The ocean’s role in climate change and variability: what have we learned so far from Argo?

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1st CLIVAR CONCEPT-HEAT workshop, Met Office, Exeter, UK
Determining Earth’s energy imbalance: 4 different approaches

**Surface flux**

- Radiative
- Turbulent

**Ocean heat content**

**Climate models**

**Radiation at TOA**

Loeb et al., 2012

IPCC, 2013

Josey et al., 2015
Determining Earth’s energy imbalance: Heat storage

Ocean Heat Content

Energy accumulation within the different components of the Earth climate system

IPCC, 2013

Abraham et al., 2013
Ocean heat content: Argo-era

Global Ocean Heat Content

3847 Floats
20-May-2015

Global Ocean Heat Content

trend 2005-2012: 0.5±0.1 Wm⁻²

von Schuckmann and Le Traon, 2011
von Schuckmann et al., 2014
Interannual to decadal changes as derived from different Argo products

Still too large spread in different estimates !!!
Ocean heat content: Argo era

Interannual to decadal changes as derived from different Argo products

Interannual OHC changes (2000-2011) vs. Decadal OHC changes (2006-2012)

Still too large spread in different estimates !!!
Coverage is not yet truly global, as Argo does not cover:

- the deep ocean below 2000m depth
- the shelf areas and marginal seas
- pole wards of 60° latitude
- the near surface layer

What can we expect to see from these different under-sampled regions?
Role of the deep ocean

Under-sampling of the ocean, especially below 700m and in the deep ocean may account for the main discrepancy

Growing disparity between the OHC changes in the upper 700m and down to 2000m after 2005:

- warming has occurred in the 700–2000m layer
The warming below 700 m remains even when the Argo observing system is withdrawn although the trends are reduced.

In the last decade, about 30% of the warming has occurred below 700 m, contributing significantly to an acceleration of the warming trend.

Balmaseda et al., 2013
Role of deep ocean in Earth’s energy balance: MetOffice climate model

Decadal Variations in Net TOA Radiation, SST Trend and Ocean Heating Rate

- Approximately 30% of decades show a trend in net TOA radiation and SST that are of opposite sign.
- Ocean re-distribution of heat is the primary reason for the larger scatter between SST and total energy.

Palmer et al., 2011
Role of undersampled regions?

\[ \text{SL}_{\text{steric}}(\text{Argo}) + \text{SL}_{\text{res}} = \text{SL}_{\text{total}} - \text{SL}_{\text{mass}} \]

Changes below Argo depths & Estimation errors (sampling and processing issues, systematic biases)

Argo: 2000-2012

Altimetrie: 1993-2012

GRACE: 2002-2012

Overlapping time window for global and re-qualified data 2005-2010:
Methods developed for global estimations

von Schuckmann and Le Traon, 2011

Averaged DM gridded product, AVISO

Chambers and Schröter, 2011
Role of other under-sampled regions?

Residual of the Sea level budget: 2005-2010

\[ \text{SL}_{\text{res}} = \text{SL}_{\text{total}} - \text{SL}_{\text{steric (Argo)}} - \text{SL}_{\text{mass}} \]

Altimeter: full grid

\[ \text{0.3} \pm 0.6 \text{ mm/years} \]

\[ \text{1.6} \pm 0.7 \text{ mm/years} \]

Altimeter: Sampled on Argo profile positions ➔ Argo sampling issue

von Schuckmann et al., 2014
Role of other under-sampled regions?

\[ \text{SL}_{\text{res}} = \text{SL}_{\text{total}} - \text{SL}_{\text{steric}}(\text{Argo}) - \text{SL}_{\text{mass}} \]

Underestimating sea level changes in the Indonesian Archipelago affects the global mean by 20%.

Total sea level (AVISO)

AVISO, but Ind. Archip. = NaN

Steric sea level (10-1500m)

2005-2010:

20%

von Schuckmann et al., 2014
Other reasons for observed discrepancies between Argo products?

GOHC trend: 2006-2012

Range of decadal GOHC trend between different products:
~0.2 to 0.7 Wm-2

von Schuckmann et al., 2015
Other reasons for observed discrepancies between Argo products?

Range of decadal GOHC trend between different products:
~0.2 to 0.7 Wm⁻²

Range of decadal GOHC trend between different products:
~0.6 to 1.2 Wm⁻²
Spurious “jump” in GOHC in almost all Argo products: brusque change of GOHC from Dec. 2012 to Jan 2013, and GOHC continue at a somewhat higher level.

Other reasons for observed discrepancies between Argo products?

von Schuckmann et al.: current work
Other reasons for observed discrepancies between Argo products?

- Real or spurious?

Spurious “jump” in GOHC in almost all Argo products: brusque change of GOHC from Dec. 2012 to Jan 2013, and GOHC continue at a somewhat higher level.
Other reasons for observed discrepancies between Argo products?

IPRC: $d(OHC)/dt$

Jul 2012-Feb 2013

Global OHC
$30^\circ S-50^\circ S$ excluded
$30^\circ N-60^\circ N$ excluded
$30^\circ S-30^\circ N$ excluded
Other reasons for observed discrepancies between Argo products?

Global OHC
30°S-50°S excluded
30°N-60°N excluded
30°S-30°N excluded
“jump” seems to be not spurious and appears below thermocline depth (see results presented in K. Trenberth talk of session1)

… BUT: work in progress …
Argo's greatest contributions to observing the global oceans are still in the future, but its global span is clearly transforming the capability to observe climate-related changes.
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Summary

Argo is already the principal base for climate research …

… first link to heat storage in the deep ocean

Von Schuckmann et al., 2009

… intense discussions and improvements on energy inventory

Loeb et al., 2012

… fundamental basis to optimize our global ocean in situ observing system in the future

Trenberth and Fasullo, 2010

… sea level budget, reanalysis systems, …
Conclusions

- Quantify relative importance of currently undersampled regions for estimating netTOA from $d(OHC)/dt$
- Inter-comparion initiatives for uncertainty assessments
- Add independent measurements from remote sensing (SST, SSH, validation through sea level budget)
- Develop framework to assure “climate monitoring data” quality for Argo era data (like IQuOD!)
THANK YOU.