Heating of Earth's climate continues in the 2000s based upon satellite data and ocean observations

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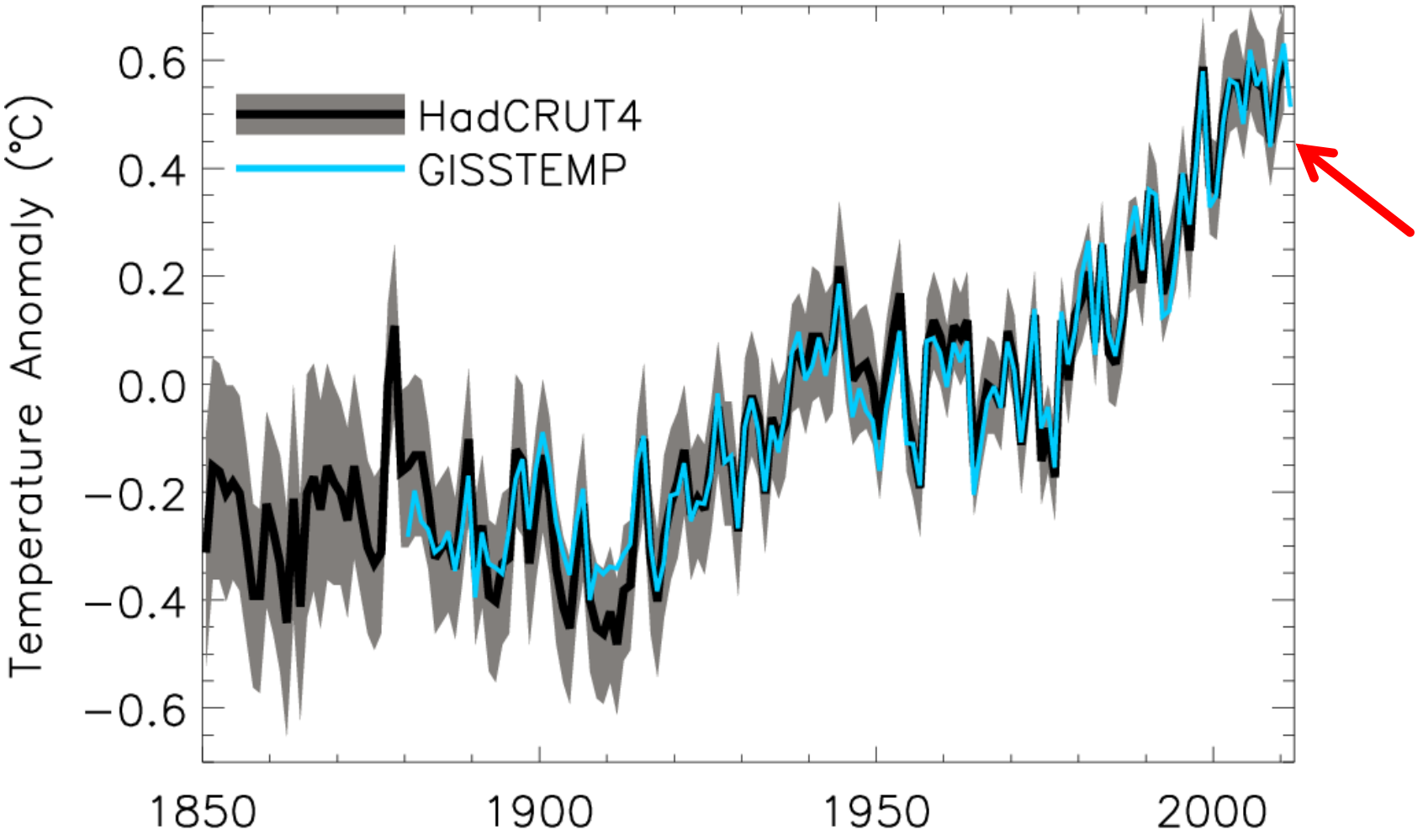
Also thanks to Brian Soden, Graeme Stephens and CERES group

Decline in rate of surface warming?



