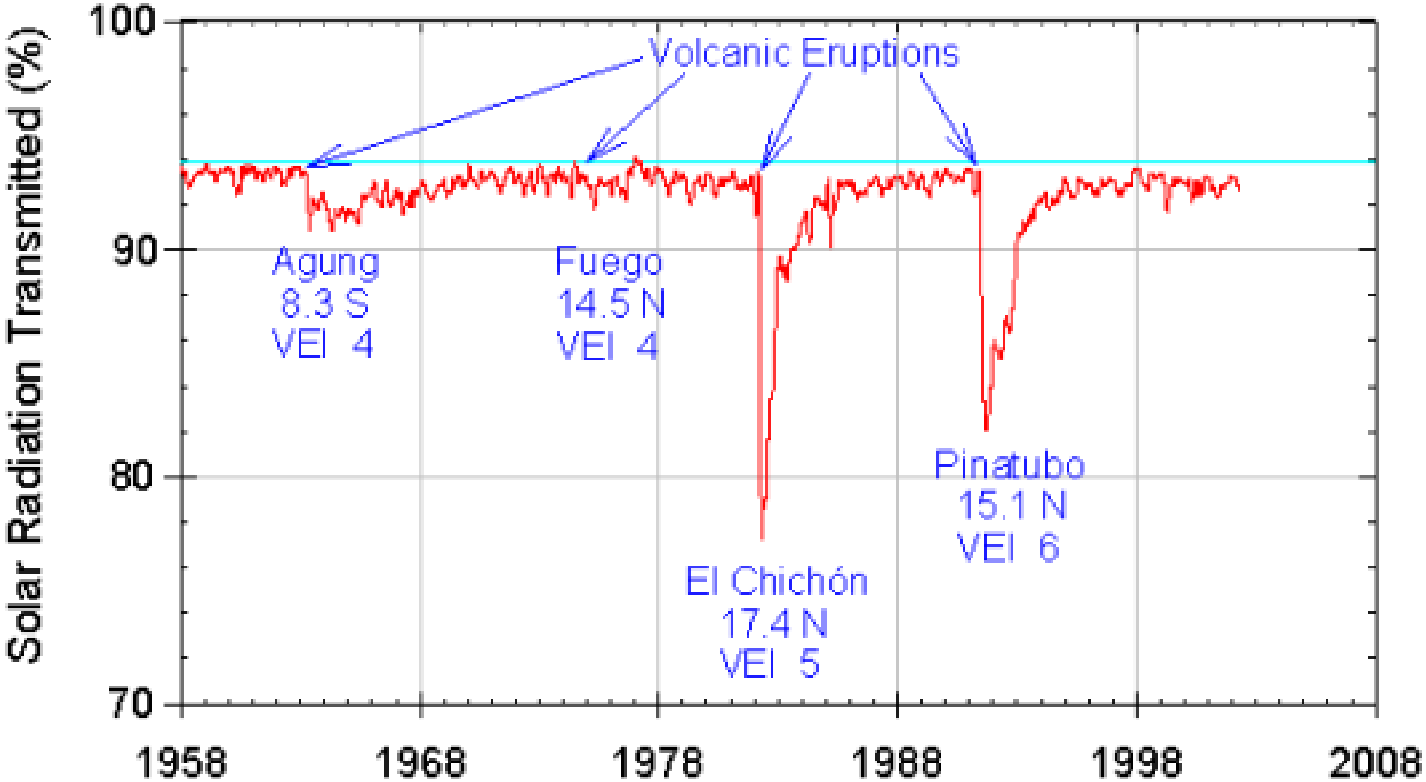


Rel to ens. mean

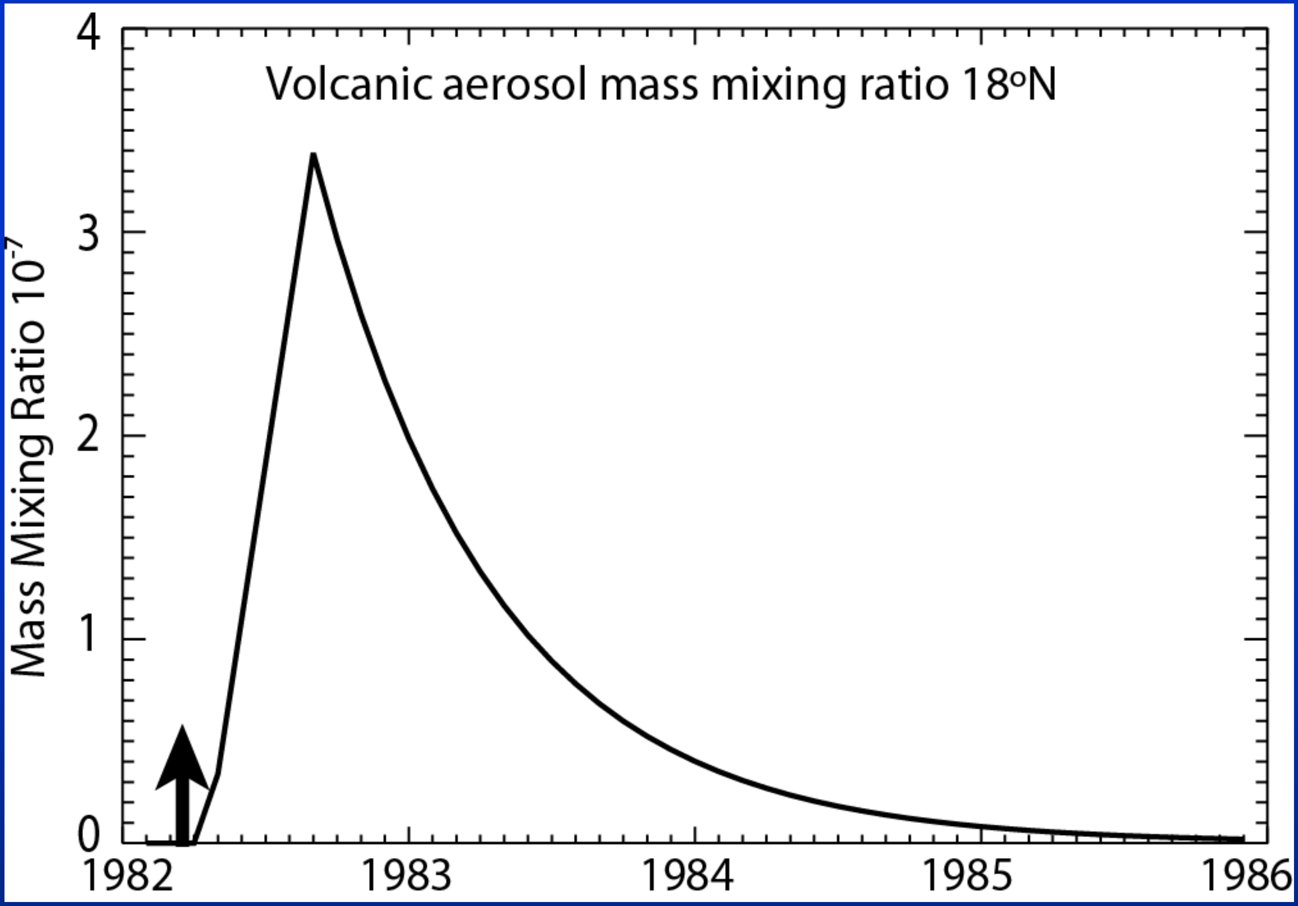
Mo s.d. 0.62

12-mo s.d. 0.25 W m^{-2}

Mauna Loa Observatory Atmospheric Transmission



