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Tracking Earth's Net Energy Imbalance

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Is the Earth still warming?

The Earth has warmed at the rate of ~0.16 K/decade over the period 1981-2010 yet no discernable warming has occurred in the most recent decade (Fig. 1)

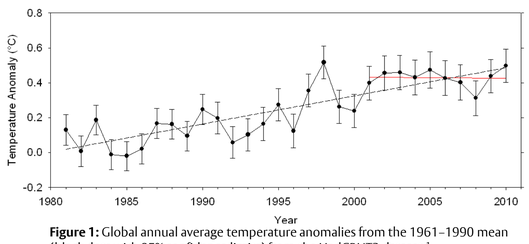


Figure 1: Global annual average temperature anomalies from the 1961–1990 mean (black dots with 95% confidence limits) from the HadCRUT3 dataset [1].

Does the recent lull in warming relate to changes in the net energy entering the climate system or does it reflect a redistribution of this energy?

To explore this question, net radiation from satellite observations are combined with in situ ocean data.

Is there missing energy?

Current observing systems appear unable to account for the recent lull in warming (Fig. 2)[2]:

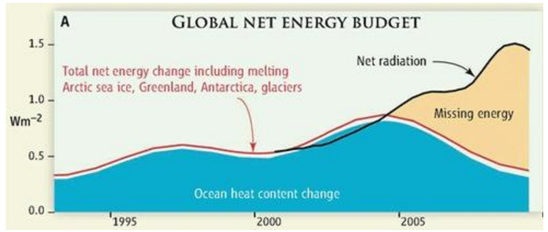


Figure 2: Estimates of net radiation from satellite data and total net energy estimated primarily from ocean heat content data, do not appear to correspond (from ref. 2).

Is there *"missing energy"* [2] *in the climate system?*

We combine the most recent ocean heat content data[4] and radiation budget data from Clouds and the Earth's Radiant Energy System (CERES[3]) with reanalysis and climate models to reassess recent changes in Earth's energy imbalance over the period 2000-2010 (Fig. 3; see ref 5 for further details).

Updated assessment of changes in Earth's energy imbalance

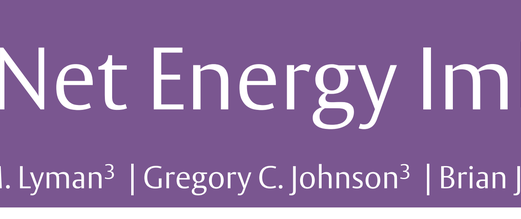
Satellite measurements from CERES have provided a stable record of *changes* in the radiation balance since 2000 (e.g. see Fig. 4).

CERES cannot measure the *absolute* net radiation to sufficient accuracy for quantifying the magnitude of the net radiation imbalance.

Ocean measurements of sub-surface temperature and salinity from ship-based measurements and automated profiling floats are required; changes in ocean heat content with time integrate to an energy flux in Wm^{-2}.

Earth's Energy Imbalance

- There is currently an imbalance between absorbed incoming solar radiation and outgoing longwave radiation to space (~0.5 Wm^{-2})[2,3,5].
- More energy is currently entering the climate system than leaving, primarily due to anthropogenic radiative forcing.



- Global warming is the transient response to this imbalance
- Natural variability such as El Niño affect the imbalance temporarily as do volcanic eruptions (see Figs. 3-4).

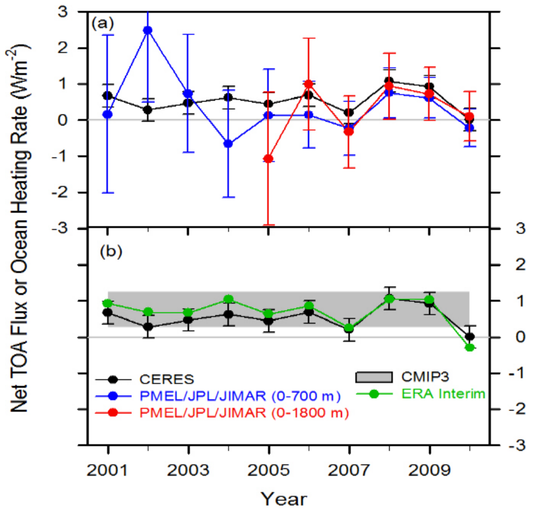
Methods

We use CERES Terra EBAF v2.6 data and solar irradiance observations from SORCE to estimate top of atmosphere net radiative flux anomalies of uncertainty ±0.31 Wm^{-2}.

Global annual means are constructed and adjusted such that the net flux over the period 2006-2010 agrees with the 0-1800m ocean heat content trend[4] combined with estimates of sub-2000m heat storage changes and additional smaller heating terms.

Results

- We calculate an observed decadal net energy imbalance of +0.54±0.43 Wm^{-2} over the period 2000-2010 (Fig. 3)[5].
- Variability in net radiation from CERES is consistent with simulations from ERA Interim and consistently sampled ocean heat content data for 0-700m depth since 2005.
- Variability is related to El Niño southern Oscillation.
- Coupled climate model simulations indicate a substantial spread in net radiation over the 2000-2010 period (Fig. 3b).



Fi gure 3 (a) Global annual average net TOA flux from CERES observations and (b) ERA Interim reanalysis are anchored to an estimate of Earth's heating rate for 2006–2010 [5] The Pacific Marine Environmental Laboratory/Jet Propulsion Laboratory/Joint Institute for Marine and Atmospheric Research (PMEL/JPL/JIMAR) ocean heating rate estimates[4] use data from Argo and World Ocean Database 2009; uncertainties for upper ocean heating rates are given at one-standard error derived from sampling uncertainties. The gray bar in (b) corresponds to one standard deviation about the 2001–2010 average net TOA flux of 15 CMIP3 models.

Where has the energy gone?

The only plausible reservoir for this continued magnitude of energy accumulation is the ocean.

The mechanism by which energy partitioning throughout the ocean varies is unclear and merits further analysis[7]

Further analysis of CMIP5 simulations of net radiation variation (Fig. 4) and ocean heat content are planned.

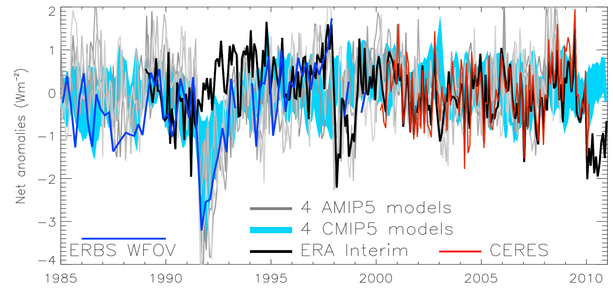


Figure 4: Deseasonalised monthly anomalies of net radiation (60°S-60°N) from satellite data (ERBS WFOV; CERES) and reanalysis simulations (ERA Interim) updated from ref 6 to include CMIP5 climate model simulations (AMIP 5 simulations from CNRM, NorESM1, HadGEM2 and INMCM4 in grey and combined historical and RCP4.5 scenario coupled simulations from CNRM, CanESM, HadGEM2-ES and INMCM4 in blue shading).

Summary

Despite a lack of surface warming in the recent decade, energy has continued to accumulate in the climate system at the rate of 0.54±0.43 Wm^{-2}.

The energy is likely to be accumulating in the sub-surface ocean; further work is required to determine the physical mechanism[7].

Interannual variability in net energy appears consistent with El Niño Southern Oscillation.

Considerable uncertainty remains in tracking Earth's energy flows using satellite and in situ data.

References

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