Global annual average temperature anomalies relative to 1951–1980 mean
(shading denotes lower and upper 95% uncertainty range for HadCRUT4)

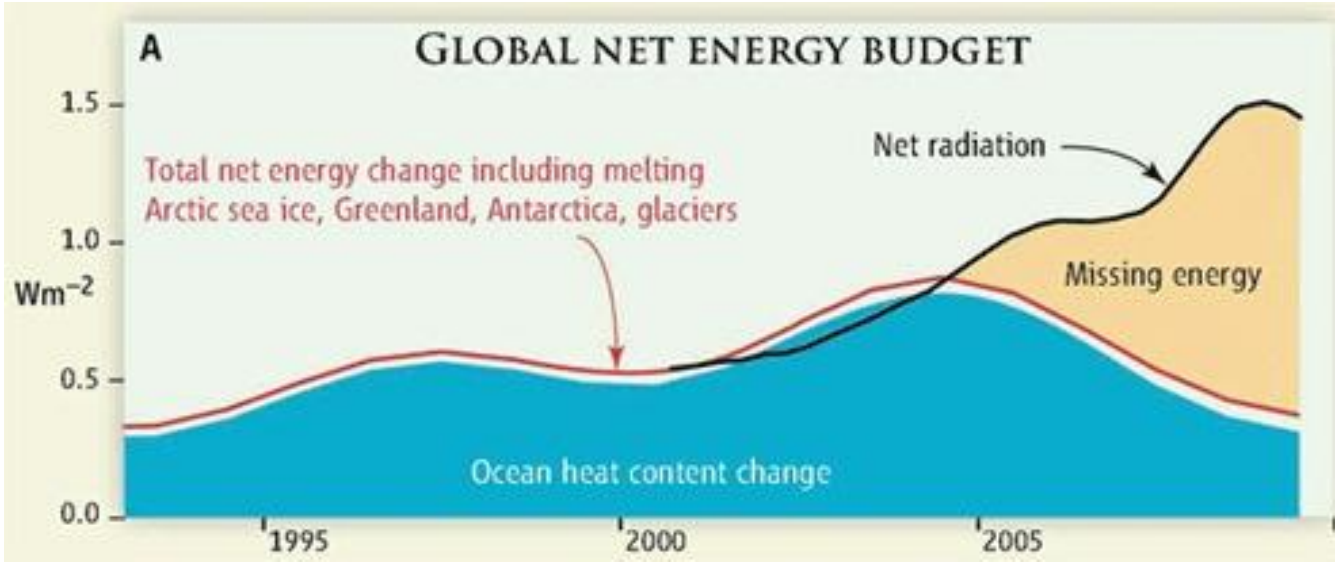
Radiative forcing or energy redistribution?

- Small, persistent volcanic forcing?
  - e.g. Solomon et al. (2011) Science
- Sulphur emissions?
  - e.g. Kaufmann et al. (2011) PNAS
- Stratospheric water vapour?
  - e.g. Solomon et al. (2010) Science
- Cloud forcing/feedbacks & El Nino?
- Ocean circulation e.g. Modelling studies:

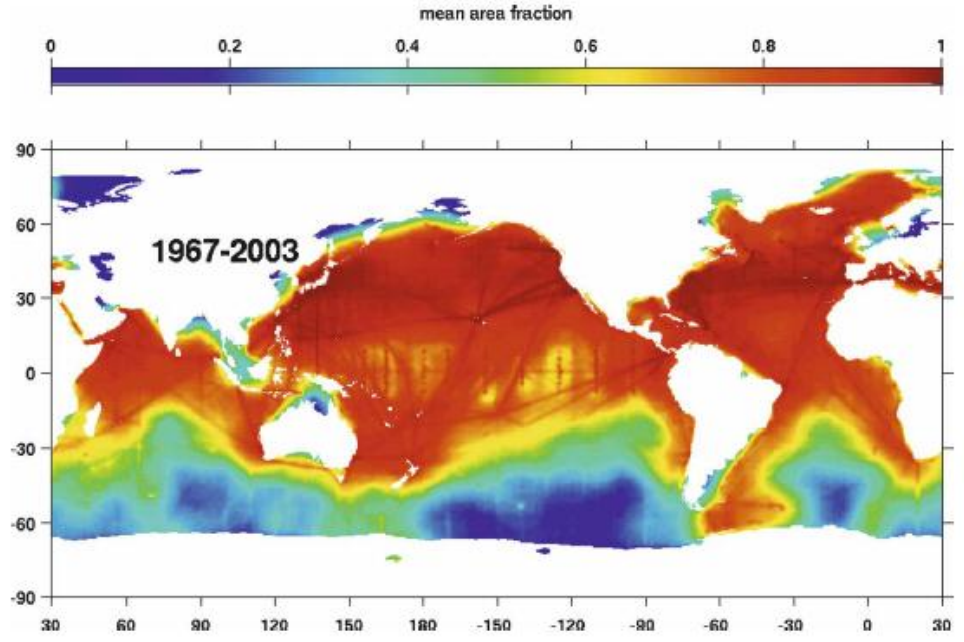
  Meehl et al. (2011) Nature Climate Change ,
  Palmer et al. (2010) GRL ,
  Katsman and van Oldenborgh (2011) GRL

Missing energy?

