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Changes in global energy budget at the top of atmosphere and surface 1985-2015

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Introduction

- **Net radiation flux at TOA prior to CERES era is reconstructed by combining satellite observations, atmospheric reanalysis and climate model simulations** *(Allan et al. 2014)***.**
- **Net surface energy flux is derived by combining TOA flux with lateral energy transport calculated from ERA-Interim reanalysis (***Liu et al. 2015***).**
- **A south to north cross equatorial energy transport of 0.32 PW by the oceans and -0.22 PW by the atmosphere is inferred** (*Liu et al. 2016*)**.**

Radiation flux at TOA

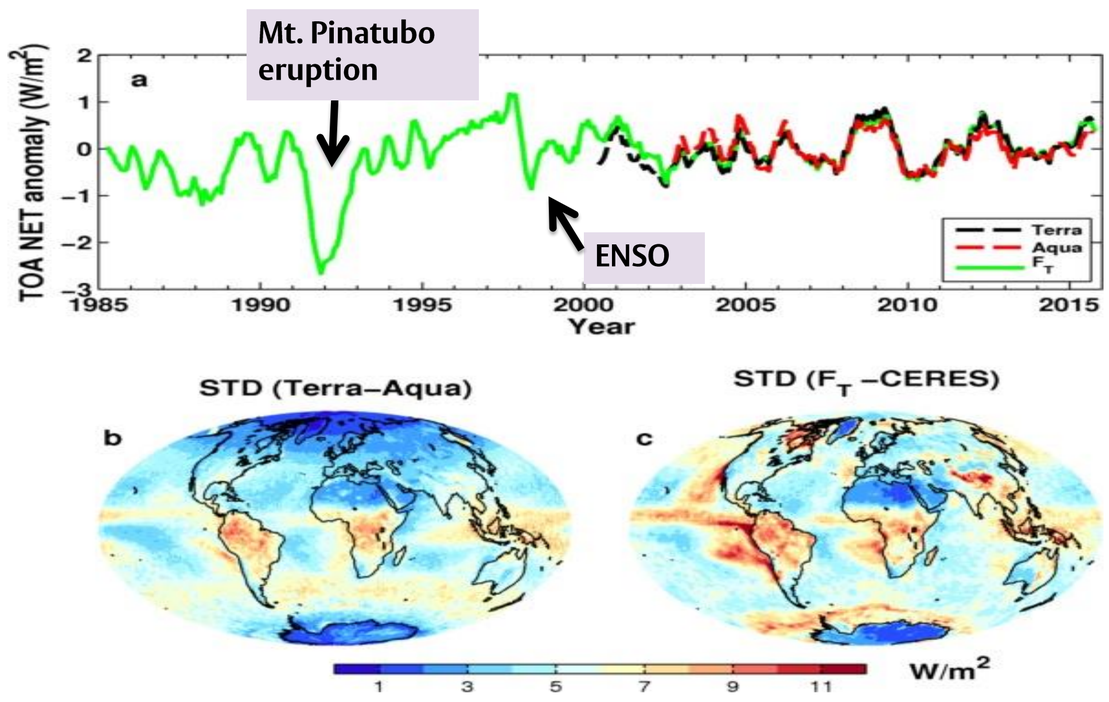

Fig. 1. (a) The anomaly time series, with reference period 2003-2014. All lines are six month running means. Spatial distribution of standard deviations from monthly anomaly differences over 2003-2014: (b) between Terra and Aqua and (c) between reconstruction method F_T and CERES (in our product CERES is used from 2000).

- TOA radiation fluxes are updated using the latest estimation of Earth system net heat uptake of 0.59±0.1Wm^{-2} over 2006-2013 (0.49 Wm^{-2} by the ocean from 0-2000m, 0.07 Wm^{-2} by the deeper ocean and 0.03 Wm^{-2} by melting ice, warming land, and an increasingly warmer and moister atmosphere).
- Updated net TOA imbalance of 0.27±0.38 Wm^{-2} for 1985-1999 and 0.59±0.14 Wm^{-2} for 2000-2015 (uncertainty at the 90% confidence level).
- An increase in energy imbalance from the 1985-1999 period to the 2000-2015 period remains likely (the magnitude 0.32±0.24 Wm^{-2} is uncertain).