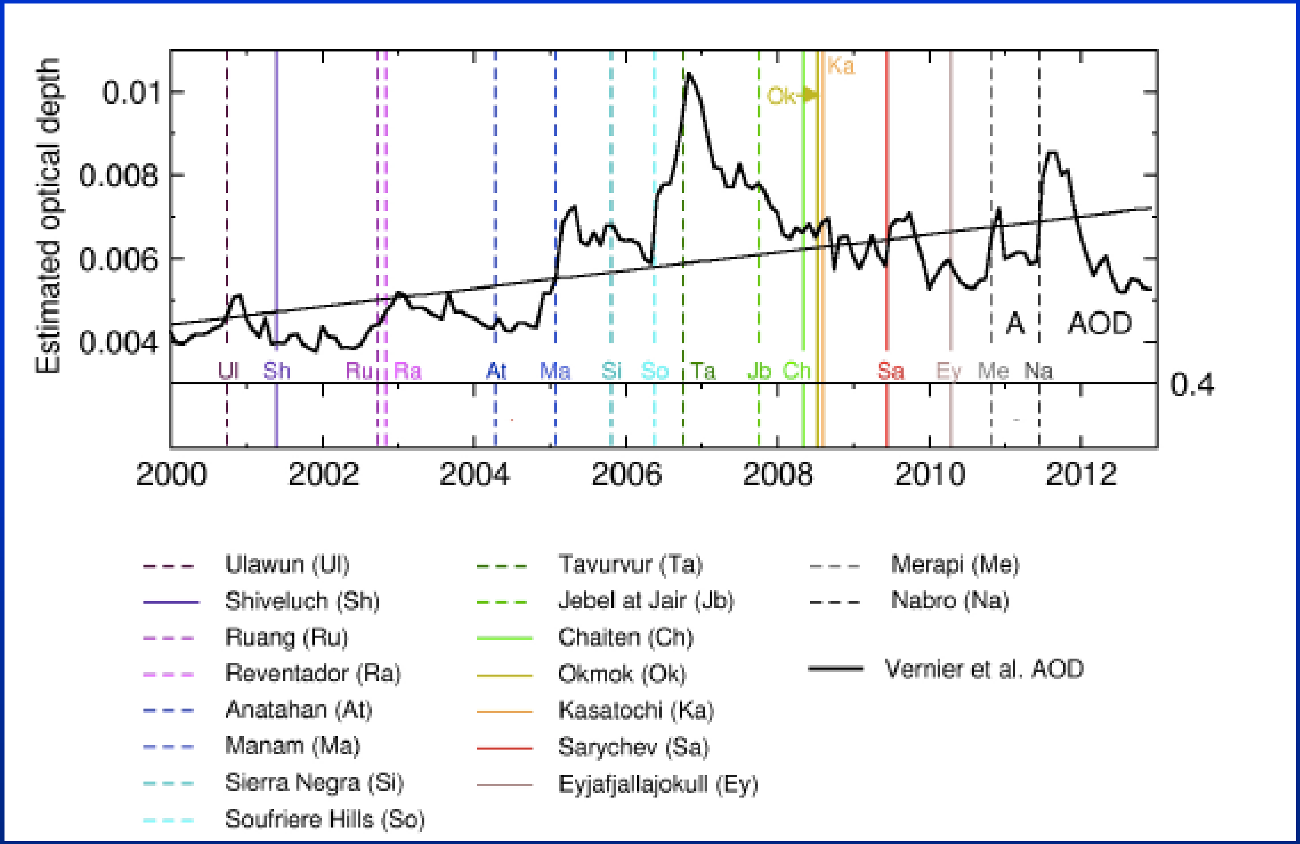
El Chichón aerosol



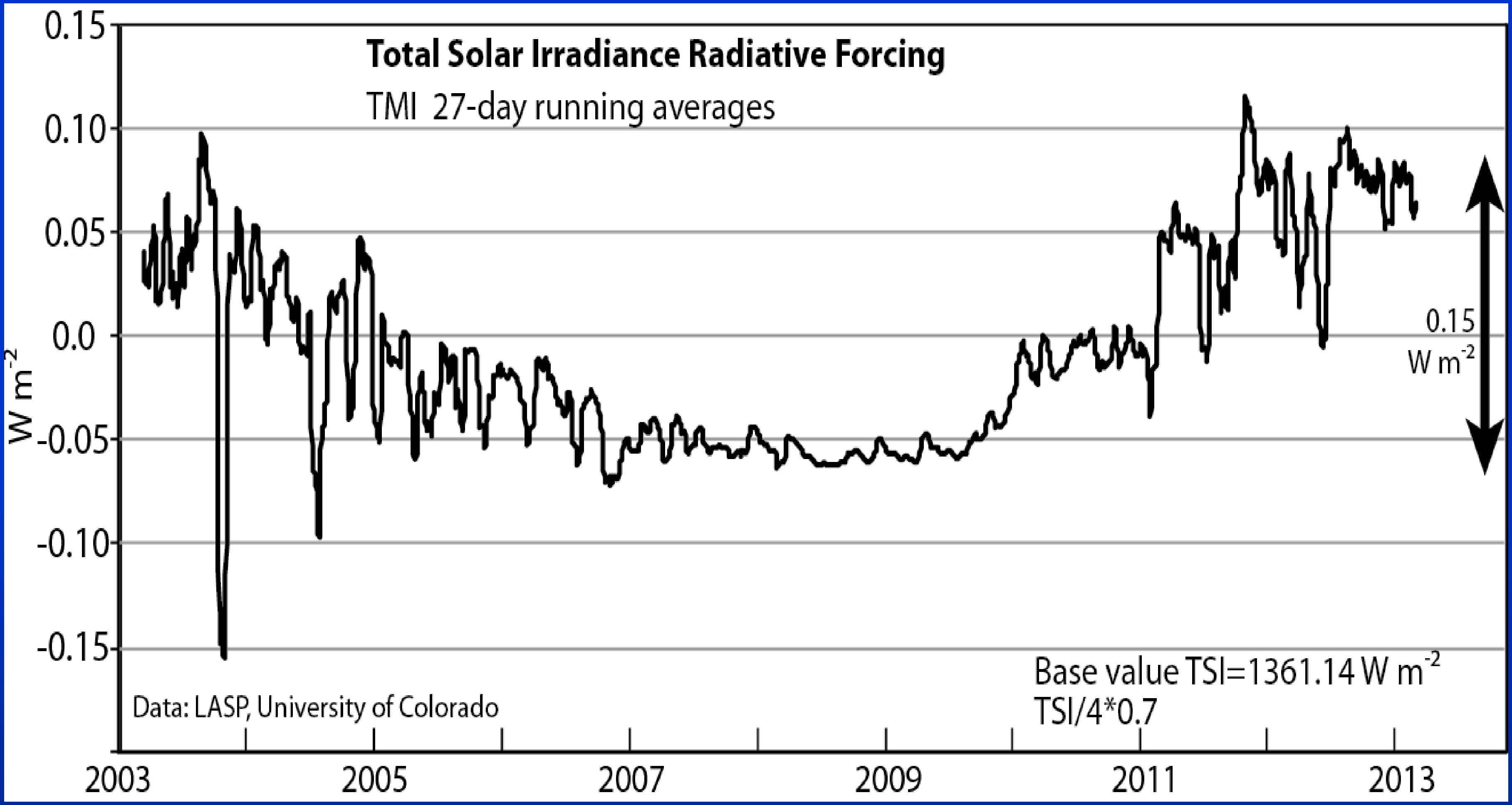
Prescribed profile in CCSM4

Courtesy Andrew Gettelman