- Trenberth and Fasullo (2010, Science) highlighted an apparent large discrepancy between net radiation and ocean heat content changes



We undertook a reanalysis of the satellite and ocean record over the period 2000-2010…



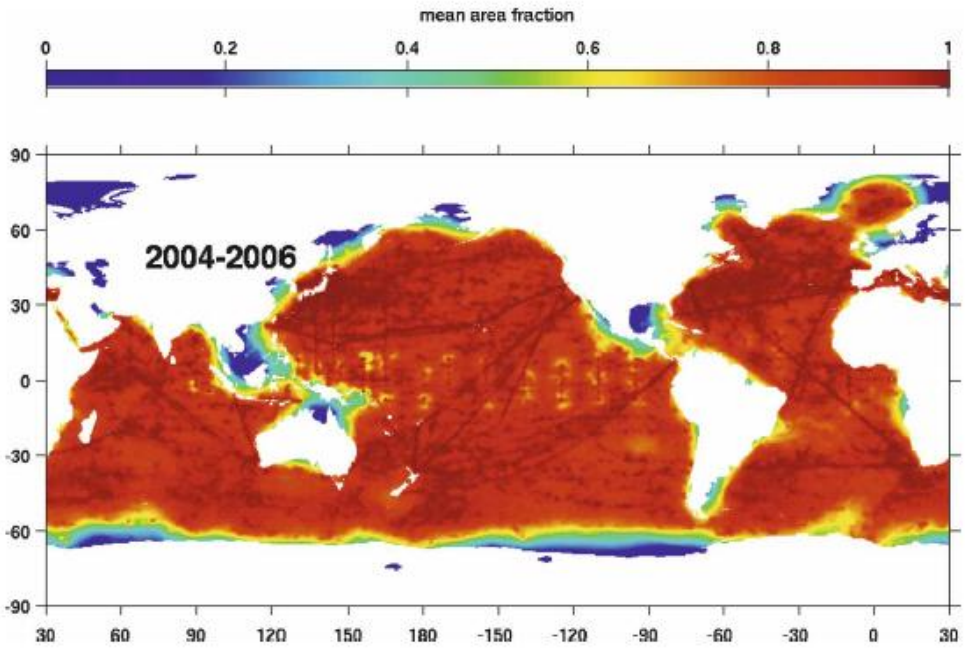


FIG. 4. Mean of annual "observed" area coverage from 2004 to 2006.

