Deep-ocean warming in the subtropical South Pacific over the last decade

Denis Volkov
Felix W. Landerer
S.-K. Lee, and R. Lumpkin

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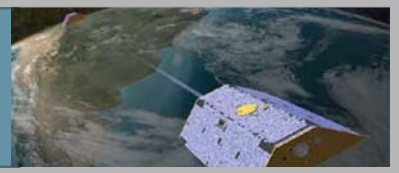
Austin, Oct-2017



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL071661

Decade-long deep-ocean warming detected in the subtropical South Pacific

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Key Points:
- Subtropical South Pacific is one of the Earth's major heat accumulators and accounts for up to a quarter of the global ocean heat increase
- Indirect and direct estimates based on satellite and in situ data show significant local heat accumulation below 2000 m depth
- Heat accumulation is due to a decade-long intensification of wind-driven convergence possibly linked to persistent La Niña-like conditions

Supporting Information:
- Supporting Information S1

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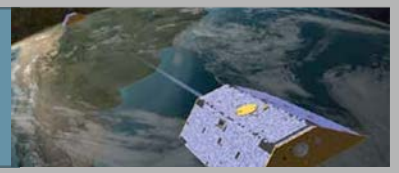
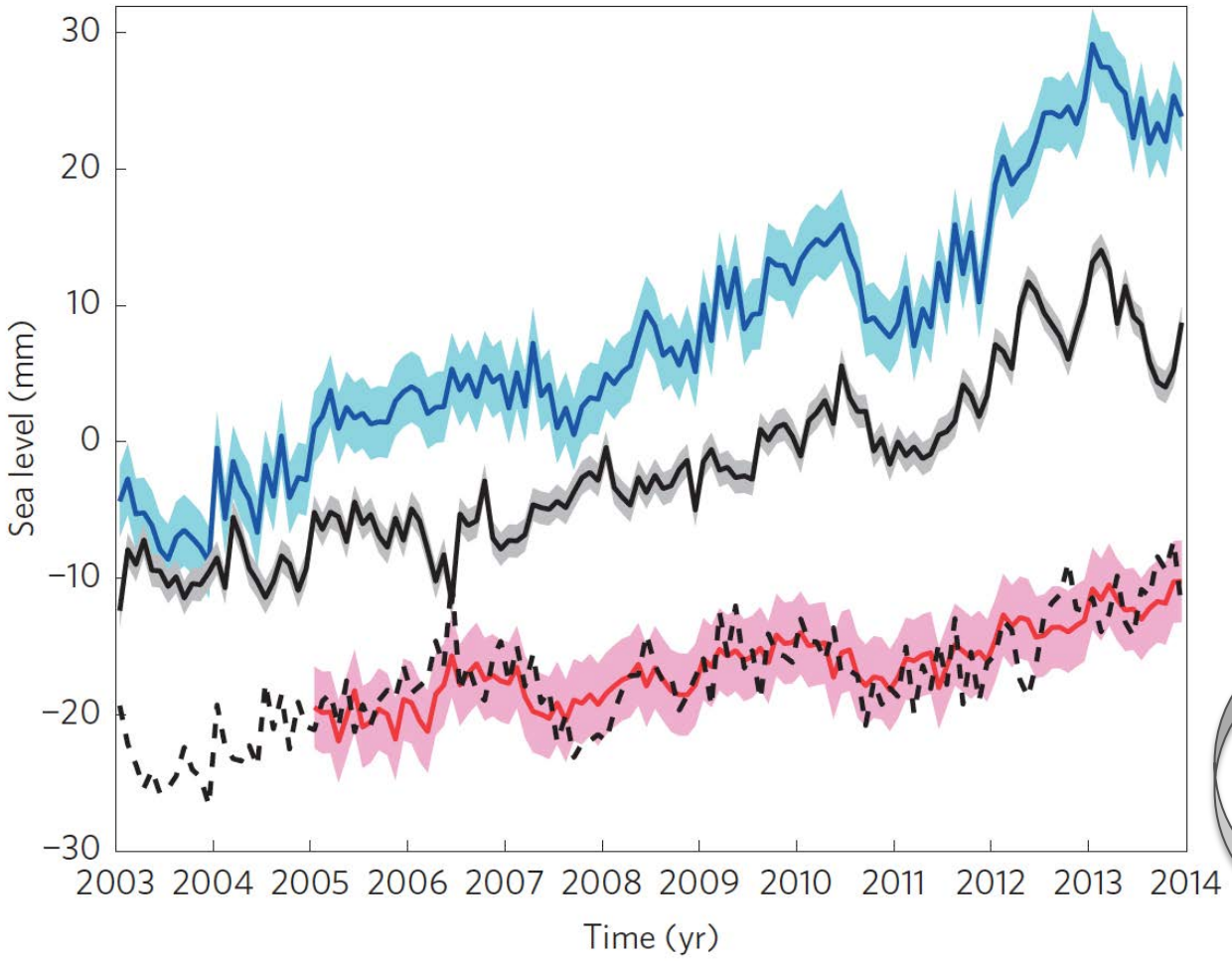
Abstract The persistent energy imbalance at the top of the atmosphere, inferred from satellite measurements, indicates that the Earth's climate system continues to accumulate excess heat. As only sparse and irregular measurements of ocean heat below 2000 m depth exist, one of the most challenging questions in global climate change studies is whether the excess heat has already penetrated into the deep ocean. Here we perform a comprehensive analysis of satellite and in situ measurements to report that a significant deep-ocean warming occurred in the subtropical South Pacific Ocean over the past decade (2005–2014). 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 $6.1–10.1 \pm 4.4\%$, respectively. We further demonstrate that this heat accumulation is consistent with a decade-long intensification of the subtropical convergence, possibly linked to the persistent La Niña-like state.

Volkov, D. L., S.-K. Lee, F. W. Landerer, and R. Lumpkin (2016), Decade-long deep-ocean warming detected in the subtropical South Pacific, Geophys. Res. Lett., 44, doi:10.1002/2016GL071661.