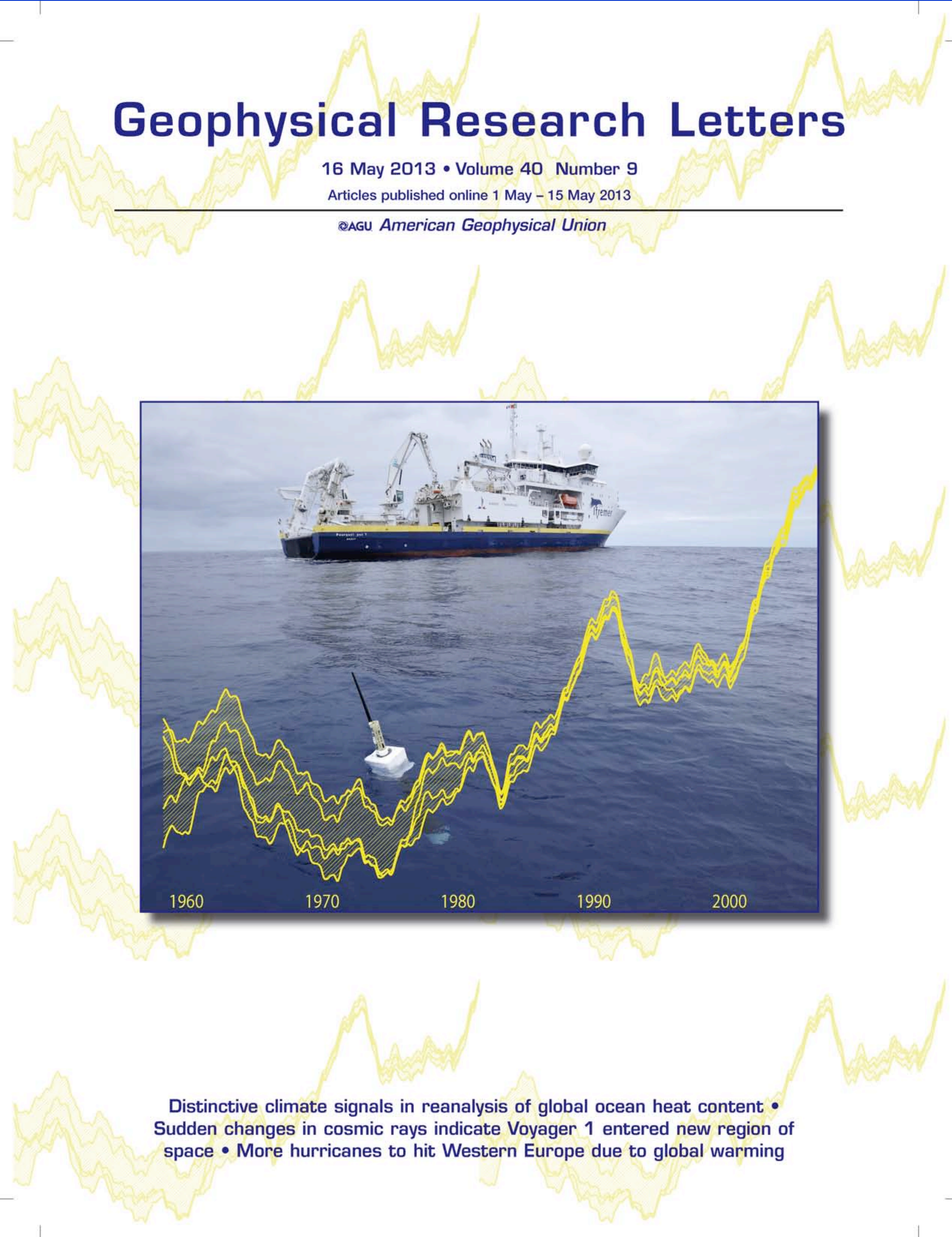
Recent volcanic eruptions:
Optical depth of aerosols



Adapted from Santer et al 2013



Radiative forcing (W m^{-2}) from changes in Total Solar Irradiance from the Total Irradiance Monitor (TIM) instrument relative to a base value of TSI of 1361.14 W m^{-2} as 27-day running averages. The arrow at right shows the range of 0.15 W m^{-2}.