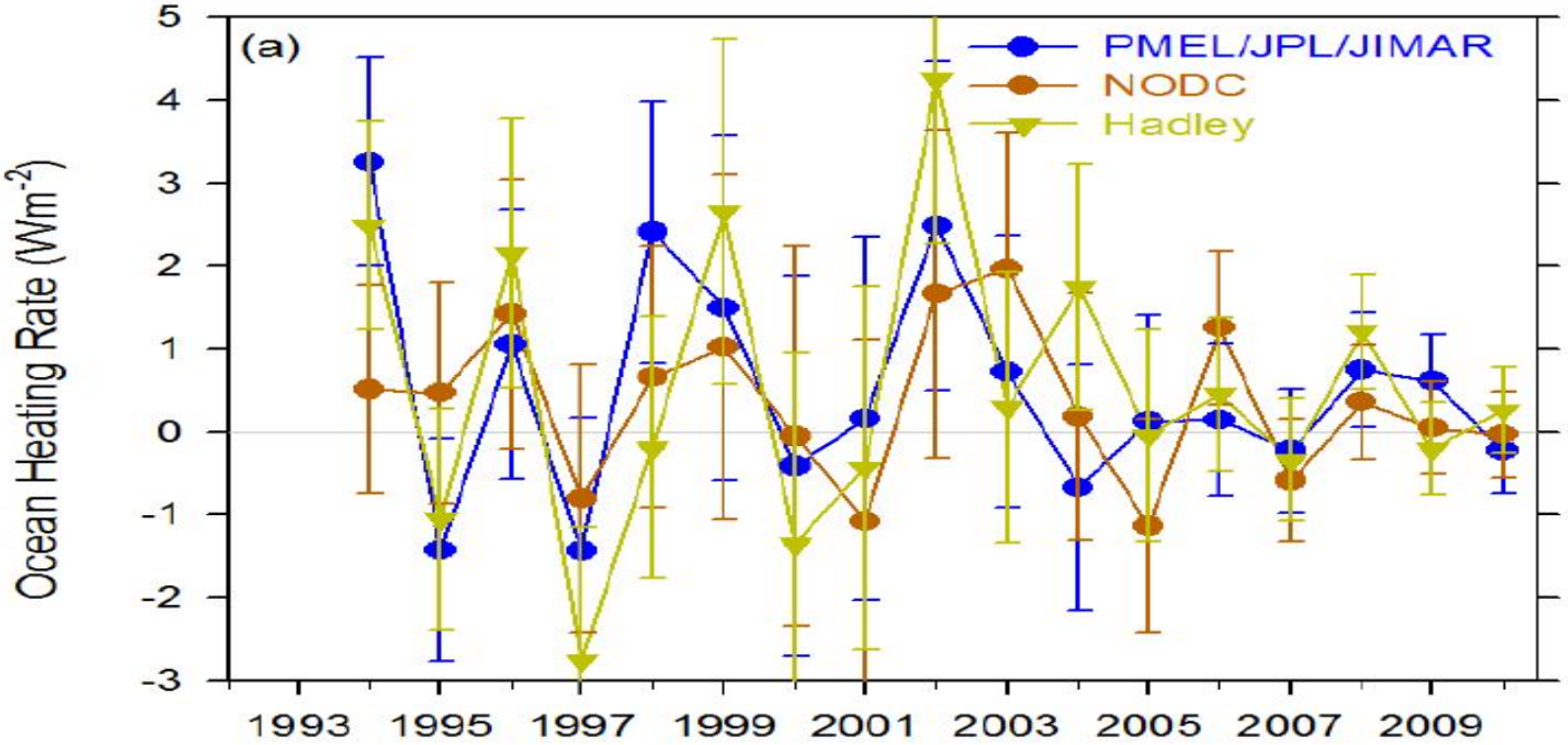
Ocean Heat Content data

- Use weighted integral to account for changes in data coverage
- Ensures transition to ARGO era does not introduce spurious variability
- Integrate ocean heat content trend over time and divide by Earth's surface area → Wm^{-2}

