GSTM 2014 - Abstractlist 01.10.

08:30 B.3

Christopher G. Piecuch, Rui M. Ponte

Presenter Rui M. Ponte

Annual Cycle in Southern Tropical Indian Ocean Bottom Pressure

The seasonal monsoon drives a dynamic response in the southern tropical Indian Ocean, previously observed in baroclinic Rossby wave signatures in annual sea level and thermocline depth anomalies. Here monthly mass grids based on Release-05 Gravity Recovery and Climate Experiment (GRACE) data are used to study the annual cycle in southern tropical Indian Ocean bottom pressure. To interpret the satellite data, a linear model of the ocean's response to wind forcing?based on the theory of vertical normal modes and comprising baroclinic and barotropic components?is considered. The model is evaluated using stratification from an ocean atlas and winds from an atmospheric reanalysis. Good correspondence between model and data is found over the southern tropical Indian Ocean: the model explains 81% of the annual variance in the data on average between 10S and 25S. Model solutions suggest that, while the annual baroclinic Rossby wave has a seafloor signature, the annual cycle in the deep sea generally involves important barotropic dynamics, in contrast to the response in the upper ocean, which is largely baroclinic.

08:45 B.3

Rui M. Ponte, Christopher G. Piecuch

Presenter Rui M. Ponte

Interannual Bottom Pressure Signals in the Australian-Antarctic and Bellingshausen Basins

Analyses of large-scale (greater than 750 km) ocean bottom pressure (OBP) fields, derived from GRACE and from an Estimating the Circulation and Climate of the Ocean (ECCO) state estimate, reveal enhanced interannual variability, partially connected to the Antarctic Oscillation, in regions of the Australian-Antarctic Basin and the Bellingshausen Basin. The OBP magnitudes are comparable to those of sea level and there is good correlation between the GRACE and ECCO OBP series. Consistent with the theory of Gill and Niiler, the patterns of stronger OBP variability are partly related to enhanced local wind curl forcing and weakened gradients in H/f, where H is ocean depth and f is the Coriolis parameter. Despite weaker H/f gradients, motions against them are sufficiently strong to play a role in balancing the local wind input. Topographic effects are as or more important than changes in f. Additionally, and contrary to the dominance of barotropic processes at subannual time scales, baroclinic effects are not negligible when balancing wind input at periods of a few years. Results highlight the emerging capability to accurately observe and estimate interannual changes in large-scale OBP over the Southern Ocean, with implications for the interpretation of low-frequency variability in sea level in terms of steric height and heat content.

09:00 B.3

B. Uebbing, J. Kusche, R. Rietbroek, C.K. Shum, Z.H. Khan

Presenter J. Kusche

Partitioning Regional Sea Level in the Bay of Bengal from a Global GRACE and Jason-1/-2 Joint Inversion

In Bangladesh, large areas are just above sea level (SL). Present-day SL rise and land subsidence pose a major threat to the coastal region, home of 30 million people. As part of the Belmont-project "Bangladesh Delta: Assessment of the Causes of Sea-level Rise Hazards and Integrated Development of Predictive Modeling Towards Mitigation and Adaptation" (BAND-AID) a global inverse method is employed to estimate SL contributors such as melting of glaciers/ice-sheets, hydrology, GIA, and shallow/deep steric effects from Jason-1/2 altimetry and GRACE. In the global method, fingerprints are computed a-priori for each process, applying the sea level equation for mass loss, and empirically for steric pattern from ARGO. GRACE data and along-track Jason-1/ -2 altimetry are then combined to estimate the temporal evolution of these patterns, which allows the partitioning of altimetric SL. The method largely mitigates truncation/leakage problems associated with GRACE resolution. Globally, our estimates are close to others, yet they point at a somewhat larger deep steric effect. We provide preliminary results for the Bay of Bengal by confronting global inversion with local measurements. Estimated trends are compared to tide gauges; differences are interpreted in terms of un-modeled regional effects such as land subsidence. Initial results provide an indication on the magnitude of contributions from different sources; e.g. the contribution from Greenland ice-sheets between 2003 and 2011 is significantly larger compared to Antarctica, but the biggest effect results from steric changes.

