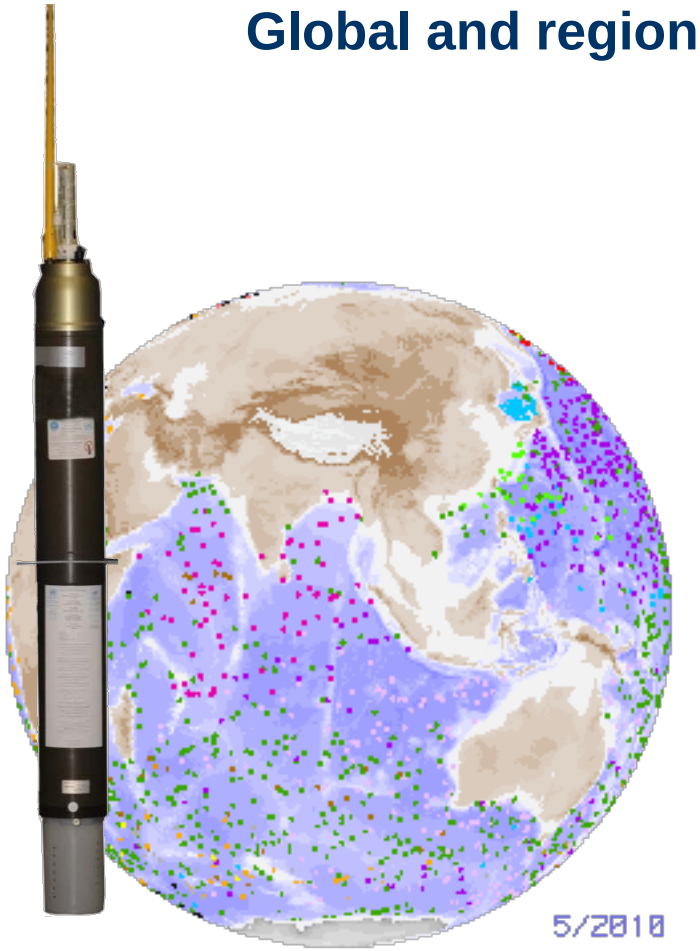
4th Euro-Argo science meeting, June 2013, Southampton, UK



Global and regional ocean climate indicators from the Argo observing system

Karina von Schuckmann

Collaborations:

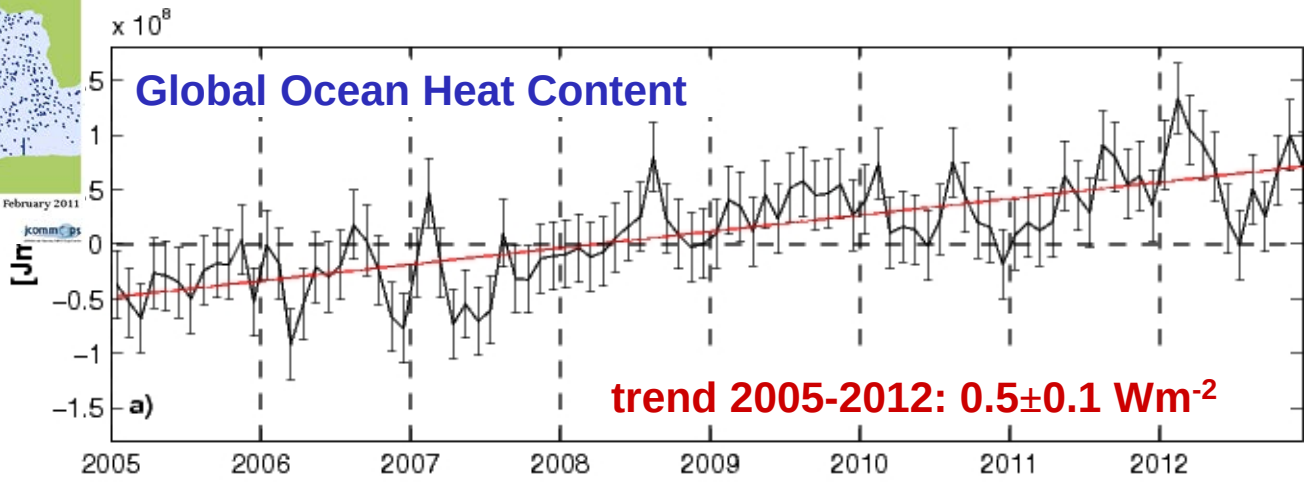
Pierre-Yves Le Traon, Cecile Cabanes

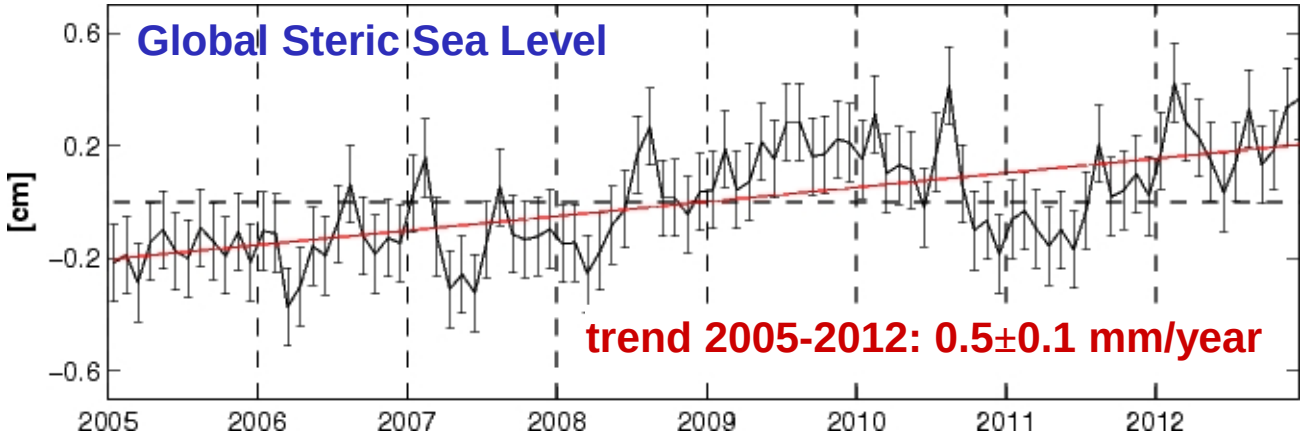
Jean-Baptiste Sallée, Don Chambers,
Fabienne Gaillard, Sabrina Speich, Mathieu Hamon

What has been observed so far ?

Argo sampling **early 2011**

Global Ocean Indicators from Argo: 2005-2012



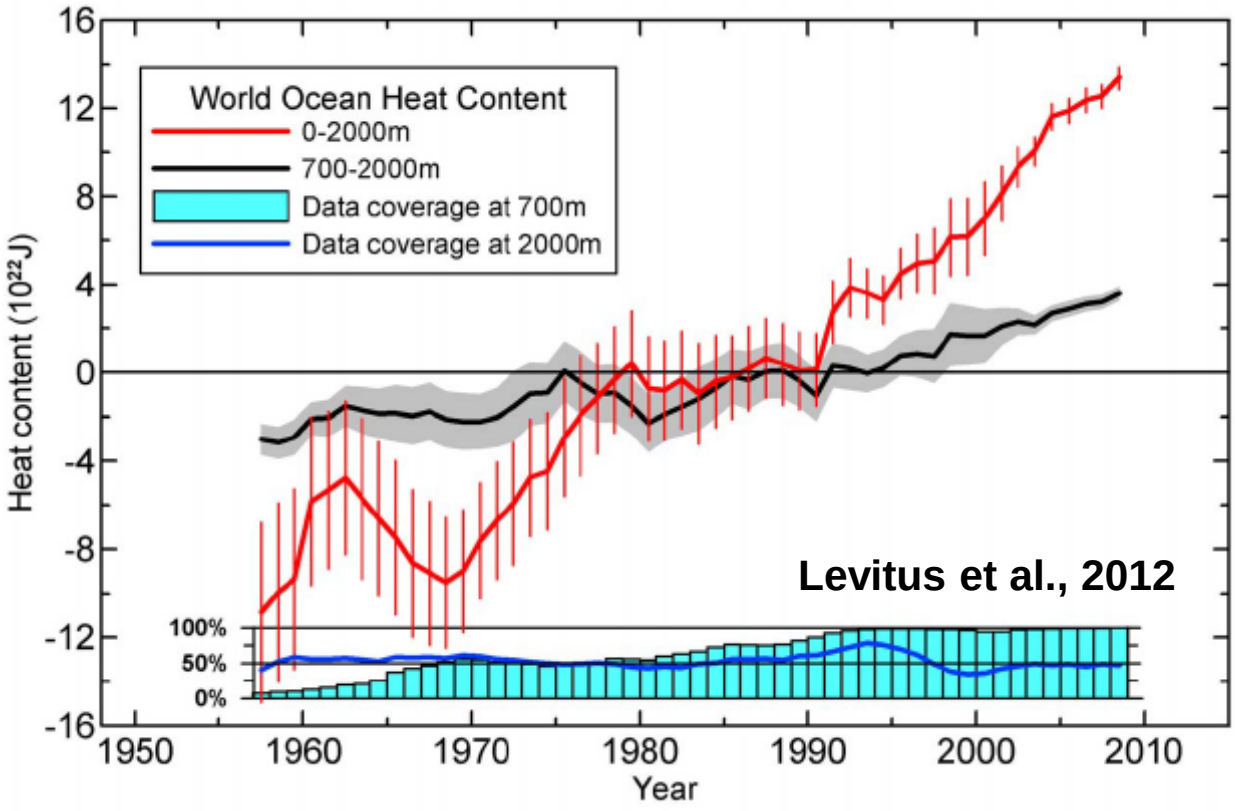


- **Box averaging method**
- **Data processing and climatology uncertainty estimations**

updated after von Schuckmann and Le Traon, 2011

What has been observed so far ?

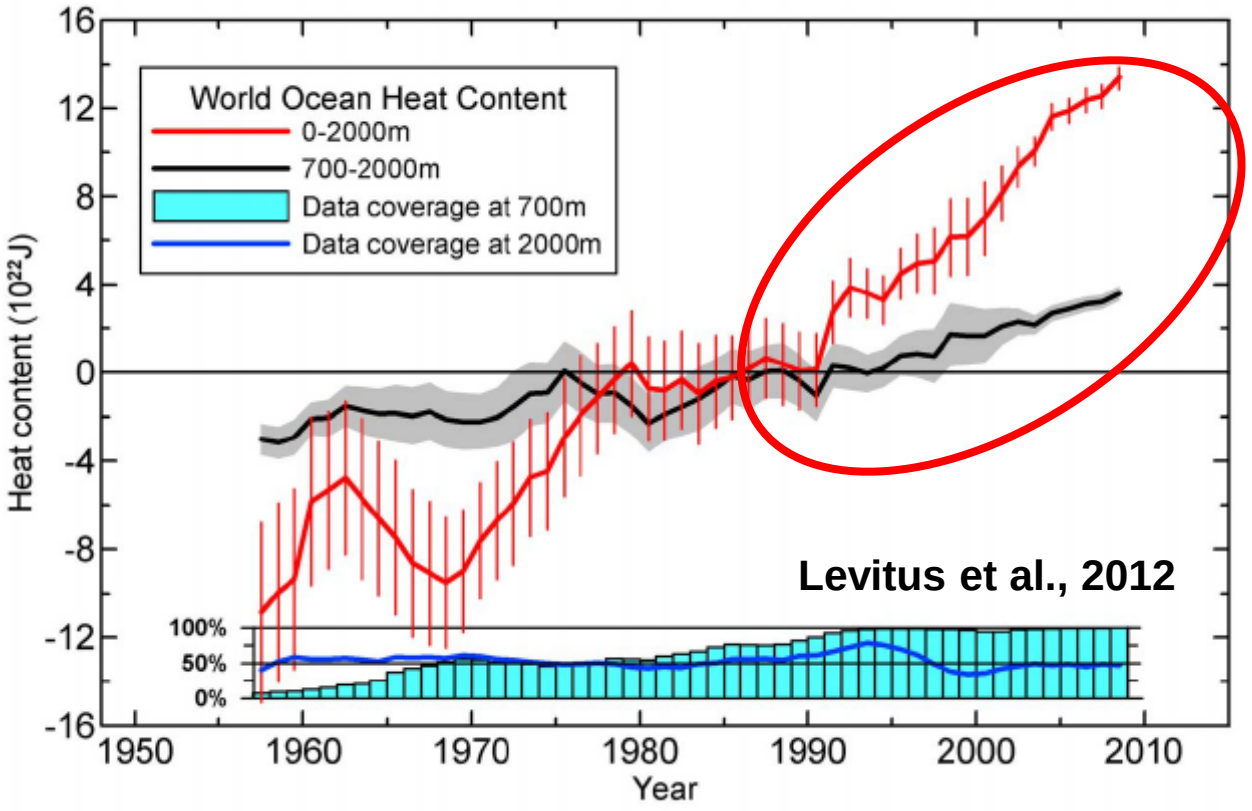
Upper ocean warming observed during the past forty years



Despite differences in measurement methods and analysis techniques, multiple studies show that there has been a multi-decadal increase in the heat content of both the upper and deep ocean regions (Abraham et al., 2013)

What has been observed so far ?

Upper ocean warming observed during the past forty years



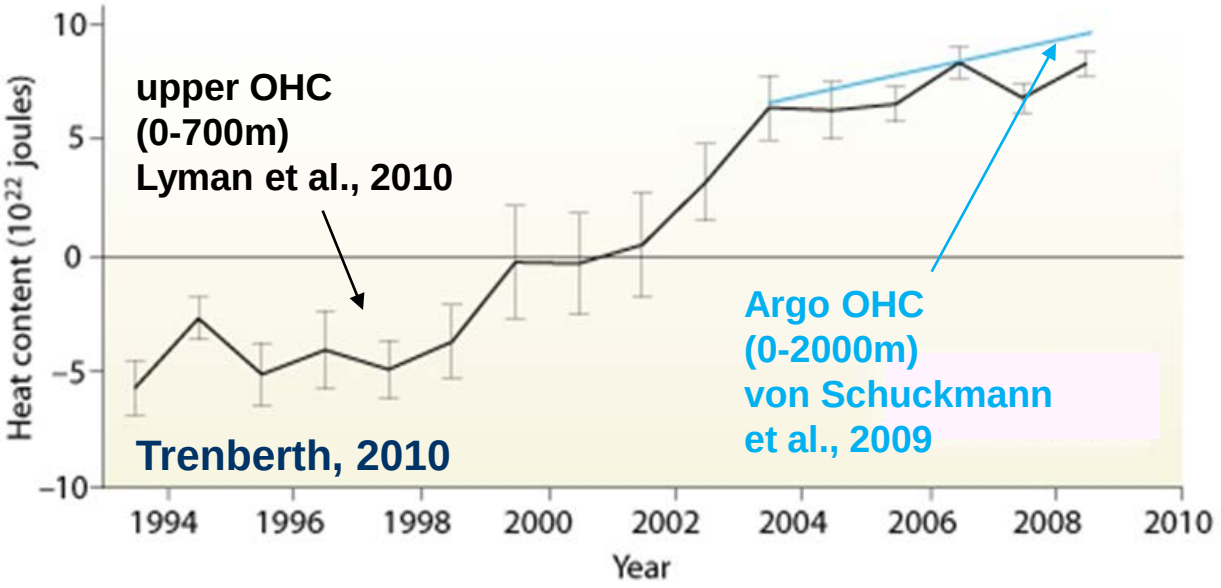
Despite differences in measurement methods and analysis techniques, multiple studies show that there has been a multi-decadal increase in the heat content of both the upper and deep ocean regions (Abraham et al., 2013)

Deep ocean warming is observed since the 1990s

What has been observed so far ?

Deep ocean warming

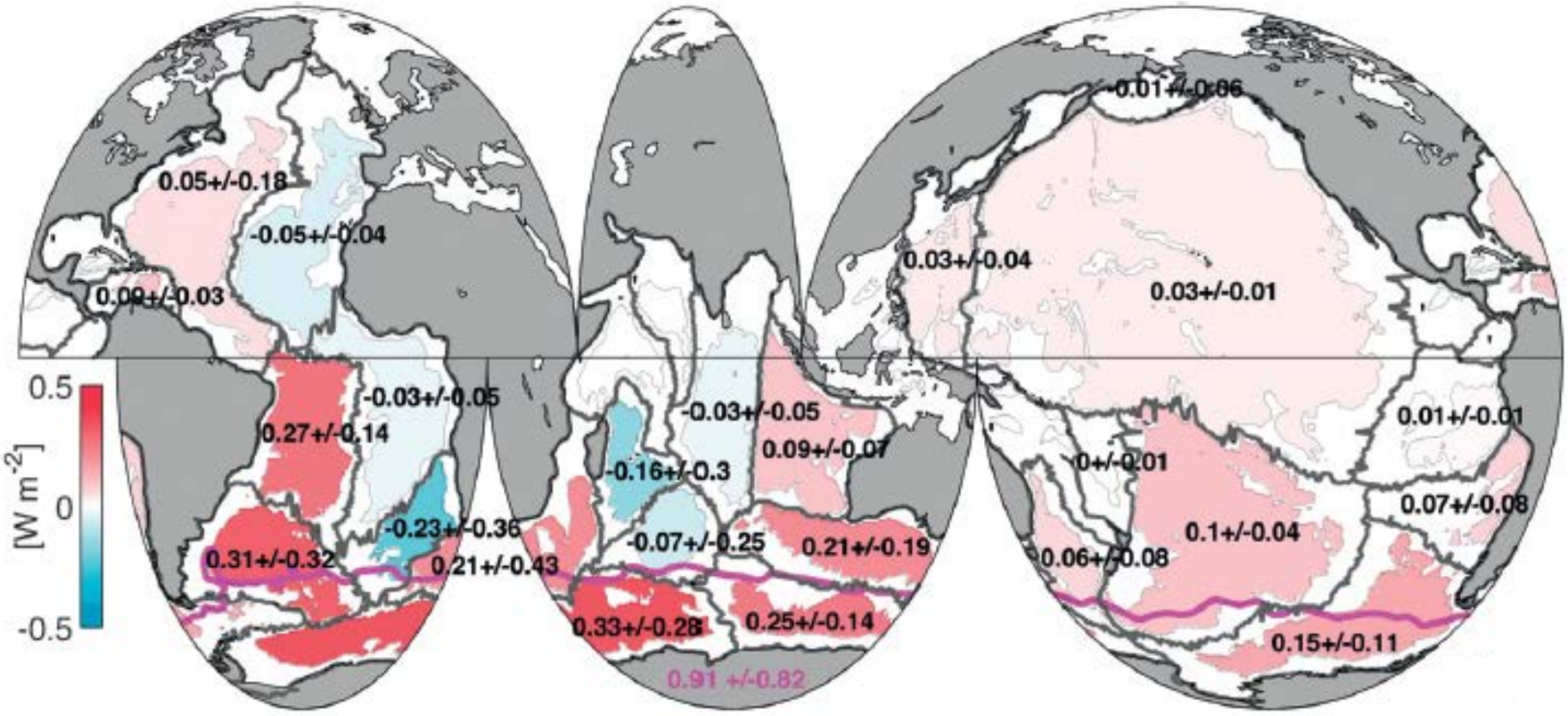
Important results from Argo global ocean observations



The differences between upper OHC (0-700m) and Argo OHC (0-2000m) after 2003 suggest that there has been significant warming below 700 m, and that rates of warming have slowed in recent years.