Lyman & Johnson (2008) J Clim

Ocean heat content data uncertainty

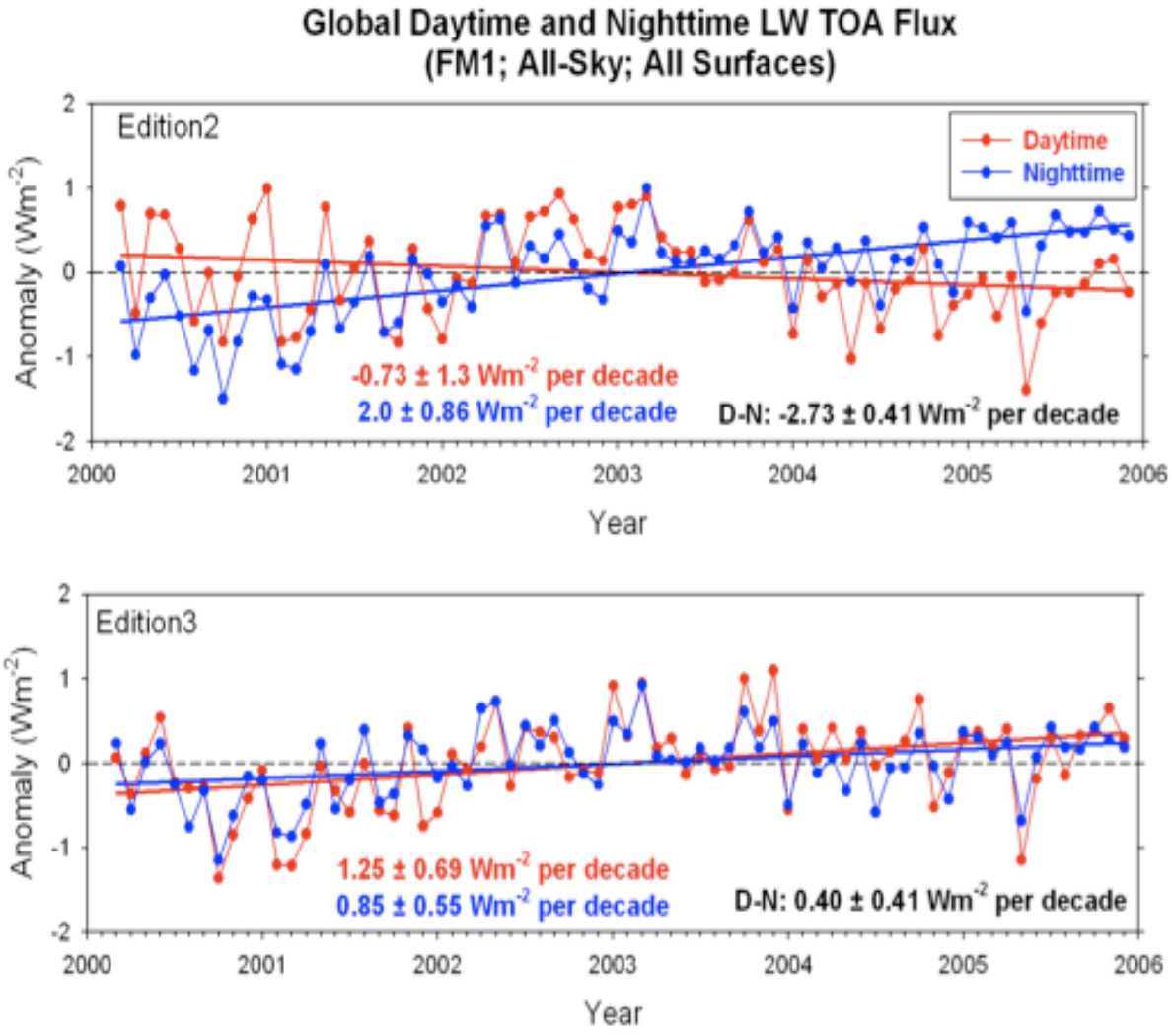
- Accounting for considerable sampling/structural uncertainty we find no evidence for a robust decline in ocean heating rate since 2005



Loeb et al. (2012) Nat. Geosci.

Updated CERES satellite data

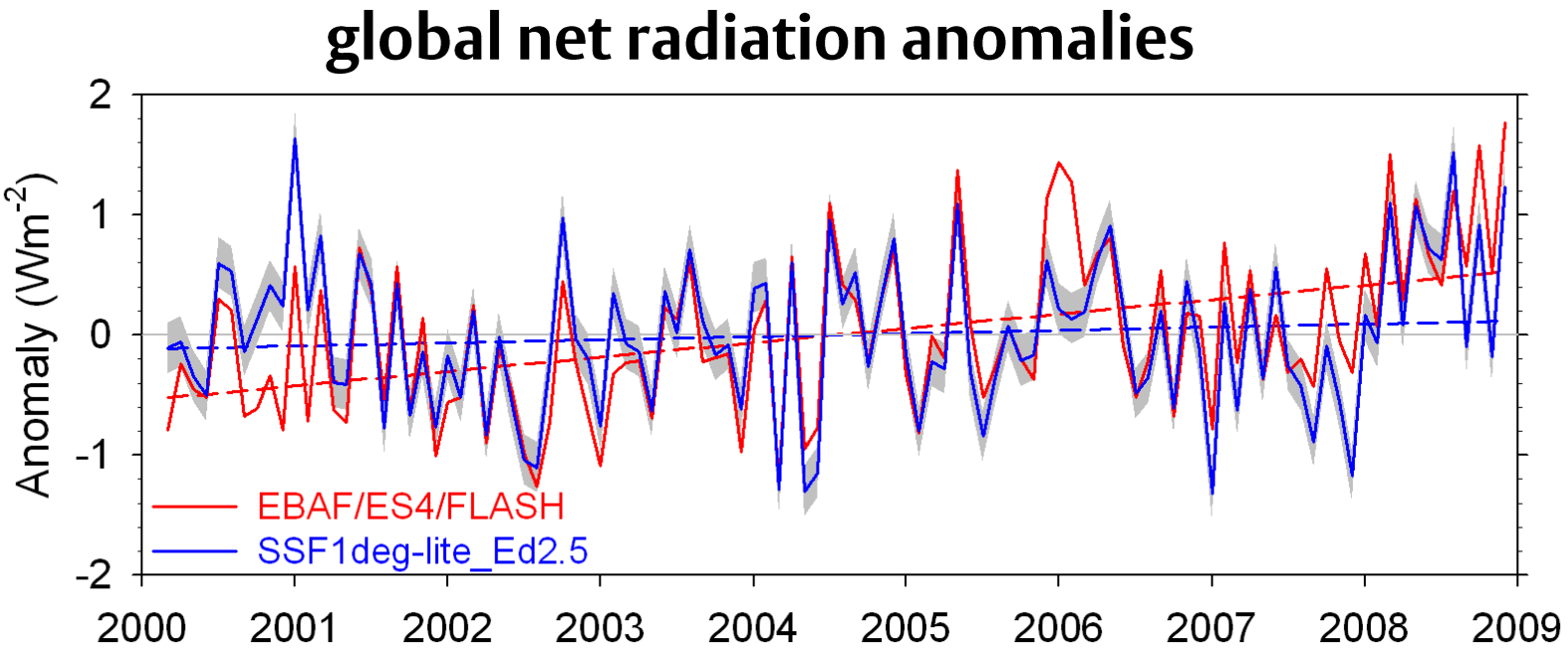
- Global Earth Radiation Balance
- Correction for degradation of shortwave filter
- Correction also improves physical consistency of trends in daytime longwave