09:15 B.3

Jessica Makowski, Don P. Chambers, Jennifer Bonin

Presenter Jessica Makowski

Using GRACE Ocean Bottom Pressure to Observe Mass Transport of the Antarctic Circumpolar Current

Previous studies have shown that ocean bottom pressure can be used to calculate the transport variability of the Antarctic Circumpolar Current (ACC). The ocean bottom pressure (OBP) observations from the Gravity Recovery and Climate Experiment (GRACE) has been used to calculate transport of the Antarctic Circumpolar Current (ACC) between Antarctica and south of Australia, and in the southern portion of the Indian Ocean. We have used a statistical model to estimate the uncertainty of the GRACE observations using a simulated OBP data set. We will look at the coherency between the Southern Annular Mode (SAM) and the transport variability of the ACC in the south Indian Ocean at low-frequencies. Further, we will observe the relationship between ACC low-frequency transport variability in the south Indian Ocean and low-frequency zonal winds. Preliminary results show a negative trend in the transport variability of the ACC in this region. Investigations into potential forcing mechanisms for this negative trend will also be presented.

09:30 **B.3**

S.-C. Han, R. Ray

Presenter R. Ray

High-frequency (20 - 60 days) ocean mass variation over the Argentine basin observed from GRACE satellite gravity

The variability of the GRACE monthly gravity fields to the resolution of 500 km (i.e., spherical harmonic degree 40) is generally in 1 - 2 cm (equivalent water height) over most of the ocean. The ocean mass variations are largest with 5 cm in RMS over the southern ocean and the north Pacific. They are well reproduced by the ocean models such as OMCT and MOG2D. These models are adopted to correct the high frequency ocean signals for the GRACE gravity fields ('dealiasing'). With such models applied, the GRACE found the ocean signals as large as 5 cm localized over the Argentine Basin. It indicates inefficacy of the ocean models simulating certain variations in the basin. The previous studies reported the counterclockwise rotational propagation with a period of 25 days around the basin from the satellite altimetry data. We examined the GRACE data to verify such signatures in the gravity data processed at 10 days and monthly intervals. We present the high-frequency (20 - 60 days) dipole patterns of ocean mass anomalies identified from the GRACE gravity data and compare with the satellite altimetry data.

09:45 **B.3**

Ichiro Fukumori, Ou Wang, William Llovel, Ian Fenty, Gael Forget

Presenter Ichiro Fukumori

Coherent Near-Uniform Fluctuations of Ocean Bottom Pressure and Sea Level across the Arctic Ocean and the Nordic Seas

A basin-wide mode of ocean bottom pressure and sea level fluctuation is identified in the Arctic Mediterranean using GRACE observations and in situ measurements in conjunction with a global ocean circulation model and its adjoint. The fluctuation extends across the interconnected deep ocean basins of the Arctic Ocean and the Nordic Seas with near-uniform amplitude and phase, uncorrelated from variations in the shallow seas. The coherent fluctuation is barotropic and dominates the region's large-scale variability from sub-monthly to interannual timescales. The model adjoint provides an effective means to identify causal mechanisms and shows that this fluctuation results from bifurcating coastally trapped waves generated by winds along the continental slope surrounding the variation's domain. The winds drive Ekman transport across the bathymetric gradient, creating mass divergence between the shallow coastal area and the deep ocean basins. The anomalies rapidly propagate away as coastally trapped waves that subsequently bifurcate at the shallow straits connecting the Arctic Mediterranean with the rest of the globe. Anomalies that remain in or enter the deep Arctic basins equilibrate uniformly across its domain while shielded from neighboring shallow variations by steep depth-integrated planetary potential vorticity gradients surrounding the basins. Anomalies outside the Arctic adjust similarly across the rest of the globe but are comparatively negligible because of the global ocean's larger area relative to that of the deep Arctic Mediterranean.