Previously:
Global mean sea level change (2005-2013)





Observed GMSL
2.78 ± 0.32 mm/yr
(altimeters)

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Ocean mass:
2.0 ± 0.11 mm/yr
(GRACE)

=

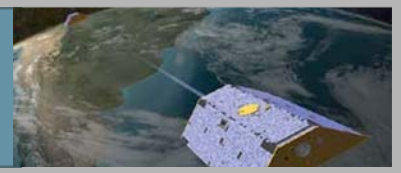
0.77 ± 0.28 mm/yr
(inferred warming
Alti. – GRACE: 0-bottom)

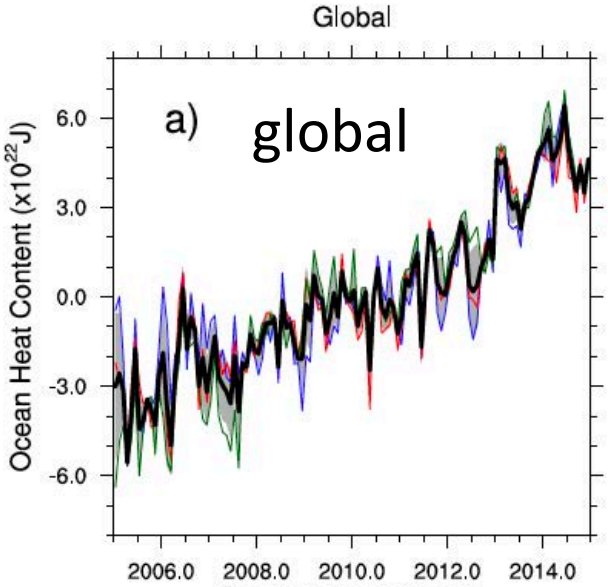
Thermal expansion
0.9 ± 0.15 mm/yr
(Argo: 0-2000m)

No clear deep ocean contribution (<2000m) to warming

[Llovel et al., 2014]

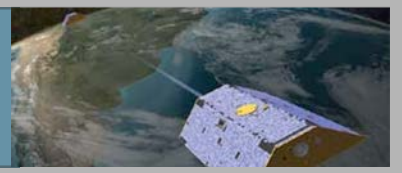
Hemispheric Ocean warming

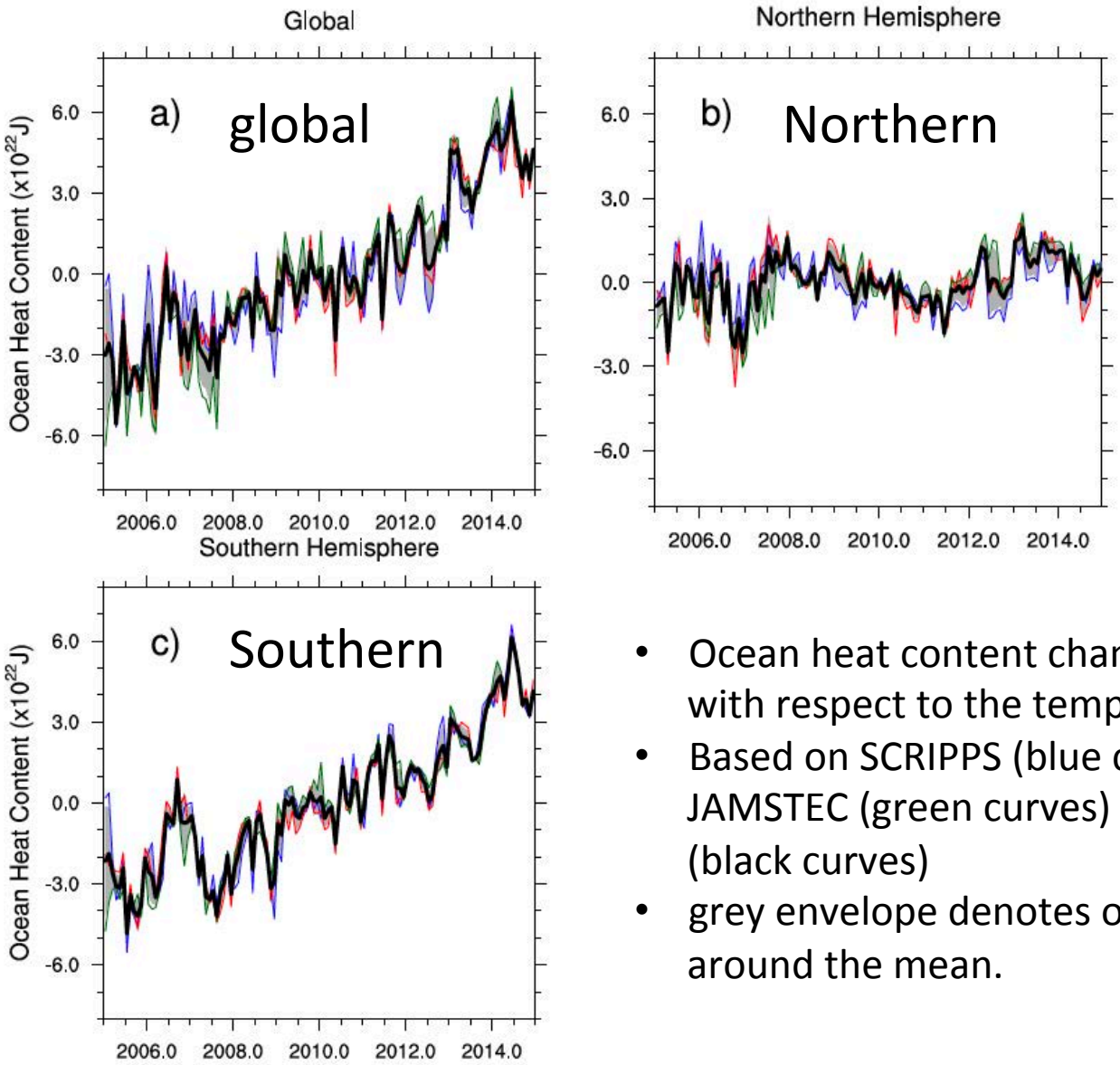




- Ocean heat content change above 2000 m depth with respect to the temperature climatology
- Based on SCRIPPS (blue curves), IPRC (red curves), JAMSTEC (green curves) and the mean estimate (black curves)
- grey envelope denotes one standard deviation around the mean.

Hemispheric Ocean warming





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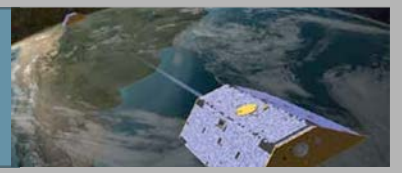
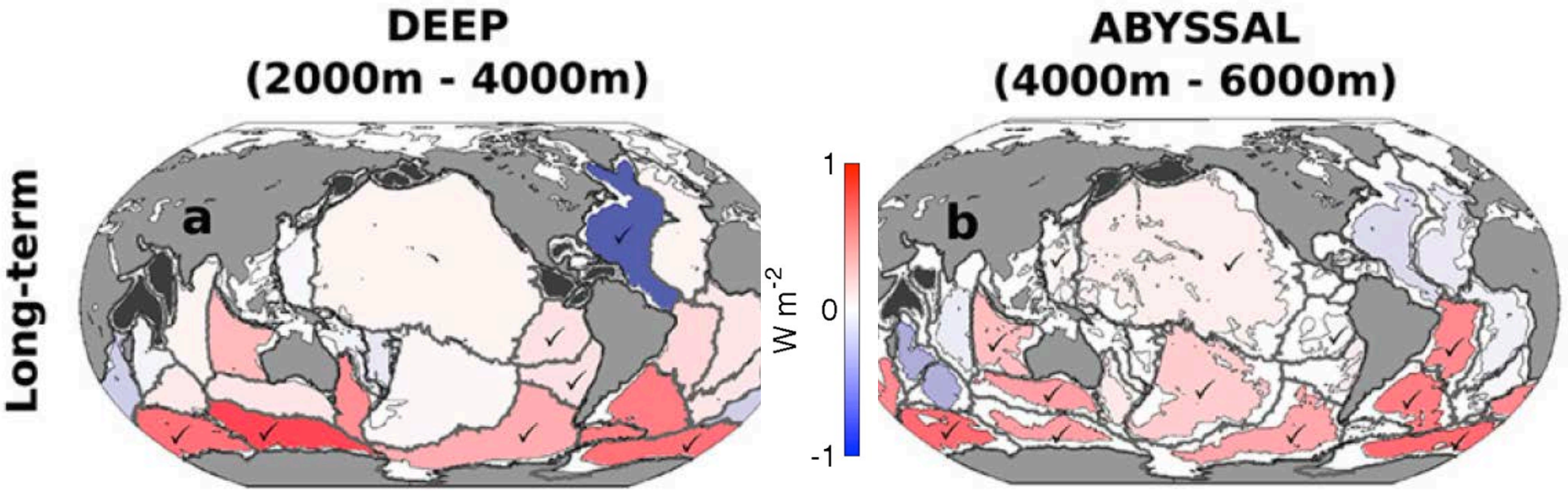
Deep ocean warming?

