CURRENT CHANGES IN EARTH’S RADIATION BUDGET AND CLIMATE

Richard Allan    r.p.allan@reading.ac.uk    @rpallanuk
Thanks to Chunlei Liu, Norman Loeb, Doug Smith, Matt Palmer
EARTH’S RADIATIVE ENERGY BUDGET AND CLIMATE

• Earth’s radiative energy budget represents a nexus between radiative forcings, feedbacks & climate response
• Powerful constraint upon hydrological cycle
• Versatile diagnostic of the impact of clouds, aerosol, water vapour greenhouse effect and atmospheric circulation
A SIMPLE ENERGY BALANCE MODEL OF EARTH’S CLIMATE

- Oceans dominate the heat capacity of climate system
- Temperature change linked to radiative forcings ($\Delta F$) and response which depends on feedbacks $Y$.
- Heat uptake by the deep ocean is important in the timescale and variability of climate change.
- Simple models are useful for interpreting climate change.

\[
\frac{d\Delta T_m}{dt} = \frac{1}{C_m} (\Delta F - Y \Delta T_m - D)
\]

\[
D = c (\Delta T_m - \Delta T_D) / d
\]

E.g. Allan et al. (2014) Surv. Geophys
SURFACE WARMING: INCOMPLETE PICTURE OF CLIMATE CHANGE

The graph that reveals how ‘95 per cent certain’ estimates of the earth heating up were a spectacular miscalculation.

- This dark red area is climate scientists’ official prediction of world temperatures to a 75% degree of certainty...
- ...and this light red area is their official prediction of world temperatures to a 95% degree of certainty...
- ...and this heavy black line is the official world average temperature - which is about to crash out of them both.

Mail on Sunday 16th March 2013
AT WHAT RATE IS EARTH HEATING?

Trenberth et al. (2014) J Clim
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...
COMBINED CERES/ARGO DATA

- Incoming Solar: SORCE Level 3 V10
- Reflected Shortwave/Outgoing Longwave from EBAF
  - (v2.6r → v2.8 → V3...)
- Added errors in quadrature to give ± 0.43 Wm$^{-2}$
  - Argo 0-2000m dOHCA/dt = 0.47 ± 0.38 Wm$^{-2}$ (2005-2010)
  - >2000m ~ 0.07 ± 0.05 Wm$^{-2}$
  - Heating/melting ice, heating land/atmos ~ 0.04 ± 0.02 Wm$^{-2}$
  - CERES standard error ± 0.2 Wm$^{-2}$

Observe changes in top-of-the-atmosphere radiation and upper-ocean heating consistent within uncertainty.

Norman G. Loeb*, John M. Lyman†, Gregory C. Johnson‡, Richard P. Allan†, David R. Doelling‡, Takmeng Wong‡, Brian J. Soden∗ and Graeme L. Stephens†
CONSISTENT CHANGES IN NET HEATING WITHIN UNCERTAINTY

Using appropriate CERES dataset that accounts for degradation of SW filter and ocean heat content data we found:

- No evidence of a decline in ocean heating
- Stable net radiative imbalance of $0.50 \pm 0.43$ Wm$^{-2}$
- Consistent variability within large uncertainty

...but what about before 2000?

Loeb et al. (2012) Nat. Geosci
EARTH RADIATION BUDGET
SATELLITE DATA

RECONSTRUCTING GLOBAL RADIATIVE FLUXES PRIOR TO 2000

Combine CERES/ARGO accuracy, ERBS WFOV stability and reanalysis circulation patterns to reconstruct radiative fluxes.
CHANGES IN NET RADIATIVE IMBALANCE

Imbalance: 0.23  0.00  0.78  0.63  0.63 (Wm\(^{-2}\))

- La Niña: 0.34±0.67 Wm\(^{-2}\)
- El Niño: 0.62±0.43 Wm\(^{-2}\)

Allan et al. (2014) GRL
DISCREPANCY BETWEEN RADIATION BUDGET & OCEAN HEATING

- Large ocean heating anomaly in 2002
- Inconsistent with radiation budget observations and simulations
- Changing observing system influence?
- Slight drop in net flux 1999-2005?

Smith et al. (2015) GRL
UNDERSTANDING CHANGES IN NET IMBALANCE

Analysis using simple energy balance model
Allan et al. (2014) GRL supplementary

\[ N = \Delta F - \Delta Y \Delta T \]

+ve RF trend
-ve RF trend
AR5 RF
0 RF trend
IMPLICATIONS FOR CLIMATE SENSITIVITY?

?Can comparisons tell us about how sensitive climate is to radiative forcing
Otto et al. (2013) Nature Geosci

Infilling data gaps influences surface temperature trends (Cowtan & Way, 2013 QJRMS) and ocean heat content (Lyman & Johnson 2014 J. Clim.)

