Supplementary material to "Applying Spaceborne Gravity Measurements to Ocean Studies"

26 April 2011

Victor Zlotnicki, Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Detlef Stammer, KlimaCampus, University of Hamburg, Hamburg, Germany

Citation:

Zlotnicki, V., and D. Stammer (2011), Applying spaceborne gravity measurements to ocean studies, *Eos Trans. AGU*, *92*(17), 145, doi:10.1029/2011EO170007. (View the full article at http://www.agu.org/journals/eo/v092/i017/2011EO170007/2011EO170007_mtg.pdf.)

Twenty-five scientists, with expertise in Physical Oceanography, Geodesy, Cryospheric Science, Geophysics and tides, met at the University of Hamburg's KlimaCampus during September 29 and 30, 2010 to discuss current analyses and future applications of spaceborne gravity measurements to studies of ocean circulation, cryospheric science and sea level rise. The CHAMP, GRACE and GOCE satellites, complemented with radar altimeters (Jason-2, Envisat and their predecessors) provide the necessary data.

Meeting attendees and their institutions were, in no special order, Jens Schroeter (Alfred Wegener Institute for Polar and Marine Research [AWI], Germany), Frank Segismund (U. Hamburg [UH], Germany), Rui Ponte (Atmospheric and Environmental Research, USA), Felix Landerer (Jet Propulsion Laboratory, California Institute of Technology [JPL], USA), Carmen Boning (JPL), James Morison (Applied Physics Laboratory, University of Washington, USA), W. Steve Nerem (University of Colorado [CU],USA), Scott Luthcke (Goddard Space Flight Center [GSFC], USA), Richard Ray (GSFC), Y. Tony Song (JPL), Don

Chambers (U. of South Florida, USA), Torsten Kanzow (Institute for Marine Sciences of the U. of Kiel-GEOMAR, Germany), John Wahr (CU), Johnny Johannesen (Nansen Environmental and Remote Sensing Center, Norway), Per Knudsen (Technical University of Denmark), Rory Bingham (U. of Newcastle, UK), Andreas Macrander (AWI), Henryk Dobslaw (Geoforschung Zentrum Potsdam, Germany), Reiner Rummel (Technical University of Munich [TUM], Germany), Martin Horwath (TUM), Thomas Gruber (TUM) , Chris Hughes (National Ocean Center [NOC], UK), Mark Tamisiea (NOC), Detlef Stammer (UH), Victor Zlotnicki (JPL).

Space-borne gravity measurements provide two important quantities for ocean circulation studies: 1) the time-averaged geoid, which when subtracted from a time-mean sea surface (MSS) from radar altimetry provides the absolute surface dynamic topography and absolute surface geostrophic currents; 2) time changes in ocean bottom pressure (OBP) and total ocean mass. For sea level rise, the difference between the globally-averaged trend from altimetry and that from GRACE infers the top-to-bottom steric component, observable with Argo and XBT data up to their respective depths. The GRACE satellites also yield the total ice mass loss from Greenland, Antarctica and larger continental glaciers, much of which is input to the oceans.

Mean dynamic topographies exist from the combination of geodetic MSS-geoid with *in* - *situ* oceanographic data (Maximenko et al, 2009); we expect them to improve significantly at short wavelengths with the addition of GOCE data.

GRACE observed ice mass loss from Greenland and Antarctica (Velicogna, 2009), and with special processing from glaciers in Alaska (Luthcke et al. 2008) and Patagonia (Chen et al, 2007). Much of this water enters the oceans. Trend retrievals depend critically on either using a model of Glacial Isostatic Adjusment (Chambers et al, 2010, Cazenave, 2009), or estimating it together with the current mass loss; another complication is the coarse 'footprint' of GRACE which mixes signals from neighboring basins (Horwath and Dietrich, 2009).