10:00 **B.3**

C. G. Piecuch, I. Fukumori, R. M. Ponte, O. Wang

Presenter Ichiro Fukumori

Vertical Structure of Ocean Pressure Variations with Application to Satellite-Gravimetric Observations

The nature of ocean bottom pressure (OBP) variability is considered on large spatial scales and long temporal scales. Monthly gridded estimates from GRACE Release-05 and the new Version 4 bi-decadal ocean state estimate of the Consortium for Estimating the Circulation and Climate of the Ocean (ECCO) are used. Estimates of OBP from GRACE and ECCO are generally in good agreement, providing an independent measure of the quality of both products. Diagnostic fields from the state estimate are used to compute barotropic (depth-independent) and baroclinic (depth-dependent) OBP components. The relative roles of baroclinic and barotropic processes are found to vary with latitude and time scale: variations in OBP at higher latitudes and shorter periods are effected by barotropic processes, whereas OBP fluctuations at lower latitudes and longer periods can be influenced by baroclinic effects, broadly consistent with theoretical scaling arguments. Wind-driven Rossby waves and coupling of baroclinic and barotropic modes due to flow-topography interactions appear to be important influences on the baroclinic OBP variability. Decadal simulations of monthly OBP variability based on purely barotropic frameworks are expected to be in error by about 30% on average. Results have implications in applying observations from GRACE such as in estimating Antarctic Circumpolar Current transports.

10:15 **B.3**

Katrin Bentel, Felix W. Landerer, Carmen Boening

Presenter Katrin Bentel

Monitoring Atlantic overturning circulation variability with GRACE-type gravity observations

The Atlantic Meridional Overturning Circulation (AMOC) is a key mechanism in basin-scale northward heat transport and thus plays an important role for global climate. In the North Atlantic, warmer water from the subequatorial region is transported northward in the upper layers of the ocean. After cooling at higher latitudes, the water sinks down and is transported back southward. This process has important influence on the climate regime in the Earth's northern hemisphere, in particular in Northwestern Europe. Coherence between ocean bottom pressure (OBP) and the AMOC has been characterized in theoretical and simulation studies. Here, we use output from the ocean state estimate ECCO2. We use the model data to (1) evaluate to what extent space-based observations of time-variable gravity and the inversion for ocean bottom pressure can be used to observe AMOC variability, and (2) to test algorithms to extract the AMOC signal from GRACE-like OBP observations. In the ocean state estimate, we find a strong correlation between the AMOC signal and local OBP variations, and are able to reconstruct AMOC variations from OBP anomalies at the model's resolution. Model outputs are smoothed and filtered to resemble the spatial resolution of GRACE. Decreased spatial sensitivity and signal leakage at some latitudes introduce significant errors in the reconstruction of the AMOC signal. Nevertheless, we show that inter-annual AMOC variations can be recovered at some latitudes, e.g. at 25 N or at 50 N. Ongoing work involves deriving the AMOC signal from recent GRACE OBP solutions.

11:00 **B.3**

W. Llovel, J.K. Willis, F.W. Landerer, I. Fukumori

Presenter Felix W. Landerer

Deep ocean contribution to sea level and energy budget not detectable over the past decade

As the dominant reservoir of heat uptake in the climate system, the world's oceans provide a critical measure of global climate change. Here, we infer deep ocean warming in the context of global sea level rise and Earth's energy budget between January 2005 and December 2013 based on satellite altimetry, GRACE and Argo floats. Direct measurements of ocean warming above 2000m depth explain 0.9 +/- 0.15 mm/yr of the observed 2.78 +/- 0.32 mm/yr rate of global mean sea level rise. Over the entire water column, independent estimates of ocean warming yield a contribution of 0.77+/-0.28 mm/yr in sea level rise and agree with the upper ocean estimate to within the estimated uncertainties. Accounting for additional possible systematic uncertainties, the deep ocean (below 2000m) contributes -0.13 +/- 0.72 mm/yr to global sea level rise and -0.08 +/- 0.43 W/m2 to Earth's energy balance. The net warming of the ocean implies an energy imbalance for the Earth of 0.64 ± 0.44 W/m2 from 2005 to 2013.

11:15 **B.3**

Inga Bergmann-Wolf, Liangjing Zhang, Henryk Dobslaw

Presenter Inga Bergmann-Wolf

Impact of global eustatic sea-level variations for the approximation of geocenter motion from GRACE

Estimating global eustatic sea-level variations from results from the Gravity Recovery and Climate Experiment (GRACE) satellite mission requires additional information of the geocenter motion which is not included due to the mission implementation in the CM-frame. These variations are expressed in the degree 1 terms of the Spherical Harmonic expansion. Global degree 1 estimates can be determined by means of the method of Swenson et al. (2008) from ocean mass variability and GRACE data. Consequently, a recursive relation between estimates of ocean mass variations from GRACE and introducing geocenter motion into GRACE data exists. In this contribution, we will present the impact of the estimated global ocean mass signal on the determination of the geocenter motion. Numerical experiments with a decade-long model time-series reveal that the methodology is generally robust with respect to assumptions on global degree-1 coefficients for the eustatic sea-level model. We also will show, that GRACE based degree 1 estimates show a good correspondance to independent results and let us conclude that this method is suited to be used for oceanographic and hydrological applications of regional mass variability from GRACE.