Allan et al. (2014) GRL supplementary
EXPLAINING THE SLOWDOWN

• Declining solar forcing (e.g. Hansen et al. 2013 PLOS ONE), more small volcanos (e.g. Ridley et al. 2014 GRL) & more La Niñas/cold NH land in winter vs late 1990s appear to explain:
  • Slowing in surface warming (e.g. Foster & Rahmstorf 2012)
  • Slower surface warming compared with coupled simulations (e.g. Risbey et al. 2014; Huber & Knutti 2014)
Continued heating from rising greenhouse gas concentrations

Enhanced Walker Circulation

Strengthening trade winds

Enhanced mixing of heat below 100 metres depth by accelerating shallow overturning cells and equatorial undercurrent

Unusual weather patterns (Ding et al. 2014; Trenberth et al. 2014b)

Heat flux to Indian ocean
Lee et al. 2015

Increased precipitation
Decreased salinity

Remote link to Atlantic?
McGregor et al. (2014)

Ocean circulation strengthens atmospheric circulation

Enhanced mixing of heat below 100 metres depth by accelerating shallow overturning cells and equatorial undercurrent

WHERE IS THE HEAT GOING?
NEW ESTIMATES OF SURFACE ENERGY FLUX

\[ F_{SFC} = F_{TOA} - \frac{\partial T E}{\partial t} - \nabla \cdot \frac{1}{g} \int_0^1 V (Lq + C_p T + \phi_s + k) \frac{\partial p}{\partial \eta} d\eta \]

Net surface downward energy flux (Wm\(^{-2}\))
Liu et al. (2015) in prep
WHERE IS THE HEAT GOING?
CHANGES IN SURFACE ENERGY FLUX

• Changes in energy fluxes 1986-2000 to 2001-2008
• Surface energy flux dominated by atmospheric transports
• Contrasting model pattern of change
• Are reanalysis transports reliable?
FEEDBACKS ON INTERNAL VARIABILITY?

← top: less heat flux out of east Pacific during warm phases?
- Models may underestimate interdecadal variability
- Are there positive heat flux feedbacks which amplify internal climate variability?

Brown et al. (2015) JGR
UNFORCED VARIABILITY IN EARTH’S ENERGY BUDGET

- Diverse range of unforced variability in CMIP5 pre-industrial control simulations
- **Left:** variations in total energy content of Earth’s climate system across CMIP5 simulations

Palmer & McNeall (2014) ERL
EARTH’S ENERGY BUDGET AND PRECIPITATION RESPONSE

\[ \Delta P \approx k \Delta T - f_F \Delta F \]

SIMPLE MODEL FOR GLOBAL PRECIPITATION

Using simple model:

\[ L\Delta P = k\Delta T - f_F\Delta F \]

\[ \frac{d\Delta T_m}{dt} = \frac{1}{C_m} (\Delta F - Y\Delta T_m - D) \]

\[ N = \Delta F - Y\Delta T \]

\[ D = c(\Delta T_m - \Delta T_D)/d \]


Zahra Mousavi (PhD project)
METRICS FOR GLOBAL PRECIPITATION

- Metrics linking emissions to precipitation response
- Precipitation and temperature response to constant emissions after 2008

Shine et al. (2015) in prep:
EARTH’S ENERGY BUDGET & REGIONAL CHANGES IN THE WATER CYCLE

- Regional precipitation changes sensitive to asymmetries in Earth’s energy budget
- N. Hemisphere cooling: stronger heat transport into hemisphere
- Reduced Sahel rainfall from:
  - Anthropogenic aerosol cooling 1950-1980s: Hwang et al. (2013) GRL
  - Asymmetric volcanic forcing e.g. Haywood et al. (2013) Nature Climate
- Sulphate aerosol effects on Asian monsoon e.g. Bollasina et al. 2011 Science (left)
- Links to drought in Horn of Africa? Park et al. (2011) Clim Dyn
OBSERVED ASYMMETRY IN EARTH’S ENERGY BUDGET

• Observed inter-hemispheric imbalance in Earth’s energy budget
• Not explained by albedo: brighter NH surface but more clouds in SH (Stephens et al. 2015)
• Imbalance explains position of ITCZ (Frierson et al. 2013)

Loeb et al. (2015) in review
EQUATORIAL HEAT TRANSPORT AND MODEL PRECIPITATION BIAS

- Clear link between bias in cross-equatorial heat transport by atmosphere and inter-hemispheric precipitation asymmetry

Loeb et al. (2015) in review

More rain in NH ➔

CERES/ERA Interim
RECENT TRENDS IN AFRICA RAINFALL

• Evaluating and understanding recent changes in Africa rainfall
  Maidment et al. (2014) JGR

• PhD project extending this work: impact-relevant metrics for Africa
  (Caroline Dunning)

Maidment et al. (2015) in prep
FUTURE WORK

• Time-scales associated with net imbalance (Harries & Futyay 2006 GRL)
• Can we reconcile ocean heating and top of atmosphere imbalance?
• Observational constraint on radiative feedbacks & climate sensitivity
• What controls decadal variability: “hiatus” and “surge” events?
• Feedbacks associated with unforced variability
  • Cloud and latent heat fluxes in the Pacific e.g. Brown et al. 2014 GRL
• Do patterned radiative forcings force distinct feedback responses?
• To what extent does inter-hemispheric imbalance control rainfall patterns? e.g. Hwang et al. (2012) GRL