GSTM 2014 - Abstractlist

A.1 **Talk**

T. Mayer-Guerr, N. Zehentner, B. Klinger, A. Kvas

Presenter T. Mayer-Guerr

ITSG-Grace2014: a new GRACE gravity field release computed in Graz

The ITSG-Grace2014 relase is the successor of the ITG-Grace2010 release and consists of several parts - A high resolution unconstrained static model (up to degree 200) provided with trend and annual signal - Monthly unconstraint solutions with different resolutions (up to degree 60, 90, 120) - Daily snapshots derived by using a Kalman smoother. The static field and the monthly solutions are provided with full variance covariance matrices. Compared to the former release multiple improvements in the processing chain are implemented: - Updated background models - GPS observations: better ionospheric modelling - Combination of star camera and angular accelerations - Combined estimation of KBR antenna center together with gravity field estimation - Estimation of error covariance functions with variance component estimation method - Combined estimation of monthly solutions together with daily gravity field variations The ITSG-Grace2014 release is presented, some effects of the changes in the processing are discussed.

A.1 **Talk**

Ulrich Meyer, Adrian Jäggi

Presenter Ulrich Meyer

AIUB-RL02 monthly gravity field solutions from GRACE kinematic orbits and range rate observations

The Astronomical Institute of the University of Bern (AIUB) presents its second release of monthly gravity field solutions from GRACE data covering the time span from March 2003 to March 2014. AIUB-RL02 is based on RL02 of the GRACE L1B data, on the dealiasing products AOD1B-RL05, and the ocean tide model EOT11A. A major improvement could be achieved by taking secondary waves (admittances) of the ocean tide model into account. Last but not least a major improvement was achieved by the additional estimation of daily accelerometer scale factors (not co-estimated in AIUB-RL02). Not only an artificial variability with a period of 160d in C20 could be removed, but the overall noise of the monthly gravity fields (evaluated by their standard deviations over the oceans) during times of pronounced solar flux was drastically reduced. The effects of all individual model improvements and changes in the parametrization are illustrated separately.

A.1 **Talk**

Jean-Michel Lemoine, Sean Bruinsma, Pascal Gégout, Richard Biancale, Stéphane Bourgogne

Presenter Jean-Michel Lemoine

Release 3 of the GRACE gravity solutions from CNES/GRGS

The GRACE mission, already more than 12 years in operation, has provided a large-scale vision of the temporal gravity variations occurring on the Earth's surface. Using the reprocessed Level-1B "v2" data, the CNES/GRGS team has done a full reiteration of the GRACE and LAGEOS data processing based on upgraded data, models and inversion procedures. This new release (RL03) is now available on the GRGS web site. It features, in addition to using the new L1B-v2 data: - an improved a priori gravity model, closely following the actual gravity variations already observed by GRACE, - the use of FES2012 ocean tide model, - the use of the atmospheric dealiasing fields ECMWF ERA-interim (every 3 hours), - the use of the oceanic dealiasing fields TUGO (every 3 hours), - some changes in the K-Band ranging and accelerometer parameterization, - an inversion procedure using truncated Eigen values allowing (as it was already the case for RL02) a direct interpretation of the gravity solutions without the need for additional filtering, - an extension of the maximal degree of the time-variable parameters from 50 to 80. The CNES/GRGS RL03 solutions will be compared with the RL05 solutions from CSR, GFZ and JPL, focusing particularly on the areas of the Earth where the spatial resolution of the solutions is important and challenging as in the vicinity of the three major earthquakes of Sumatra, Maule and Tōhoku. The small artefacts which have been identified in RL03 solutions, and were presented at the IGFS meeting, have since been studied. The outcome of these studies will be presented here.

A.1 **Talk**

B. Loomis, S.B. Luthcke, T. Sabaka

Presenter B. Loomis

Progress towards the next generation of GSFC global mascons

The latest developments of the NASA GSFC global mascon time-variable gravity product are discussed. Monthly sets of mascons are directly estimated from the inter-satellite K-band range-rate observations and take into account the full noise covariance. The primary benefit of the mascon approach is the ability to apply anisotropic constraints via a regularization matrix in the non-linear least squares update to the state. This approach reduces signal leakage and eliminates the need for post-processing steps when forming time-series of regional mass change. The current constraint strategy and other candidate strategies in development are discussed. This recent global mascon solution applies state-of-the-art models, IERS 2010 conventions, and a newly-optimized arc parameterization. Global and regional mass change signals from the GSFC mascon solution are analyzed and compared to available models and the GSFC and GRACE project spherical harmonic solutions.

A.1 Talk

Beate Klinger, Torsten Mayer-Gürr

Presenter Beate Klinger

Combination of GRACE star camera and angular acceleration data: impact on monthly gravity field models

The GRACE satellite mission provides K-band ranging (KBR) measurements between the two twin satellites GRACE-A and GRACE-B for the purpose of gravity field recovery. Although the accuracy of gravity field solutions has increased during the last years, there still remains an offset between the present error level and the GRACE baseline accuracy. Unmodeled errors in the Level-1B data products related to the alignment are one of the potential contributors to the error budget, since the precise inter-satellite pointing is one of the essential requirements for the KBR ranging. Up to now, the attitude determination and the alignment between the two satellites were carried out solely by the two star cameras on board each spacecraft. However, the accelerometer provides additional information in terms of angular accelerations. Therefore, we combine both angular accelerometer and star camera data (ACC1B, SCA1B) in a least squares approach to improve the satellites' attitude determination. As a result, the high-frequent noise of the attitude data is decreased significantly. In order to benefit from the improvements on the sensor data level, other error sources and disturbances within the GRACE observations have to be identified. Based on these results, we show that improved modeling and processing methodologies (e.g. outlier detection) contribute to the overall accuracy of the recovered monthly gravity field solutions. The purpose of the presented work is to investigate the assets and drawbacks of this type of sensor fusion and its impact on the recovered gravity field solutions.

A.1 Talk

Peter L. Bender, Frank G. Lemoine, Scott B. Luthcke

Presenter Peter L. Bender

Progress Toward Development of a Four Revolution Empirical Correction Proceedure for GRACE Type Missions

At the GST meeting in 2013, an alternate procedure for correcting for acceleration noise and other sources of low frequency noise in the data from GRACE type missions was described. It is called Ocean Calibration, and relies mainly on using the inter-satellite range results over low latitude ocean areas to determine an empirical range correction function for 4 rev arcs, where all 4 revs cross the Pacific. A model for geoid height variation uncertainties in equatorial ocean areas was constructed based on the amplitude of variations in the ECCO-JPL ocean model. Also, a model for low frequency acceleration noise based on the nominal level for GRACE was used. For these models, simulations were carried out with fitting at 23 times of crossing of preferred sites. After trying a number of fitting functions, one with 16 parameters was chosen. With this fitting function, the contribution of geoid noise to the resulting geoid error was less than 3 mm, and the range noise contribution was a factor 7 less. These levels compare with 20 mm for the monthly geoid height variation due to hydrology (Gruber et al, 2011). However, the total low freq. noise in the GRACE level 1B range data is much higher than the nominal level (Ditmar et al, 2012), and the actual uncertainty in geoid models on a given day may be considerably less than the monthly hydrology variation level. Thus, until we understand more about the GRACE error sources, it is not clear if the Ocean Calibration approach would reduce the GRACE geopotential height variation errors and striping in the results substantially.

