Weighing the ocean with bottom-pressure sensors

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PROBLEM

The total mass of water in the ocean flucuates with seasonal changes in water storage on the continents. We use ocean bottom pressure measurements from 17 tropical sites to determine the annual cycle of ocean mass. We show that such a calculation is robust, and use three methods to estimate errors in the mass determination. The simultaneous fitting of annual ocean mass also improves the fitting of bottom pressure instrument drift.

The bottom pressure $p_{\rm rec}$ measured by a given sensor is due to:

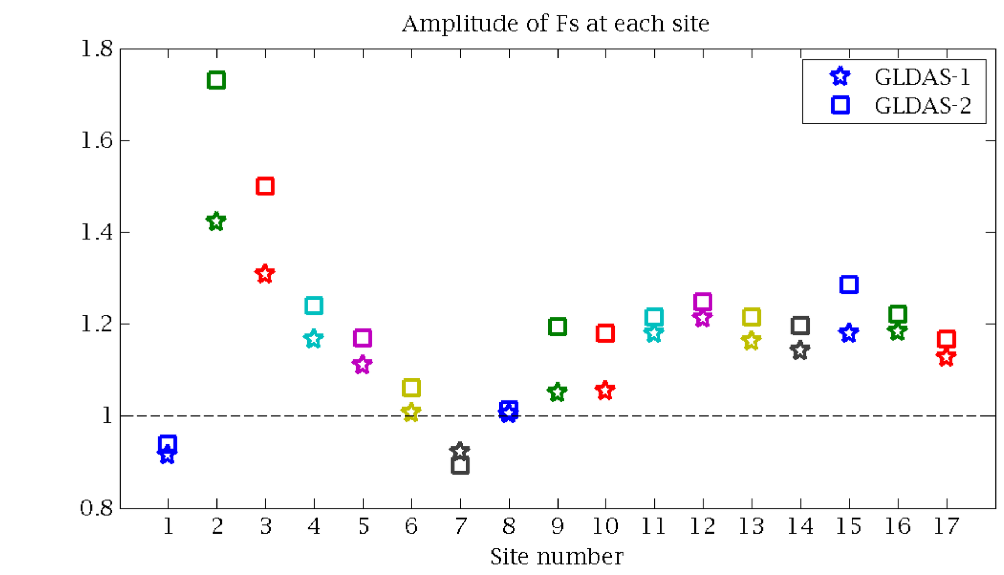
$$\underbrace{p_{\rm rec} = p_{\rm drift}}_{\text{sensor}} + \underbrace{p_{\rm dyn}}_{\text{ocean model eg NEMO}} + \underbrace{p_t}_{\text{tides fitted}} + \underbrace{p_a}_{\text{air ECMWF}} + \underbrace{p_m}_{\text{global mass}}.$$

SPATIAL VARIABILITY OF MASS SIGNAL

The pressure p_m felt at an invididual site is not the same as m_o, the global-average mass change, that we are trying to measure. This is because as water is redistributed around the earth the geoid (gravitational level surface) changes, and due to the load on the crust the sea floor moves. For the annual component, we can assume there is a function F_s such that