What has been observed so far ?

Deep ocean warming



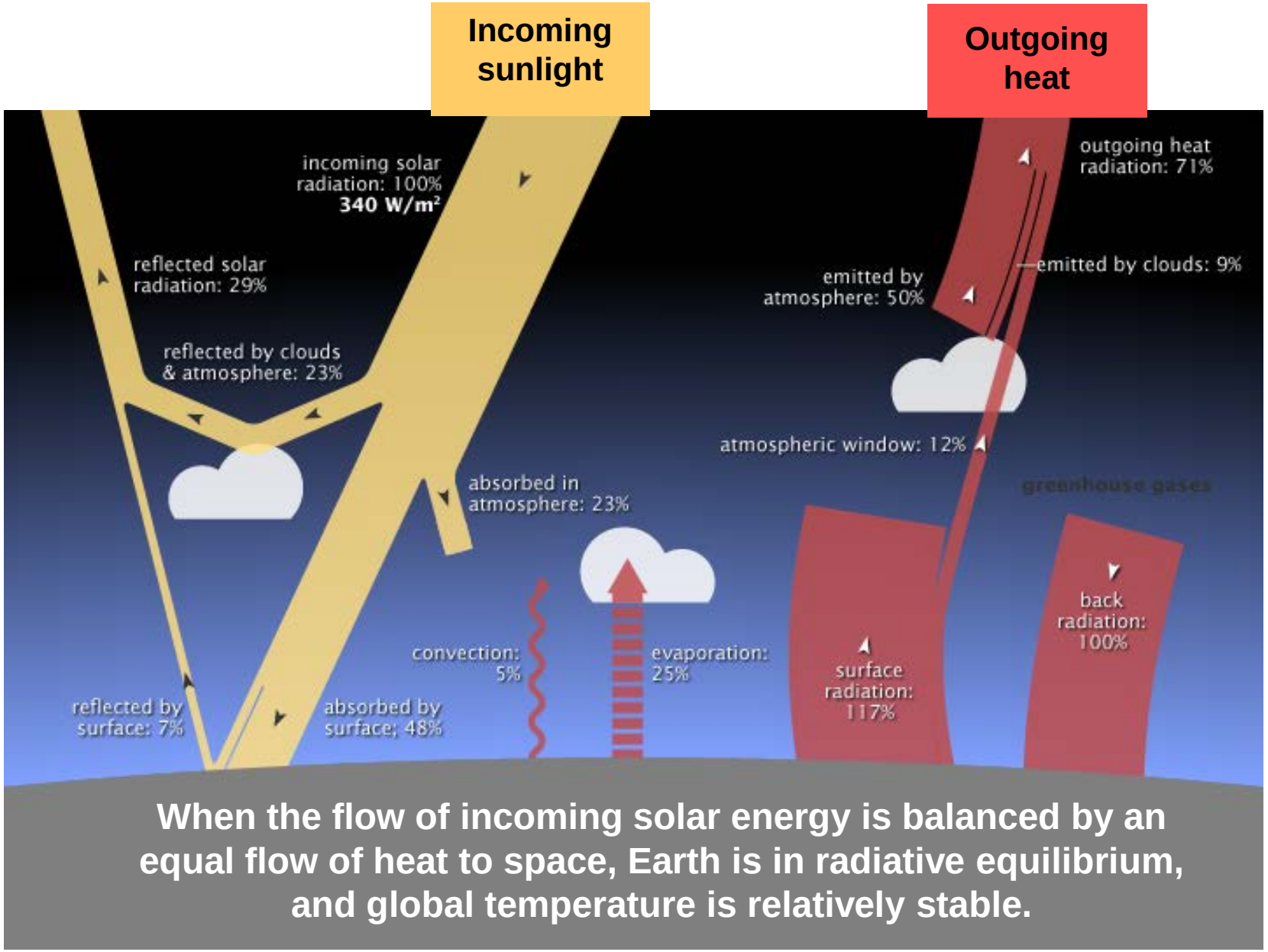
Purkey and Johnson, 2010

Mean local heat fluxes through 4000m implied by abyssal warming below 4000m depth from the1990s to the 2000s (95% confidence interval) as observed from hydrographic sections

What have we learned so far on the role of the global ocean in climate variability, in particular from Argo data?

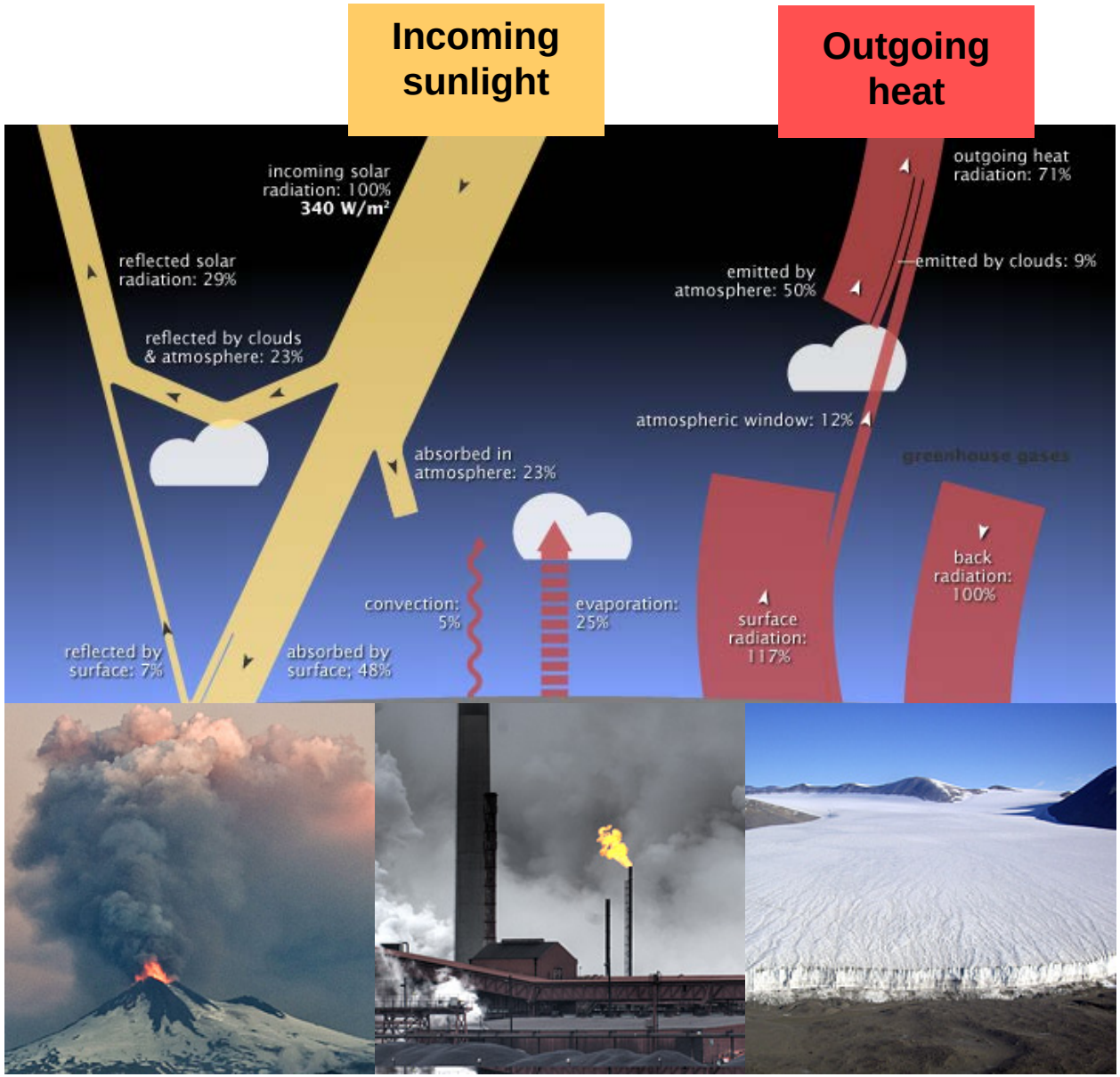
- Earth Energy Budget
- Sea Level Budget
- Decadal changes of Earth's surface temperature
- Improvement of GOIs through uncertainty and sensitivity studies

Earth energy budget



When the flow of incoming solar energy is balanced by an equal flow of heat to space, Earth is in radiative equilibrium, and global temperature is relatively stable.

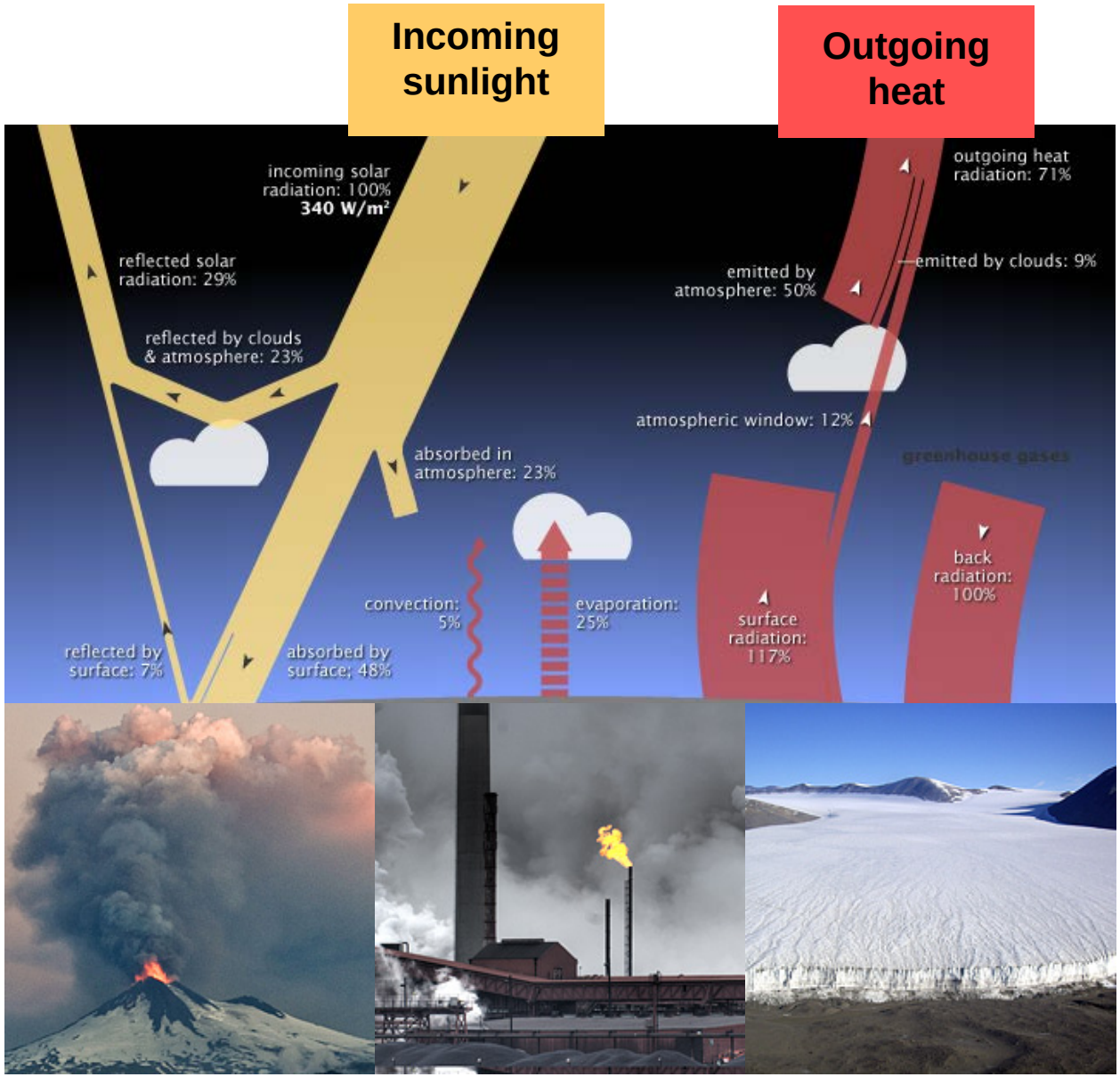
Earth energy budget



Anything that increases or decreases the amount of incoming or outgoing energy disturbs Earth's radiative equilibrium; global temperatures rise or fall in response.

➔ These destabilizing influences are called climate forcings.

Earth energy budget



Natural climate forcings

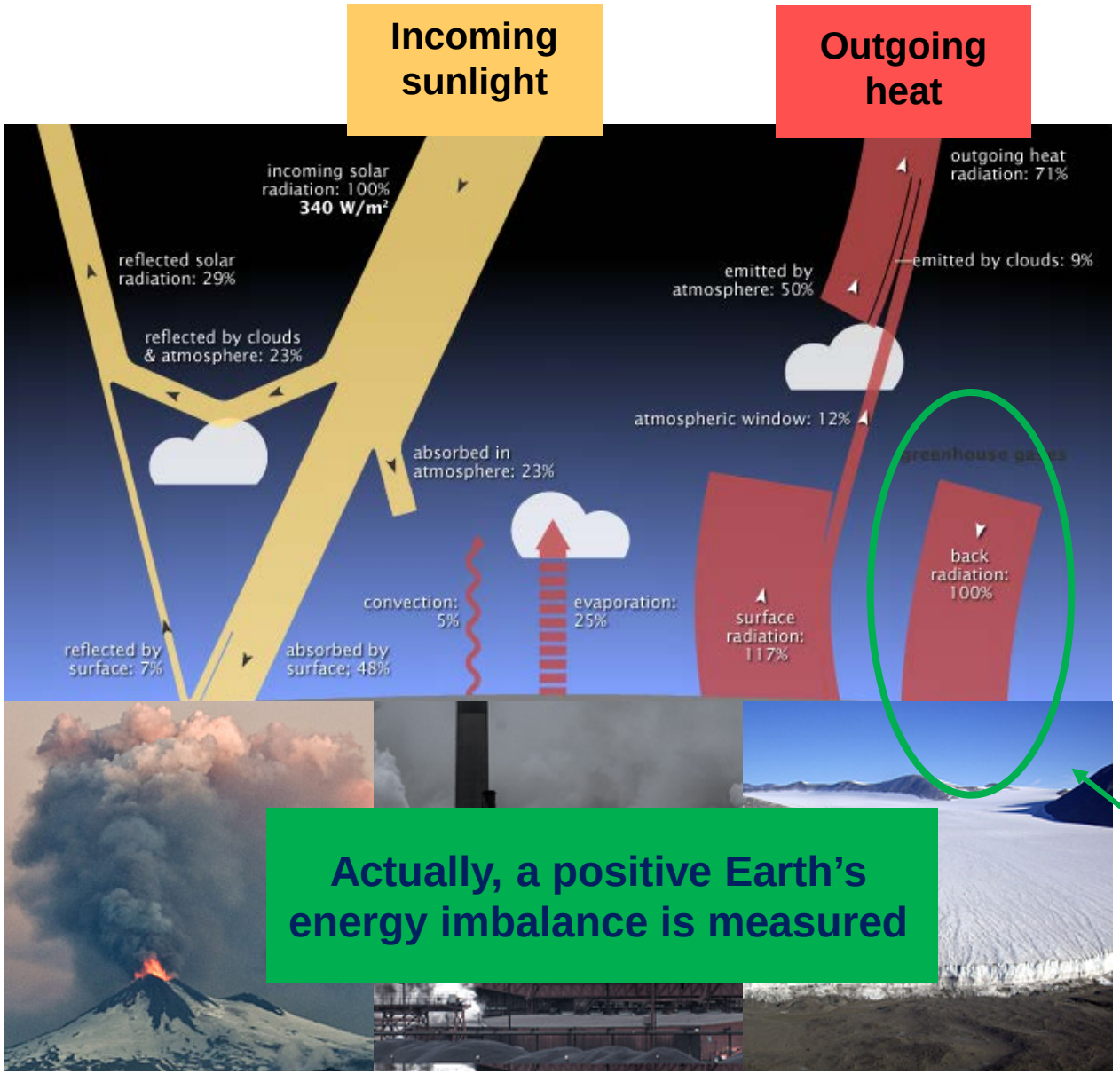
- Changes in the Sun's brightness
- Milankovitch cycles
- Volcanic eruptions

