Ocean Warming and Sea-level Change:
Three Recent PCMDI CMIP Studies

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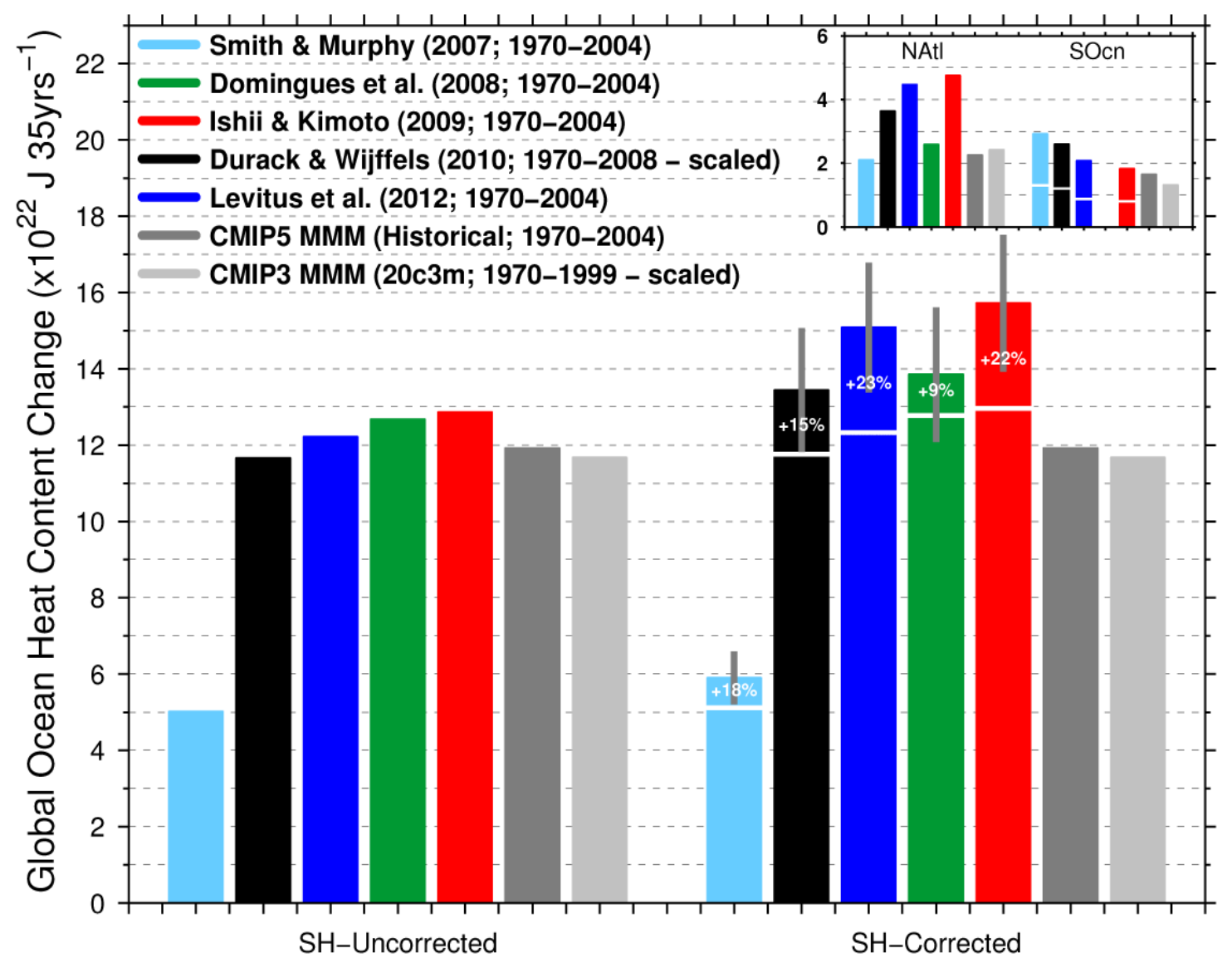
Highlight from Durack et al., 2014a