Net surface energy flux

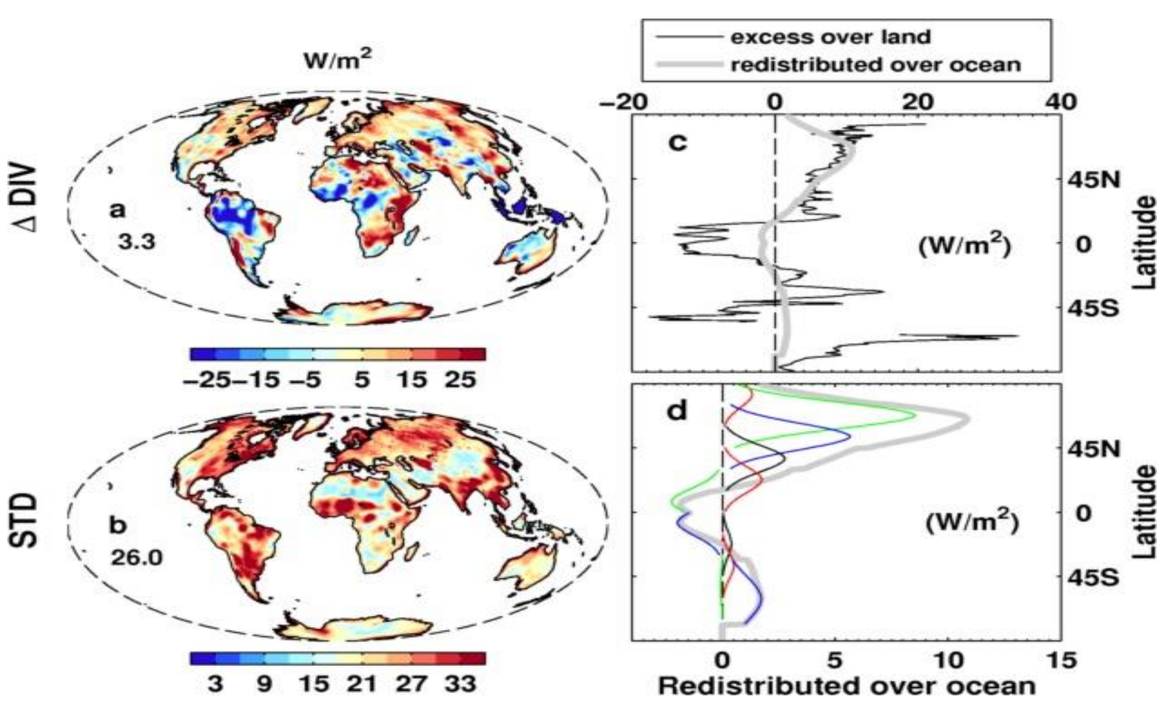

Fig. 2. (a) Multiannual (2001-2005) mean monthly divergence difference before and after the constraint; (b) standard deviation of the monthly divergence differences; (c) zonal mean excess divergence over land and the redistribution over the oceans; (d) redistributions over oceans from eleven latitudinal land bands.

- Atmospheric energy divergence is mass corrected.
- Land surface fluxes are unrealistic so are constrained using grid point relations between surface flux and surface temperature change from high resolution atmospheric model; flux adjustments are redistributed to the oceans (Fig. 2).

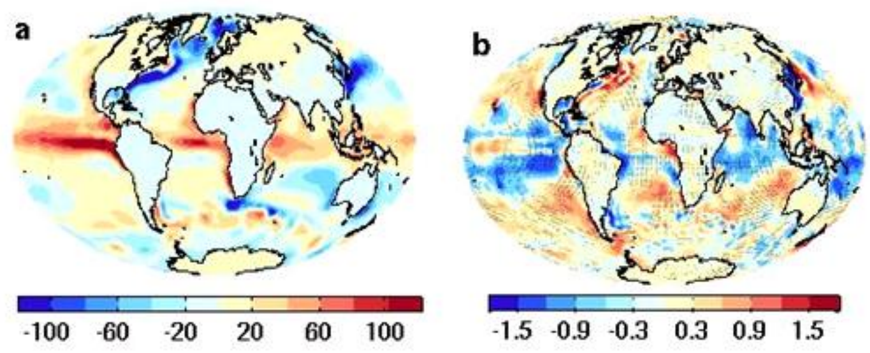

Fig. 3. (a) Multiannul means (1985-2015) of net surface energy flux (Wm^{-2}) and (b) annual mean trend (Wm^{-2}/yr); stippling shows where the trend is significant using Mann-Kendall test at significance level of 0.05.