11:30 **B.3**

Sarah Kwon , Don Chambers

Presenter Sarah Kwon

Understanding Oceanographic Contribution to Polar Motion

The Earth's axis of rotation varies with a long period of 19-24,000 years due to precession caused by gravitational torque due to the Earth not being a perfect sphere. It also 'wobbles' due to other torques. This is caused by mass redistribution within the Earth system, such as land water storage variations or mass transport in the ocean. Other contributing factors include winds hitting mountains or deep-ocean currents hitting seamounts, and resulting in a torque. Ocean mass variations contribute a significant amount to polar motion based on model studies. However, previous studies have not quantified the mechanism of the mass variability that causes these changes. This study will use the JPL_ECCO Ocean Model and observations from the Gravity Recovery and Climate Experiment (GRACE) to look at fluctuations in ocean mass. Our hypothesis is that a recently discovered large-scale mass exchange between the Indo-Atlantic and Pacific Ocean basins may be responsible. This will be tested using a simplified large-scale model of the variability. The ocean model will also be used to examine the contribution of ocean currents. Earth rotation parameters computed from the ocean observations will be compared to observed Earth rotation parameters to test the hypothesis.

11:45 **B.3**

R. Ray, S. Luthcke, J.-P. Boy, M. Schindelegger

Presenter R. Ray

Testing Tide Models and Deducing Tidal Corrections from GRACE Range-Rate Data

This contribution consists of three related investigations that concern GRACE and tides. We first report on a series of comprehensive tests of seven global ocean-tide models - a large, international effort led by Detlef Stammer (Stammer et al., Rev. Geophysics, 2014). Part of these tests consisted of processing 7 years of GRACE range-rate data with each tested tide model and then analyzing the range-rate residuals. Binned tidal analyses of these residuals are extremely useful for delineating regions which GRACE data suggest have problematic tide corrections. Although some models are better than others, no tide model is clearly superior to all others and all have flaws, especially in polar regions. Second, we report on a new analysis of solar atmospheric tides (to which GRACE is very sensitive). We have performed tidal analysis of nearly 7000 surface barometer time series and produced new empirical tidal charts by multiquadric interpolation. We compare these charts with the air-tide models now being used in GRACE processing. Finally we report on some new, but preliminary, inversions of global tides from GRACE range-rate data.

12:00 B.3

R.J. Bingham, K. Haines, D. Lea

Presenter R.J. Bingham

How well can we measure the ocean's mean dynamic topography from space?

The GRACE and GOCE gravity missions have produced a dramatic improvement in our ability to measure the ocean's mean dynamic topography (MDT) from space. To fully exploit this oceanic observation, however, we must quantify its error. To establish a baseline, we first assess the error budget for an MDT calculated using a 3rd generation GOCE geoid and the CLS01 mean sea surface (MSS). With these products, we can resolve MDT spatial scales down to 250 km with an accuracy of 1.7 cm, with the MSS and geoid making similar contributions to the total error. For spatial scales within the range 133-250 km the error is 3.0 cm, with the geoid making the greatest contribution. For the smallest resolvable spatial scales (80-133 km) the total error is 16.4 cm, with geoid error accounting for almost all of this. Relative to this baseline, the most recent versions of the geoid and MSS fields reduce the long and short-wavelength errors, with the greatest impact seen in the latter component. However, they have little impact in the medium-wavelength band. The newer MSS is responsible for most of the long-wavelength improvement, while for the short-wavelength component it is the geoid. Using a combined GRACE/GOCE gravity field reduces still further the long wavelength MDT error. We find that while formal geoid errors - potentially of value in the rigorous assimilation of MDT information into ocean models - have reasonable global mean values they fail capture the regional variations in error magnitude, which depend on the steepness of the sea floor topography.

