Ocean heat content and Earth’s energy imbalance: insights from climate models

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Outline

• Some context: the global warming “hiatus”
• CMIP5 models - unforced simulations (piControl)
• CMIP5 models - forced simulations (historical + RCP8.5)
• Summary + open questions..
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1. A change in net radiation at top-of-atmosphere (netTOA)? [0.6 Wm^{-2}]
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2. A rearrangement of ocean heat content (OHC)?
CMIP5 unforced “piControl” simulations
Approach

Assume a linear combination of forcings and internal variability in the real world

=> Analyse multi-century CMIP5 preindustrial control simulations to address the following questions:

(i) On what timescale does netTOA come into balance with changes in total OHC?

(ii) What is the potential role of internal variability in netTOA for the recent pause in surface warming?

(iii) What is the potential role of ocean heat redistribution for the recent pause in surface warming?
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Note: the analyses presented are idealised studies, where there is no attempt to account for realistic observational sampling
10-yr trends in surface temperature are NOT a robust indicator of trends in Earth System energy

10-yr trends in global OHC changes ARE a robust indicator of trends in Earth System energy

The ocean becomes the dominant term in Earth’s energy budget on a typical time scale of ~ 12 months

Internal variability => trends in GST and netTOA that are large compared to “background” warming/heating rates (2.5th and 97.5th centiles)
Internal variability => substantial ocean heat re-arrangement compared to “background” heating rates (2.5th and 97.5th centiles)

The character and magnitude of ocean heat re-arrangement varies substantially among CMIP5 models (hovmoller plots of OHC over 200 years)
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Summary of CMIP5 piControl simulations

(i) The ocean becomes the dominant term in Earth’s energy budget on a timescale of about 1 year

(ii) Changes in netTOA associated with internal variability of order 0.1-0.3 Wm\(^{-2}\) on decadal timescales [c.f. 0.6 Wm\(^{-2}\)]

(iii) Ocean heat rearrangement across 700m (1800m) isobath is of order 0.1-0.2 (0.5-0.15) Wm\(^{-2}\) [c.f. 0.6 Wm\(^{-2}\)]

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And..

(iv) 10-15 year “hiatus” in surface temperature rise could be explained by internal variability alone => see Roberts et al [2015, next 2 slides]

(v) Surface temperature trends are NOT a reliable reliable indicator of changes in Earth System energy (and hence global warming) on decadal timescales

(vi) Representation of internal variability varies considerably among CMIP5 models
CMIP5 models show different “flavours” of hiatus event, but the Pacific is a key region.

Following a hiatus decade there is a greater change of an accelerated warming.

CMIP5 hiatus multi-model composite dominated by PDO-like pattern


CMIP5 accelerated warming composite also dominated by PDO-like pattern
A role for external forcings during the hiatus?

Observed rate of sea level change 1993-2012 (relative to GMSLR)

Hatched regions are inconsistent with unforced variability in at least 2/3 of models

Bilbao et al [2015]
CMIP5 forced simulations “historical” and “RCP8.5”
Internal variability of OHC by layer (piControl)

Standard deviation of the column integrated OHC between 0-700 m, 700-2000 m or 2000-4000 m in the control simulation of the CMIP5 models HadGEM2-ES, MPI-ESM-MR, GISS-E2-R and GFDL-CM3. The multi-model means of the standard deviation in these four models are also shown for each depth range.

Garry et al [in prep]
Trends in OHC by depth layer (RCP8.5)

Linear trend from column integrated OHC during the period 2010 – 2100 (RCP 8.5 simulations). Calculated for the depth ranges 0-700 m, 700-2000 m or 2000-4000 m for the CMIP5 models HadGEM2-ES, MPI-ESM-MR, GISS-E2-R and GFDL-CM3. The multi-model means of the trends in these four models are also shown for each depth range.

Garry et al [in prep]
CMIP5 bottom water property changes under RCP8.5
Based on 25 models

RCP8.5 multimodel mean change (2081–2100 minus 1986–2005) in (a) bottom temperature, (b) bottom salinity, and (c) bottom density $\sigma_2$. Control drift has been removed. Black stippling indicates areas where fewer than 16 models agree on the sign of the change. Gray contour indicates the 3000-m isobath. Yellow lines in (c) indicate the study boundaries for the three ocean basins in the Southern Ocean.

Heuzé et al [2015]
Bias in estimate of netTOA based on $d$(OHC)/$dt$ for “historical” and “RCP8.5” simulations
Summary of CMIP5 historical and RCP8.5 simulations

(i) The Atlantic and Southern Oceans are key regions for OHC variability and the response to anthropogenic warming

(ii) The climate change signal extends over the full depth of the water column

(iii) Argo-like observations are adequate to monitor Earth’s energy imbalance historically, but deeper observations are required over the 21st Century

(iv) The patterns and magnitudes of OHC variability and change vary by CMIP5 model
Some open questions..

1. How might realistic sampling of the ocean affect the results presented here?

2. What is the relative importance of the deep ocean, ice covered regions and marginal seas for estimating netTOA from d(OHC)/dt?

3. What important processes for OHC variability and change are poorly represented or missing from CMIP5 models? (e.g. AABW formation)

4. How might the balance of processes change in the presence of eddies? (how would these results change for high(er)-resolution models?)

5. How can we determine which models are most like reality? => need for process-based constraints on climate model projections (?)
Questions and discussion..