A.1 Talk

A. Horvath, M. Murböck, R. Pail, M. Horwath

Presenter Alexander Horvath

Mass signals from GRACE gravity fields with dedicated filtering using full covariance information

Proper reduction of correlated errors is a crucial step towards resolving mass signals from GRACE monthly gravity fields. We set up an approach leading towards anisotropic decorrelation, based on information taken from full covariance matrices of all gravity field data included in our estimation process. We use full normal equations from real GRACE data (AIUB, CSR). They serve as an apriori stochastic model in our least-squares adjustment process. Extensive analysis of the full variance-covariance matrices in terms of temporal variability and correlation structures are presented. Earlier analysis (Murböck et al. 2013) showed that anisotropic decorrelation which implies destriping can be achieved by down weighting specific bands of spherical harmonic orders. The impact of our approach on such specific order bands and the ability of temporal aliasing reduction is investigated in detail. The effect of our strategy on the estimated mass signals is compared to the impact of other post-processing tools such as Gaussian or Swenson & Wahr type filter. Synthetic datasets created with a closed-loop mission simulator serve as additional basis for validation purposes. Furthermore we analyze annual variability and mass trend signals. Murböck, M.; Pail, R.; Daras, I.; Gruber, T.: Optimal orbits for temporal gravity recovery regarding temporal aliasing; Journal of Geodesy, Springer Berlin Heidelberg, ISSN 0949-7714, ISSN (Online) 1432-1394, DOI: 10.1007/s00190-013-0671-y, 2013.

A.1 Talk

Jiangjun Ran, Pavel Ditmar, Roland Klees

Presenter Jiangjun Ran

Improved post-processing of GRACE monthly gravity fields to estimate regional mass variations of the Greenland Ice Sheet

Post-processing of monthly GRACE gravity field models with the aim to enhance the spatial resolution of mass anomalies over the Greenland Ice Sheet have been presented by various authors. Typically, they use the Stokes coefficients of monthly gravity models as input and add additional constraints to improve the spatial resolution and accuracy of estimated mass anomalies. Here we improve current post-processing techniques among others by including full noise variance-covariance information of the monthly Stokes coefficients, a more sophisticated regularization, and a careful choice of various parameters to be selected during the post-processing. Moreover, we analyze the error budget of high-resolution GrIS mass balance estimates and identify the processing strategy that minimizes the total error in the estimates obtained, using synthetic data. Furthermore, compared with Forsberg & Reeh (2007) and Baur & Sneeuw (2011), our processing scheme is extended further. In particular, the stochastic model of data noise is incorporated. We processed the synthetic data using various settings of processing parameters. This allows us to draw valuable conclusions regarding the optimal combination of data processing parameters. In particular, we find that the usage of stochastic model of data noise and the first-order Tikhonov regularization scheme lead to a noticeable improvement of the obtained results. Furthermore, according to the investigation of the error budget, we are able to understand better the dependence of solution quality on the choice of data processing parameters.

A.1 Talk

Christian Gruber, Andreas Groh, Christoph Dahle, Elisa Fagiolini

Presenter Christian Gruber

Evaluation of global and regional GRACE solutions

Since 2002 the Gravity Recovery And Climate Experiment (GRACE) mission has been measuring temporal variations of Earth's gravity field with unprecedented accuracy. This data set provides valuable information on the distribution and variation of mass in the Earth's subsystems such as atmosphere, hydrosphere, ocean and cryosphere. Reprocessed GRACE time-series of monthly gravity field spherical harmonic solutions generated at GFZ (RL05a) show significantly less noise and spurious artifacts. In addition, a regional method based on radial base functions and kalman filtering is capable to compute models in regional and global representation. This new method localizes the gravity observation to the closest regions and omits spatial correlations with farther regions. The present study makes use of both solutions in order to quantify recent ice-mass changes and their contribution to global sea-level rise. We further compare ice-induced crustal deformations due to the dynamic (un-)loading of the crustal layer with GPS uplift measurements along Greenland's coastline. Mass/Volume changes derived from ICESat laser altimetry measurements both in Greenland and Antarctica are used to validate the GRACE results. Hydrogical catchment basins are used to validate total water storage variations against water storage modeling from WGHM.

A.1 Talk

Y. Sun, P. Ditmar, R. Riccardo

Presenter Y. Sun

Determination of changes in the Earth's dynamic oblateness from GRACE, an ocean bottom pressure model and a glacial isostatic adjustment model

A new methodology proposed to estimate changes in the Earth's dynamic oblateness on a monthly basis. The algorithm is simple and uses only publicly available data/models, namely monthly GRACE gravity field solutions, an ocean bottom pressure (OBP) model and a glacial isostatic adjustment (GIA) model. The result influenced by the choice of input models as well as by processing details such as what filter is applied to the GRACE solutions. We test differrent combinations of input models and processing parameters and compare the resulting time-series with an independent solution based on satellite laser ranging (SLR) data. The best time-series achieved in this study compares remarkably well with that of the SLR in terms of RMS differences, amplitudes and phases. Trend estimates, derived from the obtained time-series, denpend also on the GIA model used. The proposed method thus can provide high-quality degree-2 zonal coefficient replacement for the originally corrupted one in a monthly GRACE gravity model. It can also be used as a validation of various GIA models, in combination with independent observation of dynamic oblateness (e.g., from SLR).

A.1 Talk

Na Wei, Tonie van Dam, Matthias Weigelt, Thierry Meyrath

Presenter Na Wei

Seasonal Variations of Low-degree Spherical Harmonic Derived from GPS Data and Loading Models

We derived the seasonal variations of spherical harmonics by combing GPS displacement series from ITRF2008 residuals and modelled ocean bottom pressure (OBP) from ECCO (Estimating the Circulation & Climate of the Ocean). Monthly surface mass density coefficients are estimated up to degree 20. In this contribution, we try to separate the no-mass signals from ITRF-GPS residuals by introducing translation parameters to the joint inversion. A variance component estimation (VCE) is also adopted to optimize the stochastic model for OBP input data, and the uncertainty of ECCO data is thus estimated to be 1.4 cm. We focus on the seasonal variations of degree-1 and degree-2 terms derived from the combination. These estimations are then compared with coefficients predicted from atmospheric, oceanic, and hydrological models. They are also compared with independent coefficients from accurately measured satellite laser ranging (SLR) and Gravity Recovery and Climate Experiment (GRACE) data. Results show that the uncertainties of geocenter motion from GPS/ECCO are better than 0.5 mm in the X and Y component and 1.0 mm in the Z component. GPS/ECCO geocenter motion agree well with SLR, and the correlation coefficients are 0.74, 0.64 and 0.62, respectively. GPS/ECCO ΔC20 (0.90) and ΔS21 (0.88) are highly correlated with SLR. GPS/ECCO ΔC20 and ΔS21 have slightly larger sub-seasonal uncertainty than SLR. Obvious S2 tide aliasing errors still exists in GRACE(RL05) ΔC20 series.

A.1 Talk

A. Jäggi, M. Weigelt, F. Flechtner, A. Güntner , T. Mayer-Gürr, S. Martinis, S. Bruinsma, J. Flury, S. Bourgogne

Presenter A. Jäggi

European Gravity Service for Improved Emergency Management - a new Horizon2020 project to serve the international community and improve the accessibility to gravity field products

A proposal for a European Gravity Service for Improved Emergency Management (EGSIEM) has been submitted in response to the Earth Observation Call EO-1-2014 of the Horizon 2020 Framework Programme. EGSIEM shall demonstrate that observations of the redistribution of water and ice mass derived from the current GRACE mission, the future GRACE-FO mission, and additional data provide critical and complementary information to more traditional Earth Observation products and open the door for innovative approaches to flood and drought monitoring and forecasting. The EGSIEM project is currently in its final negotiating phase with the European Commission and is expected to start in early 2015. We present the three key objectives that EGSIEM shall address: 1) to establish a scientific combination service to deliver the best gravity products for applications in Earth and environmental science research based on the unified knowledge of the European GRACE community, 2) to establish a near real-time and regional service to reduce the latency and increase the temporal resolution of the mass redistribution products, and 3) to establish a hydrological and early warning service to develop gravity-based indicators for extreme hydrological events and to demonstrate their value for flood and drought forecasting and monitoring services. All of these services shall be tailored to the various needs of the respective communities. Significant efforts shall be devoted to transform the service products into user-friendly and easy-to-interpret data sets and the development of visualization tools.