Using high quality altimetry data and models to quantify biases in in-situ based estimates of global ocean warming

Previous work suggests that Southern Hemisphere (SH) estimates of upper ocean warming are too low (Gille, 2002 & 2008; Gregory et al., 2004; Gouretski & Koltermann, 2007; Lyman & Johnson, 2008). A culprit may be much poorer historical SH sampling compared to the NH, and the popular methods to "infill" data sparse areas which are overly conservative (relaxing to climatology). Because this can impact global estimates of ocean heat uptake **it has important implications for estimates of the global energy budget**. **Here we summarize the study results and show our concluding figure:**

1) The CMIP5 MMM NH/SH SSH changes (1984-2004) agree well with high quality altimetry data:
2) There is a close correspondence between the SSH and OHC hemispheric changes in the CMIP5 ensemble, giving us more confidence (indirectly from altimetry) that:
3) The CMIP5 MMM hemispheric ratios (SH/global) of OHC trends are not strongly biased, and we thus use this to
4) Adjust the observations by replacing the poorly constrained SH trend estimate with a value that yields a hemispheric ratio consistent with the model result, and then finally
5) **This yields adjusted values of the global ocean heat uptake that range between 9-23% greater than reported in the IPCC AR5**

Fig. 1: Uncorrected (left group) and corrected (right group) globally integrated 35-year ocean heat content change for 5 obs estimates and CMIP3/5 MMM. Corrections are calculated from the global versus SH ratio of heat uptake using all available CMIP3/5 realisations and adjusting the obs SH contribution to match the models. Error bars for the SH-corrected estimates show 1 standard deviation of the ratio from the complete model suite



Impact and Future Work

Long-term estimates of Southern Hemisphere (SH) 0-700 dbar warming are likely underestimated by up to 15-20% (~1-3 x 10^{22} J).

Future assessments of sea-level, energy budget and climate sensitivity must better consider the implications of this apparent SH underestimation

FOCUS: Durack et al., 2014b

Long-term Sea-level Change: The Role of Salinity

Of the many processes contributing to sea-level change, little attention has been paid to salinity-driven halosteric changes. We evaluate observed and simulated estimates of long-term regional halosteric patterns and compare these to the better understood thermosteric changes.

Strong and spatially coherent halosteric patterns are visible in the historical record, and are consistent with estimates of long-term water cycle amplification (Durack *et al*., 2012).