Poster B.3

Denis Volkov, Felix Landerer

Presenter Felix Landerer

Internal and external forcing of sea level variability in the Black Sea

The variability of Black Sea sea level is forced by a combination of internal and external processes of atmospheric, oceanic, and terrestrial origin. We use a combination of satellite altimetry and gravity, tide gauge, river discharge, and atmospheric re-analysis data to provide a comprehensive analysis of Black Sea sea level and to quantify the role of different factors that force the variability. The Black Sea is part of a large-scale climatic system that includes the Mediterranean and North Atlantic. The seasonal sea level budget shows similar contributions of fresh water fluxes (precip, evap, and river discharge) and Black Sea outflow, while the impact of net surface heat flux is smaller. The nonseasonal sea level in the Black and Aegean seas are significantly correlated, the latter leading by one month. This lag is due to the adjustment of sea level in the Black Sea to externally forced changes of sea level in the Aegean Sea and to the impact of river discharge. The nonseasonal sea level budget in the Black Sea is dominated by freshwater fluxes, but external processes such as river discharge and outflow changes can also cause large synoptic sea level anomalies. Sea level is strongly coupled to terrestrial water storage over the Black Sea drainage basin, which is modulated by the North Atlantic Oscillation (NAO). We show that during the low/high NAO southwesterly/northeasterly winds near the Strait of Gibraltar and southerly/northerly winds over the Aegean Sea are able to dynamically increase/decrease sea level in the Mediterranean and Black seas, respectively.

Poster B.3

Cecilia Peralta-Ferriz, James H. Morison

Presenter Jennifer Bonin

Bridging a possible gap of GRACE observations in the Arctic Ocean using existing GRACE data and in situ bottom pressure sensors

Since 2002, GRACE has provided the means of investigating month-to-month to inter-annual variability of, among many other things, ocean circulation over the entire Arctic Basin. Such a comprehensive picture could not have been achieved with the limited in situ pressure observations available. Results from the first 10 years of ocean bottom pressure (OBP) measurements from GRACE in the Arctic Ocean reveal distinct patterns of ocean variability that are strongly associated with changes in large-scale atmospheric circulation (Peralta-Ferriz et al., 2014): the leading mode of variability being a wintertime basin-coherent mass change driven by winds in the Nordic Seas; the second mode of variability corresponding to a mass signal coherent along the Siberian shelves, and driven by the Arctic Oscillation; and the third mode being a see-saw between western and eastern Arctic shelves, also driven by the large-scale wind patterns. In order to understand Arctic Ocean changes, it is fundamental to continue to track OBP. Our concern is what to do if the present GRACE system should fail before its follow-on is launched. In this work, we regress time series of pressure from the existing and potential Arctic Ocean bottom pressure recorder locations against the fundamental modes of bottom pressure variation. Our aim is to determine the optimum combination of in situ measurements to represent the broader scale variability now observed by GRACE. With this understanding, we can be better prepared to use in situ observations to at least partially cover a possible gap in GRACE coverage.

Poster B.3

Katherine Quinn

Presenter Rui Ponte

Separation of signals and noise in GRACE data over the ocean

Ocean bottom pressure maps derived from GRACE time variable gravity data have proved to be a unique and valuable tool for studying ocean dynamics. However, GRACE data over the ocean is contaminated by non-ocean signals, such as large earthquakes, land signal leakage, and noise. A noise reduction method previously used is the projection of GRACE data onto empirical orthogonal functions (EOFs) derived from an ocean model. Each EOF corresponds to a single spatial pattern and an amplitude time series. The spatial patterns are stationary. Yet typical patterns in a real physical system are changing over time. In particular, ocean dynamics tend to have propagating waves that are not captured by stationary EOFs and we have seen propagating signals in GRACE data filtered out when projected onto EOFs. One way to better represent time-varying spatial patterns is to use cyclostationary EOFs (CSEOFs). The spatial patterns of these basis functions can vary in time within a pre-selected period, typically annual. Another way to capture propagating signals is to use complex EOFs (CEOFs), where the data is complexified using a Hilbert transform. We will analyze GRACE data over the ocean by projecting the data onto CSEOFs or CEOFs derived from an ocean model. The ocean model we use is a combination of ocean variability from OMCT and adjustments due to self-attraction and loading. We will test our results against bottom pressure determined from steric-corrected altimetry and an assimilating ocean state estimate.