Manmade forcings

- Particle pollution (aerosols)
- Deforestation
- Rising concentration of atmospheric carbon dioxide and other greenhouse gases,

,

Earth energy budget



Natural climate forcings

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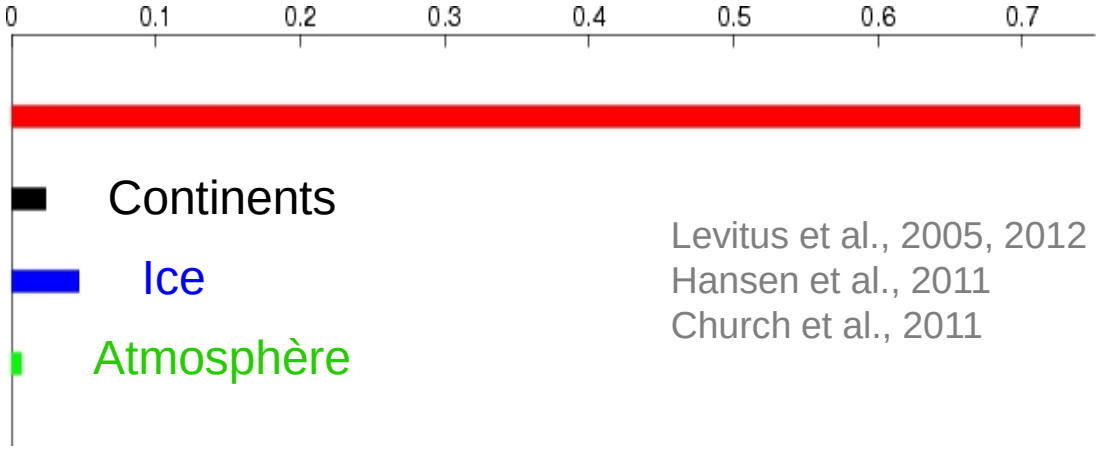
Manmade forcings

- Particle pollution (aerosols)
- Deforestation
- **Rising concentration of atmospheric carbon dioxide and other greenhouse gases**

,

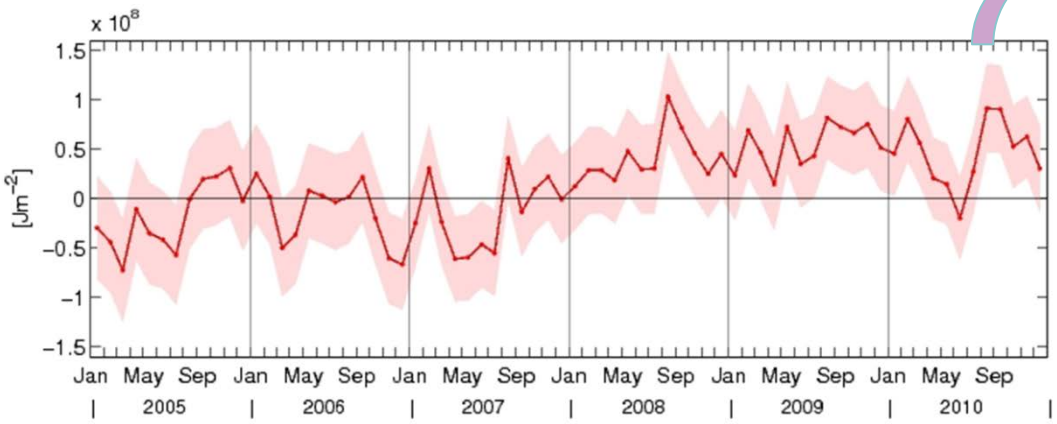
Earth energy budget

Warming of the ocean accounts for more than 90% of the extra energy stored by Earth

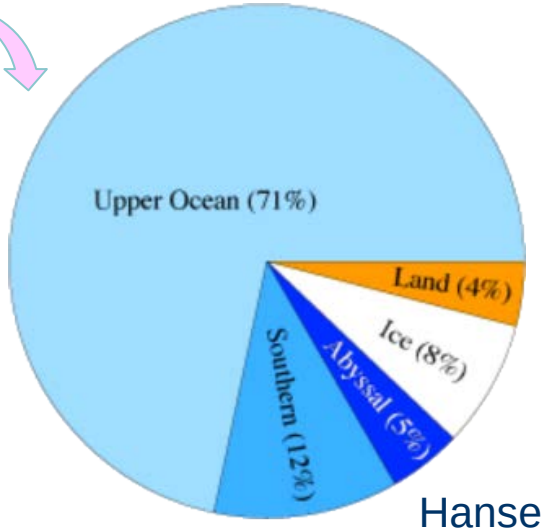


Levitus et al., 2005, 2012
Hansen et al., 2011
Church et al., 2011

Planetary energy imbalance 2005-2010
$0.58 \pm 0.15 Wm^{-2}$



von Schuckmann and Le Traon, 2011

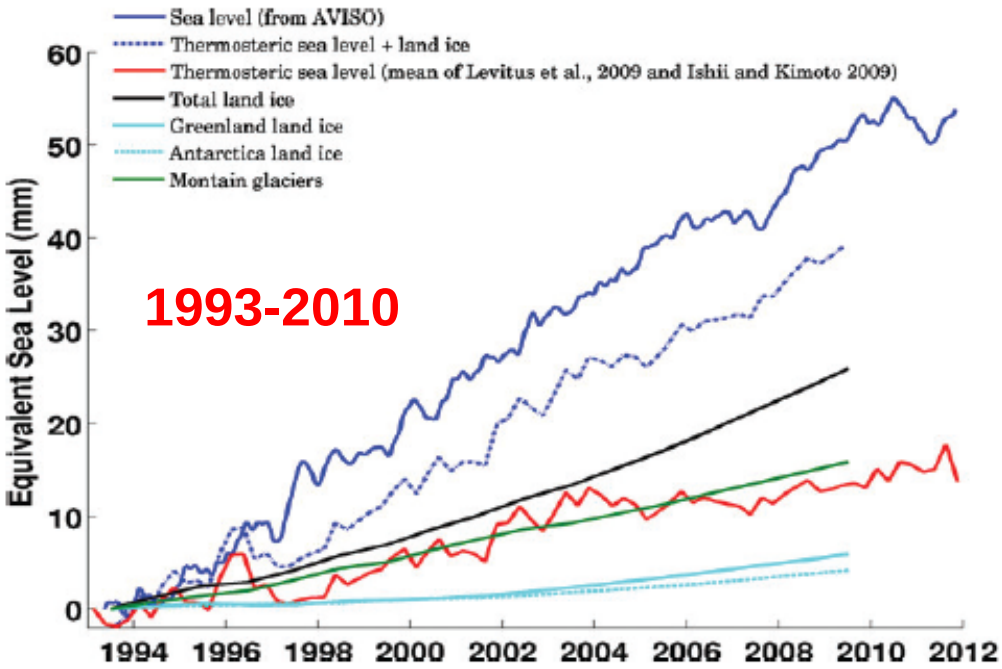


Hansen et al., 2011

Global Mean Sea Level

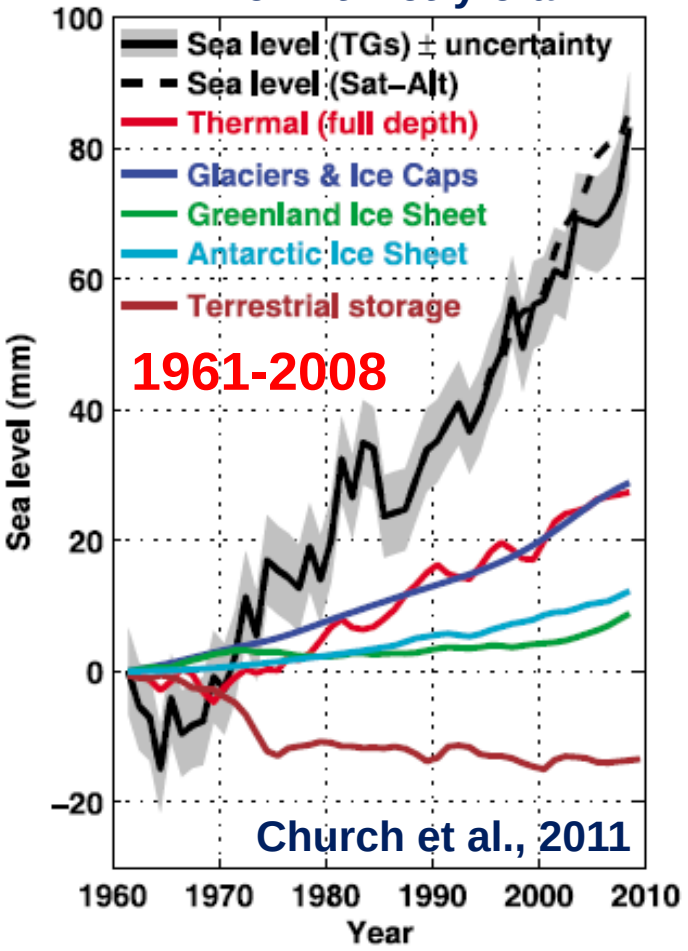
The main factors causing current **global mean sea level rise (SL_{total})** are **thermal expansion (SL_{steric})** of sea waters, **land ice loss** and **fresh water mass exchange (SL_{mass})** between oceans and land water reservoirs.

Altimetry era



Meyssignac and Cazenave, 2012

Pre- Altimetry era



Church et al., 2011

The recent trends of these contributions most likely result from global climate change induced by anthropogenic greenhouse gases emissions.

Global Mean Sea Level

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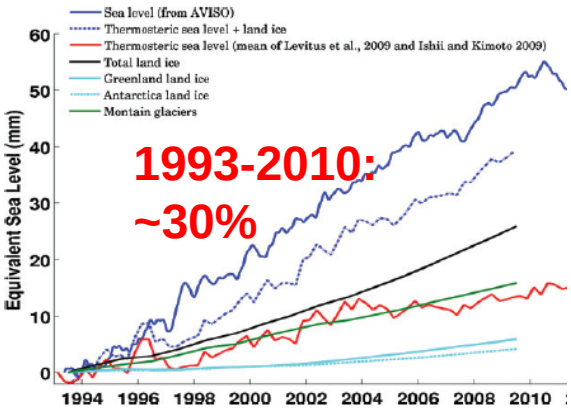

Meyssignac and Cazenave, 2012

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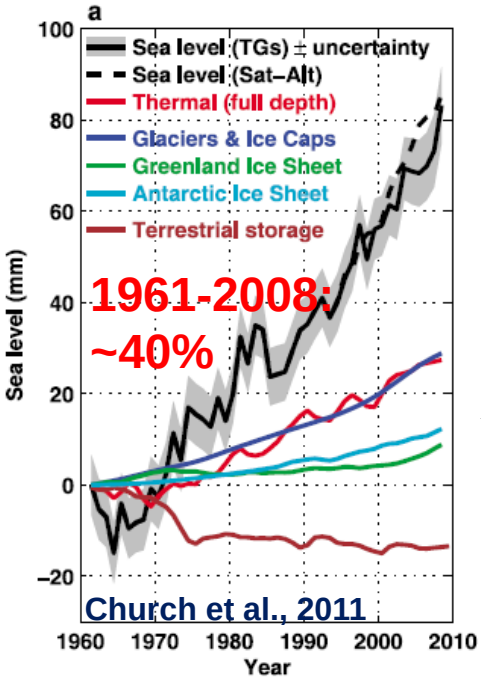
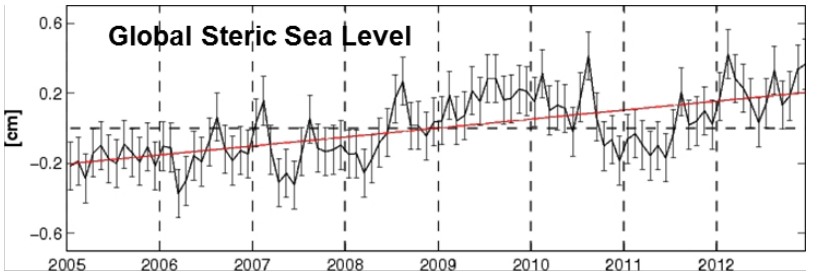
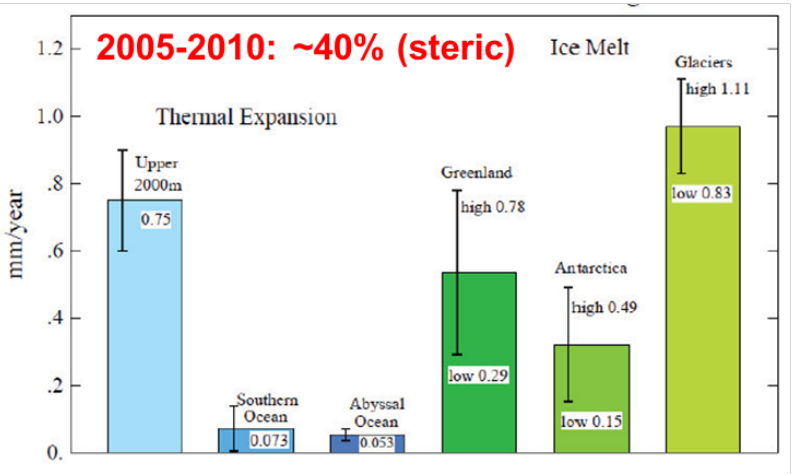


Argo era

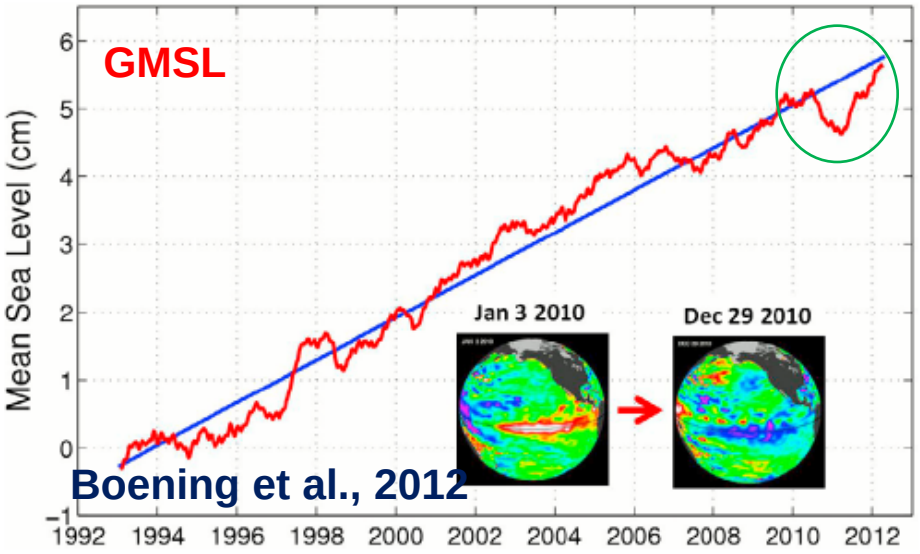




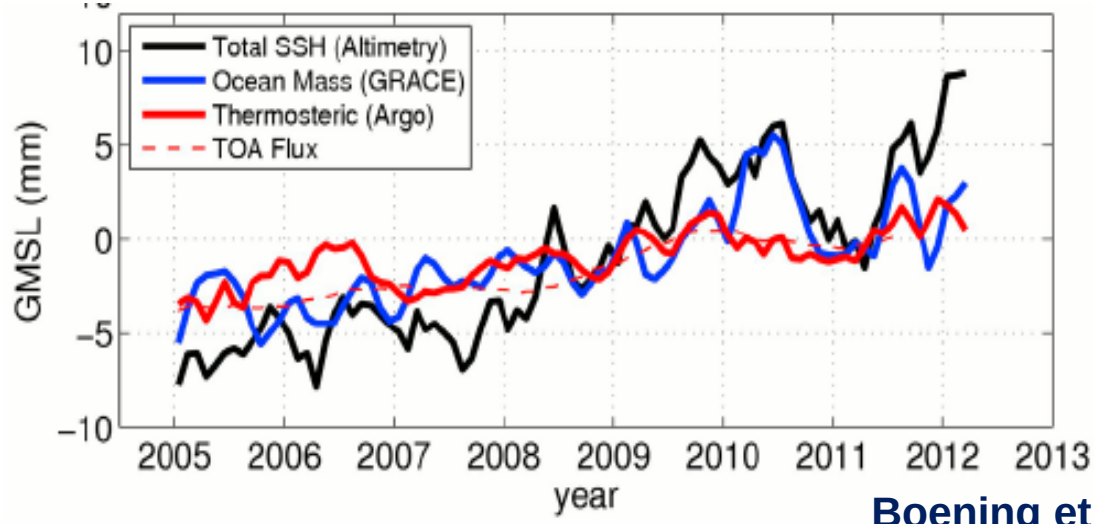
Thermal expansion accounts for 30-40% of total global sea level rise