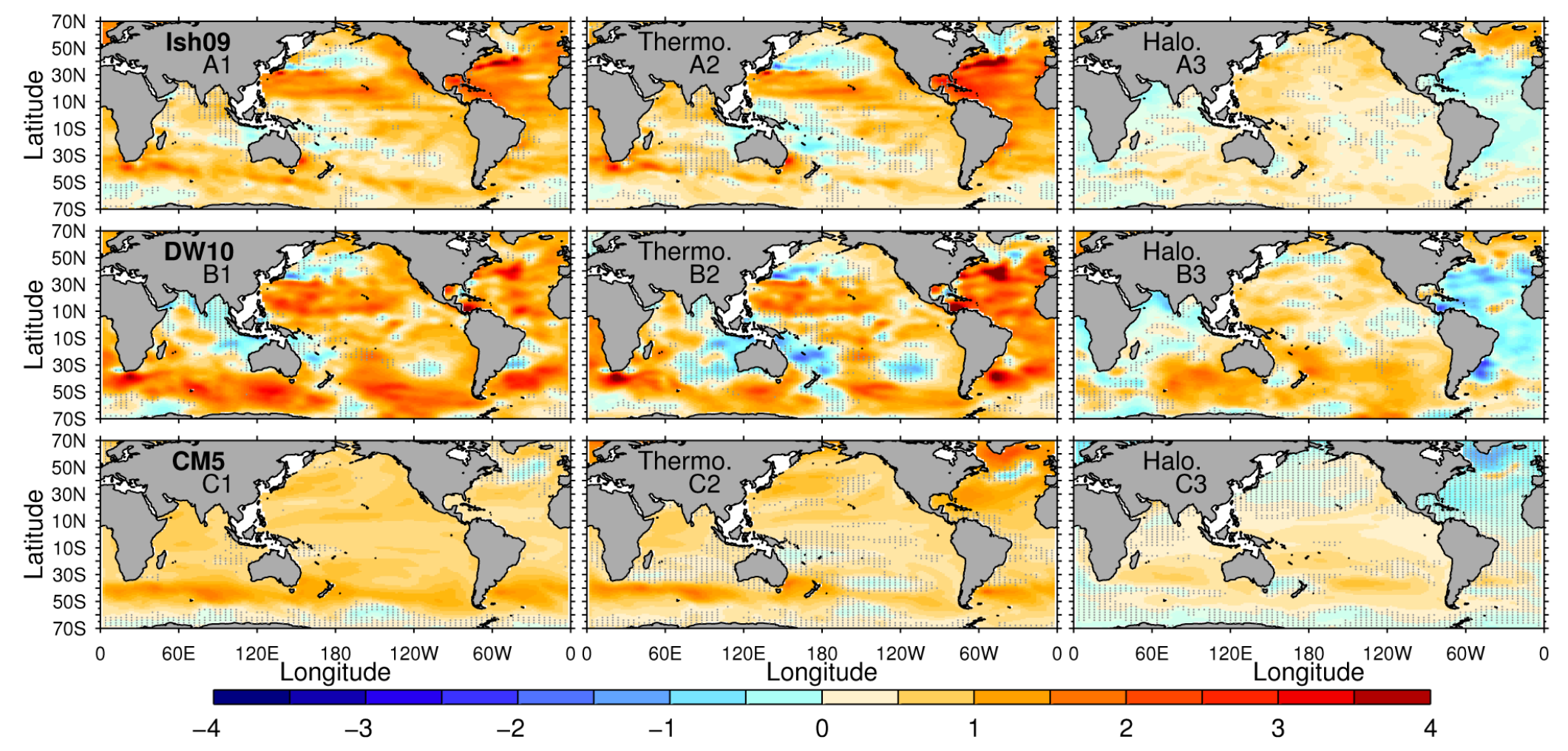


Fig. 1: Long-term trends in 0-2000 dbar total steric anomaly (left column; A1-C1), thermosteric anomaly (middle column; A2-C2) and halosteric anomaly (right column; A3-C3). Units are mm yr^{-1}. Observational maps show results from A) Ishii & Kimoto (2009; 1950-2008), B) Durack & Wijffels (2010; 1950-2008) and C) the CMIP5 Historical multi-model mean (MMM; 1950-2004). Stippling is used to mark regions where the 2 observational estimates do not agree in their sign (A1-A3, B1-B3) and where less than 50% of the contributing models do not agree in sign with the averaged (MMM) map obtained from the ensemble (C1-C3).

Thermosteric and halosteric patterns are related, and a strong spatial correspondence is found between observed and CMIP5 modeled trends. This suggests that models are simulating the processes driving observed long-term regional sea-level change. The consistency provides support for observed analyses, even though data sparsity limits confidence in regional assessments.

Our results suggest that basin-scale halosteric contributions are substantially larger than previously thought, and are found to be approximately 25% of the magnitude of corresponding Atlantic and Pacific basin mean thermosteric changes.