$$p_m = F_s(m_o).$$

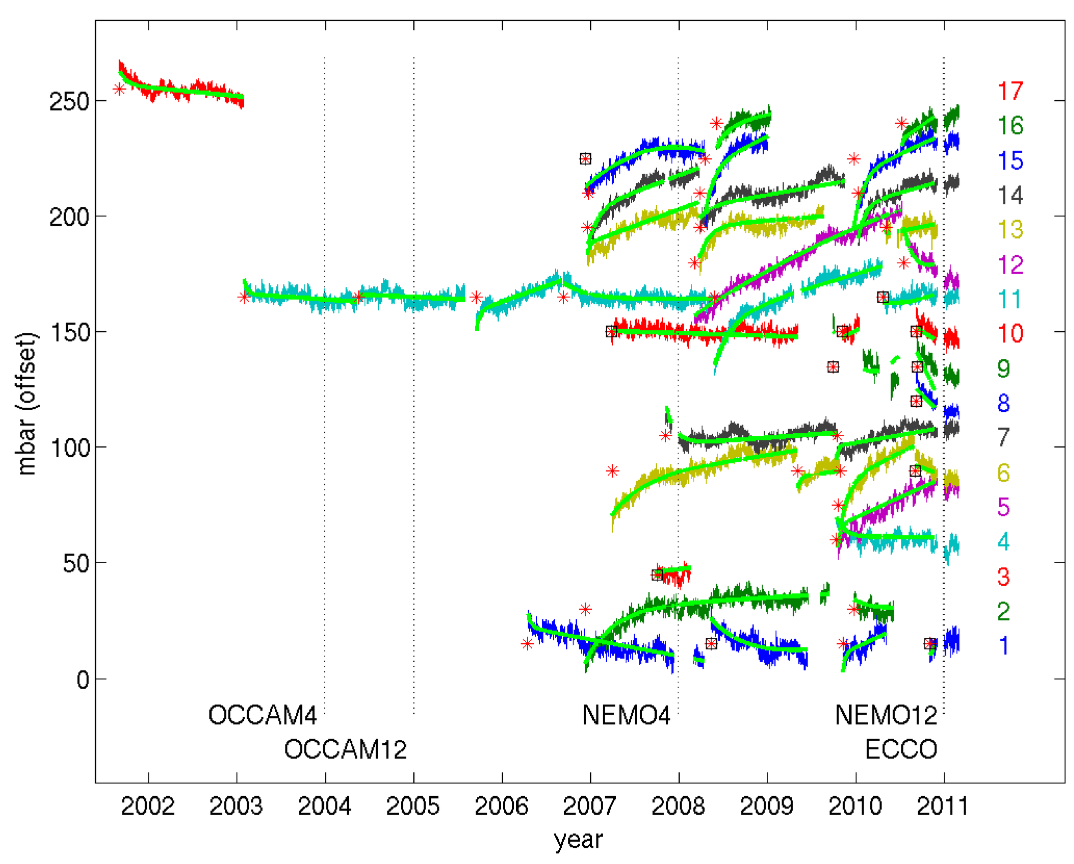
(In general F_s is dependent not just on the site location but on the distribution of ocean and continental water mass, so cannot be assumed to be stationary.)



F_s is derived from GLDAS hydrology models, with GRACE corrections for Antarctica and Greenland. The phase also varies between sites. Sites 11 and 17 in the Pacific are far enough from land to be almost independent of the source of additional mass, so at these sites the amplitude of F_s is almost constant.

DRIFT FITTING

Bottom pressure data, high-frequency tides removed



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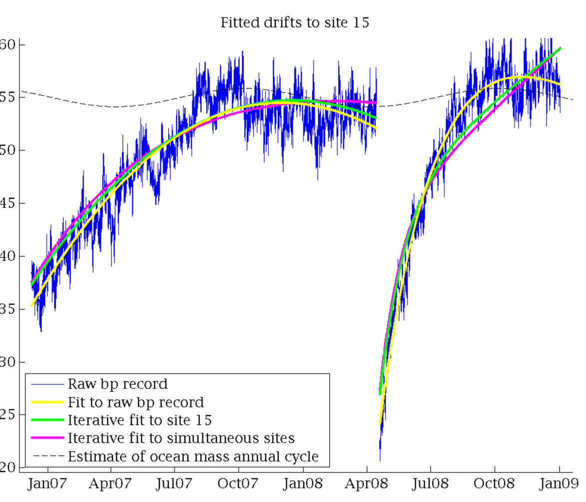