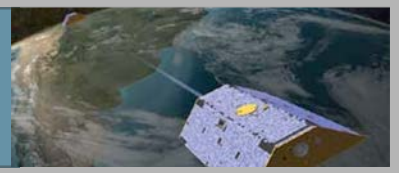




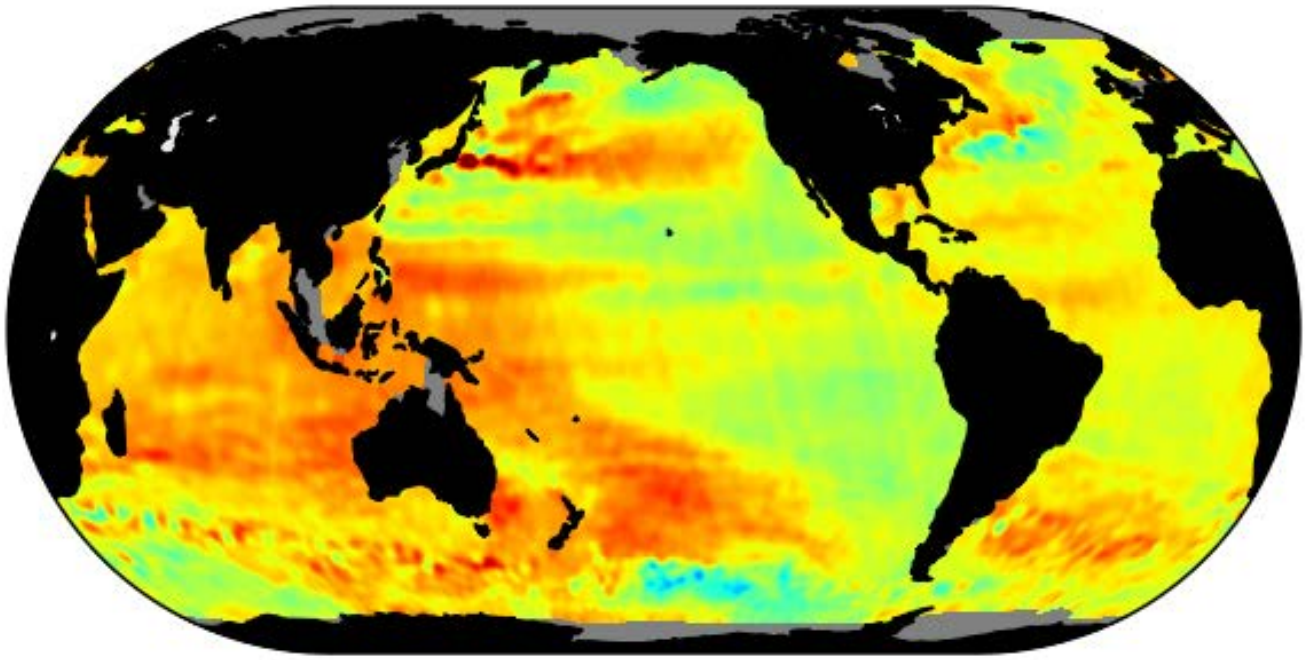
- Sparse, but consistent evidence that there's deep ocean warming in southern ocean basins (here: approx. 2003 − 2012 time coverage)
- Direct, in-situ ocean obs very sparse in time and space, with significant delay
- Combination of GRACE, altimeters, and Argo allows indirect, but relatively 'rapid' deep ocean monitoring

[Desbruyères et al., 2016]