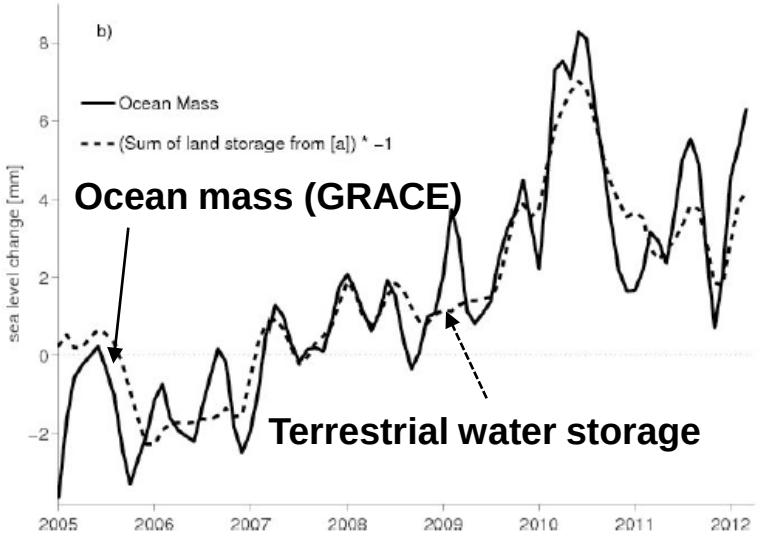
Global Mean Sea Level

Interannual to decadal GMSL variability



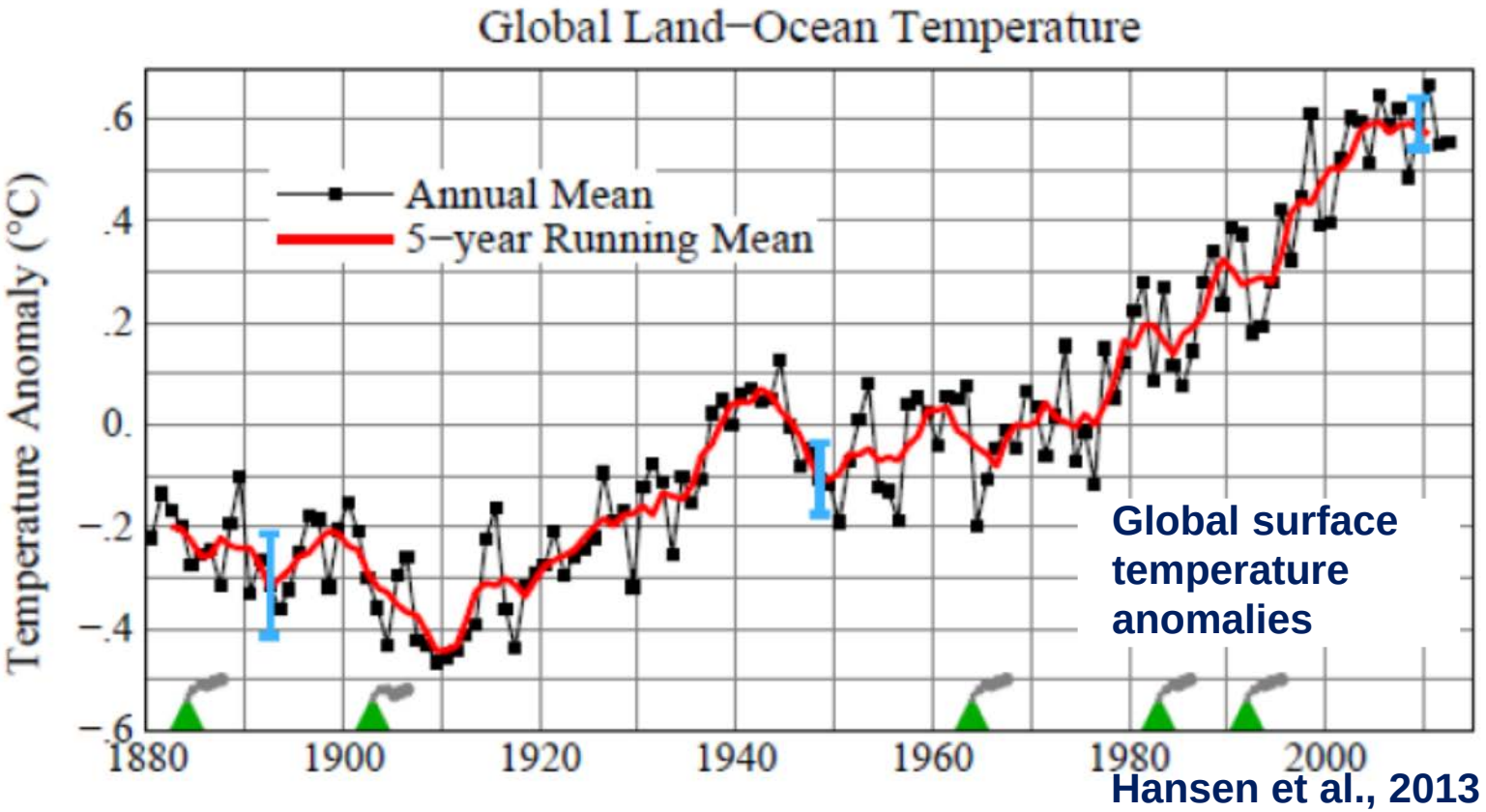
Decline in the level rise coincides with an equivalent increase in terrestrial water storage which is closely related to the transition from El Niño to La Niña conditions, which affected precipitation patterns world wide (Llovel et al., 2010, Boening et al., 2012)





Boening et al., 2012

Decadal changes of Earth's surface temperature

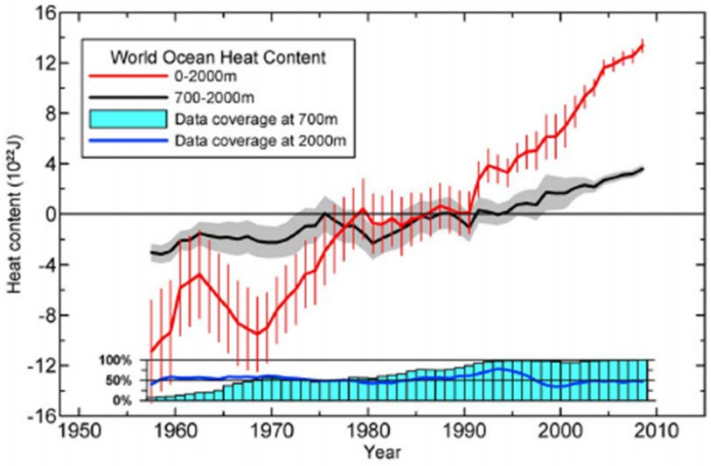


The 5-year mean global temperature has been flat for a decade due to a combination of natural variability and a slowdown in the growth rate of the net climate forcing.

What is the role of the Global Ocean?

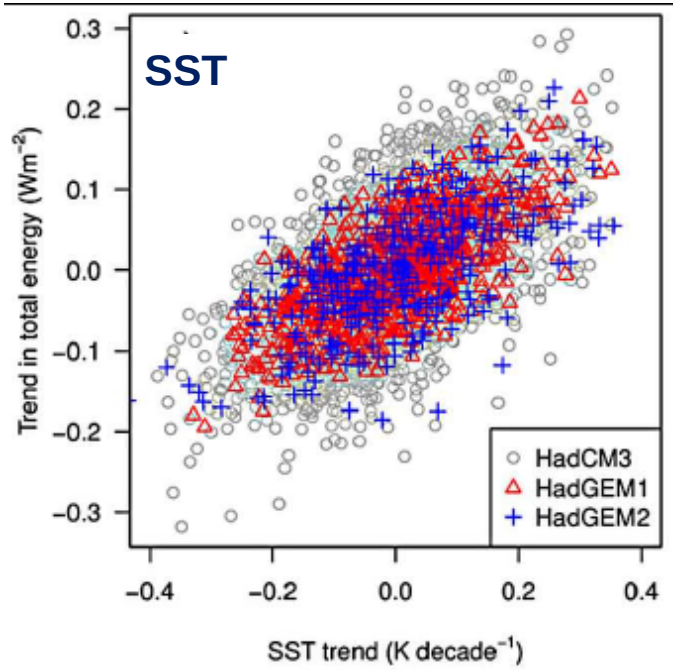
Decadal changes of Earth's surface temperature

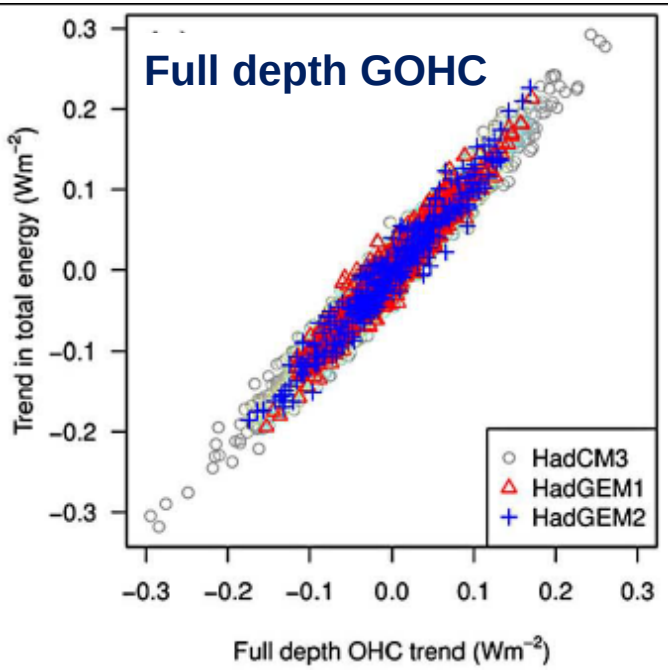
The role of deep ocean warming



Levitus et al., 2012

Regression of linear trends of total Earth energy to SST and full depth GOHC trends

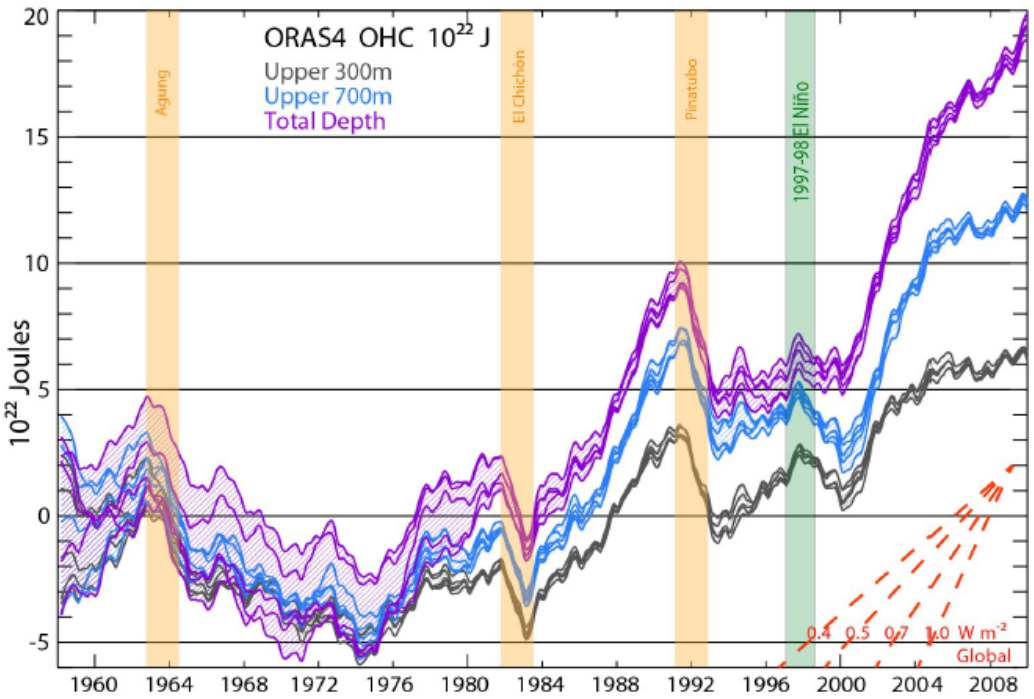




Palmer et al., 2011

Decadal changes of Earth's surface temperature

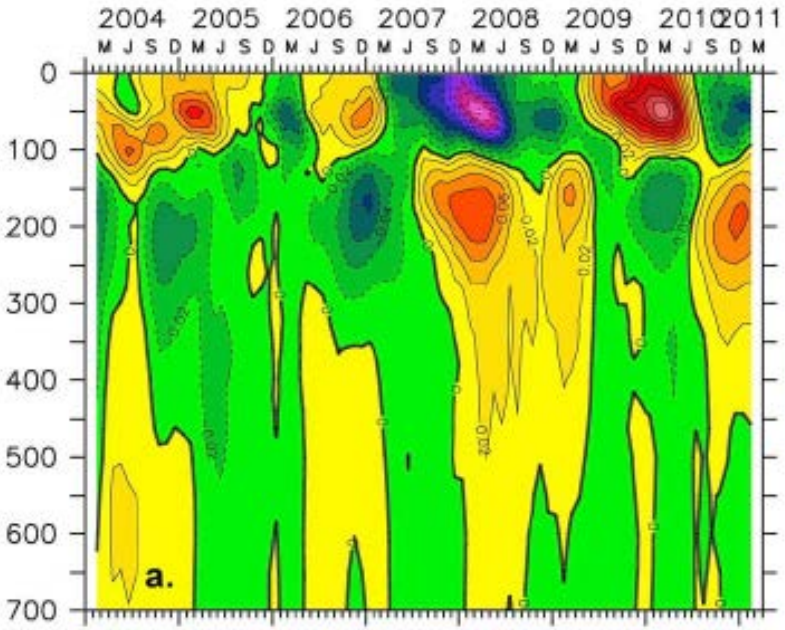
The role of deep ocean warming



Balmaseda et al., 2012

Volcanic eruptions and El Niño events are identified as sharp cooling events punctuating a long-term ocean warming trend, while heating continues during the recent upper-ocean-warming hiatus, but the heat is absorbed in the deeper ocean.

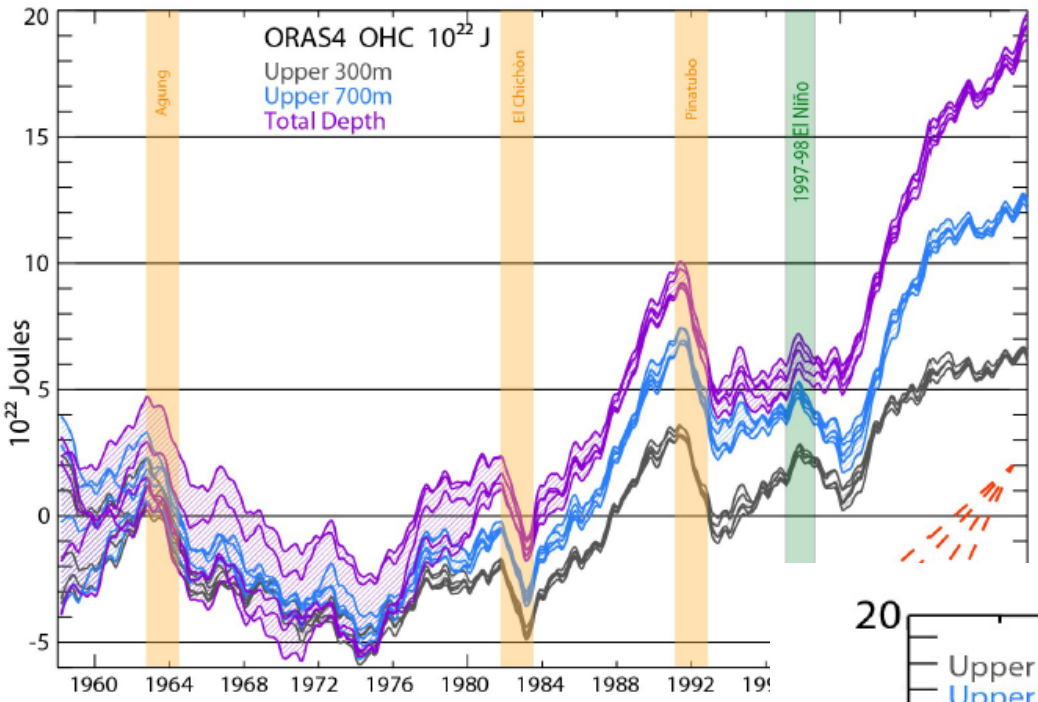
The ENSO-related vertical redistribution of globally-averaged heat content between surface and subsurface layers is due primarily to changes in the east-west tilting of the equatorial Pacific thermocline.



