DEEP-C:
WP1 overview and future plans

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**DEEP-C Work Plan**

**Start date: March 2013; Project Ends February 2017**

<table>
<thead>
<tr>
<th>Workpackage</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP1 (Reading)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP2 (Southampton)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>WP3 (Met Office)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP4 (All)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Partners</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Table 2 - Management timeline for DEEP-C.**
**WP1 Objectives/Deliverables**

**O1.** Combine satellite radiation budget measurements with atmospheric reanalyses, providing improved 2D estimates of surface heat fluxes across the ocean surface (WP1)

**D1.** Combined satellite-reanalysis atmosphere/surface energy flows: methodology, uncertainty and exploring lags in the climate system (paper 1,2; WP1, O1,4)

**O5.** Monitor co-variations in net radiative energy imbalance and ocean heating (from O1,O2,O4); quantify and understand lags between OHC and TOA radiation (WP1-4)

**O6.** Characterise spatial signatures/mechanisms of ocean and atmospheric heat re-distribution (from O4-5) during the hiatus period 2000-2013 using observations and simulations (WP1-4)
WP1 - Planned work

1. Analyse and update observed variability in TOA radiation balance (Allan et al. 2014: delivered)
2. Combine reanalyses/satellite data to provide independent estimates of surface flux (C. Liu et al. 2015: delivered)
   - Wider use of flux products by Pat Hyder et al. (Met Office)
3. Uncertainty estimates for reconstructed surface fluxes
4. Inter-hemispheric heating asymmetry (and water cycle)
5. Regional changes in surface fluxes (link to SMURPHS)
6. Reconcile TOA radiation balance and ocean heating (WP2/4)
7. Improved estimate of imbalance & changes (ongoing)
8. Other topics:
   – Investigate lags in climate system
   – Evaluation of ERA CLIM/reanalysis radiation budget?
Changes in imbalance in models & observations

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

0.34 ± 0.67 Wm^-2

0.62 ± 0.43 Wm^-2

La Niña

El Niño

Allan et al. (2014) GRL

Volcano
Energy imbalance-implied temperature changes

Temperature difference compared with 1961–1990 average from HadCRUT4 applying adjustments for incomplete coverage (Cowtan & Way, 2014)

Energy imbalance implied temperature changes assuming heat absorbed by upper 200m of ocean
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)

EQUATORIAL HEAT TRANSPORT AND MODEL PRECIPITATION BIAS

- Clear link between bias in cross-equatorial heat transport by atmosphere and inter-hemispheric precipitation asymmetry
FEEDBACKS ON INTERNAL VARIABILITY?

Brown et al. (2015) JGR

- 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?
  - New project: SMURPHS

ERAINT latent heat flux trend 1988-2008
Some recent updates to the literature:

Unforced variability:

**Schurer et al. (2015) GRL:** Probability of hiatus or rapid warming in observations consistent with previous model studies (e.g. Roberts et al. 2015); Spatial pattern relating to Interdecadal Pacific & Atlantic Variability. Combination of unforced variability and timing of volcanic eruptions also important.

**Brown et al. (2015) JGR:** strong link between east Pacific and sub-decadal global mean temperature variability. Two clusters display link with inter-decadal variability: E. Pacific and S. Ocean; models underestimate interdecadal variability and this is especially pronounced where the E. Pacific link dominates. There is some evidence of positive heat flux feedbacks to inter-decadal variability in the E. Pacific and also for high latitudes involving sea ice.
Some recent updates to the literature:

**Ocean Heating:**

**Nieves et al. (2015) Science:** observations show that heating below the upper 100m ocean have more than compensated slight cooling in the upper 100m over the 2003-2013 period, confirming that redistribution of the heat in the vertical, and in particular in the 100-300m layer in the Indian and Pacific oceans, explain the suppressed rates of surface warming.

**Zika et al. (2015) GRL:** deep ocean heating due to collapse of "thermally direct" circulation (reduced upward heat flux at higher latitudes e.g. Antarctic bottom water circulation) but continued thermally indirect circulation (upwelling/downwelling at same density) at lower latitudes. The large-scale circulation rather than small-scale mixing determine the heat uptake changes.
Some recent updates to the literature:

**Morphology:**

**Gettelman et al. (2015) Clim. Dyn.**: Forcing from aerosol-cloud interactions may have contributed to the spatial patterns of recent temperature change, but not to the global mean slowing of surface warming for the period 2000-2010.

**Li et al. (2015) GRL**: observed Eurasian winter cooling trend 1998-2012 contributed to suppressing of global warming trend; arises from internal variability.

**Saffioti et al. (2015) GRL**: Northern Hemisphere winter cooling 1998-2012 mostly explained by missing observations (particularly for recent years) and internal variability in the atmospheric circulation of the NH extratropics.