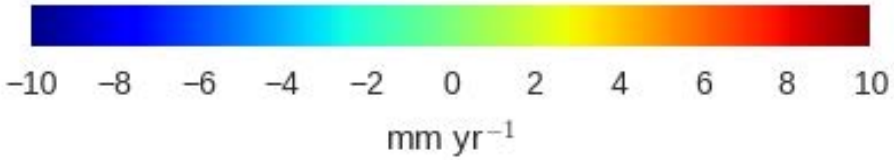
Long-term sea level change



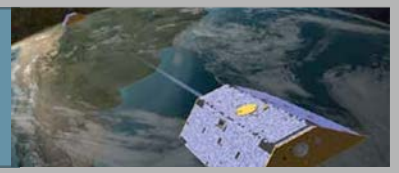
1993-2017 trend



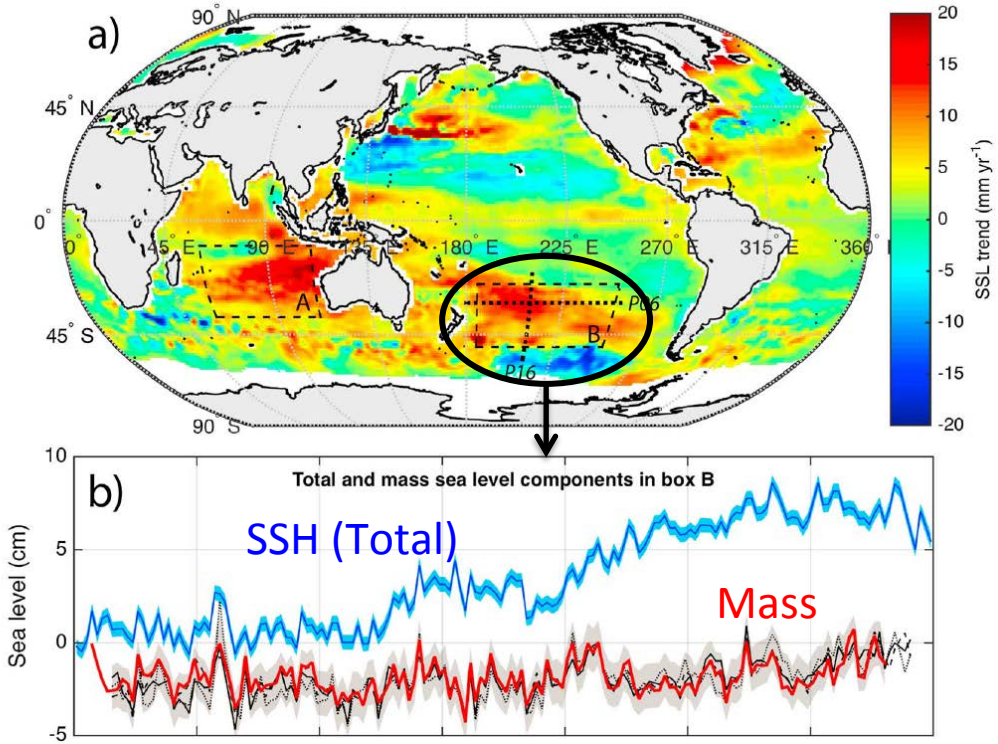
University of Colorado 2016_rel4



Regional Sea Level Budget

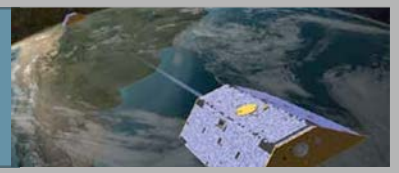


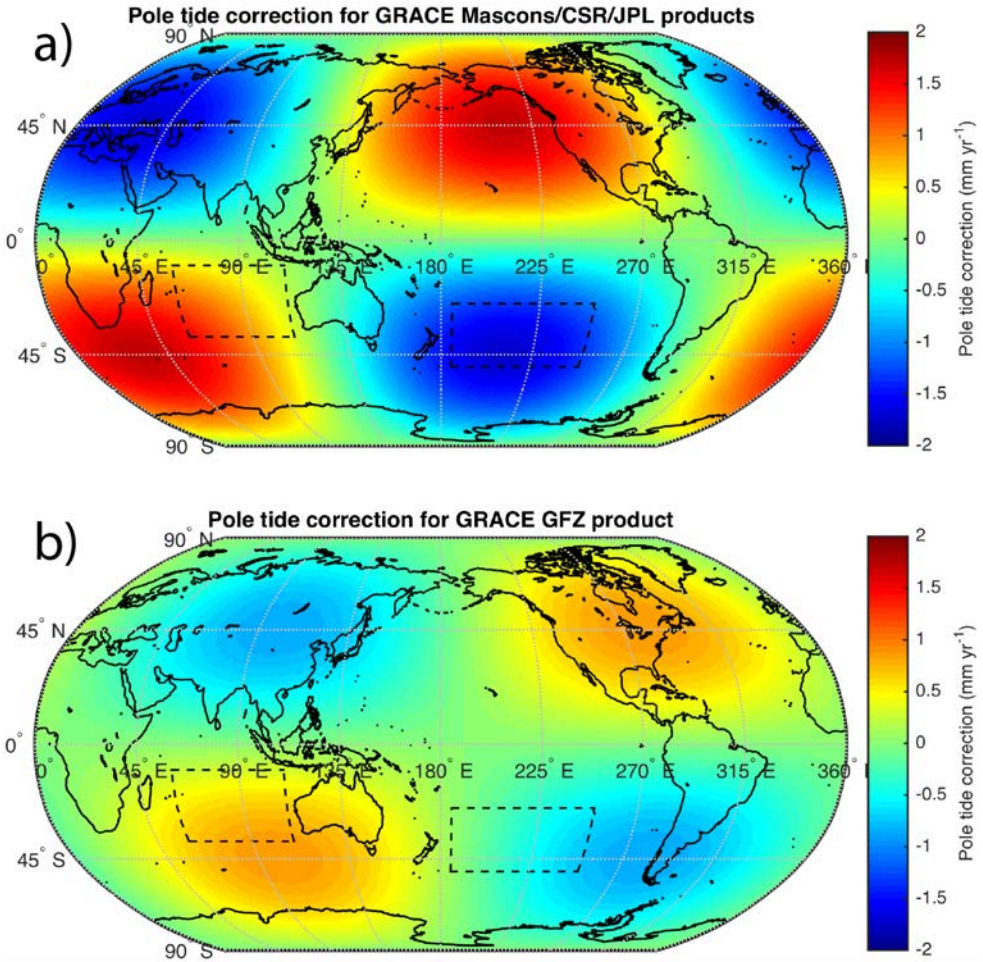
Altimeter – GRACE



Satellite-based sea level trends over 2005–2014 from *density changes* alone (i.e., the mass contribution has been removed by subtracting GRACE observations from altimetry). Warm colors typically indicate ocean warming and expansion. The study region showed large **warming**, with a clear signal originating **below 2000m**.

Pole tide bias [Wahr et al., 2016]





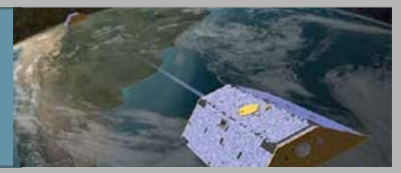
Pole tide effect that needs to be applied (i.e., *subtracted* from) to GRACE