Roemmich and Gilson, 2011

Decadal changes of Earth's surface temperature

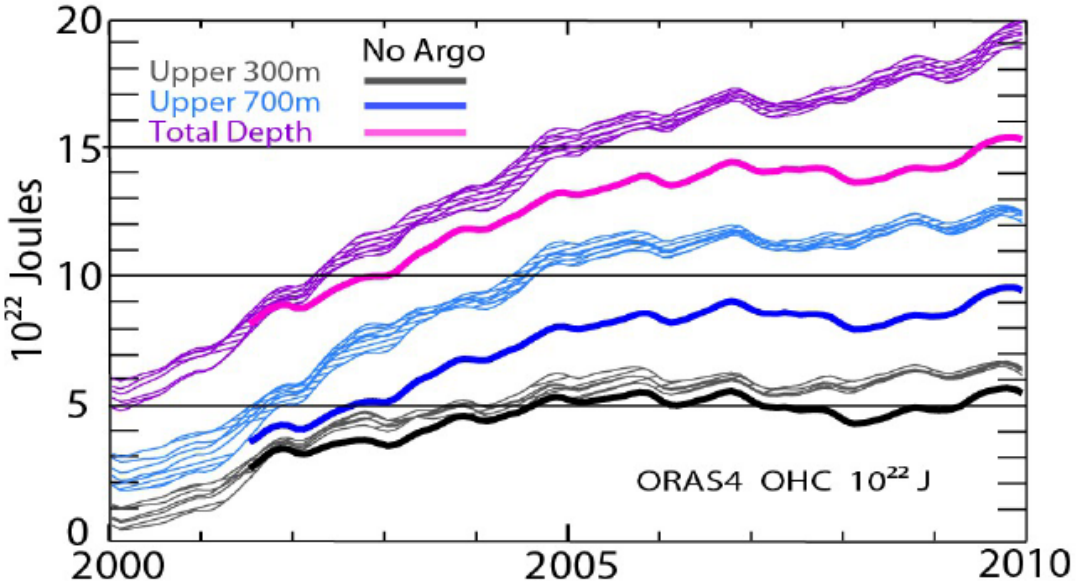
The role of deep ocean warming



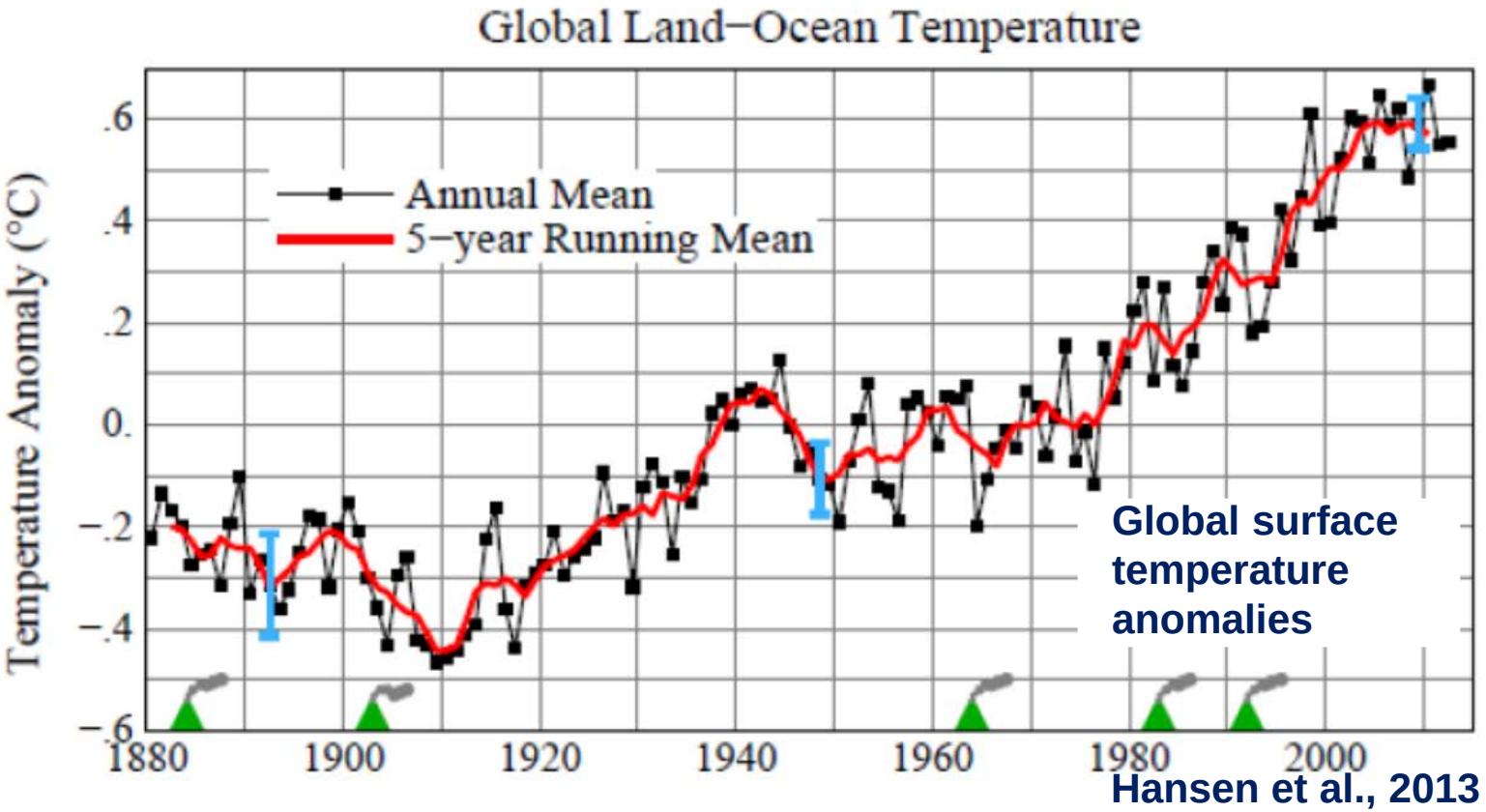
In the last decade, about 30% of the warming has occurred below 700 m, contributing significantly to an acceleration of the warming trend.

Balmaseda et al., 2012

The warming below 700 m remains even when the Argo observing system is withdrawn although the trends are reduced.



Decadal changes of Earth's surface temperature

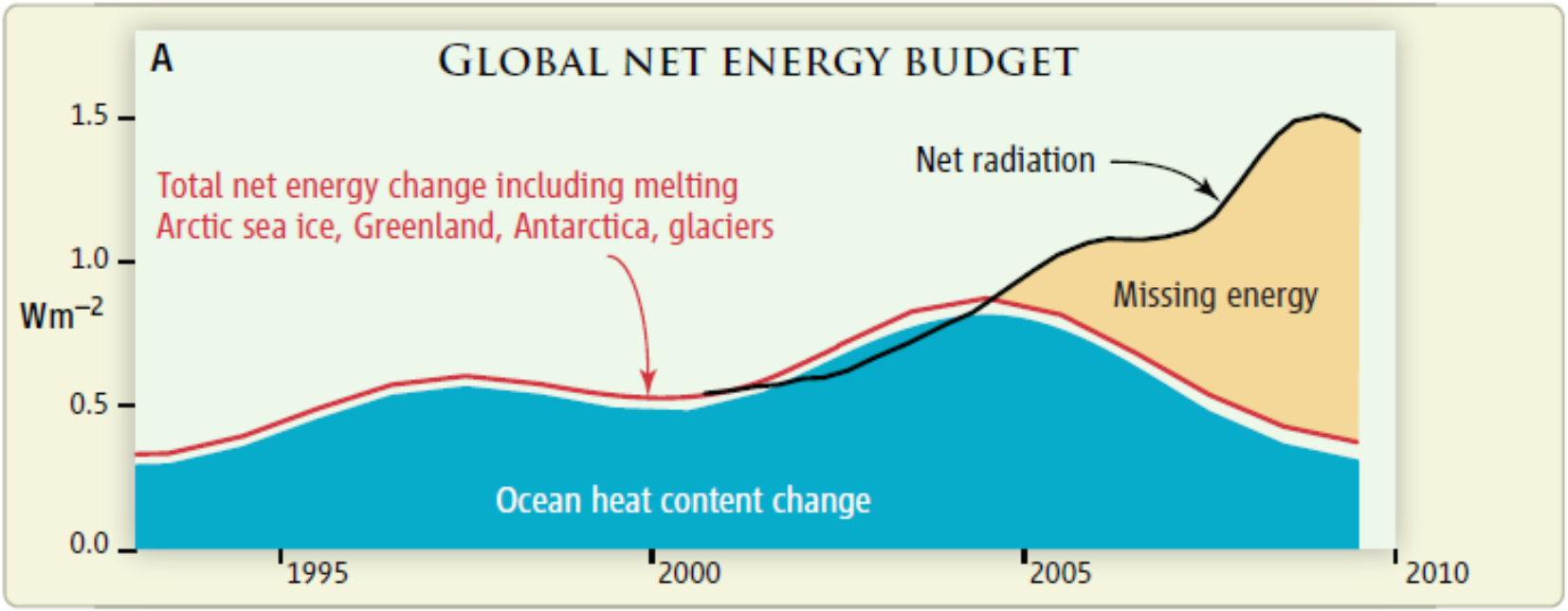


The 5-year mean global temperature has been flat for a decade due to a combination of natural variability and a slowdown in the growth rate of the net climate forcing.

What is the role of the Global Ocean? ➔ To confirm the role of deep ocean changes, continuous measurements are needed.

Improvement of GOIs through uncertainty and sensitivity studies

Estimated rates of change of global energy: **« Missing Energy «**

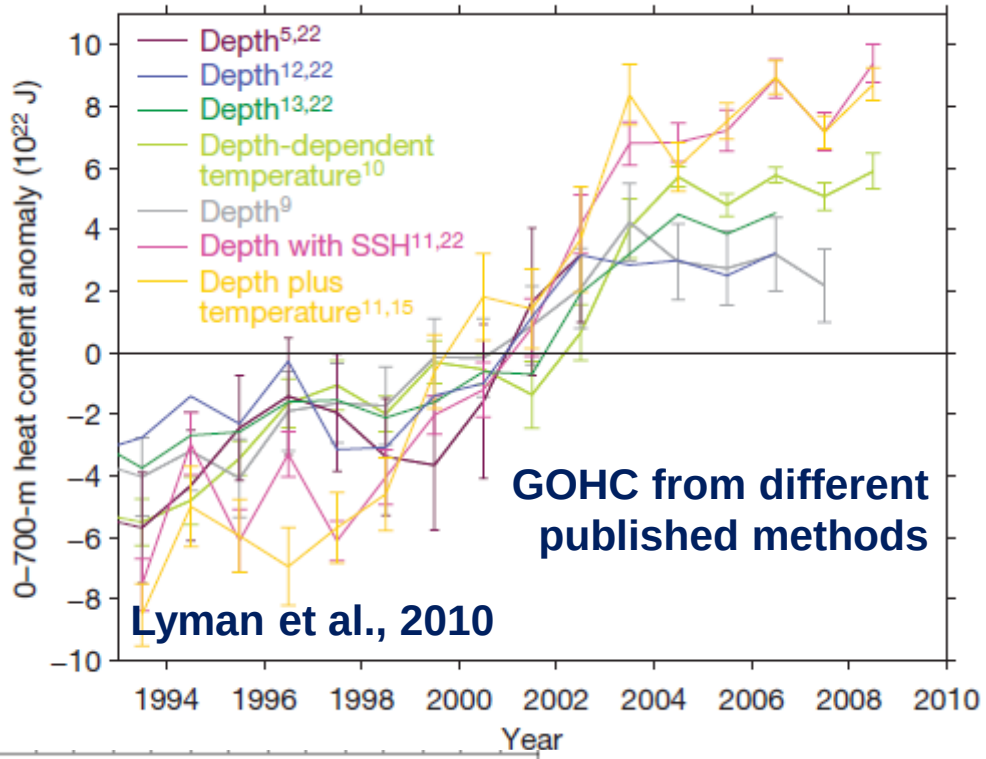


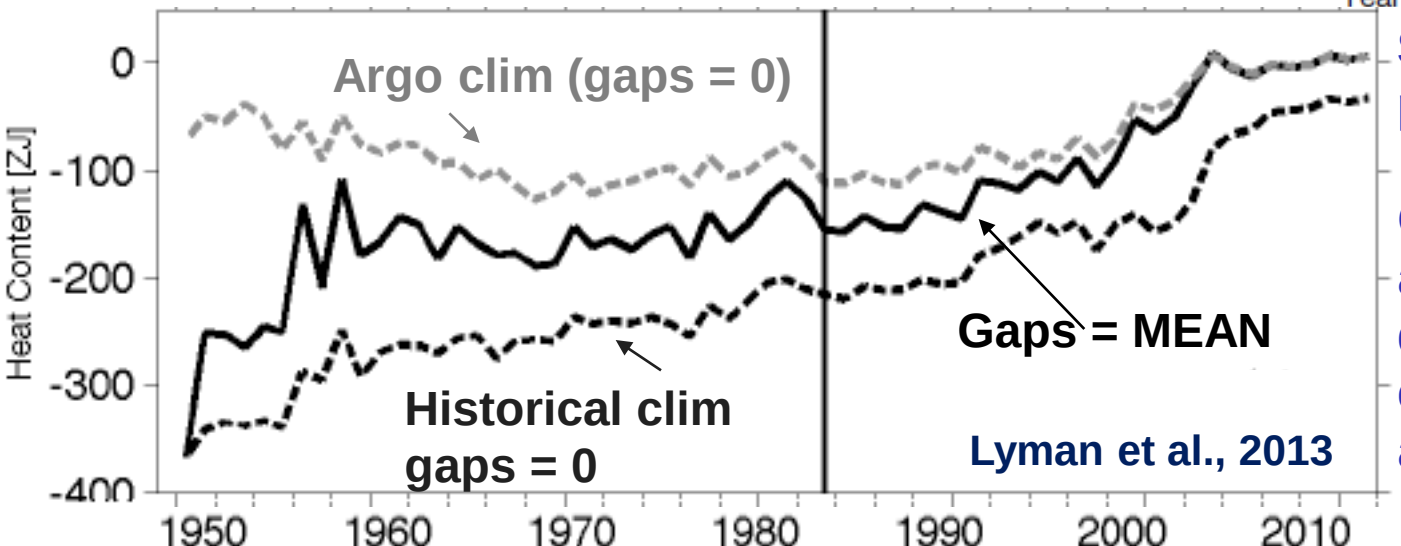
Trenberth and Fasullo, 2010

The key purpose of this paper was to challenge the different communities to work on these inconstistencies.

Improvement of GOIs through uncertainty and sensitivity studies

The majority of the Earth's total energy uptake during recent decades has occurred in the upper ocean, but the various underlying uncertainties in ocean warming are unclear, limiting our ability to assess closure of sea-level budgets, the global radiation imbalance and climate models.



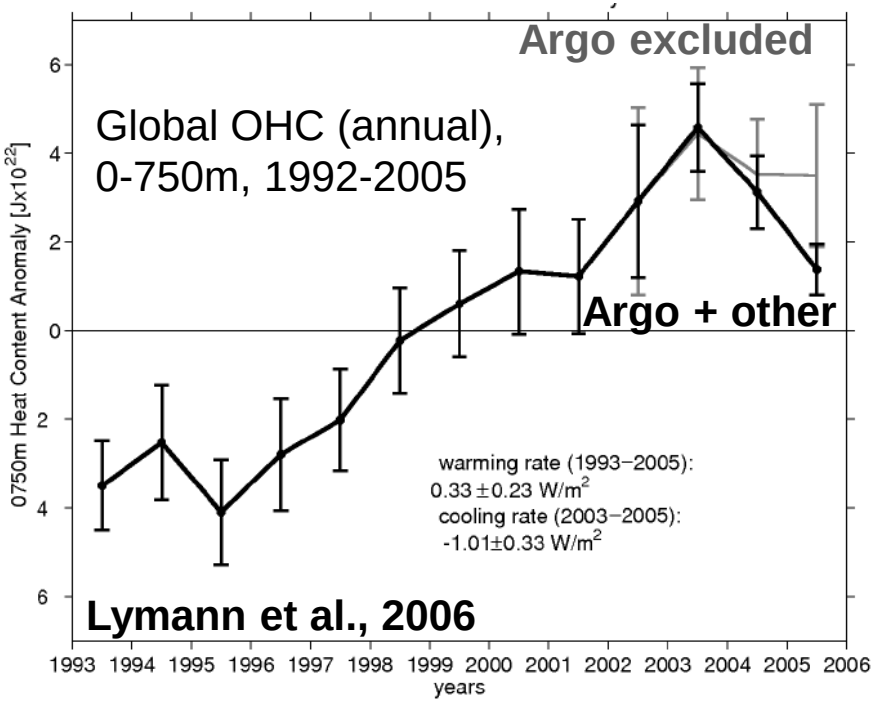


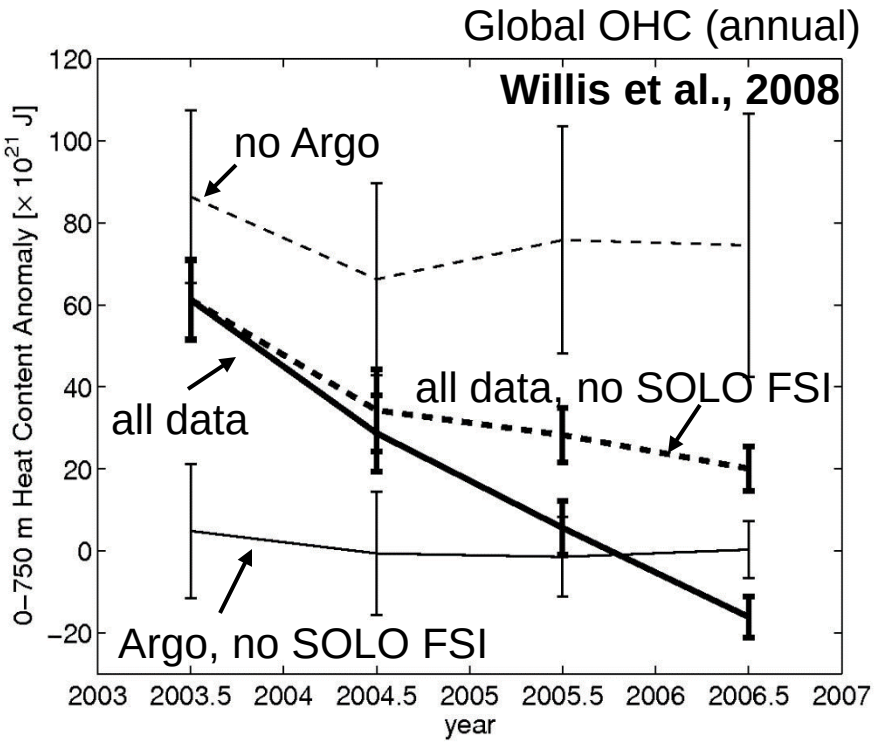
Sensitivity to data processing issues:

GOHC estimations are strongly dependend on hoice of CLIM when gaps are filled with zeros.