We use version CERES_EBAF-TOA_Ed2.6r

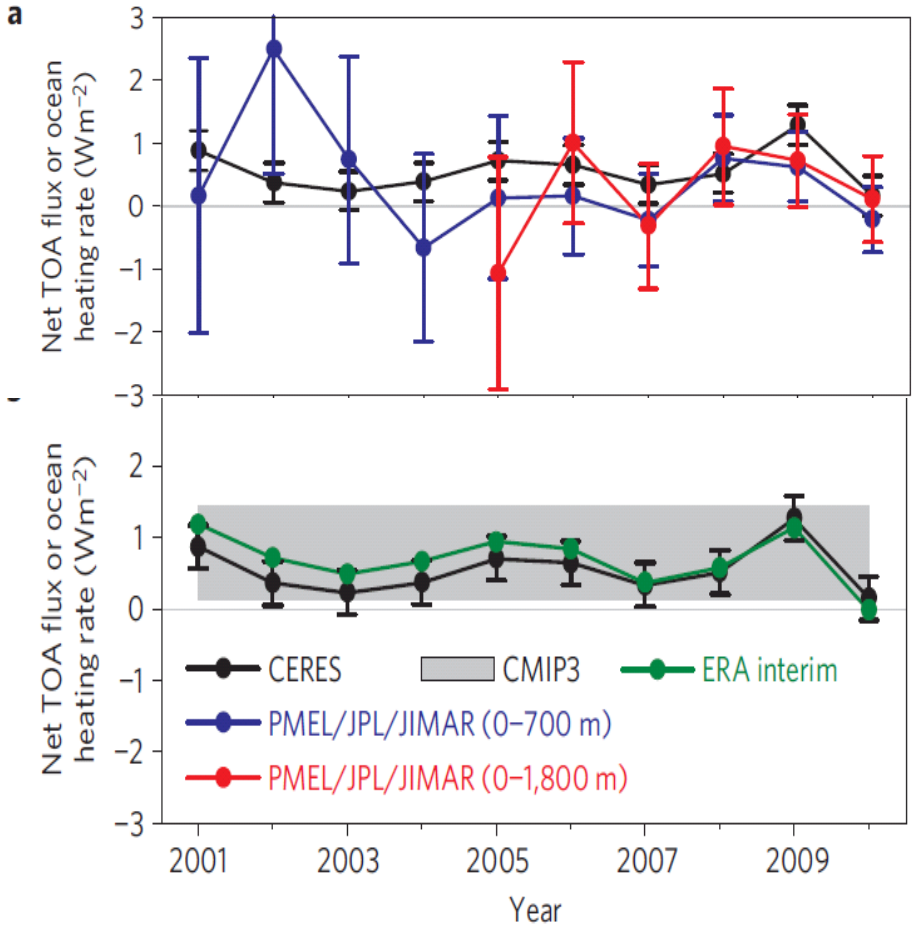
Trends in net radiation

- Errors in satellite sensors and inappropriate use of satellite products explain much of large rise in net radiative flux shown by Trenberth and Fasullo (2010)