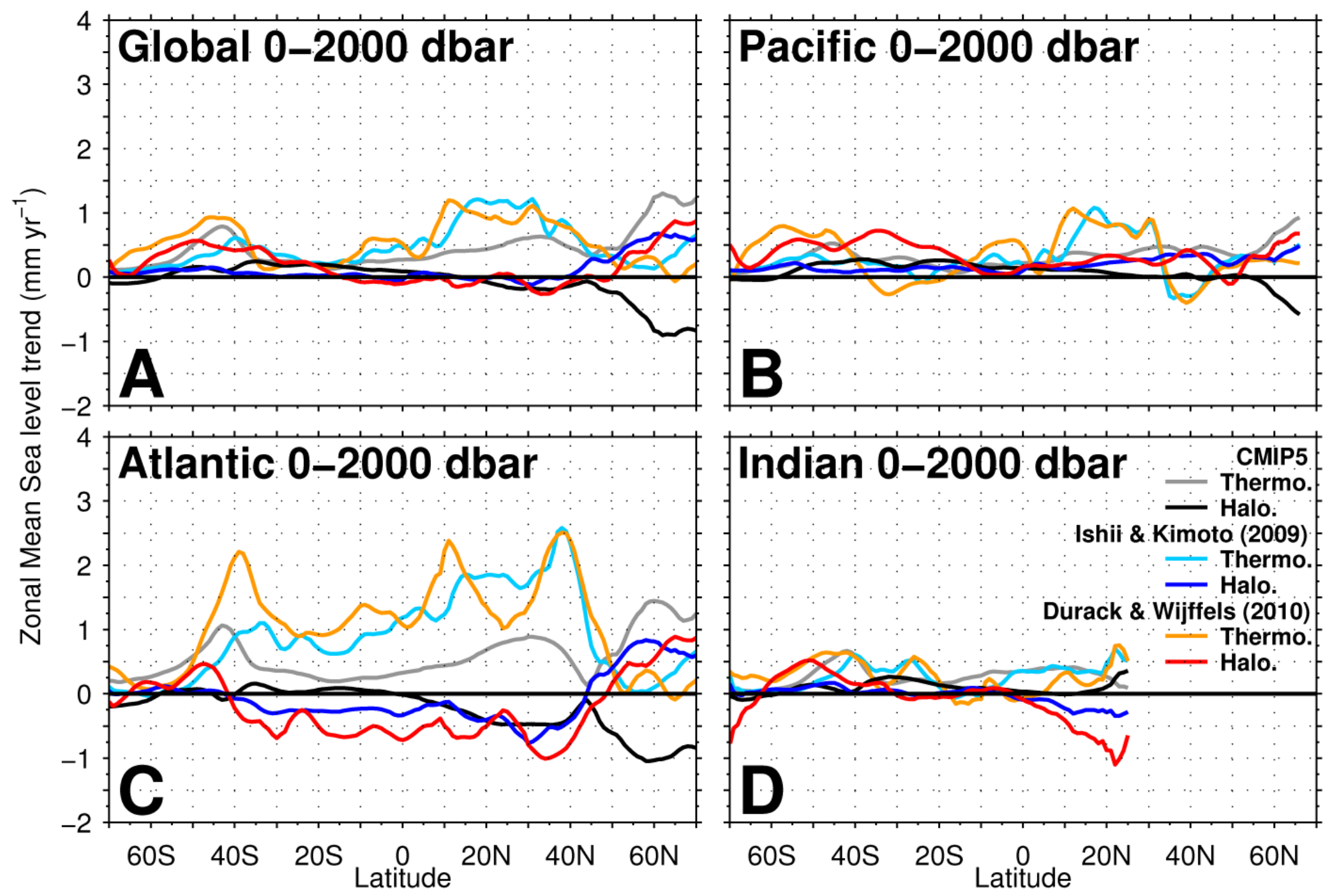


Fig. 2: Zonal mean 0-2000 dbar thermosteric anomaly (light colours) and halosteric anomaly (dark colours) for A) Global, B) Pacific, C) Atlantic and D) Indian Ocean basins. Observational results from Ishii & Kimoto (2009; Light and dark blue, 1950-2008), Durack & Wijffels (2010; Orange and red, 1950-2008) and the CMIP5 Historical multi-model mean (MMM; Grey and black, 1950-2004).

We also find that the steric compensation is a key feature and is evident in the Atlantic basin, where the largest steric anomalies are found.