Improvement of GOIs through uncertainty and sensitivity studies

Argo: Sensitivity of systematic biases on GOI estimations

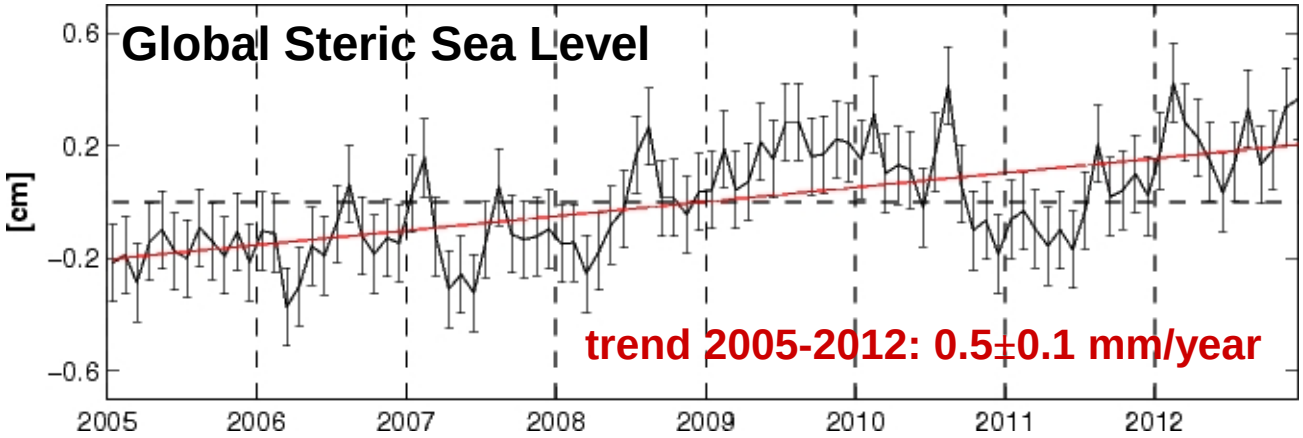




Problem of detection: large coherent signal, difficult to detect with regional quality control procedures

Significant effect on observed climate indicators (see also Barker et al., 2011)

Improvement of GOIs through uncertainty and sensitivity studies



updated after von Schuckmann and Le Traon, 2011

Monitoring ocean heat content from the current generation of global ocean observing systems

$$SL_{steric}(Argo) + SL_{res} = SL_{total} - SL_{mass}$$

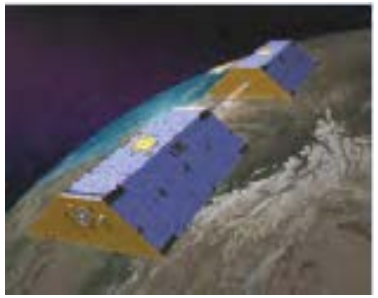
Improvement of GOIs through uncertainty and sensitivity studies

$$SL_{steric}(Argo) + SL_{res} = SL_{total} - SL_{mass}$$

Argo: 2000-2012

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

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

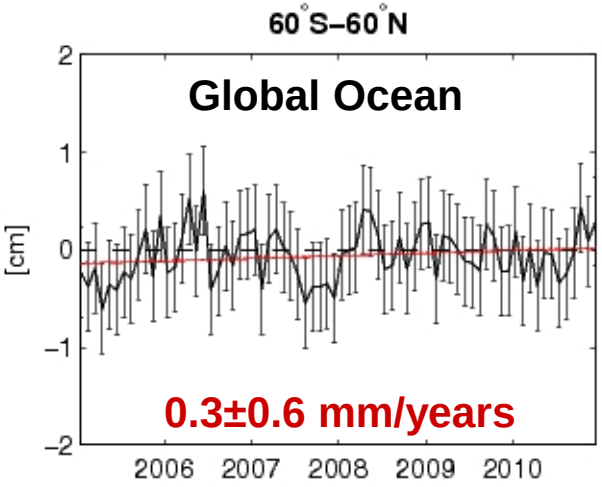
Averaged DM gridded product, AVISO

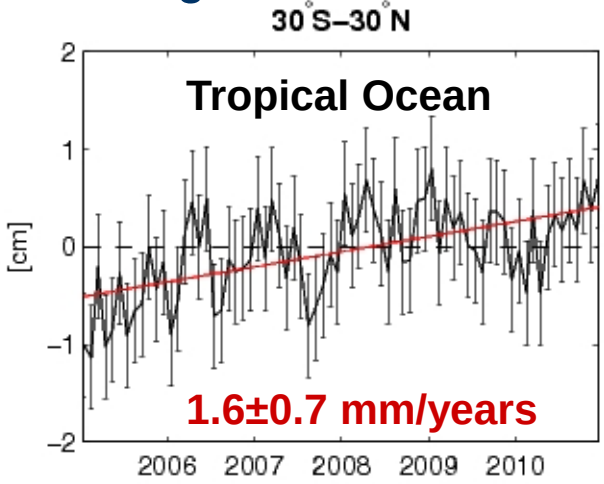
Chambers and Schröter, 2011

$SL_{res} = SL_{total} - SL_{steric}(Argo) - SL_{mass}$

Residual of the Sea level budget: 2005-2010

Altimeter: full grid





$SL_{res} = SL_{total} - SL_{steric}(Argo) - SL_{mass}$

Residual of the Sea level budget: 2005-2010

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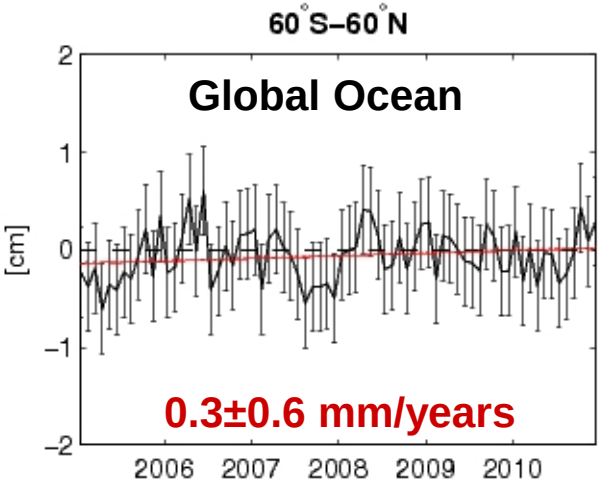
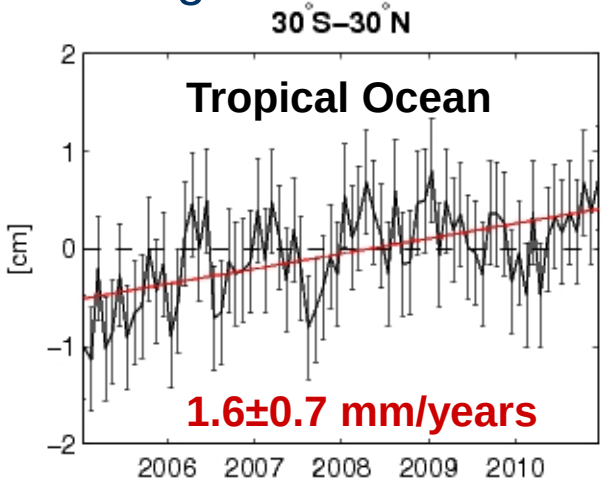
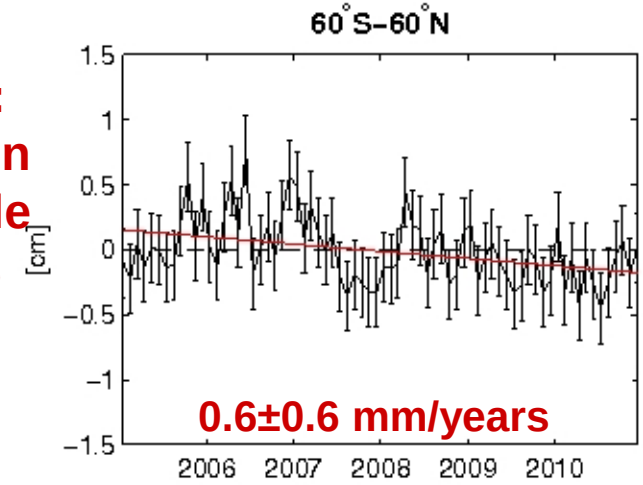
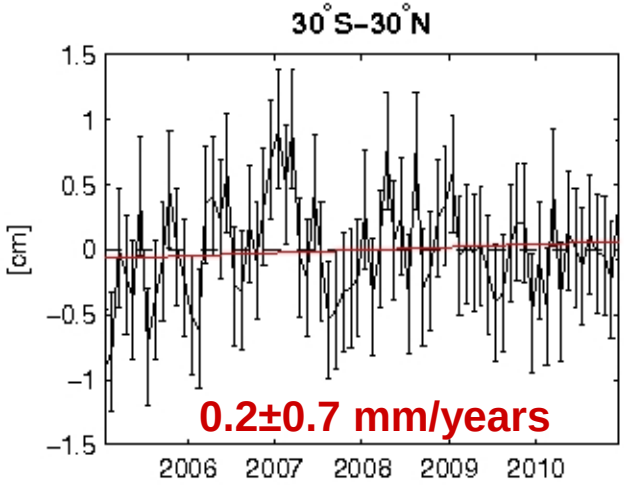




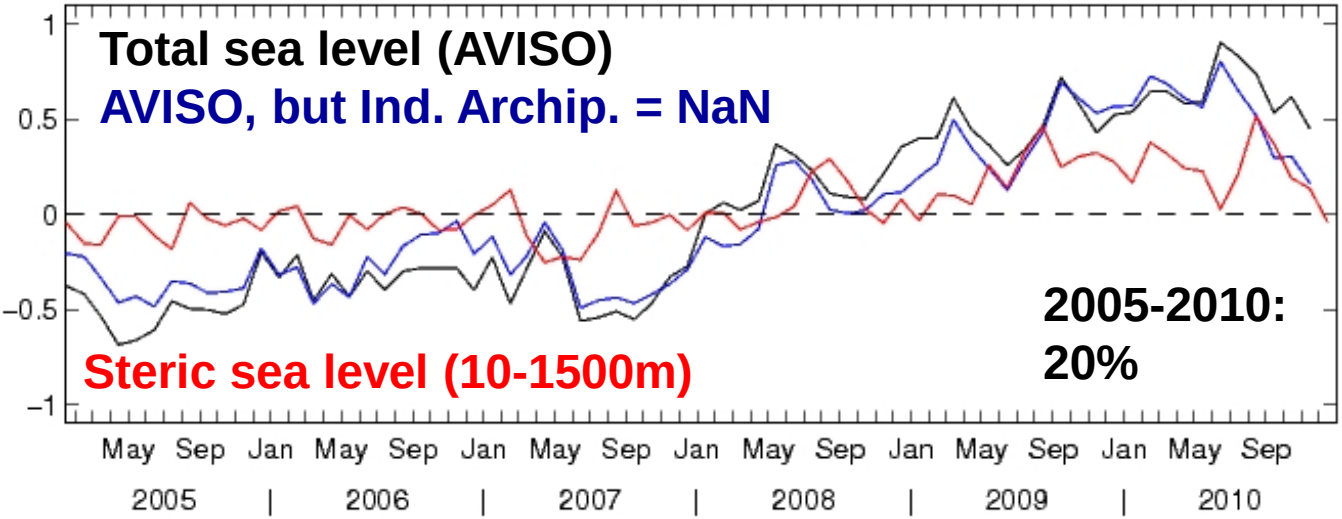
Altimeter: Sampled on Argo profile positions ➔ Argo sampling issue

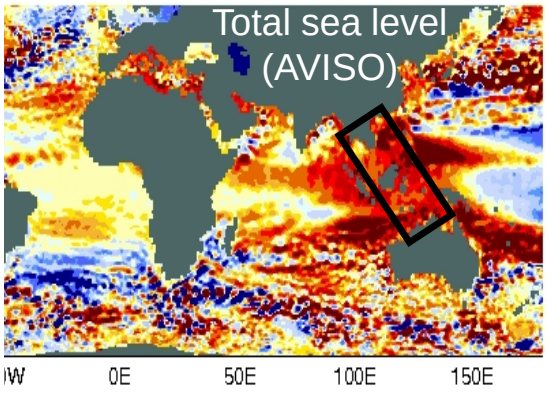


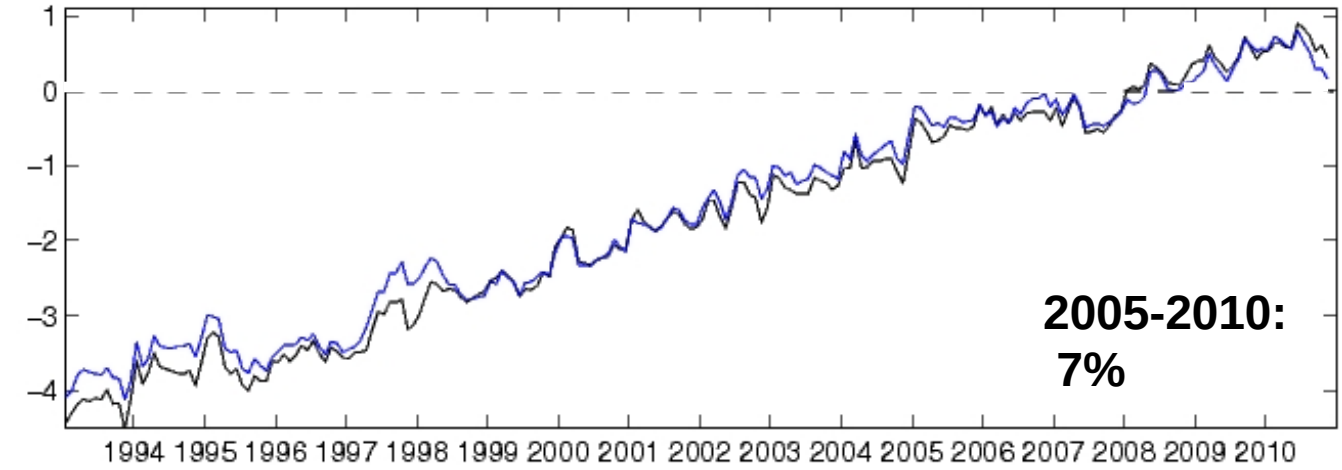


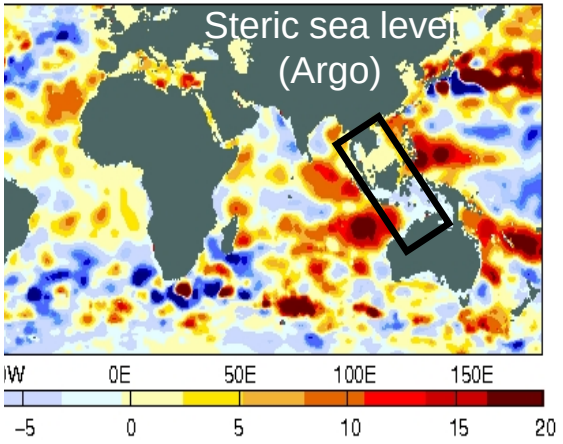
Sampling issue in the Tropical Ocean

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





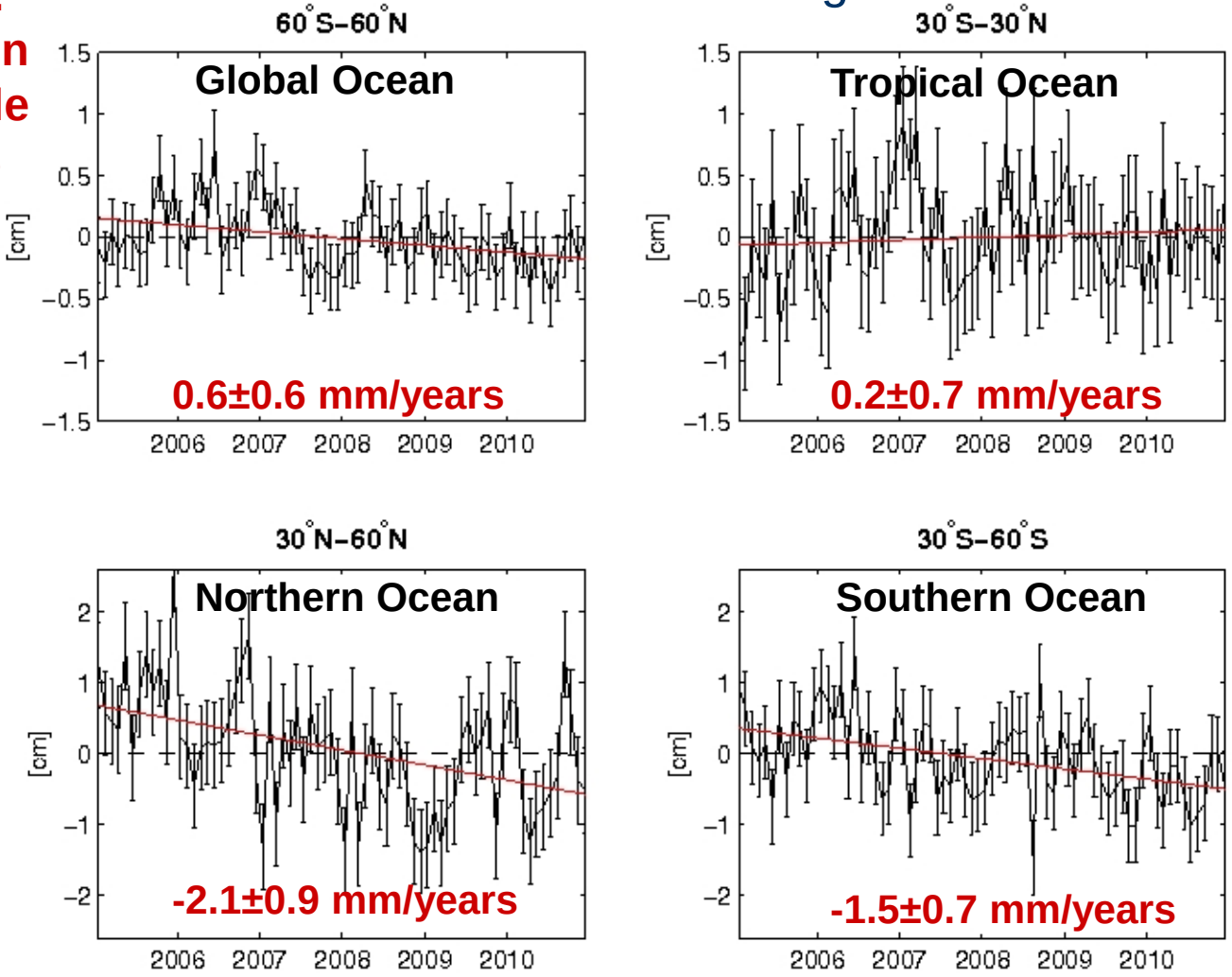




$$SL_{res} = SL_{total} - SL_{steric}(Argo) - SL_{mass}$$

Altimeter: Sampled on Argo profile positions

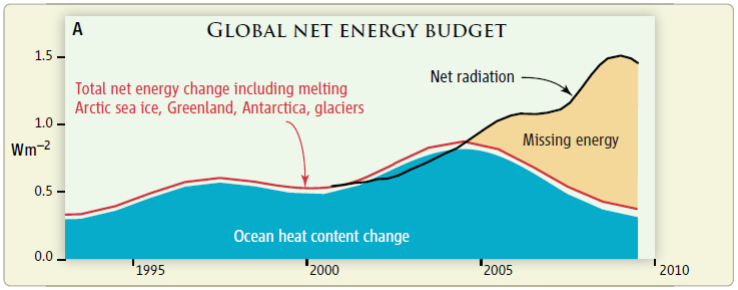
Residual of the Sea level budget: 2005-2010



We could close the global and tropical sea level budget, but regional issues remain in the extra-tropics.

