The role of Argo steric sea level within the global sea level budget

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The global mean sea level budget: Pre-Argo era

The main factors causing current global mean sea level rise ($SL_{\text{total}}$) are thermal expansion ($SL_{\text{steric}}$) of sea waters, land ice loss and fresh water mass exchange ($SL_{\text{mass}}$) between oceans and land water reservoirs.

The recent trends of these contributions most likely result from global climate change induced by anthropogenic greenhouse gases emissions.
Contribution of **steric sea level** to GMSL rise

Thermal expansion accounts for *30-40%* of total global sea level rise as derived from long-term estimations based on historical in situ measurements.

**Altimetry era**

1993-2010: ~30%

Meyssignac and Cazenave, 2012

**Pre-Altimetry era**

1961-2008: ~40%

Church et al., 2011
Argo
Global analyses of the period with the most complete data: 2005–2011

Number of measurements from 2005-2010

- **North**
  - 30° N–60° N
  - Measurements per month from January to December for 2005-2010

- **Tropic**
  - 30° S–30° N
  - Measurements per month from January to December for 2005-2010

- **South**
  - 30°S–60°S
  - Measurements per month from January to December for 2005-2010
Argo global steric sea level (GSSL): 2005-2011

Observed trend GSSL 2005-2011: 0.68±0.12 mm/year

updated after von Schuckmann and Le Traon, 2011

Budget of observed sea level changes

2005-2010: ~40%

Method includes error estimation due to data processing and climatology uncertainties. Estimation only valid under the assumption that no systematic error remains in the Argo system.

Hansen et al., 2011
What is the robustness of the Argo climate indicators?

The role of Argo steric sea level within the global sea level budget

\[ \text{SL}_{\text{steric}}(\text{Argo}) + \text{SL}_{\text{res}} = \text{SL}_{\text{total}} - \text{SL}_{\text{mass}} \]
Comparison of the three global ocean observing systems

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

**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
Comparison of the three global ocean observing systems

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

**Argo:**
- 2000-2012
- Argo depths & Estimation errors (sampling and processing issues, systematic biases)

**Altimetrie:**
- 1993-2012
- Methods developed for global estimations

**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
What we can learn from the inter-comparison of the global observing systems:

Is it possible to receive information on deep ocean changes with this method?

Observed significant warming in the 700-2000m depth layer

Levitus et al., 2012
What we can learn from the inter-comparison of the global observing systems:

Is it possible to receive information on deep ocean changes with this method?

Purkey and Johnson, 2010

Significant abyssal warming, in particular in the Southern Hemisphere Ocean
What we can learn from the inter-comparison of the global observing systems:

**SL**

**RES**

Is it possible to receive information on systematic biases in the Argo observing system?

Problem of detection: large coherent signal, difficult to detect with regional quality control procedures

Significant effect on observed climate indicators (see also Barker et al., 2011)
What we can learn from the inter-comparison of the global observing systems:

Is it possible to receive information on data processing issues?

Data processing issues can have a large impact on the estimation of ocean climate indicators

von Schuckmann and Le Traon, 2011
We assume that this geometry allows us to distinguish regions where different processes are at work:

**NO** is opened to the highest latitudes in the Atlantic

**TO** be known to have faster dynamics

**SO** has the peculiar situation of a large circumpolar basin exposed to continuous intense atmospheric forcing.
Residual of the Sea level budget: 2005-2010

The global sea level budget is closed during 2005-2010, but only while respecting data processing issues

... but regional issues remain ...
\[ SL_{res} = SL_{total} - SL_{steric}(Argo) - SL_{mass} \]

Residual of the Sea level budget: 2005-2010

Sampling issue becomes important in the tropical ocean sector
Sampling issue in the Tropical Ocean

6-year trend: 2005-2010

No Argo data in the Indonesian Archipelago which seems to be a key region for global sea level trends.
Underestimating sea level changes in the Indonesian Archipelago affects the global mean by 20%.

Sampling issue in the Tropical Ocean

- Total sea level (AVISO)
  AVISO, but Ind. Archip. = NaN

- Steric sea level (10-1500m)
  2005-2010: 20%

- Steric sea level (10-1500m)
  2005-2010: 7%
$$SL_{\text{res}} = SL_{\text{total}} - SL_{\text{steric (Argo)}} - SL_{\text{mass}}$$

Residual of the Sea level budget: 2005-2010

- **Global Ocean:** 60°S-60°N
- **Tropical Ocean:** 30°S-30°N
- **Northern Ocean:** 30°N-60°N
\[ \text{SL}_{\text{res}} = \text{SL}_{\text{total}} - \text{SL}_{\text{steric(Argo)}} - \text{SL}_{\text{mass}} \]

Residual of the Sea level budget: 2005-2010

Problem in mapping of sparse data in the presence of large mesoscale variability?
Residual of the Sea level budget: 2005-2010

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

Residual of the Sea level budget: 2005-2010

Are the differences in the **Southern Ocean** due to:

⇒ Data processing issues?
⇒ Regional halosteric effects?
⇒ Deep ocean changes?

**Southern Ocean**: 30° S-60° S

**Global Ocean**: 60° S-60° N

**Tropical Ocean**: 30° S-30° N

(\( \text{GRACE} \))

\( 2.1 \pm 0.9 \text{ mm/yr} \) (\( \text{SL}_{\text{total}} - \text{SL}_{\text{steric}} \))

\( 0.9 \pm 0.6 \text{ mm/yr} \) (\( \text{SL}_{\text{total}} \))
Conclusions (‘Argo point of view’)

We could close the recent global ocean sea level budget, but only by respecting data processing issues showing that Argo global ocean indicators are robust for the 2005-2011 period.

The regional inter-comparison of the global observing systems allows

+ to monitor the quality of the global Argo estimation (systematic biases)
+ to retrieve important information on data processing and sampling issues
+ to obtain information on key regions for global ocean changes
+ to extract information on deep ocean changes? (time series still too short? Uncertainties of the observing systems still to large?)
+ to learn on the role of volume changes due to salinity variability at regional scale.