**Gleisner et al. (2015) GRL**: Recent global warming hiatus dominated by low latitude surface temperature trends and not explained by missing data in high latitude regions.

Papers & links listed on DEEP-C website: [http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html#PAPERS](http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html#PAPERS)
WP1 Dissemination Activities

- **Nov 2015**: Paris Water/energy cycle, Paris; U3A talk; NASA sensing our planet
- **Oct 2015**: Reading International Festival outreach talk
- **Sep 2015**: NCEO meeting Southampton; CliVar workshop Exeter
- **July 2015**: Commented on Nieves et al on BBC Radio 4 Today program
- **July 2015**: Talks/posters at IUGG Prague & Common Future Climate conf.
- **June 2015**: Comments on Karl et al. paper (Carbon Brief/SMC/Reuters); Seminars at Imperial College & NCAS
- **April 2015**: Presentation at Decision Analysis for Policy Support workshop
- **Feb 2015**: Comment on detection of greenhouse gas radiative effect
- **Jan 2015**: Smith et al. (2015) GRL dissemination work & U3A outreach
- **October 2014**: Conversation article on Durack/Llovel papers; BBC2 Jeremy Vine show; CERES/GERB/ScaRaB meeting talk
- **August 2014**: Allan et al. (2014) NCAS highlight, Nature Climate Change highlight; Climate Lab Book, Carbon Brief, Met Department & Conversation blogs; Telegraph ; Eddington Astronomical Society talk
- **July 2014**: DEEP-C talks at GEWEX and AMS conferences
- **April 2014**: Royal Society “Hiatus” discussion meeting; EGU talk
- **Feb 2014**: "Where has the warming gone?" RMetS local group; Comment on England et al. (see also Guardian article).
- **Aug/Sep2013**: Comment on recent Nature paper by Kosaka and Xie (see also BBC and Independent articles); Voice of Russia; IPCC Sky/BBC/etc
- **July 2013**: Science Media Centre briefing on “slowdown”
- **May 2013**: Carbon Brief article on DEEP-C temperature obs.
- **April 2013**: Meeting with DECC partners in London

Also: twitter, Walker Institute, media interaction

http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html
CONCLUSIONS / PLANS

• Top of atmosphere/surface heat flux product delivered
  • Further work required to determine uncertainties

• Characterising changes in Earth’s energy imbalance
  • Variability from radiative forcings & internal variability
  • Manifest as positive imbalance in Southern Hemisphere
    ➢ Ocean energy transport to North offset by atmos. energy trans. to South
    ➢ Links to model precipitation biases
    ➢ Decadal changes in energy imbalance? [idea → NERC]

• Toward reconciled ocean heating/radiation budget changes
  • Where in oceans is energy going (regional/vertical structure)?
  • What are time-scales/lags associated with net imbalance?

• Do feedbacks amplify/extend hiatus/surge events?
  • New SMURPHS project
  • Toward an observational constraint on climate sensitivity?
Spare slides
Project Objectives

**O1.** Combine satellite radiation budget measurements with atmospheric reanalyses, providing improved 2D estimates of surface heat fluxes across the ocean surface (WP1)

**O2.** Calculate global 3D ocean heat content and its changes since 2003 using ARGO and ship-based observations, leading to improved understanding of energy propagation through the climate system (WP2)

**O3.** Investigate spatial patterns of surface and sub-surface temperature changes in distinct hiatus decades using simulations and observations (e.g. Fig. 4); evaluate the processes fundamental for ocean heat uptake and redistribution (WP3)

**O4.** Combine ocean and satellite data (from O1-2) to provide new estimate of Earth's net radiative energy balance (2000-2015) and compare with CMIP5 climate simulations (from O3) (WP1-4)

**O5.** Monitor co-variations in net radiative energy imbalance and ocean heating (from O1,O2,O4); quantify and understand lags between OHC and TOA radiation (WP1-4)

**O6.** Characterise spatial signatures and mechanisms of ocean and atmospheric heat re-distribution (from O4-5) during the hiatus period 2000-2015 using observations and simulations (WP1-4)
Discussion

• Activities to combine work packages?
  – Joint publications
  – Intercomparison of ocean heating/imbalance data
  – Assess uncertainty in surface flux product
  – Lags in system/feedbacks on decadal variability
  – Estimated imbalance + regional/vertical structure
  – Heating by ocean basin and surface fluxes

• Big issue questions to aim for?

• Future funding opportunities?

• Next meeting
  – Dates...
  – Should we arrange a larger 2-day workshop?
Continued heating from rising greenhouse gas concentrations

Enhanced Walker Circulation

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

Increased precipitation
Decreased salinity

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

POSSIBLE FUTURE WORK

• Can we reconcile ocean heating and top of atmosphere imbalance?
• Time-scales and lags associated with net imbalance (Harries & Futyan 2006 GRL)
• 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