Magnitudes and zonal mean patterns are consistent between observed estimates, and are broadly replicated in the MMM suggesting changes are being driven by the same processes in observations and models

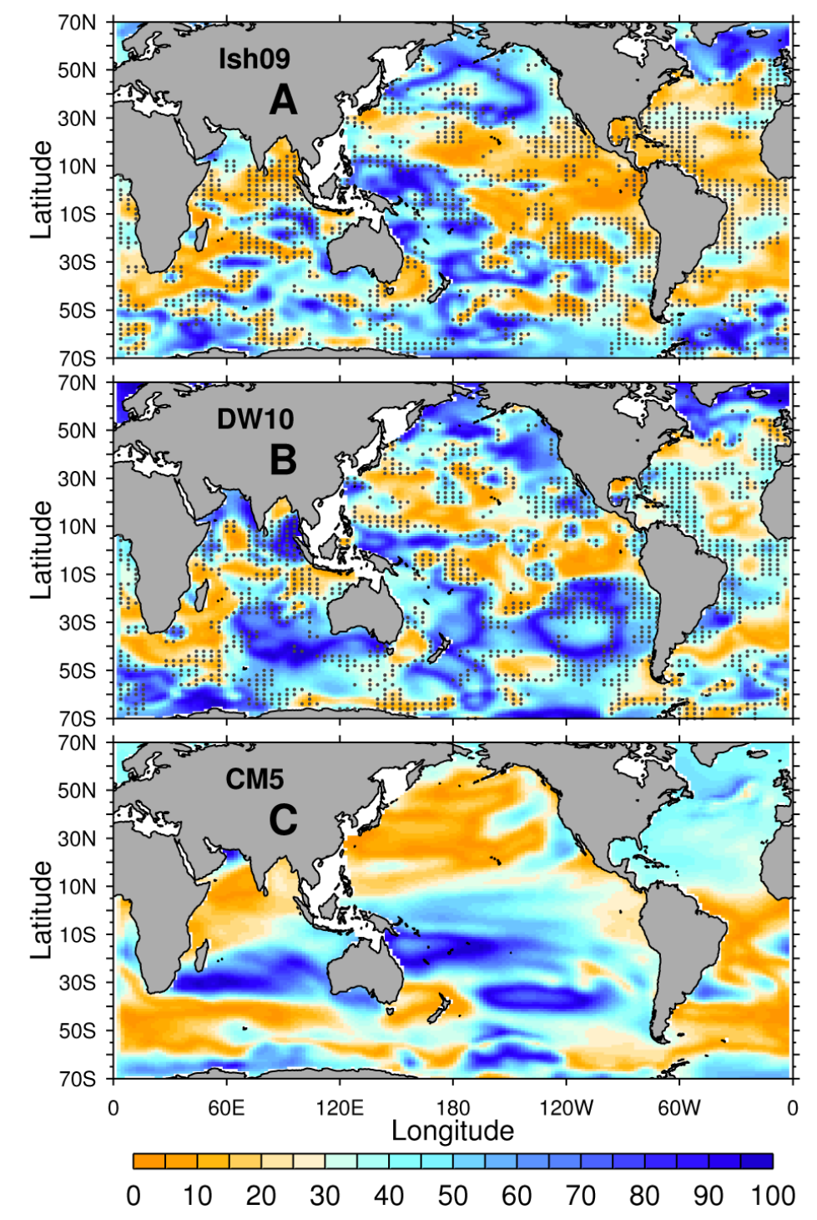
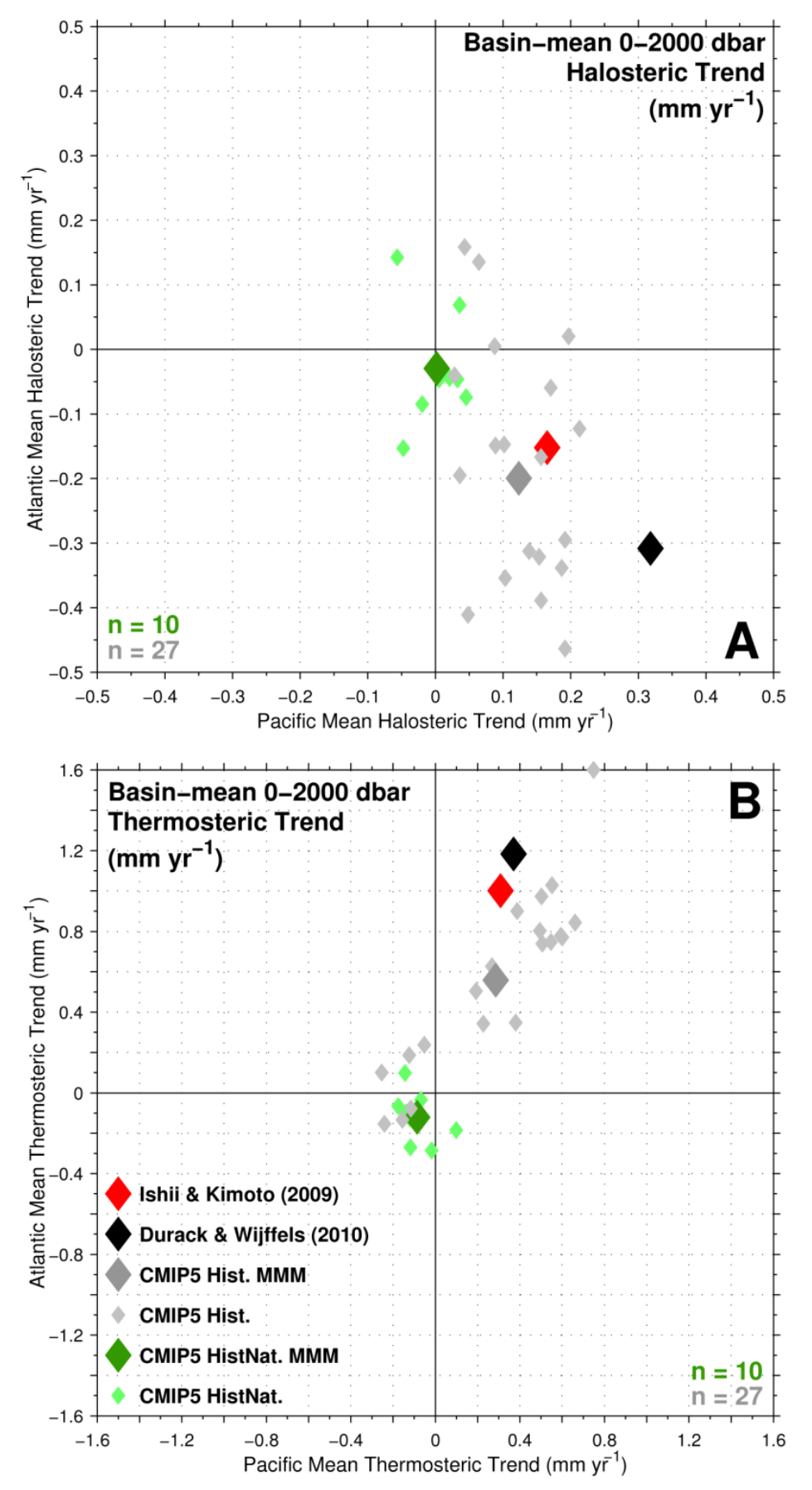