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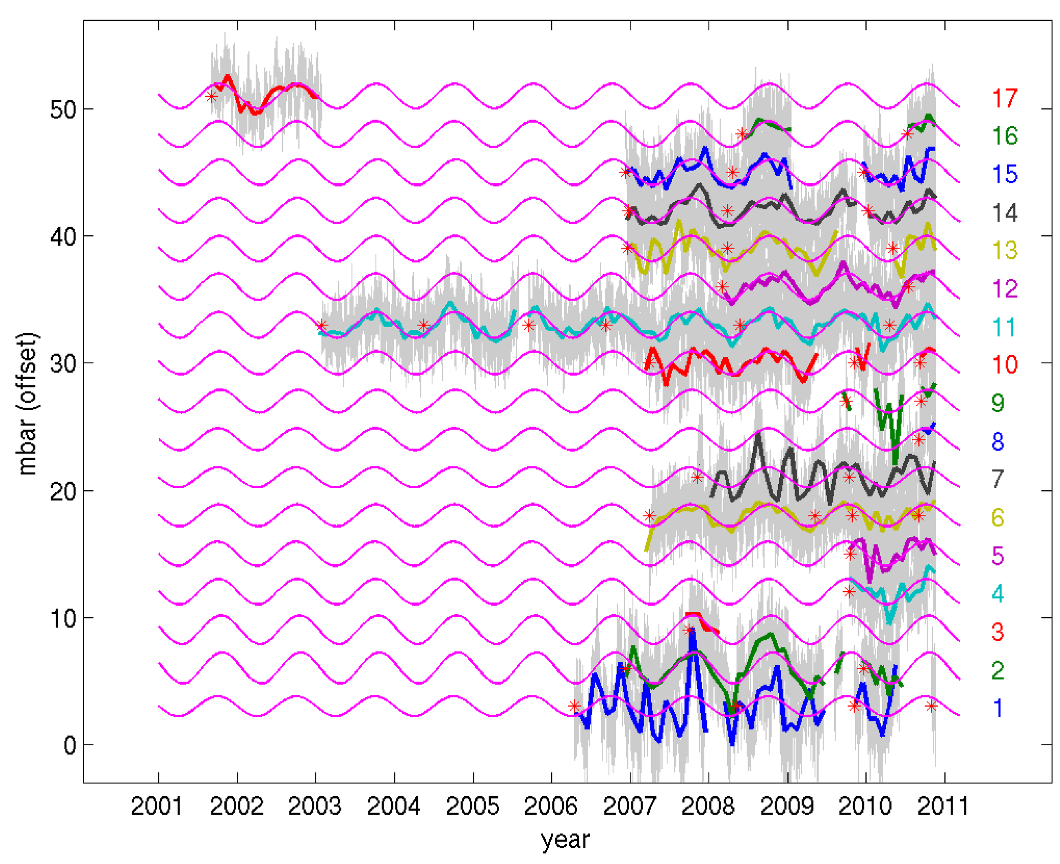
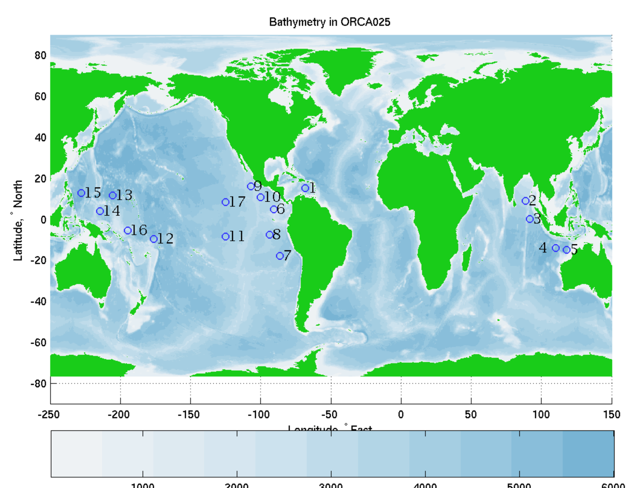
Site pressure due to global mass change

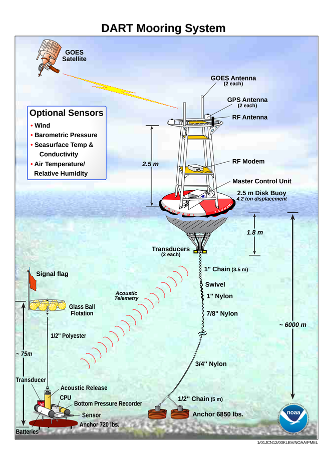


\- SAL-corrected ocean model, long-period tides, atmosphere

Bottom pressure sensors suffer from drift that can be larger than the annual cycle of bottom pressure. We assume that the drift is of the form $p_{\rm drift} = a_1 + a_2 t + a_3 e^{-t/|a_4|}$. To prevent our fitted drift from absorbing the annual cycle, we use an iterative process to remove other signals (tides, atmosphere, ocean dynamics) from the drift and fit the annual cycle of ocean mass at the same time as the sensor drift. By fitting simultaneously to multiple sites we can find drifts even for short records.