A.1 Poster

C. Siemes, M. Fehringer, R. Floberghagen, B. Frommknecht, R. Haagmans

Presenter Christian Siemes

Evolution of GOCE gravity gradient performance during mission lifetime

This presentation provides an overview of the performance evolution of gravity gradients provided by the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission during mission lifetime. GOCE was launched on 17 March 2009 when the solar cycle was close to a minimum. Since then, the solar cycle advanced towards an expected maximum in early 2013, while accordingly the drag environment became harsher. In addition, beginning in August 2012, GOCE's orbit has been lowered several times from an altitude of 256 km to eventually 224 km, which led the satellite into an even harsher drag environment. Since the gravity gradiometer requires a "quiet" environment for providing ultimate performance, the GOCE satellite is equipped with a drag-free control system that compensates drag in flight direction. Drag perpendicular to the flight direction, however, is not compensated. Therefore, we oppose the evolution of gravity gradient performance to the evolution of drag measured by the accelerometers, in particular for the across-track direction where drag attacks the largest cross-section of the satellite. Through combining frequency and spatial domain analyses, we show that the performance evolution in regions around the geomagnetic poles is different from the one outside these regions. Furthermore, special attention is paid to gravity gradients acquired before, after and also during orbit lowering maneuvers. In addition to the analysis of gravity gradients, we show a time series of GOCE gravity field solutions, each based on SGG and SST data of two months.

A.1 Poster

Tamara Bandikova, Ulrich Meyer, Beate Klinger, Paul Tregoning, Jakob Flury, Torsten Mayer-Gürr

Presenter Tamara Bandikova

Improved star camera attitude data and their effect on the gravity field

Efforts are ongoing to decrease the noise of the GRACE gravity field models and hence to arrive closer to the GRACE baseline. The most significant error sources belong the untreated errors in the observation data and the imperfections in the background models. The recent study (Bandikova&Flury,2014) revealed that the current release of the star camera attitude data (SCA1B RL02) contain noise systematically higher than expected by about a factor 3-4. This is due to an incorrect implementation of the algorithms for quaternion combination in the JPL processing routines. Generating improved SCA data requires that valid data from both star camera heads are available which is not always the case because the Sun and Moon at times blind one camera. In the gravity field modeling, the attitude data are needed for the KBR antenna offset correction and to orient the non-gravitational linear accelerations sensed by the accelerometer. Hence any improvement in the SCA data is expected to be reflected in the gravity field models. In order to quantify the effect on the gravity field, we processed one month of observation data using two different approaches: the celestial mechanics approach (AIUB) and the variational equations approach (ITSG). We show that the noise in the KBR observations and the linear accelerations has effectively decreased. However, the effect on the gravity field on a global scale is hardly evident. We conclude that, at the current level of accuracy, the errors seen in the temporal gravity fields are dominated by errors coming from sources other than the attitude data.

A.2 Talk

Mike Watkins, Frank Flechtner, Phil Morton, Frank Webb, Franz-Heinrich Massmann, Ludwig Grunwaldt

Presenter Mike Watkins

Status of the GRACE Follow-On Mission

GRACE Follow-On, a joint US/German satellite mission to extend the critical global mass flux data records from the GRACE mission, continues to mature and advance on both sides of the Atlantic. In early January 2012, GRACE-FO was advanced by NASA to Phase A following the successful Mission Concept Review in late October, 2011. The transition into Phase B happened in September 2012 following a successful System Requirements and Mission Definition Review in July 2012. In January 2014 the Preliminary Design Review (PDR) was conducted, followed by the transition into phase C in March 2014. The current launch date is August 2017. The presentation will focus on the project status after the successful Project PDR and the Science Data System (SDS), Mission Operations System (MOS) and Launch Vehicle System (LVS) PDRs as well as science payload Critical Design Reviews (CDR) of the microwave instrument (MWI), accelerometer and laser ranging interferometer (LRI) demonstrator.

A.2 Talk

Bernard Foulon, Bruno Christophe, Vincent Lebat, Damien Boulanger, Francoise Liorzou

Presenter Bruno Christophe

Development status of the GRACE Follow-On accelerometer and first results of the Engineering Model testing

The design of the electrostatic space accelerometers developed by Onera for the GRACE Follow-On mission is very similar to the one of the SuperStar accelerometers operating in orbit on board the twin GRACE satellites since more than twelve years. However, they take advantage of the return of experience of the GRACE and GOCE missions, in order to improve their thermal behaviour, in particular the stability of the front end electronics functions. The presentation will provide the status of the GFO accelerometer at the time of its Critical Design Review with in particular the results of the Engineering Model testing on the Onera's laboratory pendulum bench and during catapult free falls at ZARM drop tower facility.

A.2 **Talk**

Christina Bogan for the LRI team

Presenter Christina Bogan

The Laser Ranging interferometer for GRACE Follow On - current status

Apart form the microwave ranging the Grace Follow On mission will use in parallel a laser interferometer to sense the inter satellite distant changes. This laser ranging interferometer (LRI) will on the one hand demonstrate, for the first time, the operation of an inter satellite laser interferometer. On the other the LRI will improve the measurement sensitivity to dissolve the spatial variations and temporal evolution of the Earth?s gravitational field. In this talk we will present the current status of the LRI which is a joint US/German project. The instrument consists of several subsystems that are a laser, an optical bench subsystem, a triple mirror assembly, a laser ranging processor, cavity assembly, baffles and harness. During the last year the LRI, including all subsystems, has successfully passed the critical design review. Thus, the engineering models have demonstrated the required performance and flight hardware is currently being build.

A.2 **Talk**

Srinivas Bettadpur, Christopher McCullough, John Ries, Minkang Cheng

Presenter Srinivas Bettadpur

Use of GNSS and SLR tracking of LEO satellites for bridging between GRACE and GRACE-FO

Simple experimentation shows that direct discrimination of the broad, continental scale feature requires gravity field determination to at least degree 7 or more. We show that both GRACE-GPS and SLR data are essential for independent estimation of the field to this degree/order. We look at the quality of these estimates at different time-scales, discuss the best parametrization strategies, and the validation of the results. The applications to filling potential gaps between GRACE and GRACE-FO missions are also discussed.

A.2 Talk

M. Weigelt, T. van Dam, O. Baur, M. J. Tourian, H. Steffen, K. Sosnica, A. Jäggi, N. Zehentner, T. Mayer-Gürr, N. Sneeuw

Presenter Matthias Weigelt

How well can the combination hlSST and SLR replace GRACE? A discussion from the point of view of applications

GRACE is undoubtedly one of the most important sources to observe mass transport on global scales. However, GRACE has outlived its predicted life time and the satellite system is showing signs of fatigue. As the value of any geophysical or environmental record is proportional to the length of the time series, the geo-scientific communities are seriously concerned about maintaining the gravity field time-series. In recent times efforts are undertaken to bridge a possible and likely gap between GRACE and GRACE-Follow On. One promising candidate is high-low satellite-to-satellite tracking (hlSST) of low-Earth orbiting satellites by GNSS in combination with SLR. SLR is known to provide highest quality time-variable gravity for the very low degrees (2-5). HlSST provides a higher spatial resolution but at a lower precision in the very low degrees. Thus it seems natural to combine these two techniques and the benefit has already been demonstrated in the past. However, how well can such a combination "replace" GRACE? Having both techniques available at this moment we are able to scrutinize the combined hlSST-SLR product versus GRACE from the application point of view. We will look at various aspects such as GNSS loading observations, mass trends for various regions, compare to hydrological and hydro-meteorological observations and attempt as the ultimate challenge the recovery of the GIA signal in Fennoscandia and North-America. We provide insight into the current quality of this type of time-variable gravity solution and identify limitations and challenges for future work.