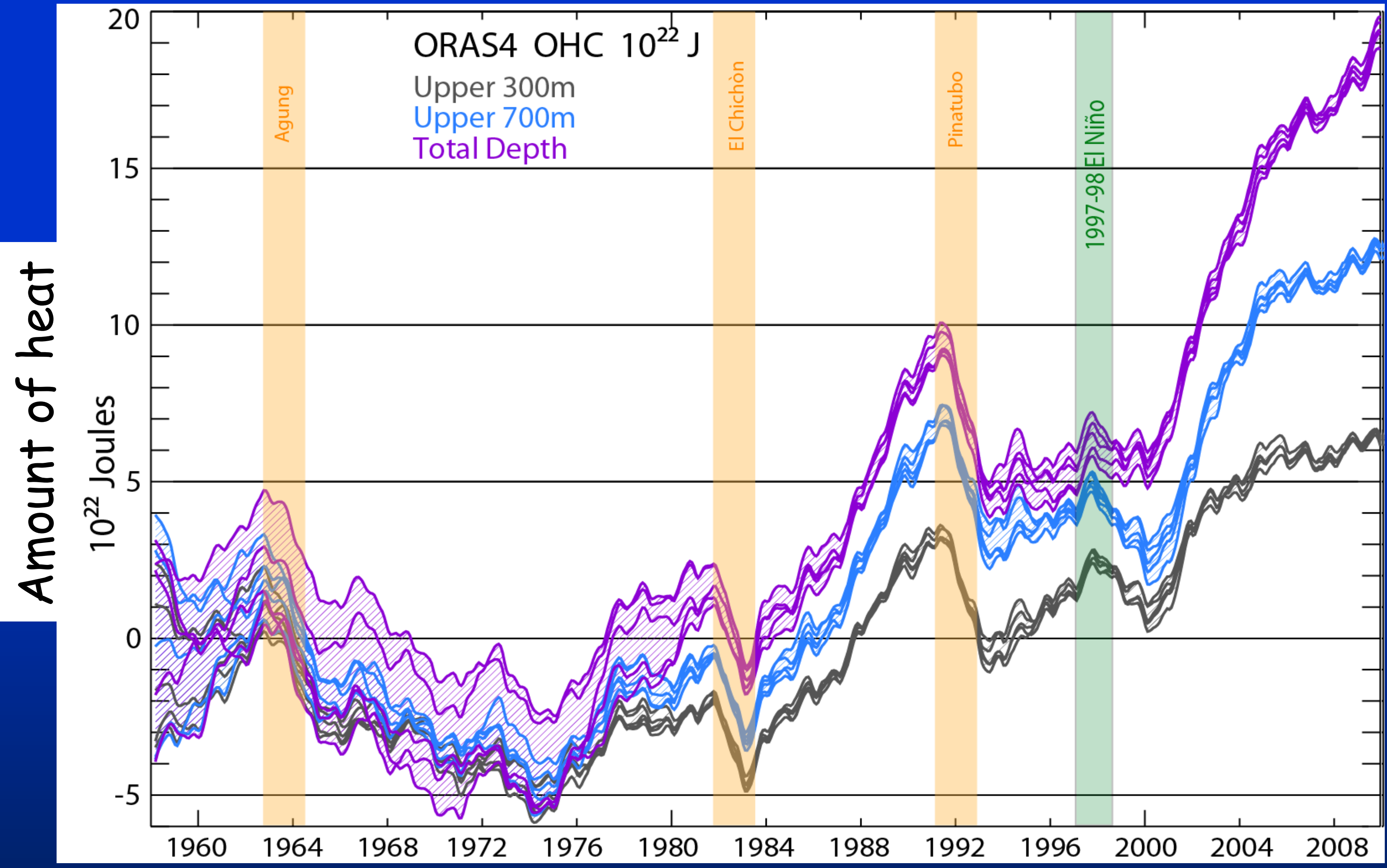


Ocean Heat Content ORAS4

- 5 member ensemble;
- perturbed initial states
- 1958 through 2009
- NEMO 1° 42 level 3Dvar
- Bias corrected Argo era
- Sfc fluxes from ERA,
- Relaxed to obs SST (2-3 days)
- Corrected XBTs, altimetry
- 10 day cycle

