Consistent multi-technique geodetic estimates of present-day contributions to regional sea level change (NE/F102519/1)

Peter.Clarke@newcastle.ac.uk

Peter Clarke[1], Philip Moore[1], David Lavallée[2,1], Mark Tamisiea[3], Chris Hughes[3], Richard Gross[4], Pascal Willis[5,6], Matt King[1], Nigel Penna[1], and many others

[1] School of Civil Engineering and Geosciences, Newcastle University, UK • [2] DEOS, Faculty of Aerospace Engineering, Technical University of Delft, Netherlands • [3] NERC Proudman Oceanographic Laboratory, Liverpool, UK • [4] NASA Jet Propulsion Laboratory, Pasadena, USA • [5] Institut Géographique National, Marne-la-Vallée, France • [6] Institut de Physique du Globe de Paris, France

1. Introduction

Changes in sea level will not be the same world-wide, because the oceans must respond gravitationally to the changes in water mass situated on the continents, as ice sheets thicken or melt and other stores of water accumulate or drain into the oceans (the total water mass must remain fixed). We can use these patterns of change in sea level to identify the contributing factors to sea level rise: in principle, each locality of varying continental water storage will produce a different "fingerprint" of sea level variation (Tamisiea *et al*., 2001), although in practice we can only resolve changes over areas spanning several hundreds of kilometres (Figure 1).

At decadal timescales, globally-averaged sea level will change either (1) because there is a change in the mass of water in the ocean, or (2) because the ocean has expanded in volume due to changes in its temperature and/or salinity. Here, we seek to evaluate the extent of these two effects.

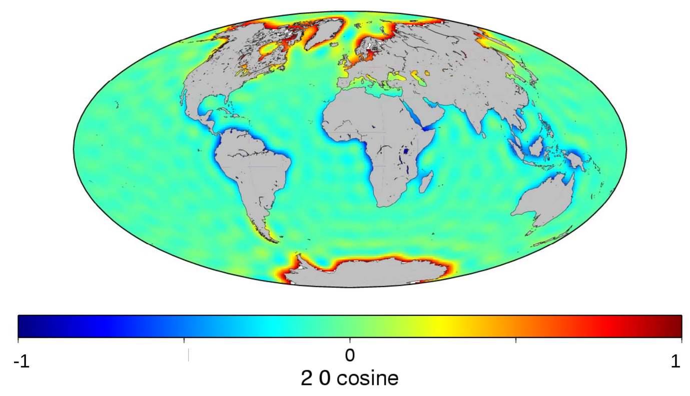

Figure 1. Non-uniform "fingerprint" of sea level response due to a unit decrease in equatorial continental water storage (and corresponding increase in high-latitude continental water storage).

2. Measures of sea level change

In dealing with sea level, we must recognise that there are two ways of measuring it: geocentric (also known as "global" or "absolute") sea level, measured with respect to the centre of mass of the whole Earth-ocean-atmosphere system, and relative sea level, measured with respect to the Earth's surface (Blewitt & Clarke, 2003). Relative sea level is what is important to coastal communities, but it varies from place to place (a) because the land may be moving vertically due to plate tectonics, glacio-isostatic adjustment (GIA, also known as post-glacial rebound), present-day changes in the pattern of mass weighing on the Earth's surface, and local effects, and (b) because in addition to steric changes, the ocean responds non-uniformly to the changed gravity field of the Earth system (Figure 2).

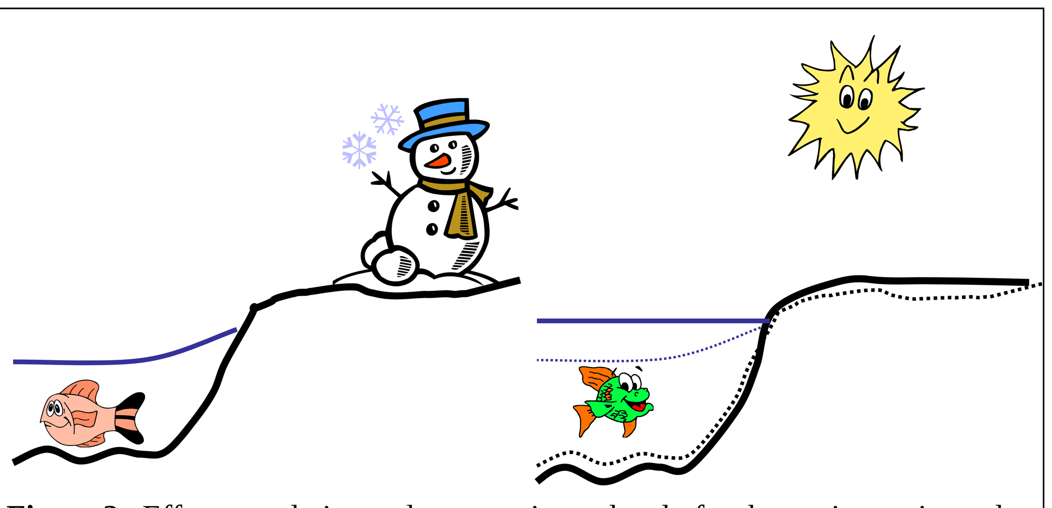

Figure 2. Effect on relative and geocentric sea level of a change in continental water storage. Note the non-uniformity both in the vertical land motion and in the ocean response.