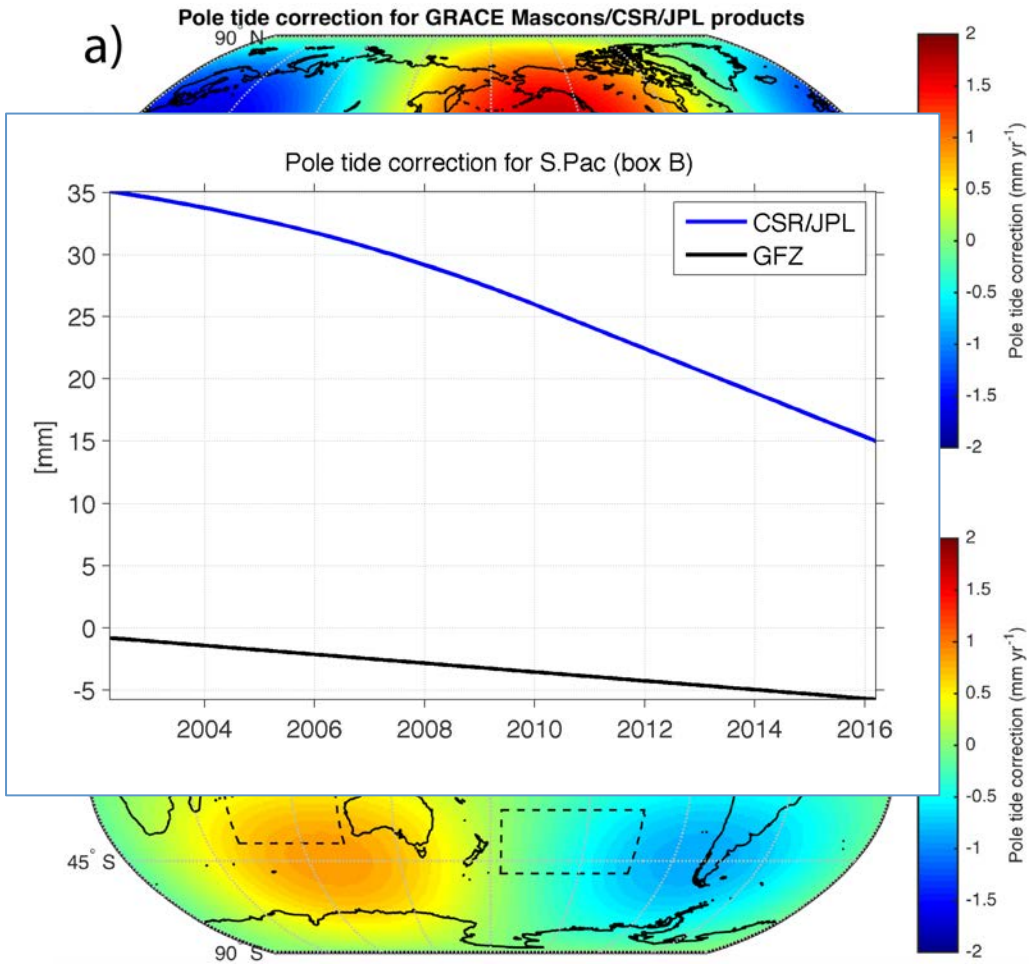
(a) Mascons/CSR/JPL
(b) GFZ ocean

mass/bottom pressure trends to correct for apparent mass changes over the 2005-2014 period [*Wahr et al.,* 2015].

pole tide effect is negative in the South Pacific, actual ocean mass trends effectively *increased* by about 1.6 mm yr^{-1} for Mascons/CSR/JPL, and by about 0.3 mm yr^{-1} for GFZ.

Pole tide bias [Wahr et al., 2016]





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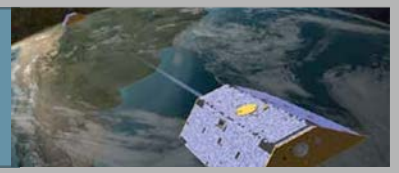

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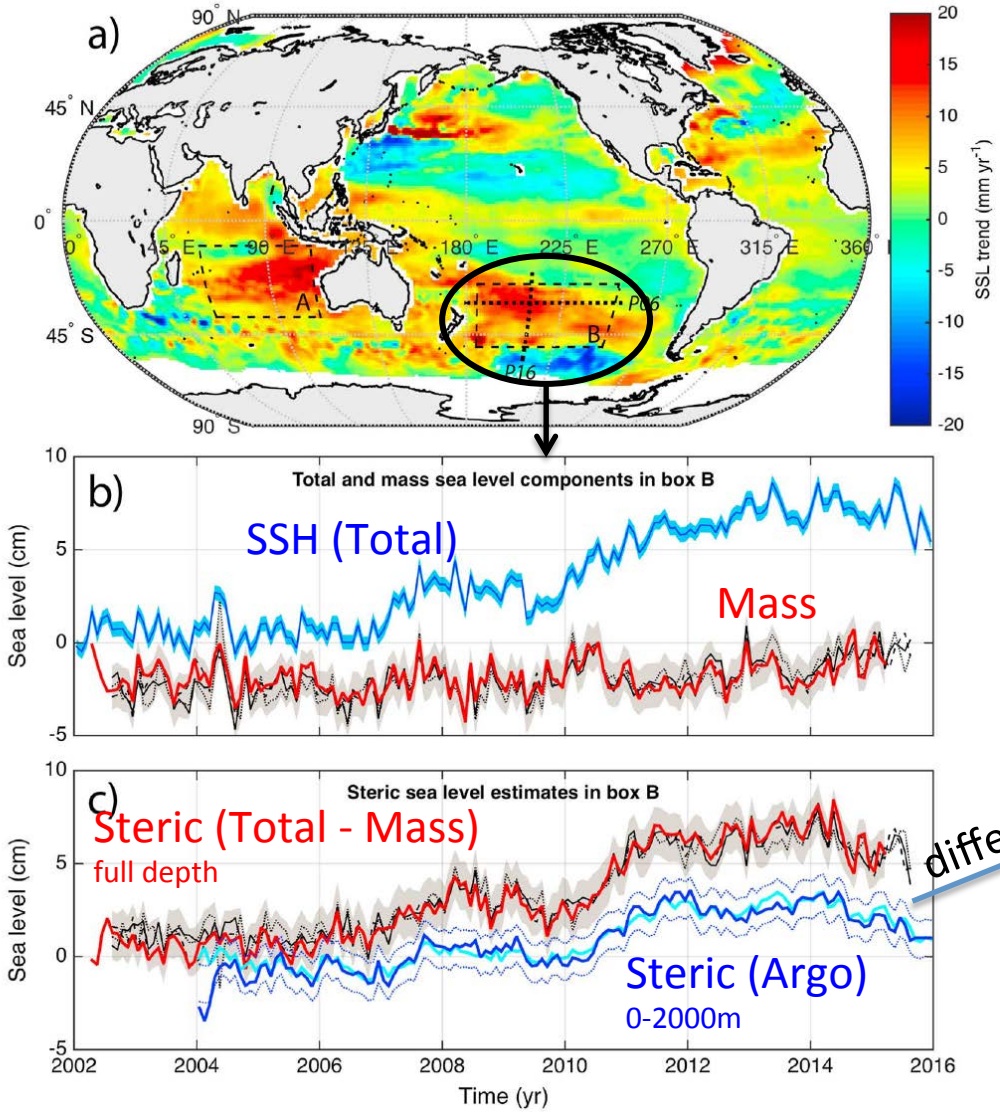
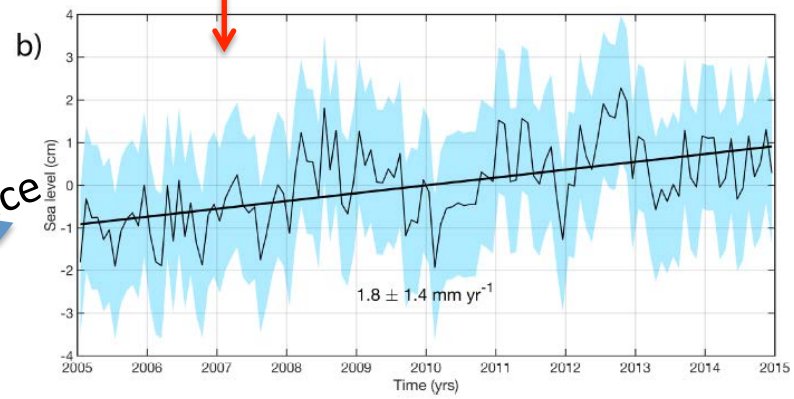