Combining Earth Radiation Budget and Ocean Heat Content data

- Tie 10-year CERES record with SORCE TSI and ARGO-estimated heating rate 2005-2010
- Best estimates for additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- Estimate of decade long net energy imbalance of **0.54±0.43 Wm^{-2}**

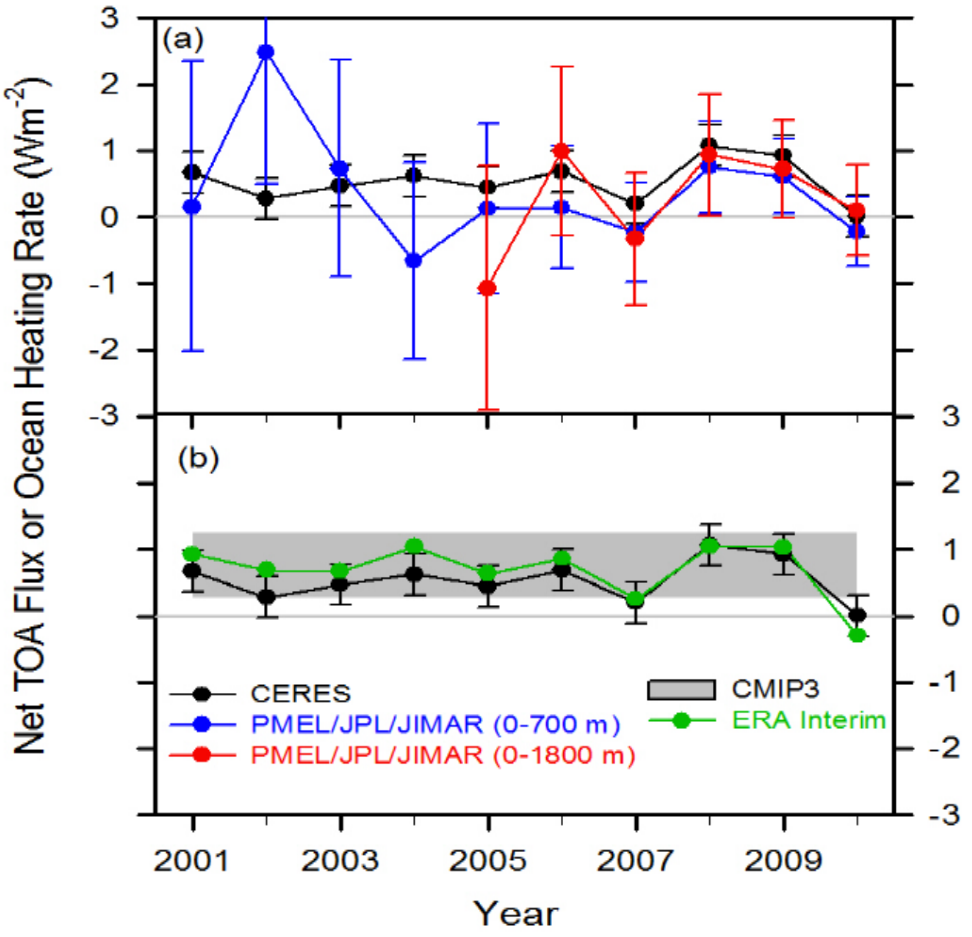


Loeb et al. (2012) Nat. Geosci.