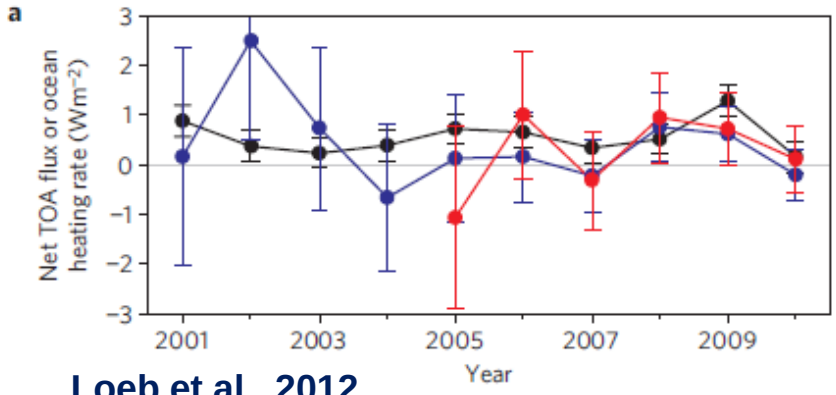
Improvement of GOIs through uncertainty and sensitivity studies

Estimated rates of change of global energy: **« Missing Energy «**

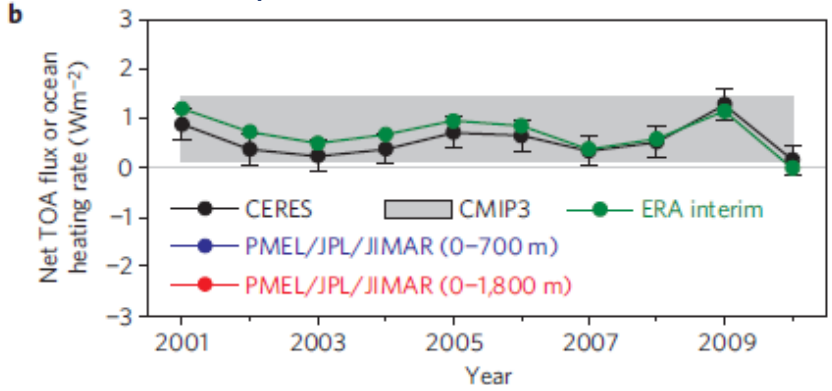


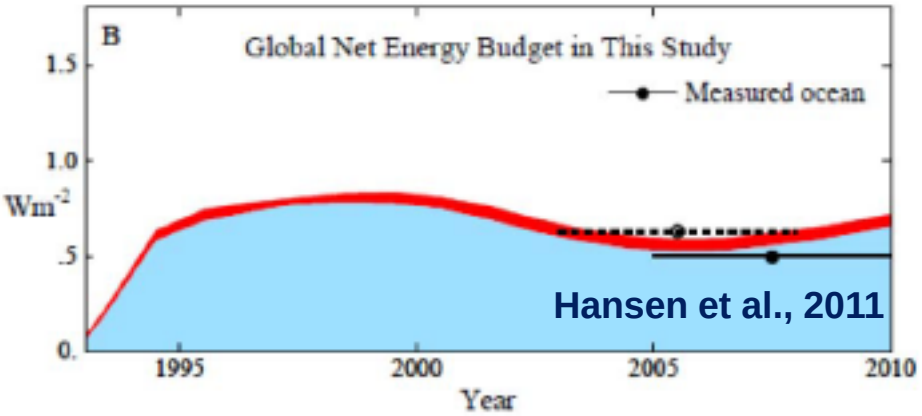
The key purpose of this paper was to challenge the different communities to work on these inconstistencies.

Trenberth and Fasullo, 2010



Loeb et al., 2012





Hansen et al., 2011

Communities have improved their estimates, especially for GOHC, but there remain some major problems. Indeed, budgets can be closed « within uncertainties », but the uncertainties are still large and unclear.

New CLIVAR research opportunity

Consistency between planetary heat balance and ocean heat storage

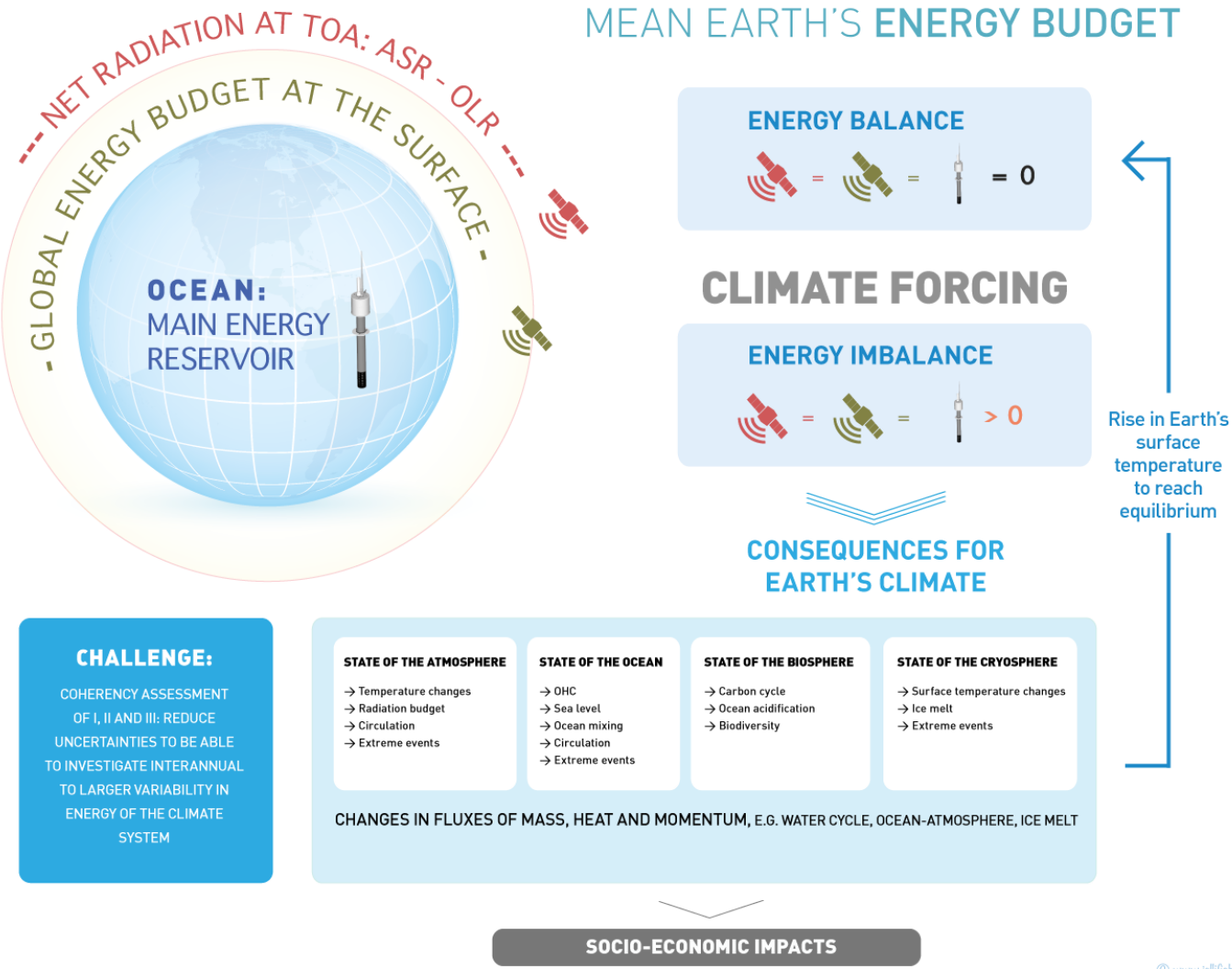
Karina von Schuckmann*, Martin Visbeck, Pierre-Philippe Mathieu, Keith Haines, Sergey Gulev, Bernard Barnier

http://www.clivar.org/science/clivar-research-opportunities#six

*karina.von.schuckmann@ifremer.fr

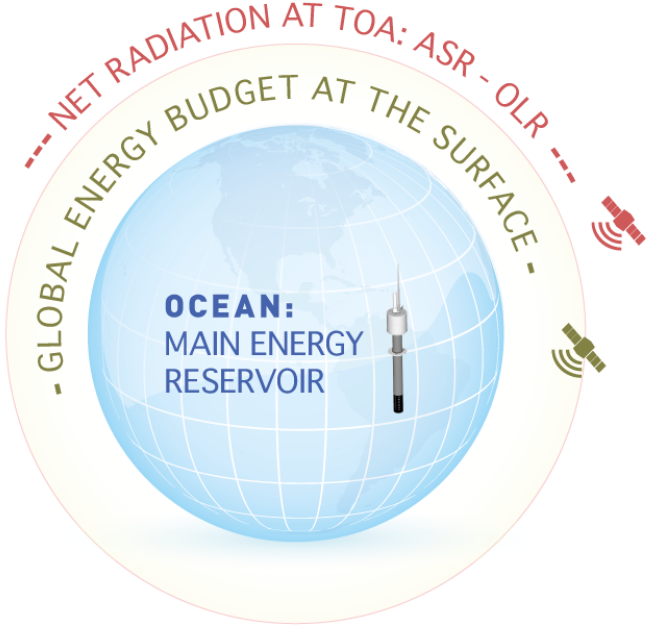
challenge

New CLIVAR research opportunity



challenge

New CLIVAR research opportunity



Large **uncertainties** on the estimate of the **energy flows and storage**, as well as the **challenge of their accurate measurements** at the global scale.

An overarching scientific challenge facing the whole climate science community is related to achieve the adequate **accuracy necessary for climate state and variability studies**, thus dealing with the **detection and decrease of uncertainties of the global climate observing systems** and related data and information products.

motivation

New CLIVAR research opportunity

Improving the **accuracy of our estimates of Earth's climate state and variability** is critical for advancing our understanding and prediction of the evolution of our climate.

There are **independent measurement approaches** based on remote sensing and in situ measurements, as well as from climate models and ocean synthesis.

➔ Each approach has problems. **Reconciling the different approaches remains a challenge.**

➔ There is merit in pursuing all methods, because confidence in the result will become high only when they agree or at least the reasons that they differ are understood.

➔ Only by using conservation and physical principles can we infer the likely resolution.

objective

New CLIVAR research opportunity

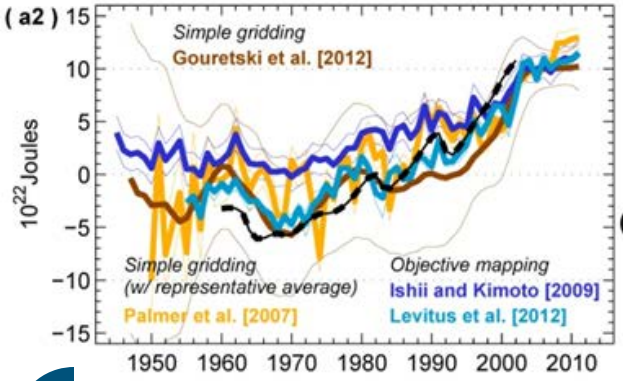
The main objective of the activity is to analyze the **consistency between planetary heat balance and ocean heat storage** estimates, data sets and information products based on different parts of the global observing systems (remote sensing (ESA/EO) and in situ) and ocean reanalysis under three foci:

- Earth Observation Measurement Constraints on Ocean Heat Budget (ESA EO)
- In situ observations of ocean heat content changes (GOOS and CLIVAR/GSOP)
- Ocean reanalysis for atmosphere-ocean heat exchange and ocean heat content estimate (CLIVAR/GSOP, SeaFlux)

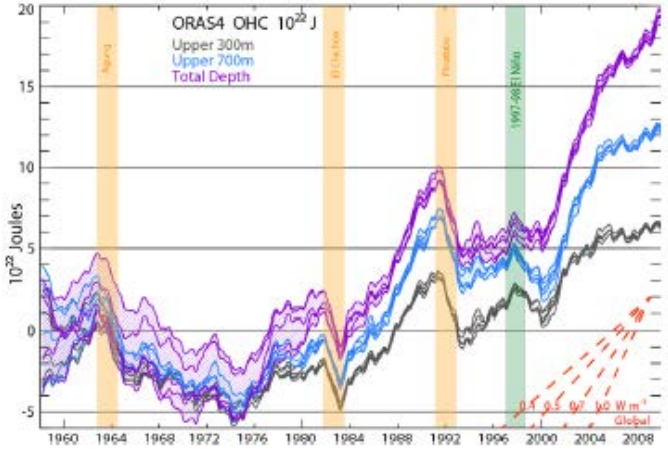
expected outcomes

Refinement of a scientific framework on consistency between planetary heat balance and ocean heat storage