- Net downward flux (ocean heating) over equatorial central and east Pacific area.
- Net upward fluxes (cooling) over the Gulf Stream and Kuroshio currents regions.
- Negative trend central eastern Pacific, positive trend southern subtropical oceans.

Energy flow

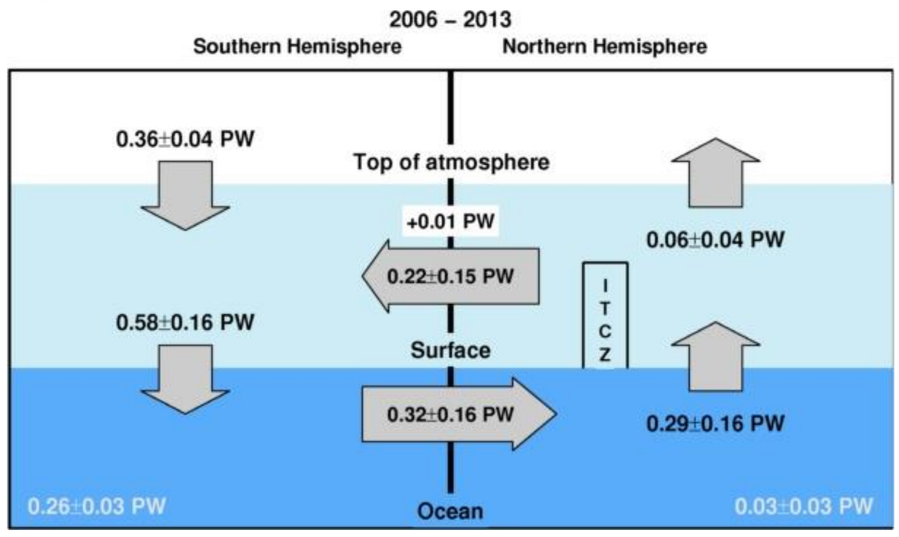

Fig. 4. Schematic of observed energy flows in the climate system in petawatts (PW) over 2006-2013 and the location of the Inter Tropical Convergence Zone (ITCZ). Ocean heat storage is based on observations (*Roemmich et al. 2015***).**

- TOA radiation flux from CERES EBAF anchored to 0.59W/m^2 over 2006-2013.
- Ocean heat storage is from observations (*Roemmich et al. 2015*).
- Southern hemisphere energy gain and northern hemisphere energy loss at TOA.
- Estimated net atmospheric energy transport of 0.22PW from northern hemisphere to southern hemisphere.
- Computed net ocean heat transport of 0.32PW – smaller than previous estimates.

Further study

- Investigate the trend of surface fluxes over central eastern Pacific and its relations with surface warming slowdown and latent heat flux.
- Link cloud feedback with the surface flux variations and temperature trends.

References

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2. Liu, C., R. P. Allan, P. Berrisford , M. Mayer , P. Hyder, N. Loeb , D. Smith , P.-L. Vidale, J. Edwards (2015) Combining satellite observations and reanalysis energy transports to estimate global net surface energy fluxes 1985-2012, *J. Geophys. Res*., doi: 10.1002/2015JD023264.

3. Liu, C., R. P. Allan, M. Mayer, P. Hyder, N. Loeb , C. D. Roberts, M. Valdivieso, J. Edwards, P.-L. Vidale (2016) Evaluation of satellite and reanalysis-based global net surface energy flux and uncertainty estimates. Submitted to *J. Geophys. Res*..

4. Roemmich, D., J. Church, J.Gilson, D. Monselesan, P. Sutton, and S. Wijffels (2015), Unabated planetary warming and its ocean structure since 2006, *Nature Climate Change*, *5*, doi: 10.1038/NCLIMATE2513.

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