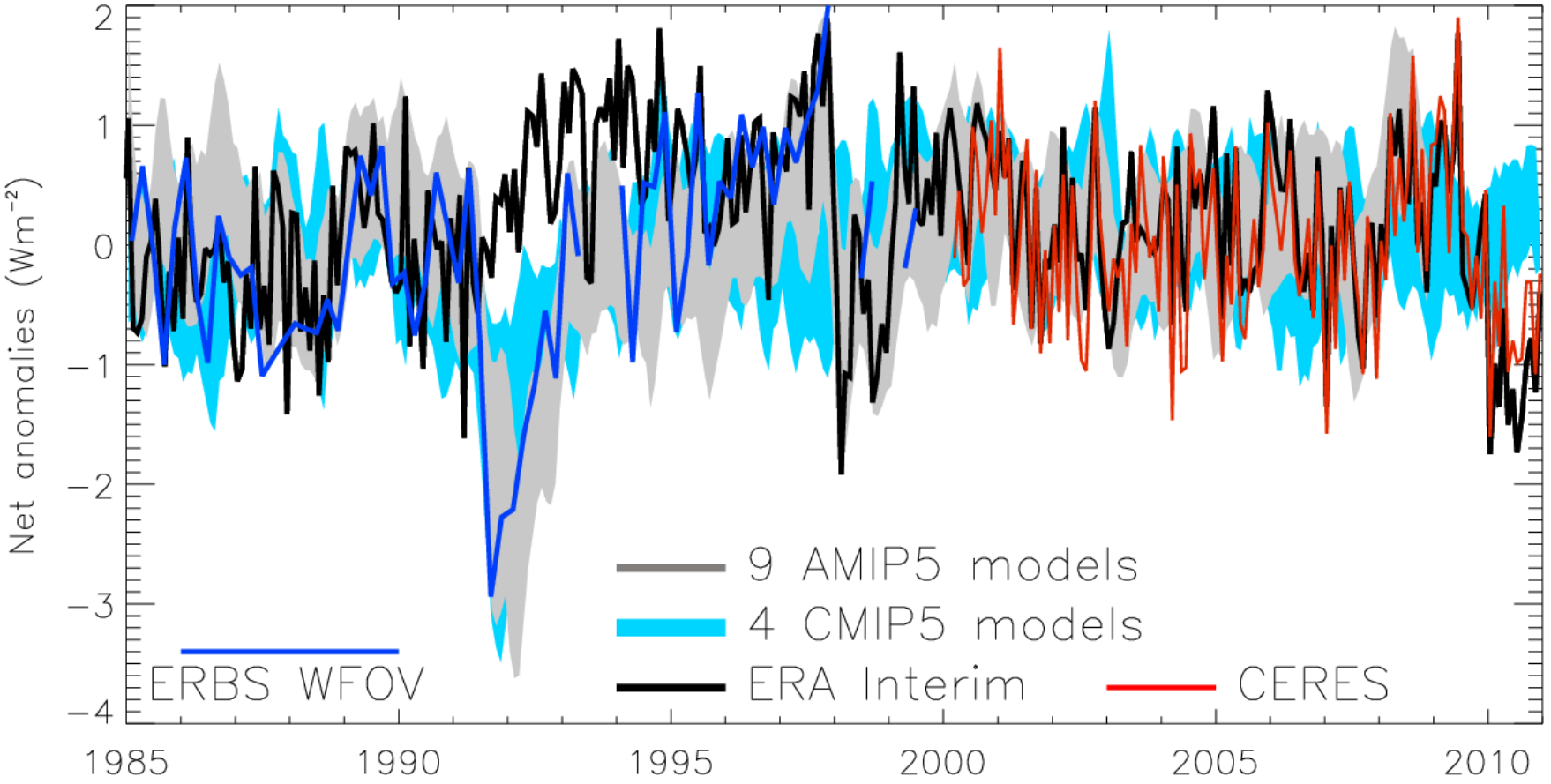
Combining Earth Radiation Budget and Ocean Heat Content data

- Replotted so that CERES and ERA Interim sample 6-months later than ARGO

- Is there a lag in the system?
- Where in ocean is energy accumulating?
- Mechanism?



Variation in net radiation since 1985



60S-60N, after Allan (2011) Meteorol. Apps

Conclusions and Future work

- Previously highlighted "missing energy" explained by ocean heat content uncertainty combined with inappropriate net radiation satellite products
- Heating of Earth continues (~0.5 Wm^{-2})
  - Negative radiative forcing does not appear to strongly contribute
- Implications:
  - Energy continues to accumulate below the ocean surface
  - Strengthening of Walker circulation, e.g. Merrifield (2011) J Clim?

  See also poster A203 (CL2.10), Hall A Friday AM (Matthias Zahn)
  - Implications for hydrological cycle, e.g. Simmons et al. (2010) JGR?

  See also poster A204 (CL2.10), Hall A Friday AM (Chunlei Liu)