A.2 Talk

K. Sośnica, A. Jäggi, M. Weigelt, T. van Dam, N. Zehentner, T. Mayer-Gürr

Presenter Krzysztof Sośnica

Time varying gravity from SLR and combined SLR and high-low satellite-to-satellite tracking data

The SLR observations to spherical geodetic satellites, e.g., LAGEOS-1/2, Starlette, Stella, AJISAI and LARES, provide remarkable information about the temporal variations of the very long wavelength part of the Earth's gravity field. As opposed to the low Earth orbiting satellites tracked by GPS high-low satellite-to-satellite tracking (GPS hl-SST), the spherical geodetic SLR satellites are not continuously tracked and the number of SLR observations is limited by the sparse and inhomogeneous network of SLR stations. Despite these limitations, the combination of the SLR data with the GPS hl-SST data reveals that the strong SLR observations substantially contribute to the recovery of time variable signals and do not only improve the gravity field coefficients of degree 2 but also those of higher-degrees. We present the methodology, results, and limitations of SLR-only gravity field estimates as obtained from rigorous multi-satellite SLR solutions. We then combine the normal equations from the multi-satellite SLR solutions with normal equations based on GPS hl-SST tracking from CHAMP, GRACE, GOCE, and other low Earth orbiting satellites to generate monthly solutions. Dedicated post-processing such as spatial and temporal filtering further enhances the solutions and allow recovering the time-variable gravity field with remarkable precision and spatial resolution. The methodology thus resembles an important step towards bridging a possible gap between GRACE and GRACE-FO.

A.2 Talk

Norbert Zehentner, Torsten Mayer-Gürr, Matthias Weigelt, Adrian Jäggi

Presenter Norbert Zehentner

Non-dedicated satellite missions for time variable gravity field estimation

For most investigations based on time variable gravity field information it is of crucial importance to have a time series which is almost continuous and as long as possible. The series of GRACE gravity field solutions will be continued by GRACE-FO. Nevertheless there is a possible gap between the two time series. In recent years high-low satellite-to-satellite tracking has been proposed as a possible gap filler for several times. However, most investigations concentrated on data from gravity field missions, like CHAMP, GRACE or GOCE, and assumed similar performance for other missions in the future. We used data from a wide range of satellite missions and investigated the possibility to retrieve time variable gravity field signal from kinematic orbits. Our investigation not only includes dedicated missions, like CHAMP, GRACE and GOCE, because the more interesting question is which other satellite mission is capable of providing comparable results based on the principle of SST-hl. Therefore, we used observation data from the satellite missions TerraSAR-X, TanDEM-X, MetOpA, MetOpB, Swarm, COSMIC, and SAC-C. We will present individual results as well as different combinations and discuss advantages and disadvantages of certain missions. The results will show which mission can be used to observe variations in the Earth's gravity field.

A.2 Talk

Christian Siemes, Olivier Carraz, Luca Massotti, Roger Haagmans, Pierluigi Silvestrin

Presenter Christian Siemes

ESA's Activities related to Next Generation Gravity Mission Concepts

The presentation addresses the activities and preparatory studies of future ESA mission concepts devoted to improve our understanding of the Earth’s mass transport phenomena causing temporal variations in the gravity field. ESA’s initiatives started in 2003 with a study on observation techniques for solid Earth missions, continued thereafter with several system studies and technology developments. Preferred mission concepts under Earth Explorer programmatic boundary conditions were identified in the “Assessment of a Next Generation Gravity Mission to Monitor the Variations of the Earth’s Gravity Field” (NGGM) and studied with prioritized science requirements and detailed system designs. These activities received precious inputs from the in-flight lesson learnt from the American-German GRACE mission and ESA’s GOCE mission. Since then, several complementary science and technology studies were initiated and are currently running. The latest results concerning the satellite architectures and constellations will be presented as well as remaining open issues for future concepts. Recently, a new gravity gradiometer instrument concept based on cold atom interferometry has been developed (see http://arxiv.org/pdf/1406.0765v1.pdf). It provides measurements of the diagonal components of the gravity gradient tensor, the spacecraft angular rates and non-gravitational forces acting on the spacecraft. We present a first assessment of the instrument’s performance including first simulations of mean and time-variable gravity field retrieval.

A.2 Talk

R. Pail, R. Bingham, C. Braitenberg, A. Eicker, R. Floberghagen, R. Haagmans, M. Horwath, T.J. Johnson, L. Longuevergne, I. Panet, C. Rolstad-Denby, B. Wouters

Presenter Roland Pail

Consolidated science requirements for a next generation gravity field mission

Before the background of a cooperation by ESA with other space agencies to jointly realize a future gravity field mission (beyond GRACE-FO) most probably in the form of a double- our multi-pair formation, in an internationally coordinated initiative among the main user communities of gravity field products the science requirements for such a mission have been reviewed and defined. This activity was realized as a joint initiative of the IAG, the GGOS Working Group on Satellite Missions, and the IUGG. After about one year of preparation, in a user workshop that was held in September 2014 consensus among the user communities of hydrology, ocean, cryosphere, solid Earth and atmosphere on consolidated science requirements could be achieved. Based on limited number of mission scenarios which took also technical feasibility into account, a consolidated view on the science requirements among the international user communities was derived, research fields that could not be tackled by current gravity missions have been identified, and the added value (qualitatively and quantitatively) of these scenarios with respect to science return has been evaluated. The resulting document shall form the basis for further programmatic and technological developments. In this contribution, the main outcomes of the user workshop will be presented. An overview of the specific requirements of the individual user groups, the consensus on consolidated requirements as well as the new research fields that have been identified during this process will be discussed.

A.2 Talk

M. Murböck, Th. Gruber and NGGM-D team

Presenter T. Gruber

Next generation satellite gravimetry mission study (NGGM-D)

The main goal of this project is to develop an advanced mission concept for long term monitoring of mass variations in the system Earth in order to improve our knowledge about the global and regional water cycle as well as about processes of the solid Earth. In times of global change this is needed to make more realistic predictions of system Earth parameters. Starting from the existing concepts of the GRACE and GRACE Follow-On missions, sensitivity and spatial resolution shall be increased, such that also smaller scale time variable signals can be resolved, which cannot be detected with the current techniques. For such a mission new and significantly improved observation techniques are needed. This concerns in particular the measurement of inter-satellite distances, the observation of non-gravitational accelerations and the configuration of the satellite orbits or of a constellation of satellites. These new components and their complex interactions form the basis for a new space based observation concept for mass variations in system Earth. The German Aerospace Center (DLR) funded a preparatory study in order to develop a mission concept for a next generation gravity field mission. The study was coordinated by Technische Universität München and incorporated all major players in the field of satellite gravimetry in Germany. By joining scientific, technological and industrial expertise the resulting mission concept can form the baseline for a potential and realistic mission proposal. The paper presents the results obtained from this study and the proposed mission concept.

A.2 **Talk**

I. Daras, R. Pail, P. Visser, M. Weigelt, S. Iran-Pour, M. Murböck, S. Tonetti, T. Gruber, J. de Teixeira da Encarnação, S. Cesare, C. Siemes, J. van den IJssel, S. Cornara, T. van Dam, N. Sneeuw, R. Haagmans

Presenter Ilias Daras

Treatment of temporal aliasing on future gravity satellite missions - an insight into ESA-SC4MGV project

One of the biggest constrains for future gravity satellite missions on their way to achieve the expected accuracy that new generation sensors could provide, is the error induced by temporal aliasing, which remains one of the biggest contributors to the error budget. Within the scope of the ESA-SC4MGV project, we investigate the impact of temporal aliasing on future gravity satellite missions as well as methods for its minimization. This is succeeded on one hand by optimizing the choice for the orbital configuration, and on the other by optimizing the gravity field techniques accordingly. Our optimized orbit constellation consists of two in-line pairs of a Bender type configuration and is used as our "basis" scenario. Using the "basis" scenario, we investigate gravity field processing methods that lead in a reduction of the temporal aliasing errors. As a first step we apply the so-called "Wiese" approach, which suggests co-estimating low resolution gravity fields at short time intervals in order to directly compute the short-term signals that alias into the combined solution. We demonstrate the ability of the "Wiese" approach to minimize temporal aliasing errors for our "basis" scenario. As a step forward, we experiment with alternative parameterizations that combine low and medium gravity fields at different time intervals, in order to achieve the best results in terms of minimization of temporal aliasing errors. Our preliminary results show a further improvement compared to the standard "Wiese" approach.

A.2 **Talk**

M. Weigelt, S. Iran-Pour, M. Murböck, S. Tonetti, P. Visser, I. Daras, J. de Teixeira da Encarnação, S. Cesare, C. Siemes, J. van den IJssel, S. Cornara, T. Gruber, T. van Dam, R. Pail, N. Sneeuw, R.