Fig. 3 (above): Spatial maps representing the magnitude of the 0-2000 dbar column-integrated halosteric changes compared to the integrated absolute steric change (the sum of absolute halosteric and thermosteric changes). Orange colours indicate where the column-integrated halosteric comprises 0-30% of the total steric magnitude, whereas blues indicate where halosteric comprises >30%. Stippling is used to mark regions where the 2 observational estimates (A, B) do not agree in their magnitude (either greater than [blue] or less than 30% [orange] which is a threshold obtained from the analysis of basin average halosteric and thermosteric changes [Figure 4]). Observational maps show results from A) Ishii & Kimoto (2009; 1950-2008), B) Durack & Wijffels (2010; 1950-2008) and C) the CMIP5 Historical multi-model mean (MMM; 1950-2004).

Fig. 4 (below): Area-weighted basin mean 0-2000 dbar A) halosteric and B) thermosteric trends for the Pacific and Atlantic Oceans. Observational results from Ishii & Kimoto (2009; red, 1950-2008), Durack & Wijffels (2010; black, 1950-2008), CMIP5 Historical simulations (grey; 1950-2004) and CMIP5 HistoricalNat simulations (green; 1950-2004).



Impact and Future Work

Our findings highlight salinity's importance to regional and even basin-scale sea-level changes.

Comparison of CMIP5 simulations and observations suggests anthropogenic forced changes are driving coherent broad-scale halosteric (salinity-driven) changes in the world ocean in agreement with past studies (Pierce *et al*., 2012). Like dynamic (circulation) changes, we show halosteric patterns can be regionally very important even though they don't contribute to global mean sea-level change.

Future assessments are underway to attribute the cause of resolved halosteric sea-level patterns.

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Highlight from Gleckler et al., 2014

Deep Ocean Heat Uptake in Observations and Models

We have diagnosed OHC changes in the CMIP5 Historical simulations in the upper (0-700m), intermediate (700-2000m) and abyssal (2000m-bottom) layers.

Working with the deeper ocean requires removing simulation drift (estimated from the corresponding control run), which can be larger than the signal itself in the deeper layers.

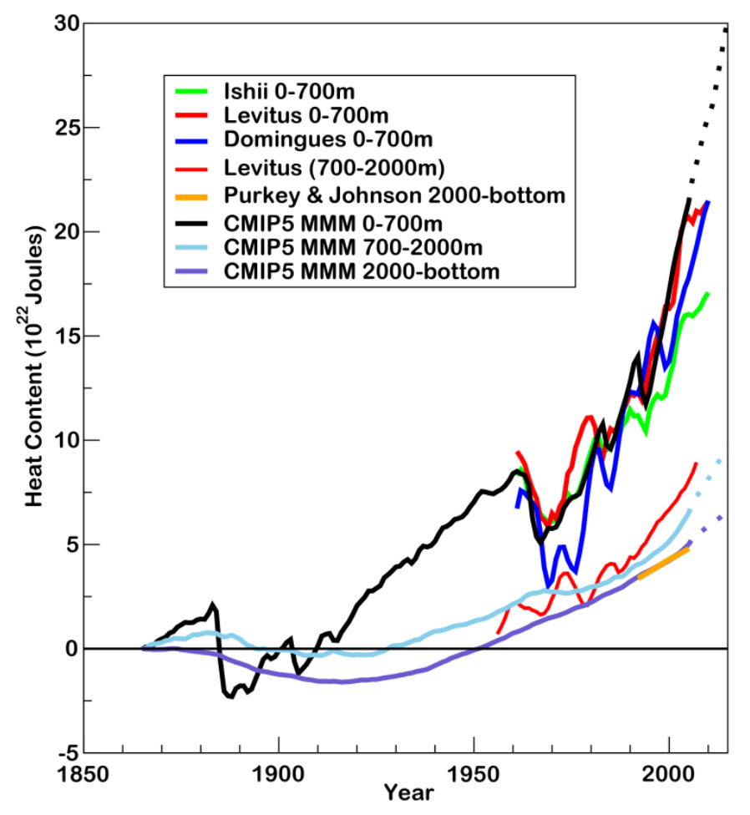
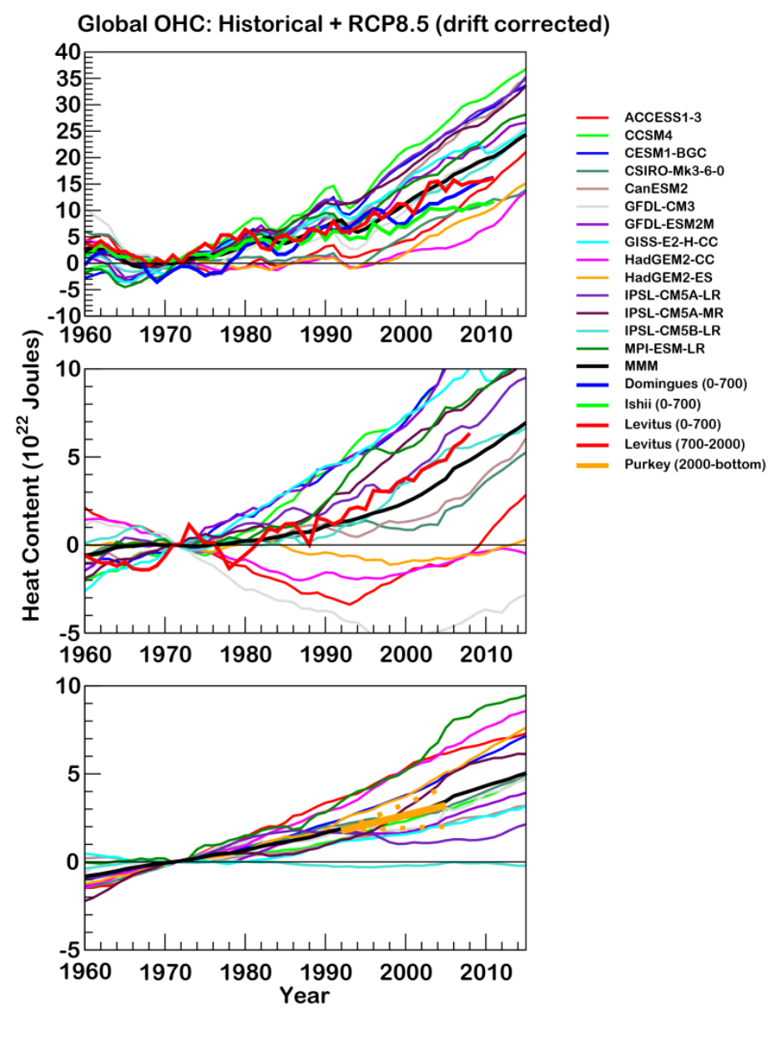