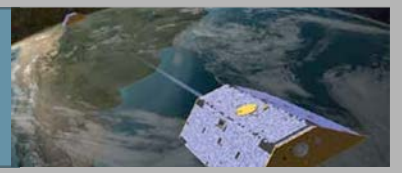
difference

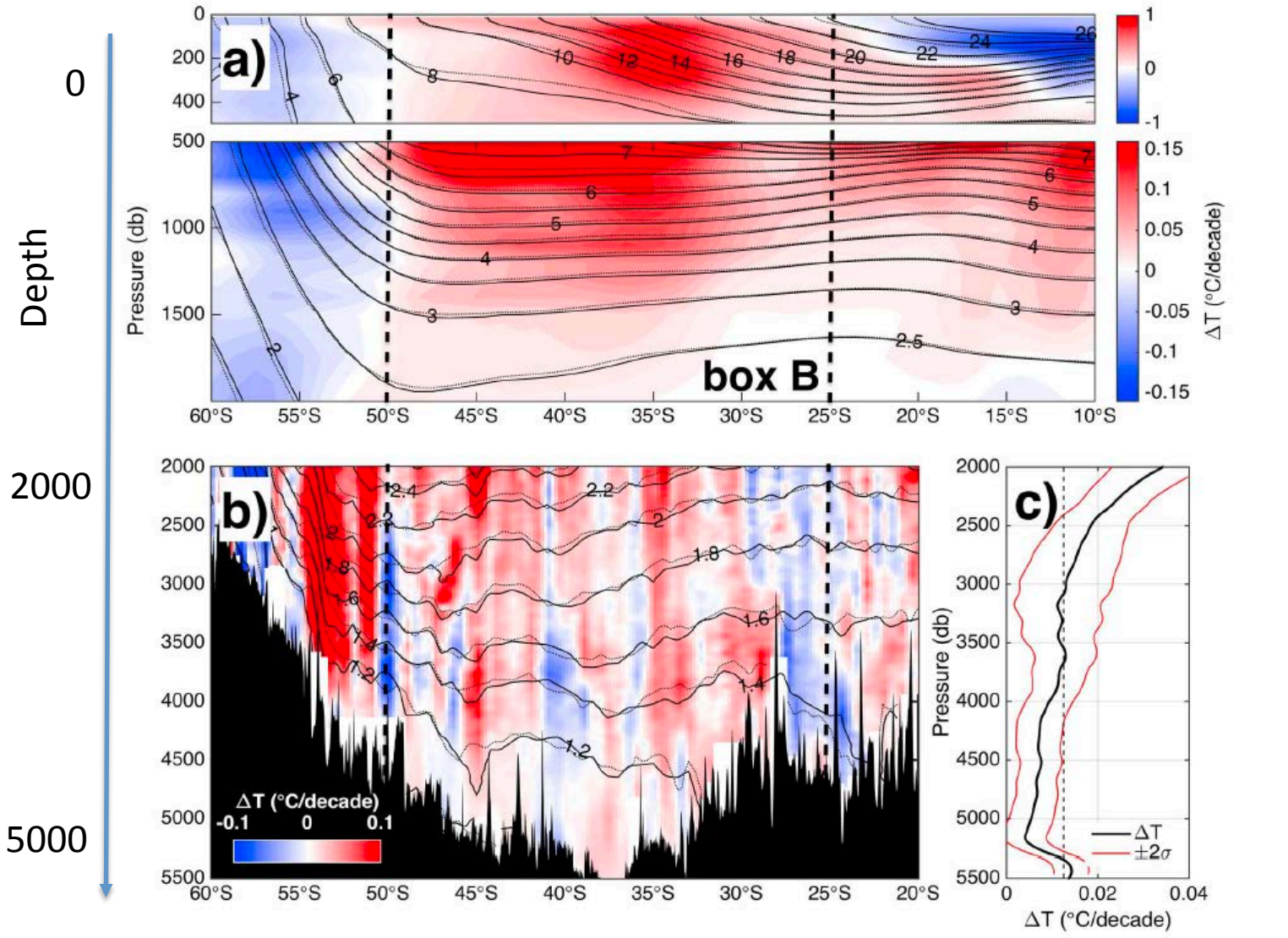
Satellite-based sea level trends over 2005–2014 from *density changes* alone (i.e., the mass contribution has been removed by subtracting GRACE observations from altimetry). Warm colors typically indicate ocean warming and expansion. The study region showed large **warming**, with a clear signal originating **below 2000m**.