Presenter Matthias Weigelt

A methodology to choose the orbit for a double pair scenario future gravity satellite mission ? experiences from the ESA SC4MGV project

For next generation gravity field missions (NGGM) a likely mission scenario is to fly two pairs of satellites in a Bender configuration, where one satellite is in a (near-)polar and another satellite is in an inclined orbit (normally around 70°). Naturally the question of an optimal orbit configuration arises especially in the view of optimizing the temporal and spatial resolution whilst minimizing aliasing of undesired signal content such as e.g. ocean tides, among others. The parameters search space for finding near-optimal scenarios is a function of orbital parameters of both pairs. Each parameter has its own impact on gravity recovery quality. Based on experience from previous studies, the search space can be reduced but the remaining parameters still need to be optimized. We employ within the ESA-SC4MGV project a genetic algorithm. The approach yields a set of candidate scenarios which are scrutinized afterwards. In this talk we focus on the importance of the latter, i.e. an in-depth analysis of the simulated results down to the level of applications e.g. in hydrology. We will present examples where the results of the gravity field recovery itself seem reasonable but derived water storage changes suffer from an artificial quarterly signals. Therefore, we emphasize the need to employ a full-scale end-to-end simulation which is ongoing in the current project phase.

A.2 Poster

Ilias Daras, Roland Pail

Presenter Ilias Daras

Towards a full exploitation of next generation sensors on-board future LL-SST type gravity field missions

Next generation gravity field missions of low-low satellite-to-satellite tracking (LL-SST) type are expected to fly optimized formations and make use of the most accurate sensors. In the upcoming GRACE Follow-on mission, the traditional K-band ranging instrument will be supplemented with a laser interferometer of several nms accuracy. Consequently, the processing method for gravity field recovery has to meet the performance requirements of those new generation sensors to deliver the most precise gravity field possible. In this study we present an analysis of the potential performance of new sensors and their impact in gravity field solutions. We investigate the ability of current gravity field processing methods to fully exploit the new sensor accuracies. We demonstrate that processing with standard precision may be a limiting factor for taking full advantage of new generation sensors that future satellite missions will carry. Therefore an alternative version of our simulator is presented, which uses in hybrid mode double and quadruple precision at different processing steps, primarily aiming to minimize round-off system errors. Results using the enhanced precision show a big reduction of system errors that were present at the standard precision processing. As a next step, error sources with a priori known frequency behavior are assessed via stochastic modeling. Alternatively, empirical parameterization is also engaged in order to minimize the effect of the propagated noise into the solutions, and the results are compared with the stochastic modeling.

A.2 Poster

Henryk Dobslaw, Inga Bergmann-Wolf, Robert Dill, Ehsan Forootan, Volker Klemann, Jürgen Kusche, Ingo Sasgen

Presenter Henryk Dobslaw

The Updated ESA Earth System Model for Gravity Mission Simulation Studies

The ability of any satellite gravity mission concept to monitor mass transport processes in the Earth system is typically tested well ahead of its implementation by means of numerous simulation studies. For such simulations, a suitable source model is required to (i) represent rapid mass motions in for example the atmosphere and oceans, in order to realistically include the effects of temporal aliasing due to non-tidal high-frequency mass variability into the retrieved gravity fields. Moreover, (ii) low-frequency variability needs to present at realistic amplitudes and frequencies at in particular small spatial scales, in order to assess to what extent a new mission concept might provide further insight into physical processes not observed by a satellite system before. The new source model presented in this study attempts to fulfill both requirements: Based on ECMWF's recent atmospheric reanalysis ERA Interim and corresponding simulations from numerical models of the other Earth system components, it offers spherical harmonic coefficients of the mass variability in atmosphere, oceans, the terrestrial hydrosphere including the ice-sheets and glaciers, as well as the solid Earth with high temporal (6 hours) and spatial (d/o 180) resolution for a period of 12 years.

A.2 Poster

Matthias Ellmer, Torsten Mayer-Gürr

Presenter Matthias Ellmer

GRACE follow-on sensor noise with realistic background models

We performed multiple simulation studies of a GRACE-like satellite mission based on the current K-Band ranging instrument (KBR), while also using a laser-ranging instrument (LRI) as a drop-in replacement. We based our simulated data on real GRACE observations for April 2006. We used the variational equation approach to generate reduced dynamic orbits that were fitted to the actual GRACE kinematic orbits. Synthetic satellite ranging, star camera, accelerometer and kinematic orbit data was computed from these orbits. We synchronized all simulated instruments with the real measurements to account for data gaps. The next step was the introduction of effects that would reproduce the features of the real observations. For this, we used the two parameters of accelerometer noise and time-variable gravity. We degraded the AOD1B dealiasing product used in the generation of the fundamental orbit data with partial components of the updated ESA earth system model dataset in the recovery step. The resulting residual time-variable gravity signal lead to results that are similar to, and slightly better than, those of the real solution in both spectral and spatial domains. The LRI showed improved performance above degree and order 100. A further increase of accelerometer noise by a factor of 9 brought KBR degree variances in line with real data.

A.2 Poster

Bernard Foulon, Bruno Christophe, Francoise Liorzou

Presenter Bernard Foulon

MICROSTAR, a "miniaturized" ultra sensitive accelerometer for future space missions

With its mature technology inherited from the electrostatic accelerometers of the GRACE and GOCE geodesy missions, the MicroSTAR accelerometer is a new electrostatic accelerometer with limited weight-volume-power budgets for small satellite missions. The Sensor Unit comprising its Front End Electronics is weighting 1.5 kg inside less than 1 litre and with a maximum power consumption of 1.5 W. If not directly provided by the satellite, an associated Interface and Control Unit, contained in ¾ litre weighting 1.2 kg and consuming 2 W, insures the data packaging and transfer toward the satellite bus and provides to the instrument regulated power lines. With its cubic proof-mass positioned at the CoG of the satellite, MicroSTAR can provide, along its 3 axes, the measurements of the non gravitational forces acting on the satellite with a resolution performance up to 1.5E-11 m/s2/sqrt(Hz) in the measurement bandwidth from 0.2 mHz to 100 mHz. The poster will present a description of the MicroSTAR instrument, its detailed performance budget, the status of the prototype model developed under Onera's internal funding and its possible interest for some future small satellite LEO missions (as GRACE 2 or GRASP) or for planetary missions inside the solar system.

A.2 Poster

Bernard Foulon, Bruno Christophe, Vincent Lebat, Karim Douch, Isabelle Panet

Presenter Bernard Foulon

GREMLIT: a planar electrostatic gradiometer for airborne geodesy

Taking advantage of technologies, developed by ONERA for the GRACE and GOCE space missions, the GREMLIT airborne gravity gradiometer is more particularly developed to provide complementary measurements at the short wavelengths in particular in the areas where spatial distribution and quality of ground data remain quite uneven like for example land/sea transition. Built using a double deck of a compact planar assembly of 4 electrostatic accelerometers leading to a cubic configuration gradiometer, the GREMLIT instrument is mounted on a dedicated stabilized platform which is controlled by the common mode outputs of the instrument itself along the horizontal directions. In addition to the realization of a one axis prototype model, detailed numerical simulations have been conducted over some realistic coastal test areas. Taking into account the data sheet performance of the associated commercial angular and data rate sensors and assuming actual airplane acceleration measurements, they lead to exhibit accuracy below 1E along the Txx and Tyy horizontal components. The poster will present the description and the characteristics of the whole instrument including the specific controlled platform and also some synthetic results of the simulations.

A.2 Poster

Vitali Müller for the LRI-D team

Presenter Vitali Müller

Inter-satellite ranging for GRACE Follow-On and NGGM

The GRACE Follow-On mission will use microwaves and laser light to determine variations in the satellite separation. The main microwave ranging instrument has been used successfully already in GRACE. The novel laser ranging instrument (LRI) shall demonstrate feasibility and functionality of inter-satellite laser interferometry with the benefit of an improved ranging sensitivity. The technology and instrument is attracting attention due to potential applications in future geodesy missions and in the gravitational wave mission LISA. Concepts, noise sources and challanges of satellite-satellite laser interferometry will be introduced. In particular the GRACE Follow-On LRI working principle will be explained.