These variations make it important to calibrate relative sea level observations, to avoid bias in their global average; conversely, the impact of geocentric sea level change can only be understood if we know the expected vertical movement of the land. "Fingerprinting" provides a unified framework in which the land load and ocean response can be estimated together.

3. Geodetic observations

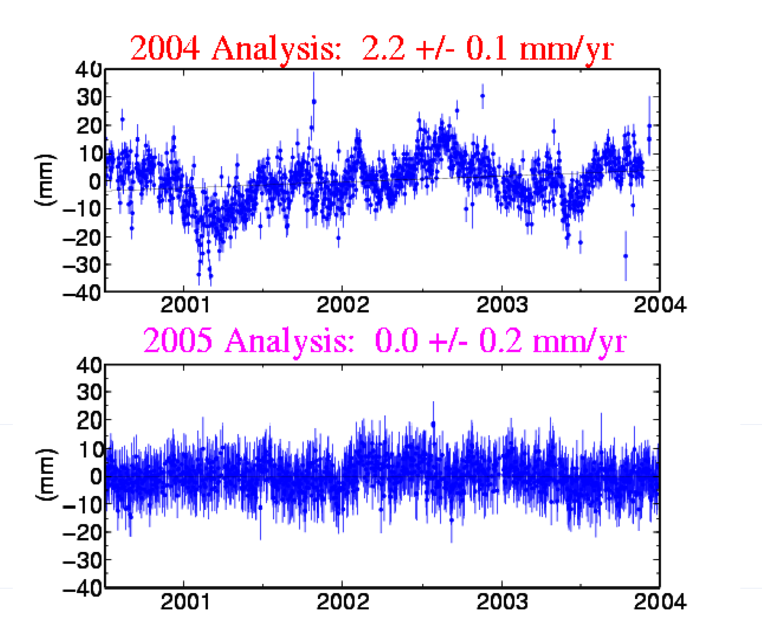

Figure 3. Contrast between old and reanalysed GPS coordinate time series, showing spurious seasonal signals and trend [figure courtesy Paul Tregoning, ANU].

In this project, we will bring together a wide range of geodetic measurements. Direct observations of the changing gravity field of the Earth, from the GRACE twin-satellite mission and from laser and microwave ranging to other satellites, will constrain the changes in oceanic and continental water mass distribution. Measurements of the changes in Earth's shape, again from laser and microwave ranging to satellites including GPS, will also constrain the loading effects of this mass redistribution on the solid Earth.

In contrast, satellite radar altimetry will measure the sea surface height (including both mass change and thermal expansion) with respect to the Earth system's centre of mass; tide gauges will measure sea surface height with respect to the local land surface, but many of them can have their vertical land movements calibrated with GPS. Of particular relevance is NERC responsive-mode project NE/E007023/1 (PI: King, 2007-2010) in which we will reanalyse nearly two decades of GPS data, to improve estimates of tide gauge motion and GIA. This reanalysis is essential because of biases in earlier analyses (Figure 3) which cause both systematic and random errors. Our efforts relate to the International GNSS Service (IGS) Tide Gauge Benchmark Monitoring (TIGA) and global reanalysis projects, to which we contribute.

The differences between these various sea surface and ocean mass estimates will help constrain the oceanic heat and salinity content, which can be compared with the sparse data and models that exist. We will then be able to identify the recent and likely future contributions of different locations of continental water storage, and oceanic heat/salinity content, to sea level rise.

4. Seasonal and secular changes

At short-term (e.g. seasonal) timescales, gravity changes and deformation due to time-varying loading and sea level can easily be separated from GIA and tectonic deformation, which show steady (secular) behaviour. In concurrent responsive-mode project NE/E017495/1 (PI: Lavallée/Clarke, 2008-2011), we are developing methods to separate these phenomena at longer timescales by taking advantage of (a) assumptions of lateral plate rigidity (e.g. Kreemer *et al*., 2007), (b) basis functions that explicitly parameterise the load in a mass-conserving and gravitationally consistent manner (Clarke *et al*., 2005, 2007), (c) combined constraints on deformation using GPS/SLR/DORIS and gravity using GRACE/SLR, and (d) an ensemble of credible models of GIA (e.g. Tosi *et al*., 2005) to act as constraints. This will result in a more rigorous definition of the evolution of the terrestrial reference frame (Lavallée *et al*., 2006), and we will therefore be in a position to apply our sea level analysis at all timescales within the geodetic observation record.