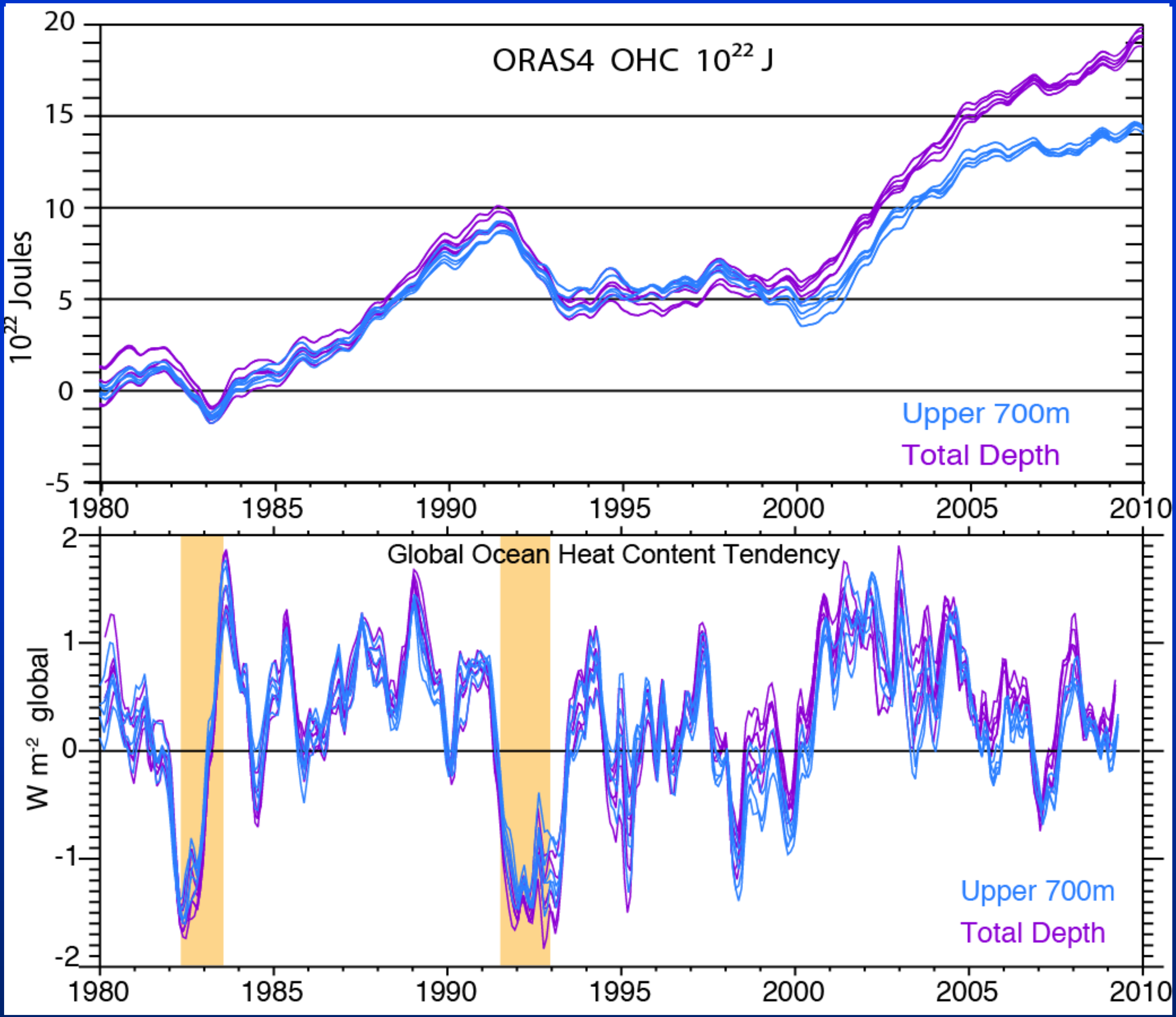
Balmaseda, Trenberth and Källén
2013 GRL