B.1 **Talk**

Xiaoping Wu

Presenter Xiaoping Wu

Accelerations in Surface Mass Transport – A Global Reassessment

During the 12 years of GRACE mission operation from 2002.3 to 2014.0, accelerations in measured geocenter motion and J2 are either statistically insignificant or somewhat uncertain when compared with other estimates, despite various reports of significant accelerations in surface mass transport. This has motivated us to re-examine accelerations in spherical harmonic domain and global geographic domain. Time series of GRACE measured spherical harmonic coefficients up to degree/order 60 and their calibrated full covariance matrices are used to estimate linear, annual, semiannual and acceleration components in these coefficients. Mass acceleration and time variation budgets for major geographical regions are derived using regional spherical harmonic functions and a priori multi-regional variance functions up to degree/order 180 in addition to the estimated spherical harmonic accelerations or time series. We will also evaluate various aspects in the determination of these accelerations, including effects of interannual variations and sampling period, the fidelity and possible errors in the low degree coefficients, data error correlations, atmospheric model correction, kernel leakage, as well as reasonableness and impact of various assumed a priori variation patterns.

B.1 **Talk**

I. Sasgen, M. Horwath, V. Klemann, E. J. Petrie, N. Schoen, R. Pail, A. Horvath, J. L. Bamber, P. J. Clarke, H. Konrad, M. R. Drinkwater

Presenter Martin Horwath

The glacial-isostatic adjustment signature in Antarctica inferred from GRACE, Enivsat/ICESat and GPS (ESA-STSE project REGINA).

The glacial-isostatic adjustment (GIA) of the solid Earth to past ice-load variations in Antarctica induces contemporary trends in the gravity-field and surface displacement. Due to the lack of direct observations, GIA remains poorly constrained and represents a major uncertainty in determining the mass balance of the Antarctic ice sheet from satellite gravimetry, and, to a considerably lesser extent, altimetry measurements such as CryoSat-2. Here, we present an improved regional GIA estimate derived from improved temporal linear trends in time series of GRACE, Envisat/ICESat and GPS. First, Envisat/ICESat rates of surface-elevation are used to estimate present-day ice-mass changes and removed it from GRACE and GPS measurements, yielding our first-order GIA estimate. In the second step, remaining elastic components in the GIA estimate, related to recent ice changes, are identified using the distinctive signatures of elastic and viscoelastic processes in the rates from GRACE and GPS, and subsequently removed. The improved GIA field is interpreted using an ensemble of viscoelastic response functions, focusing on West Antarctic ice load changes of the recent past in the presence of a low-viscous upper mantle. Finally, we present how our improved GIA estimate regionally impacts the GRACE and CryoSat-2 measurements when determining ice-mass balance in Antarctica. The results are part of the ESA-STSE project REGINA, www.regina-science.eu.

B.1 **Talk**

Erik R. Ivins, David Wiese, Michael Watkins, Felix Landerer, Alexander Simms, Dah-Ning Yuan, Carmen Boening, Eugene Domack

Presenter Erik R. Ivins

Glacial Isostasy and Mass balance of Graham Land and the greater Antarctic Peninsula 2002-2014 and over the past 150 years using GRACE and GNSS station data

The process of ice shelf breakup and outlet glacier speedup has been repeating itself throughout the northern Antarctic Peninsula since the late 1980?s. Larsen A Ice Shelf breakup (LAISb) occurred, for example, in the Austral summer of 1993. Rott et al. (2011) have estimted that the speedup at the trunks of 11 LAISb outlet glaciers for which flux-gate mass transport can be measured. Butress loss caused in increase of discharge of $\delta M = 4.3 \pm 1.6$ Gt/a in 2008, relative to measurements that span 1995-1999 for 11 Larsen B feeding glaciers. GRACE analysis centers have now released 12.25 years of monthly solutions (RL05) for global mass change. Solutions for the region of the Peninsula north of 69 ° S (Graham Land using both constrained and unconstrained mascon methods show 2002-2014 net ice loss to the oceans with a trend of 31.5 ± 4 Gt/yr, approximately the same as reported by Ivins et al. (2011) and Luthcke et al. (2013) over shorter time spans. We offer a new model for mass loss history that must involve substantial losses atleast back into the 1980's in order to explain the current uplift rates and patters recorrded by GNSS station data. The modeled GIA correction is 6.9 ± 1.5 Gt/yr, placing Graham Land in a negative balance of -38.4 ± 5.5 Gt/yr . We infer that much of this mass loss began at least 50 years ago, and we attempt to quantify this ice mass history as it drives a substantial viscoelastic flow in the mantle.

B.1 **Talk**

Jolanta Nastula, Małgorzata Wińska, Monika Biryło

Presenter Jolanta Nastula

Comparison of polar motion excitation functions computed from different sets of gravimetric coefficients

B.1 Poster

M. Srinivasan, E. Ivins, M. Jasinski, J. Famiglietti, M. Rodell

Presenter Margaret Srinivasan

Developing a Comprehensive GRACE Applications Strategy

Successful strategies to enhance science and practical applications of the proposed GRACE-FO mission will require engaging with and facilitating between science and societal applications communities. The NASA Applied Science Program supports development of a systematic approach to identify existing and potential users of GRACE-derived products and models to engage applications-oriented users and stakeholders and to identify projects where GRACE data may improve decision-making. We will engage GRACE Science Team members in this effort to incorporate information and knowledge towards solutions for broadened applications of GRACE data. Extending the time series of observations with GRACE FO and GRACE II may provide unique and innovative solutions to some of the most pressing hydrological issues facing society. Recent applications from both academic and operational users will be presented. We want to identify solutions to relevant societal needs, and how they can help guide our GRACE Applications strategy. Some key objectives include:
• Document existing science and applications projects using GRACE, • Engage current users and GST to identify potential projects, • Develop an Applications and Implementation plan, • Facilitate contact, exchange of ideas, and partnering between GST, project, data experts, stakeholders, international partners, • Identify GRACE capabilities, • Promote applications; special sessions, town halls, publications, • Engage science and applications community via web, plan, printed items, workshops, etc. • Assess user data needs and access for decision support.

B.2 Talk

Jianli Chen

Presenter Jianli Chen

Reducing Leakage Error in GRACE-Estimated Antarctic Mass Balance

Spatial leakage is a major limitation for quantitative interpretation of satellite gravity measurements from the Gravity Recovery and Climate Experiment (GRACE). It arises from the limited range of spherical harmonics (SH) available and additional filtering to suppress noise in high degree and order SH coefficients. Using synthetic data to simulate ice mass changes over Antarctica, we illustrate the quantitative effects of a limited range of SH coefficients (degree and order 60) and additional filtering, which in combination can attenuate signal amplitudes by up to 60%, and evaluate potential leakage effects on Antarctic mass rate estimates from ocean bottom pressure and terrestrial water storage (TWS) changes using model estimates and ice melting over Greenland, and Canadian Arctic Archipelago (CAA). We present details of a forward modeling algorithm used successfully in previous studies, and show that it is capable of removing these biases from GRACE estimates. Examples show how to implement the method by constraining locations of presumed mass changes, or leaving these locations unspecified within a continental region. Our analysis indicates that leakage effect from far-field TWS change and Greenland and CAA ice melting on Antarctica mass rate estimates appears minimal and negligible. However, leakage from long-term ocean bottom pressure change in the surrounding Antarctic Circumpolar Current regions may bias Antarctica mass rate estimates by up to 20 Gigatonne per year (Gt/yr).

B.2 **Talk**

Jennifer Bonin, Don Chambers, Himanshu Save

Presenter Jennifer Bonin

What GRACE resolution is required to numerically separate Greenland's glacial mass balance from its surface mass balance?