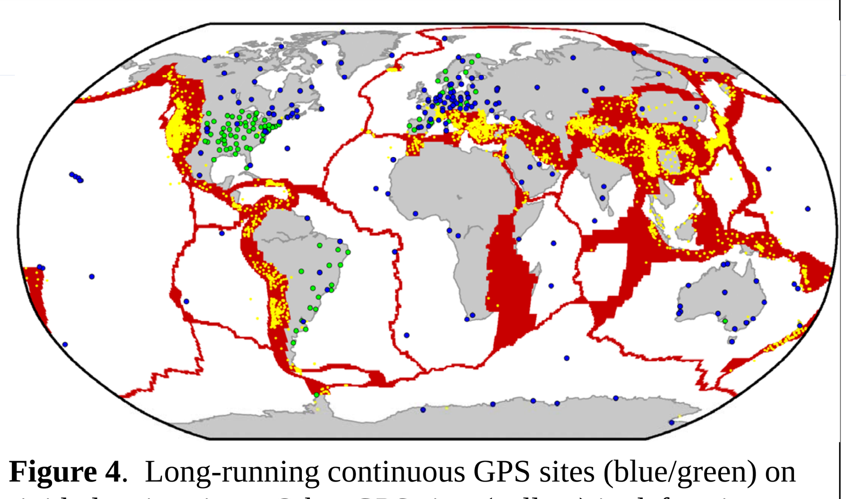

Figure 4. Long-running continuous GPS sites (blue/green) on rigid plate interiors. Other GPS sites (yellow) in deforming plate boundary zones (red) are also shown.

5. Outlook

Work will begin in late 2008. At first we will carry out synthetic calculations to test and improve numerical accuracy of the "fingerprinting" method, and to incorporate a suitable parameterisation of steric sea level changes. Reprocessed GPS data from project NE/E007023/1 will become available from late 2009, although we can in the meantime carry out trials using the less densely sampled IGS Reanalysis dataset, which does not include as many tide gauge sites. We will apply our techniques to the corrected tide gauge data, first with the GPS/DORIS/altimetry (and GRACE) data, and then with the longer history of SLR data, to identify continental sources/sinks of water (including snow/ice) and steric ocean changes. Finally, we will investigate the possible effects of future changes in continental water storage on sea level.

References

Blewitt, G., & P. Clarke (2003). Inversion of Earth's changing shape to weigh sea level in static equilibrium with surface mass redistribution. *J. Geophys. Res.*, 108(B6), 2311.
Clarke, P.J., D.A. Lavallée, G. Blewitt, T. van Dam, & J.M. Wahr (2005). Effect of gravitational consistency and mass conservation on seasonal surface loading models. *Geophys. Res. Lett.*, 32(8), L08306.
Clarke, P.J., D.A. Lavallée, G. Blewitt & T. van Dam (2007). Basis functions for the consistent and accurate representation of surface mass loading. *Geophys. J. Int.*, 171(1), 1–10.
Kreemer, C., D.A. Lavallée, G. Blewitt & W.E. Holt (2006). On the stability of a geodetic no-net-rotation frame and its implication for the International Terrestrial Reference Frame. *Geophys, Res, Lett,*, 33, L17306.
Lavallée, D.A., T. van Dam, G. Blewitt & P.J. Clarke (2006). Geocenter motions from GPS: A unified observation model. *J. Geophys. Res.*, 111, B05405.
Tamisiea, M.E., J.X. Mitrovica, G.A. Milne & J. L. Davis (2001). Global geoid and sea-level changes due to present-day ice mass fluctuations. *J. Geophys. Res.*, 106, 30,849-30,864.
Tosi, N., R. Sabadini, A.M. Marotta & L.L.A. Vermeersen (2005). Simultaneous inversion for the Earth's mantle viscosity and ice mass imbalance in Antarctica and Greenland. *J. Geophys. Res.*110, 1-14.

Acknowledgements

This work is funded in the UK by NERC grants NE/F102519/1 (SOFI) to PJC, NE/E017495/1 to DAL/PJC and NE/007023/1 to MAK, and by a variety of agencies in other countries. It would be impossible without continued free data provision from the International GNSS Service, the International Laser Ranging Service (including the NERC Space Geodesy Facility), the International DORIS Service, the NASA/DLR GRACE mission, various NASA and ESA satellite altimetry missions, and the Permanent Service for Mean Sea Level.