Global Ocean Heat Content



Balmaseda, Trenberth and Källén 2013

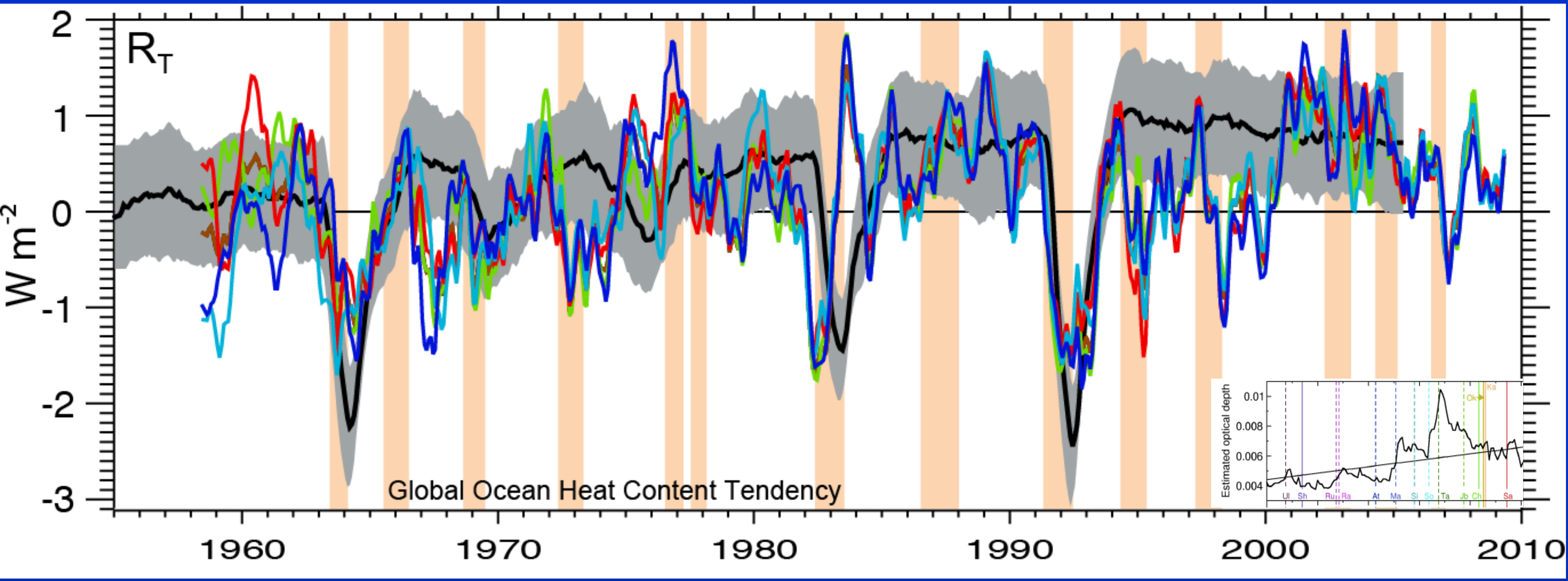
OHC from ORAS4 and rates of change



12-mo running means

Diff: 0.21 W m^{-2} 2000s

Rates of change of OHC from ORAS4



Full depth 5 member ensemble members of ORAS4 OHC in global W m^{-2}.
The ensemble mean and monthly standard deviation of CCSM4 TOA radiation R_T.
El Niño events are marked by the orange bars, as defined by the ONI index of NOAA.

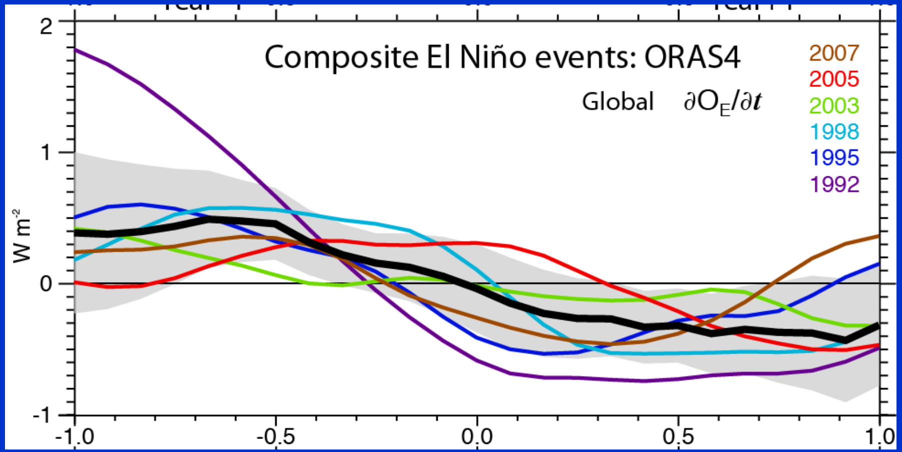
ENSO and volcanic events conflated

El Niño events occurred

1) July 1963-January 1964 vs Agung Feb-Mar 1963;
2) May 1982-June 1983 vs El Chichon Mar-Apr 1982; and
3) May 1991-July 1992 vs Pinatubo June 1991.

ENSO in ORAS4

The tropical Pacific Ocean first, then the global ocean loses heat over an El Niño event.



Decadal variability

The stronger and more frequent La Niña events since 1998 – related to the Pacific Decadal Oscillation (PDO) – are also a major source of natural variability: does the CCSM get these adequately?

ORAS4 [1999-2011] – [1976-1998]

Sea level trends

OHC 0-700m

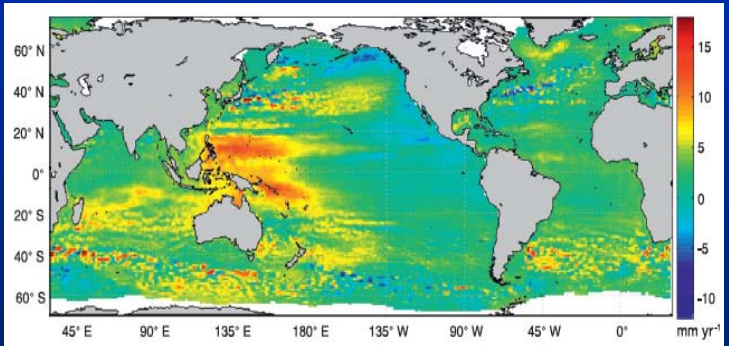
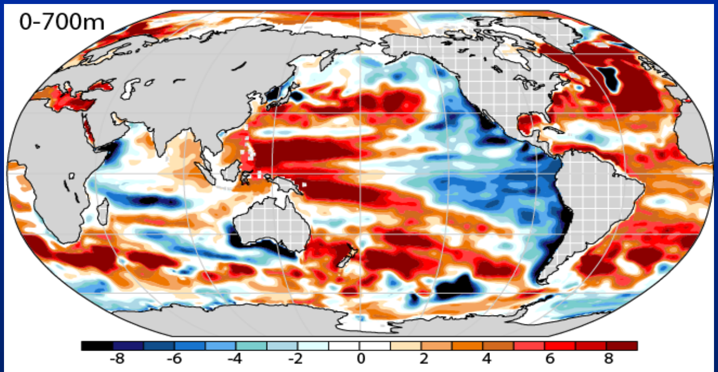