Deep warming trend in S. Pacific: 1.8 +/- 1.4 mm/yr

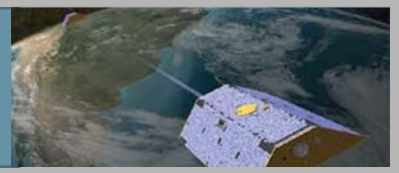


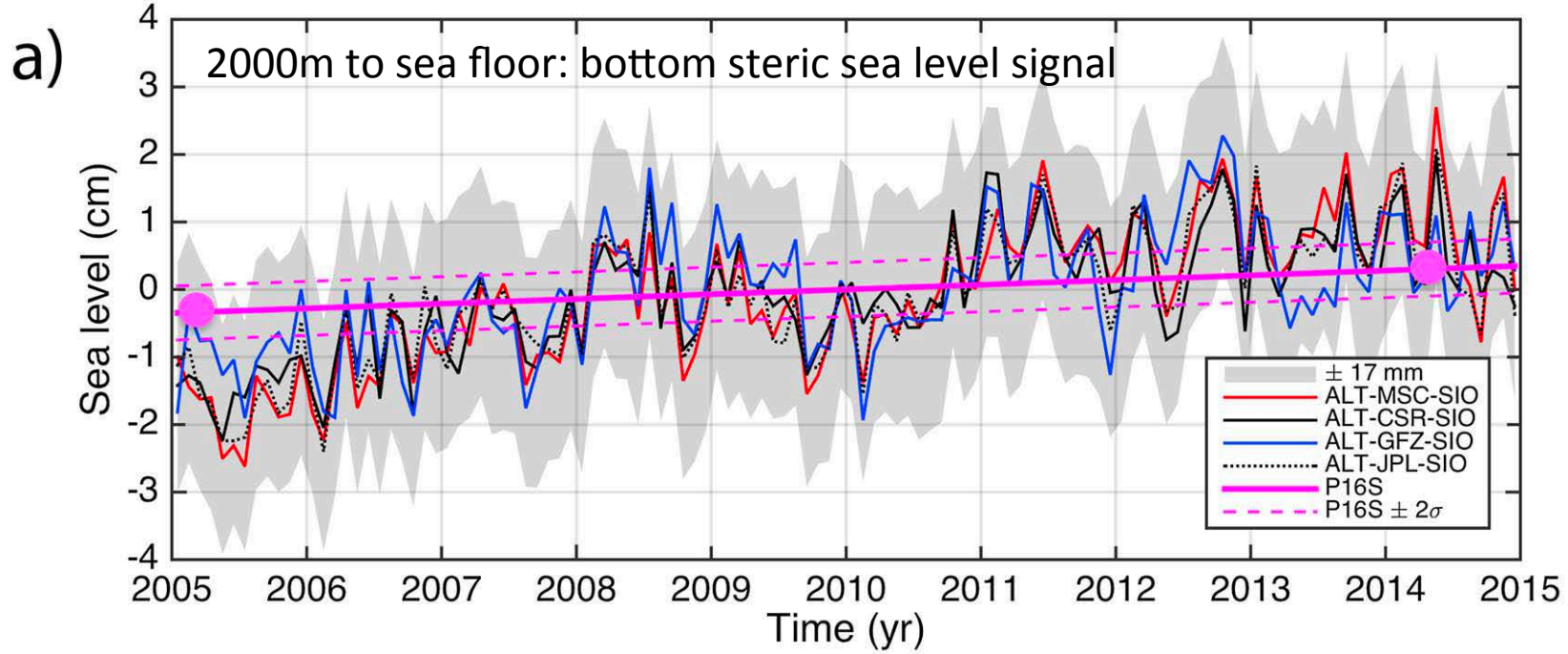
In-situ warming observations





In-situ *vs.* Satellite observations of the deep ocean warming

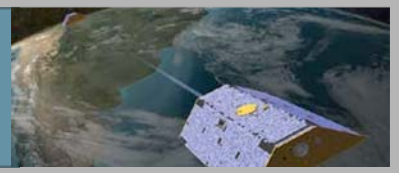




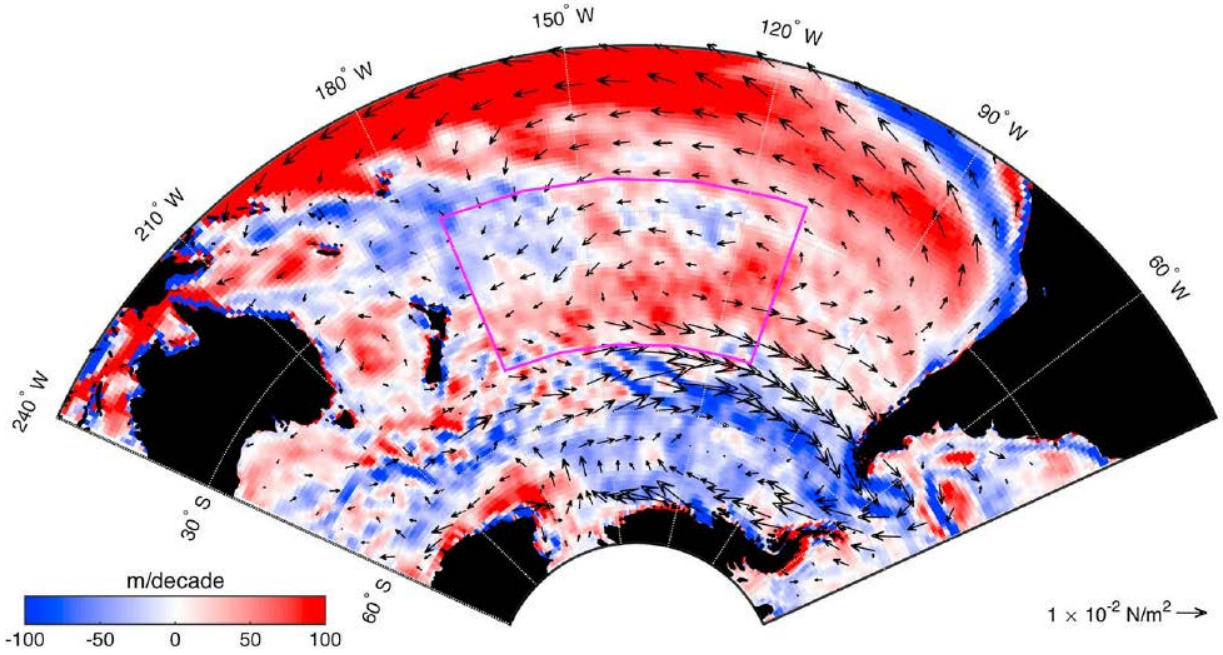
Differences: satellite-derived (entire water column) *vs.* in situ-derived (upper 2000 m) steric sea levels. The uncertainty (shaded area) is shown with respect to the ensemble averaged time series.

In-situ 'trend': 0.7 +/- 0.4 mm/yr
Satellite trend: 1.8 +/- 1.4 mm/yr

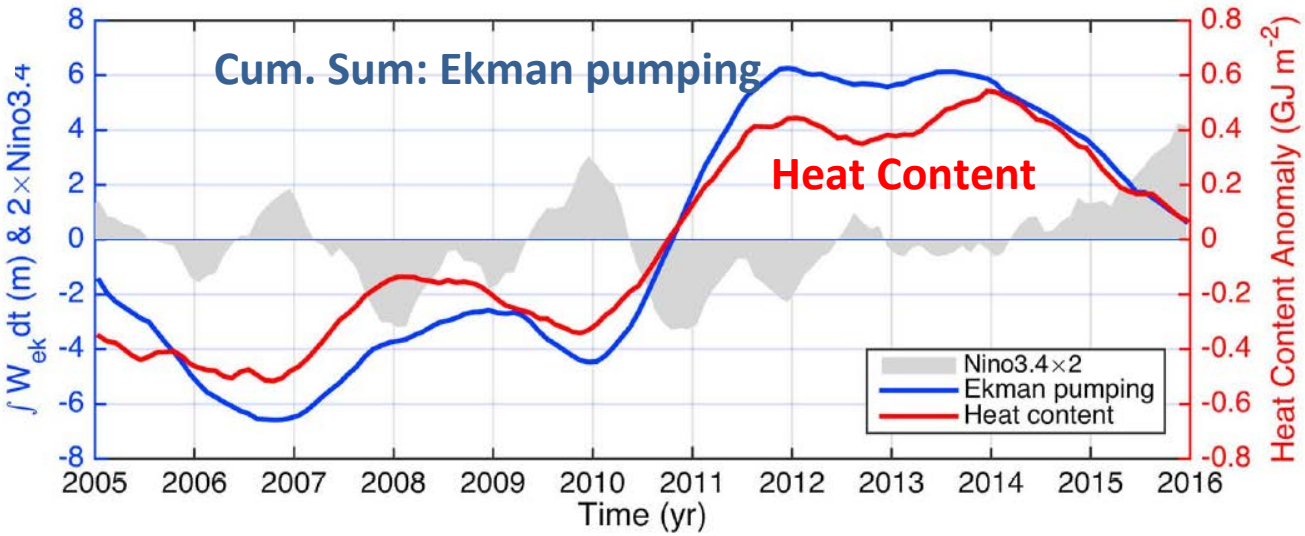
South Pacific Deep Ocean Warming - Causes



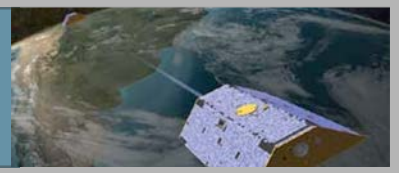
Anomalies:
Wind stress (arrows) and **Ekman pumping (color; positive downward)** 2005–2014 relative to the climatological (1979–2015).