BOTTOM PRESSURE RECORDS

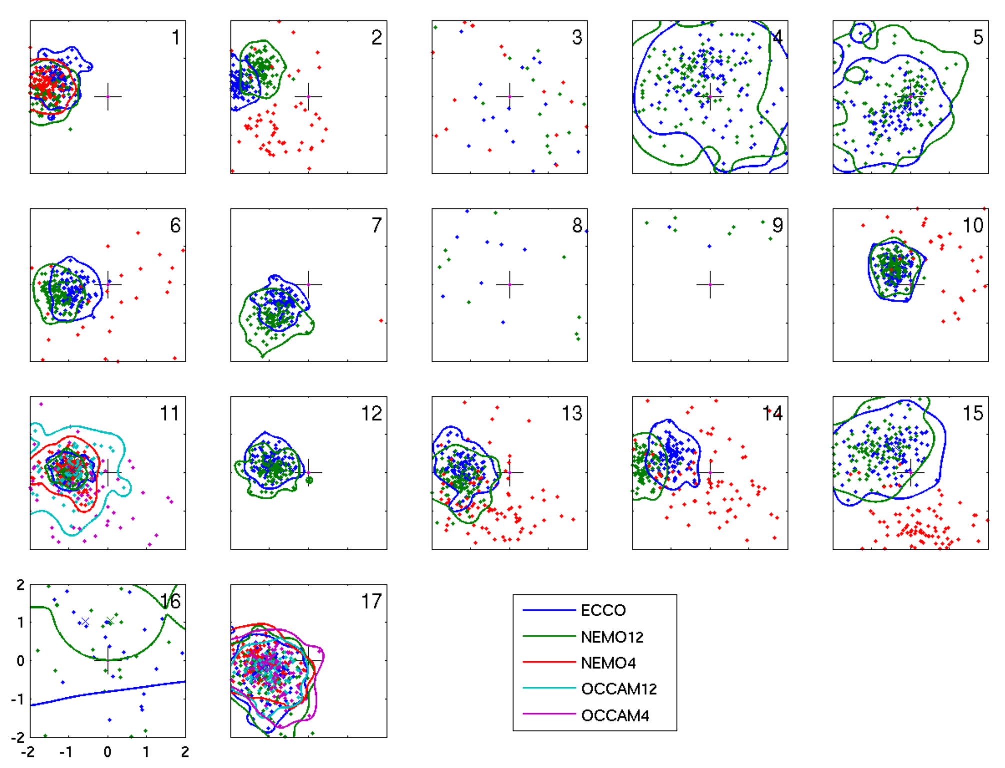




Bottom pressure data came from 17 tsunami monitoring stations in the equatorial ocean. We remove high-frequency tides by fitting, but tides longer than a month are modelled and corrected for self-attraction and loading.

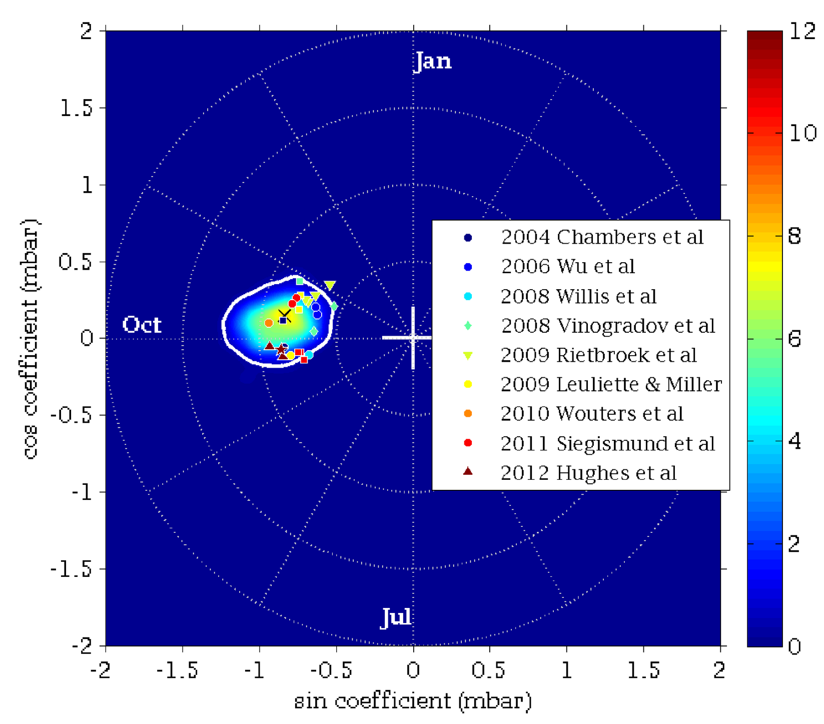
SPREAD OF RESULTS

We add noise with the spectrum of the residual errors in our model, to test the robustness of the fit to each single site. This also depends on the length of overlap with the dynamical model data. In general, longer records are more reliable.



Annual cycle at each site with noise added (axes as final panel)

BEST ESTIMATE



Probability distribution function (colours) of annual amplitude and phase for best sites (6, 10–15, 17) simultaneously with noise added, using both ECCO and NEMO12. 95% of noise results fall inside the white contour.

Our best estimate is that the annual cycle has an amplitude of 0.85 mbar (equivalent to 8.4 mm of sea level, or 3100 Gt of water), peaking at 10 October.

REFERENCES

[1] Hughes, C. W., Tamisiea, M. E., Bingham, R. J., and Williams, J.: Weighing the ocean: Using a single mooring to measure changes in the mass of the ocean, Geophysical Research Letters, 39, L17602, doi:10.1029/2012GL052935, 2012.

[2] Williams, J., Hughes, C. W., Tamisiea, M. E., and Williams, S. D. P.: Weighing the ocean with bottom-pressure sensors: Robustness of the ocean mass annual cycle estimate., Ocean Science (Submitted 2013)

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