FIG. 1. The linear trend in satellite altimetry SSH for the period 1993–2009 based on the Aviso

Merrifield 2011



Trenberth and Fasullo 2013

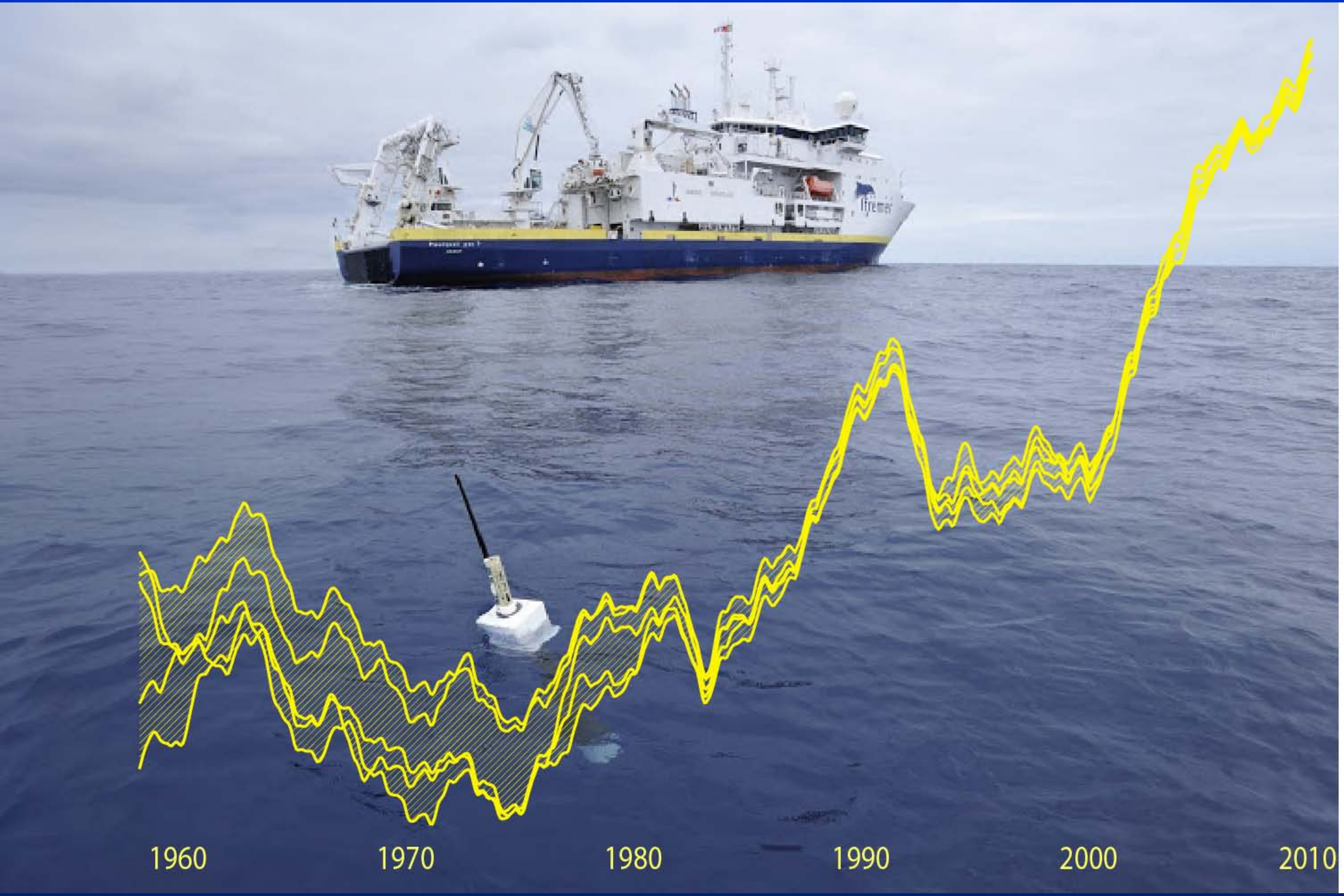
Earth's energy imbalance

- Varies from day to day with clouds and weather
- Varies from year to year with ENSO
- Has sharp drops with volcanic eruptions
- Varies with the PDO
- During the positive phase of PDO, more heat is deposited at shallow depths, while in –ve PDO more heat is deposited below 700 m depth.
- The net imbalance of energy in the 2000s went from order 1 W m^{-2} to 0.7 W m^{-2} with the quiet sun and minor volcanic activity

CESM questions and issues

TOA and surface energy budgets are useful diagnostics

- Are variations from day to day realistic?
- Does ENSO in CESM have right energy cycle:
  - recharge and discharge?
  - Are there super El Niño events (1982-83; 1997-98)?
  - Are these triggers for the PDO?
- Is decadal variability realistic?
  - Magnitude, duration, teleconnections
- Can we track the energy?
  - Global
  - Regional, ocean, ice, land



Cover of GRL with Balmaseda et al 2013