Fig. 1: Area-weighted globally-integrated OHC changes for the upper (0-700m), intermediate (700-2000m) and abyssal (2000-bottom) ocean layers for observations and the multi-model mean. Observational results from Ishii & Kimoto (2009; green, 1960-2012), Levitus et al.(2012; red, 1960-2012), Domingues et al, (2008; blue, 1960-2010), Purkey & Johnson (2008; orange; 1990-2005) and CMIP5 Historical simulations (black, light blue and mauve; 1860-2005)

- For each depth layer the MMM is broadly consistent with available estimates (that become increasingly uncertain with depth)
- An ocean cooling response to the Krakatoa eruption (1886) is evident in all three layers, whereas there is little indication other eruptions penetrate into deeper layers
- When extended with RCP8.5 to near present the MMM heat uptake by 2013 is noticeably higher than the observed estimates



- There is a large model spread in all three layers
- Several models exhibit cooling in the intermediate layer although warming persists above and below, suggesting different processes dominate in the three layers
- Although the MMM exhibits faster warming than the 0-700m observed estimates, some do not, contrary to the case of surface temperature during the "hiatus" period

Fig. 2: Area-weighted globally-integrated OHC changes for the upper (0-700m), intermediate (700-2000m) and abyssal (2000-bottom) ocean layers for all models. Observational results from Ishii & Kimoto (2009; green, 1960-2012), Levitus et al.(2012; red, 1960-2012), Domingues et al, (2008; blue, 1960-2010), Purkey & Johnson (2010; orange; 1990-2000s) and CMIP5 Historical simulations (1960-2005)

Impact and Future Work

Previously unconsidered intermediate and deep OHC changes appear consistent between CMIP5 models and available observations

Further work will focus on important regions of heat uptake to help quantify the relative role of different mechanisms in each layer

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