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On the decade-long deep-ocean warming in the subtropical South Pacific Ocean

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The persistent energy imbalance at the top of the atmosphere, inferred from satellite measurements, indicates that the Earth climate system continues to accumulate excess heat. As only sparse and irregular measurements of ocean heat below 2000-m depth exist, one of the most challenging questions in global climate change studies is whether the excess heat has already penetrated into the deep-ocean. The deep-ocean warming can initiate and advance in the regions where the air-sea interactions and ocean internal dynamics favor transfer of heat from the surface to the deeper waters. It is important to identify such regions, preferably using as many independent observing systems as possible, and to understand the associated dynamics. Combination of the present-day satellite and in situ observing systems has a potential to provide a more complete view on the horizontal and vertical distribution of heat in the ocean.

While the uncertainties associated with the observing systems are decreasing, the combined use of satellite altimetry, GRACE, and Argo measurements may theoretically become an ideal method to indirectly infer deep-ocean temperature changes below 2000-m depth. The difference between the total sea level (observed by altimetry) and the mass-related sea level (observed by GRACE) gives the steric (due to changes in seawater density) sea level variability, which is mostly a function of the full-depth heat content. The deep-ocean (below 2000-m) contribution can be inferred indirectly, as the difference between the satellite-based (altimetry minus GRACE) and Argo-based steric sea level.

Carrying out a comprehensive analysis of satellite and in situ measurements, and atmospheric re-analyses, here we report on deep-ocean warming signatures observed in the subtropical South Pacific during the past decade of 2005-2014. We show that the local accumulation of heat accounted for up to a quarter of the global ocean heat increase, with directly and indirectly inferred deep ocean (below 2000-m) contribution of 2.4 ± 1.4 and $6.1\text{-}10.1\pm4.4\%$, respectively. By realizing the potential pitfalls of the residual calculation, we note that our study is the first to report on consistency between the indirect and direct estimates of the deep-ocean warming in the subtropical South Pacific. We further demonstrate that the observed warming is consistent with a decade-long intensification of the Southern Hemispheric westerly and trade winds and associated subtropical convergence, possibly linked to the persistent La Niña-like conditions.