Mass change occurring over Greenland can be divided into two parts. Large-scale patterns in surface melting, runoff, and sublimation, as balanced by precipitation, result in changes in the surface mass balance (SMB), while changes in rates of ice discharge of marine-terminating outlet glaciers determine the glacial mass balance (GMB). While in most cases, these two types of mass change are modeled and measured separately, GRACE intrinsically lacks the direct ability to separate one cause from the other. We demonstrate one theoretical way to separate SMB from GMB with GRACE, using a least squares inversion technique. However, we find that the limited 60x60 spherical harmonic representation of GRACE RL05 does not provide sufficient resolution to adequately accomplish the task. We then determine the GRACE spatial resolution needed to actually separate the SMB from GMS signals, within acceptable error limits.

B.2 **Talk**

S.B. Luthcke, B. Loomis, T. Sabaka

Presenter S.B. Luthcke

Current estimates of land ice mass evolution from the NASA GSFC mascon solution

Current land ice mass changes are determined from the latest NASA GSFC global mascon solution. The mascons describe the time variable gravity signal at monthly intervals and are directly estimated from the GRACE K-band range-rate observations, taking into account the full data noise covariance, and applying a mascon regularization matrix which acts to reduce signal leakage while maximizing signal recovery. The solution signals and errors are analyzed and discussed. An optimized Ensemble Empirical Mode Decomposition (EEMD) algorithm is applied to each land ice region to accurately determine the timing of the non-stationary seasonal signal without relying on a priori information. This approach enables the construction of meaningful annual net balance maps which highlight the spatial and temporal variability of land ice mass evolution throughout the GRACE mission.

B.2 **Talk**

M. J. Talpe, R. S. Nerem, F. G. Lemoine, F. Landerer

Presenter R. S. Nerem

Two Decades of Mass Change in Greenland and Antarctica

We use complimentary SLR/DORIS solutions to extend the record of time-variable gravity prior to GRACE by a full decade. The reconstructed fields are generated by combining the EOF spatial modes from GRACE with the temporal modes from an SLR/DORIS solution computed at NASA/GSFC. The most recent solution contains a weekly solution for 33 coefficients (up to degree and order 5, without the [5,0] terms but with [6,1] terms) and a full error covariance. The errors in the reconstruction were considered from two sources: (1) the fact that the GRACE EOF modes do not span the entire solution time frame, and (2) the errors in the SLR/DORIS solutions. We will focus on the mass change over 1992 – present for Greenland and Antarctica, because the signals are largest in these regions. We will also show the mass change of two regions away from the poles that have experienced notable interannual variability as a way to evaluate the spatial resolution of the reconstructed fields. In these reconstructed mass change curves, we also show the contribution of each mode as well as the contribution of different degrees from the SLR/DORIS solutions.

B.2 **Talk**

Isabella Velicogna

Presenter Isabella velicogna

Regional pattern of ice mass balance with GRACE in Greenland, Antarctica and the Canadian Arctic Archipelago

We apply a mascon approach to the data of the NASA/DLR GRACE mission to determine the regional acceleration in mass loss of Greenland, Antarctica and the Canadian Arctic Archipelago for 2003-2013. In Greenland, the southeast and northwest generate 70% of the loss (280±58 Gt/yr) mostly from ice dynamics, the southwest accounts for 54% of the total acceleration in loss (25.4±1.2 Gt/yr2) from an increase in runoff, followed by the northwest (34%). We find no significant acceleration in the northeast. In Antarctica, the Amundsen Sea Embayment (ASE) sector and the Peninsula account for 64% and 17%, respectively, of the total loss (180±10 Gt/yr) mainly from ice dynamics. The ASE contributes most of the acceleration in loss (11±4 Gt/yr2). This result is consistent with independent observations from altimetry (Operation IceBridge, Envisat and ICESat-1) and the mass budget method (surface mass balance versus ice discharge along the periphery). Queen Maud Land, East Antarctica is the only sector with a significant mass gain due to a local increase in snowfall (63±5 Gt/yr). In the Canadian Arctic Archipelago (CAA), we find a mass loss of 73 Gt/yr in 2003-2013, which corresponds to a mass loss per unit area disproportionally large compared to that in Greenland. We also show updated time series for the remaining glaciers and ice caps. This work was performed at UCI and JPL under a contract with NASA and CSR.

B.2 **Talk**

Yvonne Firing, Carmen Boening, David Wiese, Michael Watkins, Nicole Schlegel, Eric Larour

Presenter Carmen Boening

Antarctic Ice Mass Balance from GRACE

The Antarctic ice mass balance and rates of change of ice mass over the past decade are analyzed based on observations from the Gravity Recovery and Climate Experiment (GRACE) satellites, in the form of JPL RL05M mascon solutions. Surface mass balance (SMB) fluxes from ERA-Interim successfully account for the seasonal GRACE-measured mass variability. Trends in the residual (GRACE mass - SMB accumulation) mass time series in different Antarctic drainage basins are consistent with time-mean ice discharge rates based on radar-derived ice velocities and thicknesses. GRACE also resolves accelerations in regional ice mass change rates, including increasing rates of mass gain in East Antarctica and accelerating ice mass loss in West Antarctica. Most of the increasing mass loss rate in West Antarctica is explained by decreasing SMB (principally precipitation) over this time period, part of the characteristic decadal variability in regional SMB. The residual acceleration of 2+/-1 Gt/yr, which is concentrated in the Amundsen Sea Embayment (ASE) basins, represents the contribution from increasing ice discharge rates. An Ice Sheet System Model (ISSM) run with constant ocean forcing and stationary grounding lines both underpredicts the largest trends in the ASE and produces negligible acceleration or interannual variability in discharge, highlighting the potential importance of ocean forcing for setting ice discharge rates at interannual to decadal time scales.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Talk**

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.

B.3 **Poster**

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.

B.3 **Poster**

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.

B.3 **Poster**

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.

B.4 **Talk**

Matthew Rodell

Presenter Matthew Rodell

Hydrological Extremes in the GRACE Record

This presentation will identify wet and dry extremes around the world based on GRACE's ~12 year record of terrestrial water storage anomalies. These will be explained in the context of other information on major floods and droughts during 2002-2014. In most cases the GRACE based extremes are consistent with other measurements and newsworthy events. In other locations the maximum and minimum anomalies occur at the ends of the data record, reflecting ongoing climate- or human-induced trends in TWS.

B.4 Talk

Sarah Elizabeth McCandless, Srinivas Bettadpur, Teresa Howard, Gordon Wells

Presenter Srinivas Bettadpur

Utilizing GRACE TWS, NDVI, and Precipitation for Drought Identification and Classification in Texas

The "Merged-dataset Drought Index" (MDI) is a new quantitative drought index calculated using GRACE total water storage (GRACE TWS), MODIS-derived normalized difference vegetation index (NDVI), and precipitation data. These datasets constitute MDI because each correlates with a different drought type. Dataset deviations from established climatology are used, where negative deviations indicate deficits. MDI is objectively and transparently calculated based on dataset z-scores. GRACE TWS is the least mature dataset used in these calculations, but TWS solution variance does not negatively impact MDI. A new classification scheme to categorize drought severity is also proposed. MDI is studied in Texas and its smaller sub-regions. Within these sub-regions, MDI identifies multiple droughts during 2002 - 2014, with the most severe beginning in late 2010. Drought analysis using MDI shows for the first time that GRACE data provides information on a sub-regional scale in Texas, an area with low overall signal amplitudes. Past studies have shown TWS capable of identifying drought, but MDI is the first index to quantitatively use GRACE TWS in a manner consistent with current practices of identifying drought. MDI also establishes a framework for a future, completely remote-sensing based index that can enable temporally and spatially consistent drought identification across the globe. This study is useful as well for establishing a baseline for the necessary spatial resolution required from future geodetic space missions for use in drought identification at smaller scales.