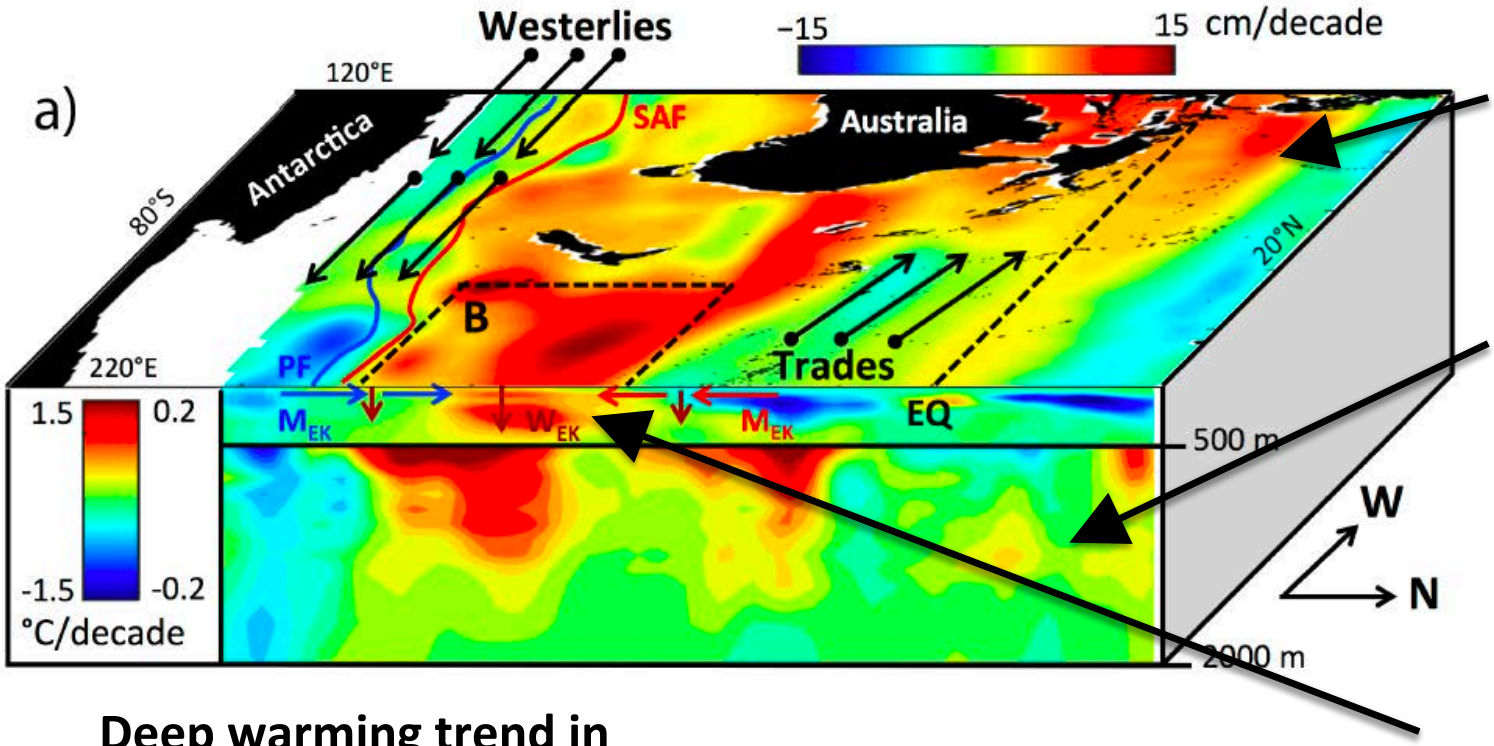


Cumulative sum of Ekman pumping anomaly (blue) and heat content anomaly (red) averaged over box B in the South Pacific. The time series are smoothed with a yearly running mean. The monthly Niño3.4 index scaled by 2 is shown by grey-shaded area.



South Pacific Deep Ocean Warming - Causes
The full picture

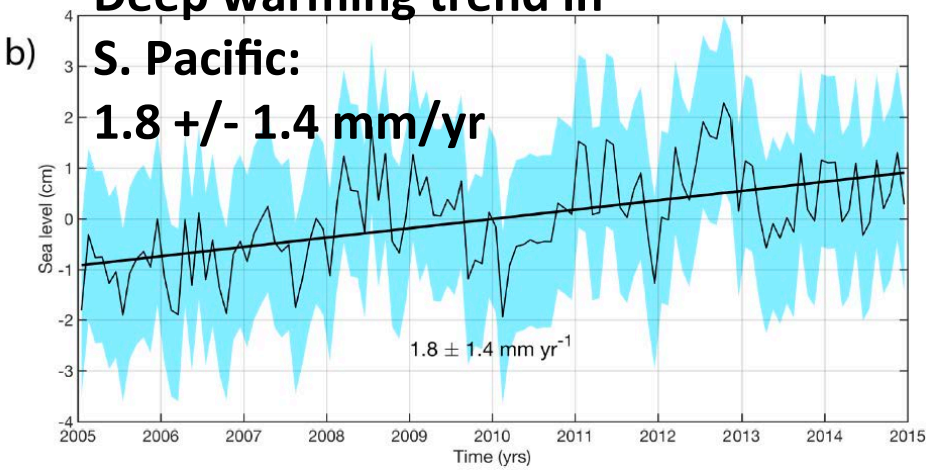




Decadal trends of steric sea level (altimetry minus GRACE)

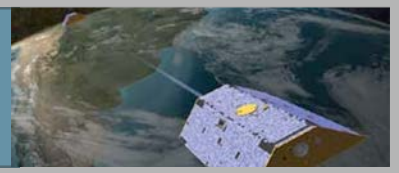
temperature profile at 220°E 2005-2014

Deep warming trend in S. Pacific:
1.8 +/- 1.4 mm/yr



Winds drive Ekman transports
-> converge in subtropical South Pacific
-> intensification of downward Ekman pumping

Summary



- first evidence of consistency between indirect and direct deep-ocean warming in subtropical South Pacific;
- likely driven (at least favored) by persistent wind-driven convergence intrinsic to La Niña-like conditions; suggests this warming is interannual variation;
- the S. Pacific deep-ocean contributed from 2.4 up to 10.1% of the total global ocean mean steric sea level / ocean heat increase
- For GRACE processing: Mean pole correction is crucial

Volkov, D. L., S.-K. Lee, F. W. Landerer, and R. Lumpkin (2016), Decade-long deep-ocean warming detected in the subtropical South Pacific, Geophys. Res. Lett., 44, doi:10.1002/2016GL071661.