Ocean bottom pressure signals (of order 10 mbar at high latitudes and ten times smaller at low latitudes) are close to the noise level of GRACE, and require special processing and filtering. Signals larger than several hundred kilometers in extent match those obtained from *in* - *situ* bottom pressure recorders in energetic regions (Park et al, 2008), and have been used to study the Antarctic Circumpolar Current (Ponte and Quinn, 2009), the Arctic (Morison et al, 2007), and interbasin mass exchanges (Chambers and Willis, 2009). The data are now successfully assimilated into numerical ocean models (Schroeter, pers. comm.; Stammer, pers. comm.) although current models lack some of the physics measured by GRACE (loading and self attraction; mass conservation, Vinogradova et al, 2010); the global ocean mean constrains the total freshwater flux.

In summary, time-averaged and time-varying satellite gravity data have demonstrated to be instrumental physical oceanographic and sea level rise studies. The discussions centered on future processing, future applications of GRACE-like data, and future missions. Future processing includes improved dealiasing fields, 'mascon' estimates. Future missions include an expected GRACE Continuity mission, strongly endorsed by the attendees, approved by NASA and under study in Germany for launch in 2016, which is expected to close the gap between GRACE and missions under discussion for launch in the 2020s. From the improved processing and the future missions we expect more accurate retrievals over smaller regions. Longer time series are essential to obtain stable estimates of trends in the presence of natural variability. OBP signals are small and require accurate removal of land signals, whether continental hydrology, strong earthquakes, or glacial isostatic adjustment. The addition of bottom pressure recorders at TOGA TAO locations would yield the overall ocean mass variability precisely because the region is dynamically quiet. It is time GRACE studies go beyond the barotropic response to wind (Bingham and Hughes, 2009)

Acknowledgements

This work was performed, in part, at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Partially funded through the excellence initiative “CLISAP” of the University of Hamburg.

References

Cazenave A., K. Dominh, S. Guinehut, et al. (2009) Sea level budget over 2003–2008: A reevaluation from GRACE space gravimetry, satellite altimetry and Argo. Global and Planetary Change 65 (2009) 83–88

Chambers, D. P., and J. K. Willis (2009), Low-frequency exchange of mass between ocean basins, J. Geophys. Res., 114, C11008, doi:10.1029/2009JC005518.

Chambers, D. P., J. Wahr, M. E. Tamisiea, and R. S. Nerem (2010), Ocean mass from GRACE and glacial isostatic adjustment, J. Geophys. Res., 115, B11415, doi:10.1029/2010JB007530.

Chen J.L., C.R. Wilson, B.D. Tapley, et al (2007) Patagonia icefield melting observed by GRACE, *Geophys. Res. Lett.* vol. 34 (No. 22) (2007), p. L22501 10.1029/2007GL031871

Horwath M. and R. Dietrich (2009) Signal and error in mass change inferences from GRACE: the case of Antarctica. Geophys. J. Int. (2009) 177, 849–864

Luthcke S.B., A.A. Arendt, D. Rowlands, et al (2008), Recent glacier mass changes in the Gulf of Alaska region from GRACE mascon solutions. J. of Glaciology, v54 (188), 767-777.

Maximenko N., P. Niiler, M.-H. Rio, et al. (2009) Mean Dynamic Topography of the ocean derived from satellite and drifting buoy data using three different techniques. J. Oceanic and Atmosph. Tech., v 26, pp 1910-1919.

Morison, J., J. Wahr, R. Kwok, and C. Peralta-Ferriz (2007), Recent trends in Arctic Ocean mass distribution revealed by GRACE, Geophys. Res. Lett., 34, L07602, doi:10.1029/2006GL029016.

Park, J.-H., D. R. Watts, K. A. Donohue, and S. R. Jayne (2008), A comparison of in situ bottom pressure array measurements with GRACE estimates in the Kuroshio Extension, Geophys. Res. Lett., 35, L17601, doi:10.1029/2008GL034778

Ponte, R. M., and K. J. Quinn (2009), Bottom pressure changes around Antarctica and wind-driven meridional flows, Geophys. Res. Lett., 36, L13604, doi:10.1029/2009GL039060.

Velicogna, I. (2009), Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE, Geophys. Res. Lett., 36, L19503, doi:10.1029/2009GL040222.

Vinogradova, N. T., R. M. Ponte, M. E. Tamisiea, J. L. Davis, and E. M. Hill (2010), Effects of self-attraction and loading on annual variations of ocean bottom pressure, J. Geophys. Res., 115, C06025, doi:10.1029/2009JC005783