Reconciling GOHC



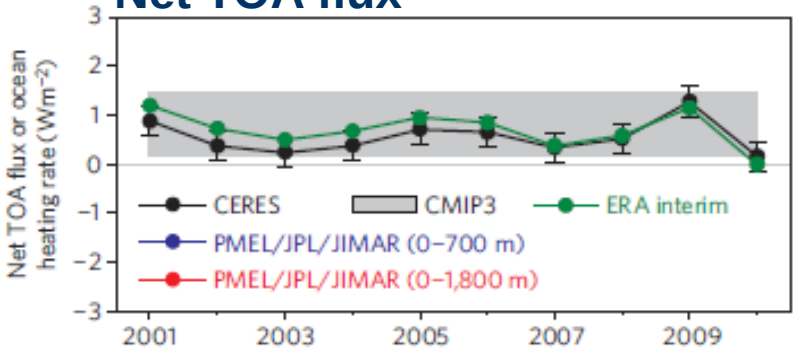
Abraham et al., submitted



Balmesada and Trenberth, 2013

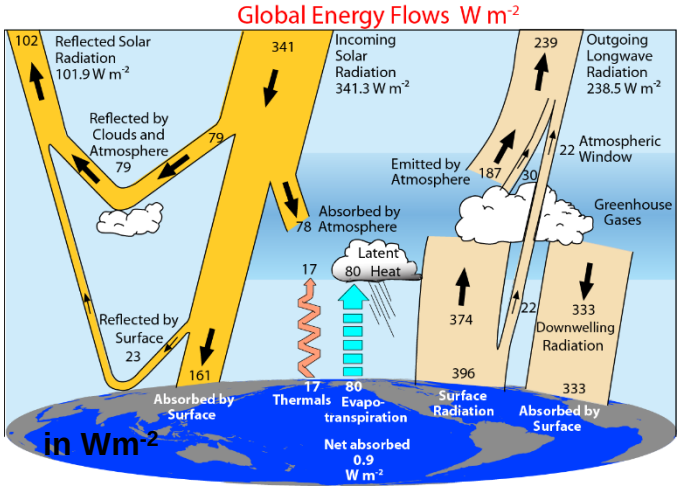
Estimations from reanalyses

Net TOA flux



Loeb et al., 2012

Mean Earth's energy budget

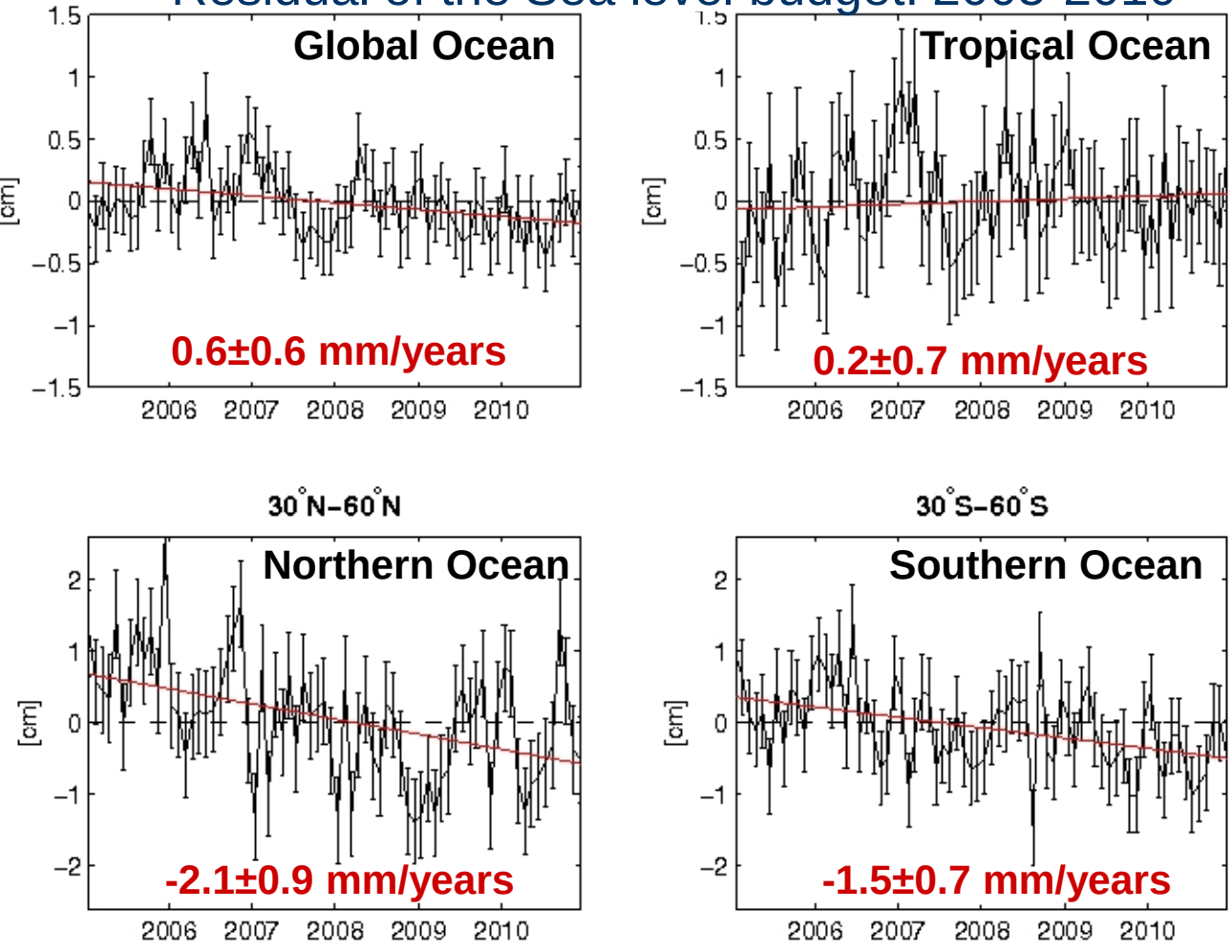


Trenberth and Fasullo, 2011

expected outcomes

Evaluation of existing **data** sets and information products and their **consistency**

Residual of the Sea level budget: 2005-2010

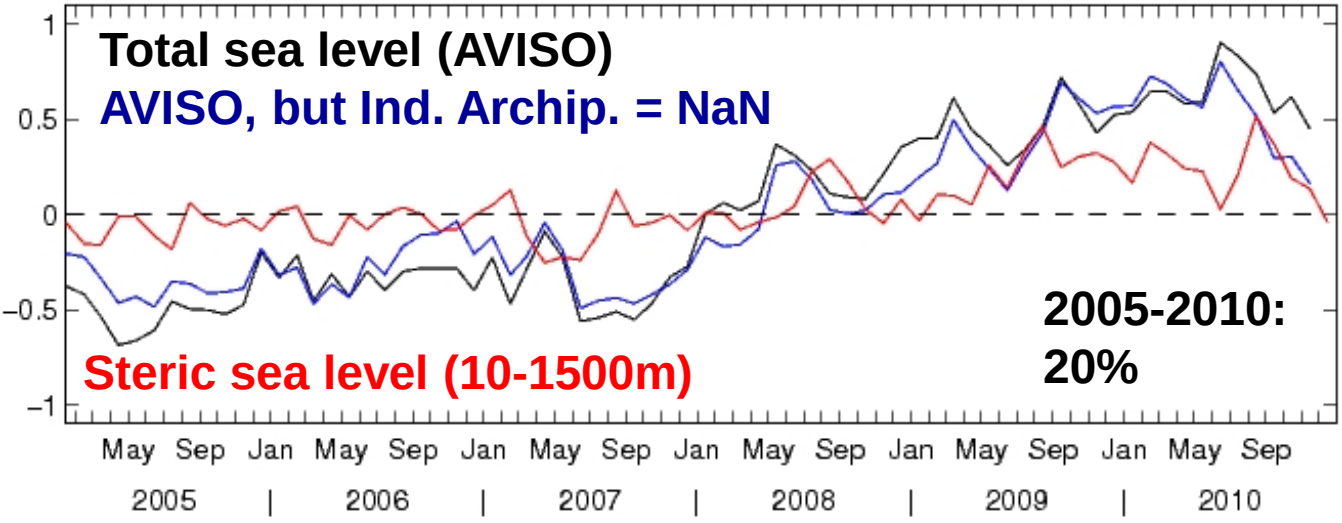


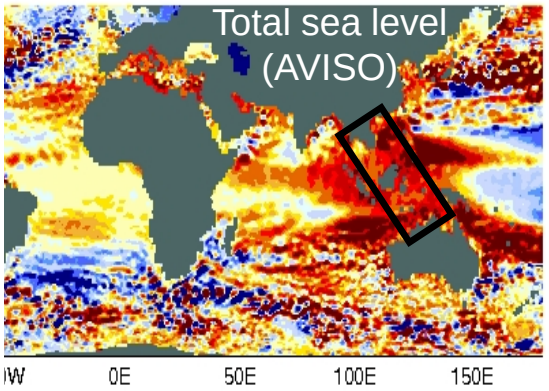
We could close the global and tropical sea level budget, but regional issues remain in the extra-tropics.

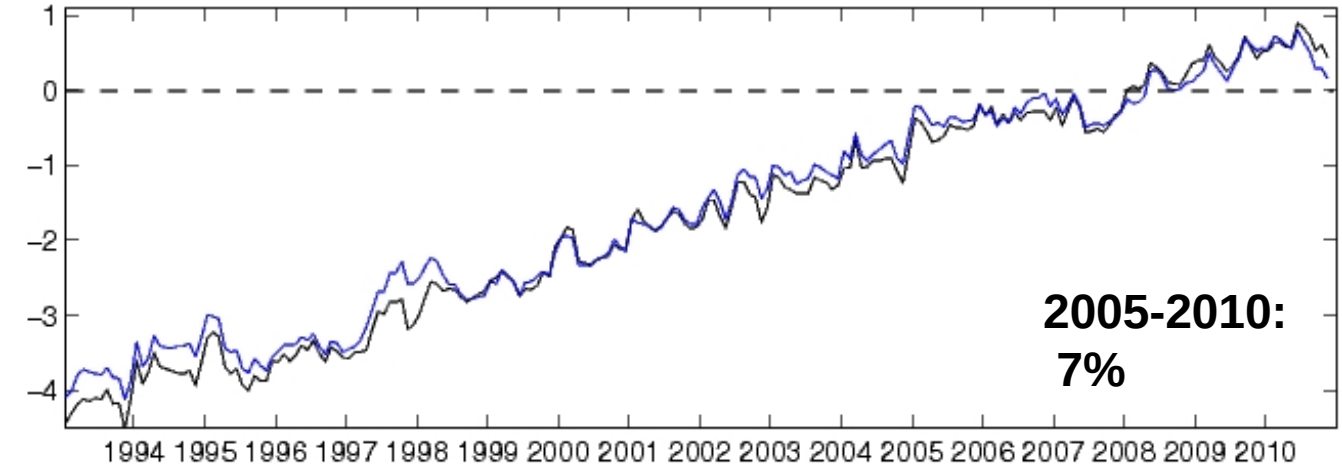
von Schuckmann et al., 2013 (under review)

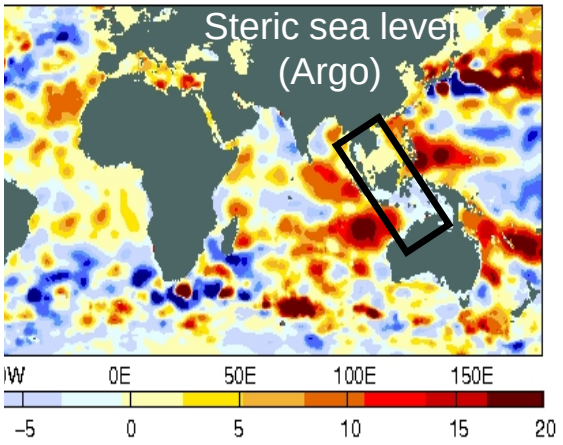
expected outcomes

Recommendations on how **to** improve the **observing systems and** derived information **products, assimilation methods, ocean and climate models and surface fluxes**





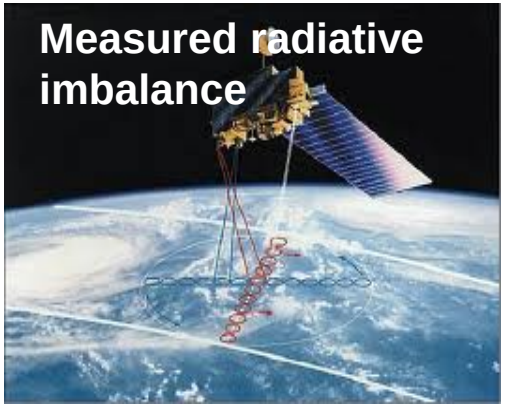




von Schuckmann et al., 2013 (in prep.)

expected outcomes

Contributing insights to related climate research topics such as anthropogenic climate change, seasonal climate prediction, decadal variability, predictability and prediction, sea-level variability and change



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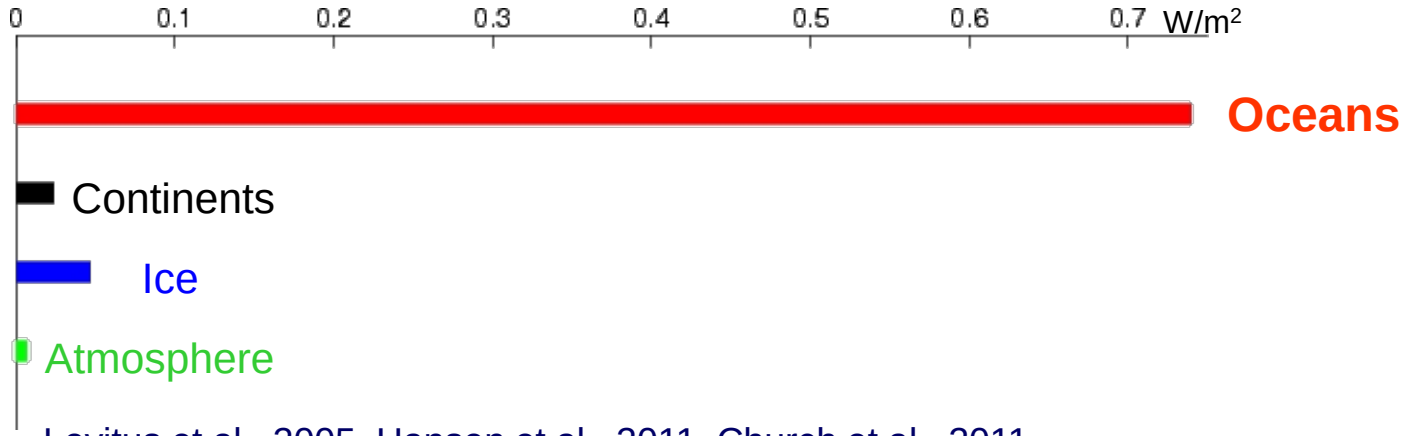
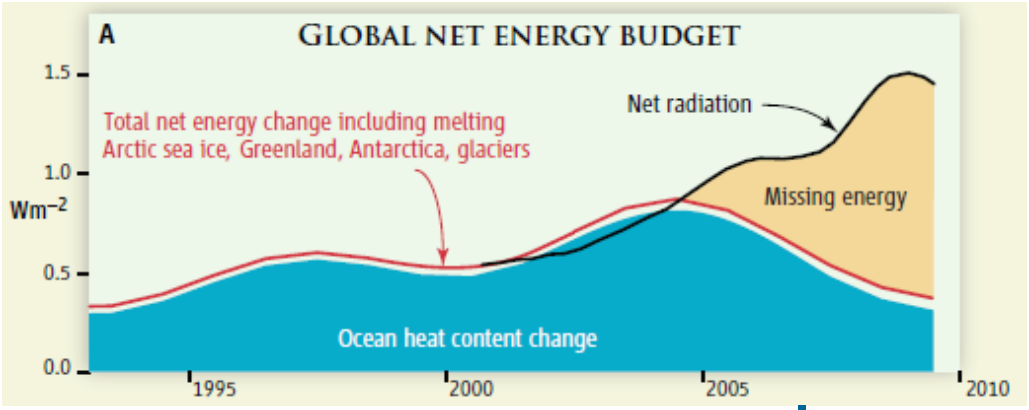


Levitus et al., 2005, Hansen et al., 2011, Church et al., 2011

expected outcomes

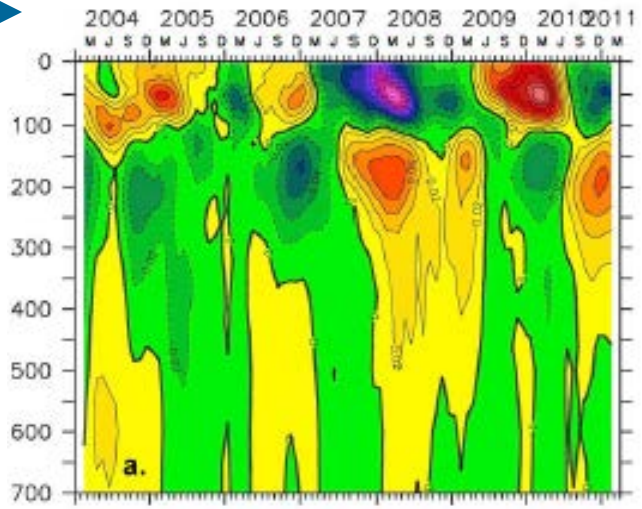
Contributing insights to related climate research topics such as anthropogenic climate change, seasonal climate prediction, decadal variability, predictability and prediction, sea-level variability and change

"missing energy"



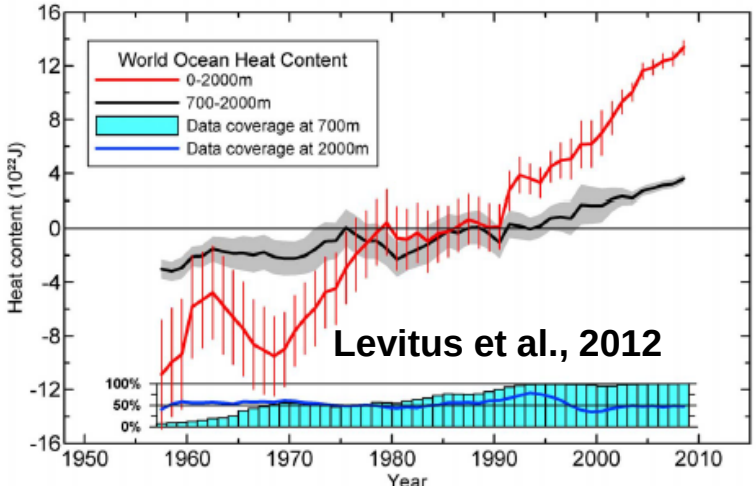
Trenberth and Fasullo, 2010

Role of ENSO

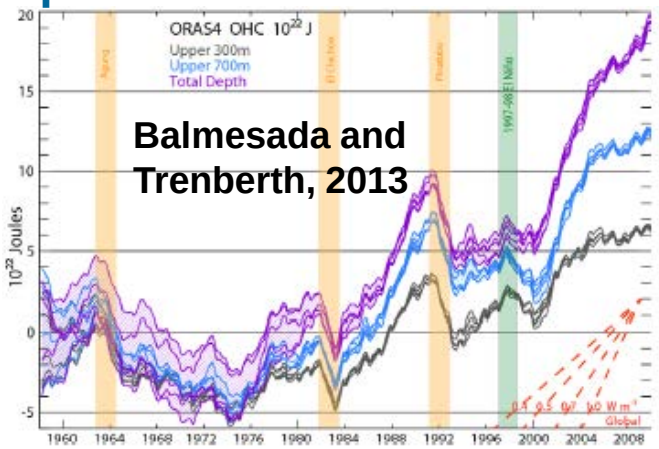


Roemmich and Gilson, 2011

Role of deep OHC



Levitus et al., 2012



Balmesada and Trenberth, 2013

planned workshop

New CLIVAR research opportunity

Venue: ECMWF, Reading, 3.-4. July

Earth Observation Monitoring Constraints on Ocean Heat Budget addressing the global **EO component (ESA)** aiming to:

- Produce the **best estimate of ocean surface fluxes**, in particular from ESA missions and programmes.
- Exploit diverse **ocean heat budget constraints** to achieve **regional Cal/Val of surface fluxes** as recommended by GSOP.
- Develop a **methodology and reference data sets** to benchmark different flux data sets, and assess their **quality and uncertainty**.
- Advance our understanding of the ocean surface heat balance, by **reconciling measurements from independent observing systems and methods**.
- Provide **ESA with recommendations** regarding generation **of flux products**, and **design of observing systems** dedicated to climate and heat budget studies.

Thank you !