B.4 Talk

Mohamed Ahmed, Mohamed Sultan, John Wahr, Ahmed Mohamed, Eugene Yan

Presenter Mohamed Ahmed

Quantifying recharge and depletion rates of the Nubian Sandstone Aquifer System: An integrated approach

An integrated approach using the GRACE, outputs of the CLM4.5 model, remote sensing, geological, and geochemical data were used to quantify the recharge and depletion rates of the Nubian Sandstone Aquifer System (NSAS) over the past 10 years (2003–2012). The adopted approach includes: (1) extraction of recharge rates over the NSAS outcrops in Sudan and Chad (area: 0.83 million square km [msk]); (2) estimation of depletion rates over the NSAS in Egypt (area: 0.66 msk); and (3) removal of contributions from non-groundwater Terrestrial Water Storage (TWS) compartments (i.e., soil moisture and river channel) using outputs of CLM4.5 model. Findings include: (1) average annual precipitation over recharge areas in Chad and Sudan was estimated (from TRMM data) at 65 billion cubic km (bck), (2) GRACE-derived NSAS recharge rates were estimated at 2.79 ± 0.98 bck/yr over Sudan and Chad and up to 3.20 ± 1.0 bck/yr if annual extraction rates (~ 0.40 ± 0.20 bck) over these areas were considered; (3) GRACE-derived groundwater depletion rates of NSAS in Egypt were estimated at 2.04 ± 0.99 bck/yr of which 0.50 bck/yr are related to natural discharge; (4) replenishment of the NSAS in Egypt by groundwater flow from the south is hindered by the East-West trending Uweinat-Aswan basement uplift; and (5) assuming current GRACE depletion rates, the recoverable groundwater of the NSAS in Egypt (5180 bck) will last for 2500 years. Plans are underway to quadruple the artificial extraction rates in Egypt; under such conditions, the recoverable groundwater will last for some 800 years.

B.4 **Talk**

Carmen Boening, Marie-Estelle Demory, David Wiese, Pier Luigi Vidale, Malcolm Roberts, Reinhard Schiemann, Matthew Mizielinski, Michael M. Watkins

Presenter Carmen Boening

The use of GRACE satellite data to validate the global hydrological cycle as simulated by a global climate model

This study investigates the use of the Gravity Recovery and Climate Experiment (GRACE) data to validate the global hydrological cycle as simulated by an atmospheric General Circulation Model (GCM), particularly the transport of water from the ocean to the land and vice-versa. We make use of the UPSCALE campaign, a traceable hierarchy of global atmospheric simulations, with mesh sizes ranging from 130 km to 25 km, for which five-member ensembles of 27-year, atmosphere-only integrations are available, using present-day forcing. We show here the ability of this climate model, to simulate the inter-annual variability of terrestrial water storage, compared to GRACE. We particularly find that the model is able to capture the regional distribution of changes in terrestrial water transport during El Nino Southern Oscillation events, implying its ability to import more or less water over land during an ENSO event.

B.4 **Talk**

Annette Eicker, Maike Schumacher, Jürgen Kusche, Hannes Müller Schmied, Petra Döll

Presenter Annette Eicker

Calibration/data assimilation approach for WGHM using gridded GRACE observations

Global hydrological models contribute to the understanding and quantification of the global water cycle. However, large model uncertainties persist due to climate forcing data not being available with sufficient spatial/temporal resolution on the global scale. The GRACE mission provides an independent observation of water storage change with global coverage, which can be used to improve global hydrological models. In our group, an ensemble Kalman filter approach has been developed to improve the WaterGAP global hydrological model (WGHM) by assimilating GRACE-derived gridded terrestrial water storage changes and by calibrating WGHM steering parameters within the same step. In this presentation we will show the current state and results of our assimilation approach. In particular we will discuss the influence of the GRACE spatial discretization to explore as much spatial information of the GRACE data as possible, and we will show some validation experiments.

B.4 **Talk**

Liangjing Zhang, Henryk Dobslaw

Presenter Liangjing Zhang

Validation of MPI-ESM Decadal Hindcast Experiments with Terrestrial Water Storage Variations as Observed by GRACE

Time-variations in the gravity field as observed by the GRACE mission launched in 2002 provide for the first time quantitative estimates of the terrestrially stored water masses at monthly resolution over more than one decade. TWS from GRACE is applied here to validate different sets of ensemble hindcasts performed with the coupled climate model MPI-ESM that have been prepared within the German Research Initiative on Decadal Climate Prediction (MiKlip) during recent years. Moderately positive skill scores of the initialized hindcasts are obtained both with respect to the zero anomaly forecast and the uninitialized projections in particular for leadyear 1 in particular in moderate to high latitudes of the Northern Hemisphere. Skill scores gradually increase when moving in more recent experiments and also for experiments performed at higher spatial resolution, thereby documenting improvements of the MPI-ESM decadal prediction system during course of the Miklip project. Analyses indicate that the skill changes obtained here reflect in particular changes in the large-scale precipitaiton pattern between the individual experiments, which itself is an important target quantity of the climate prediction. We will explain in this talk how GRACE-based TWS might contribute to the validation of precipitation changes in particular in regions of the world where reliable in-situ observations are sparse.

B.4 **Talk**

Akbar Shabanloui, Jürgen Müller

Presenter Jürgen Müller

Assimilation of GRACE, satellite altimetry and hydrological data for determining mass variations in the Siberian permafrost region

The permafrost in Siberia (Russia) plays an important role for the global water cycle and climate change in the Earth system. In this study, data from satellite altimetry missions, hydrological models and GRACE are assimilated to retrieve a more realistic pattern of surface mass variations in Siberia. GRACE provides the integral mass variations with different spatial-temporal resolution depending on the applied filters and reduction models. We used the new release L2 products from GFZ (RL05a) and tested various filters. Geometrically, surface mass variations are determined based on satellite (radar/laser) altimetry tracking data (e.g. Jason-2, ICESat), where especially lake level variations are extracted. In addition, hydrological surface mass variations are obtained from hydrological water cycle models based on observations of precipitation, evapotranspiration and run-off data. We tried to quantify the individual signal contributions in Siberia and to consistently combine the various data to get a better estimate on how big the real permafrost change might be.

B.4 Talk

Mohamed Sultan, Mohamed Ahmed, John Wahr, Eugene Yan

Presenter Mohamed Sultan

Assessing the performance of land surface models over Africa using GRACE and remote sensing data

There has been an increased interest in integrating Land Surface Model (LSM)-derived TWS (TWS[LSM]) compartments with GRACE-derived TWS (TWS[GRACE]) given the fine vertical resolution of the LSM. We evaluated the performance of TWS[LSM] simulated from GLDAS/NOAH, and CLM4.5 over Africa's major watersheds (10 basins) using monthly (2003–2012) TWS[GRACE] and relevant remote sensing datasets: (1) temporal GLDAS/NOAH-derived TWS (TWS[GLDAS]) and CLM4.5-derived TWS (TWS[CLM]) were extracted, (2) spatial and temporal correlations of TWS[LSM] with TWS[GRACE] were performed to examine the degree to which simulated TWS estimates (TWS[LSM]) correspond to measured (TWS[GRACE]) values, (3) the degree to which differences in LSM forcing precipitation (P) influence model outputs was evaluated by conducting spatiotemporal correlations with TRMM-derived precipitation, (4) the validity of evapotranspiration (ET) outputs from LSM was evaluated by comparisons to MODIS-derived evapotranspiration. Our findings include: (1) high correspondence between TWS[GRACE] and TWS[GLDAS] (R square range for 10 basins: 0.34 to 0.88) compared to TWS[CLM] (R square range for 10 basins: 0.05 to 0.90); (2) the similarities in total precipitation across examined basins for GLDAS and CLM suggest that variations in model forcing parameters are not responsible for observed differences in TWS[LSM] outputs, and (3) the poor correspondence between ET[CLM] (range: 83 to 100 % precipitation) and ET[MODIS] suggests that TWS[CLM] could be improved if the evapotranspiration algorithms are reevaluated.

B.4 Talk

J. Kusche, A. Springer, C. Ohlwein, K. Hartung, L. Longuevergne, S. Kollet, J. Keune, H. Dobslaw, E. Forootan, A. Eicker, P. Krahe, W. You

Presenter J. Kusche

Synergies between GRACE and regional atmospheric modeling efforts

In the meteorological community, efforts converge towards implementation of high-resolution data-assimilating regional climate modelling/monitoring systems; driven by improving process understanding, better representation of land surface interaction, atmospheric convection, orographic effects, and the wish to better forecast. It is relevant for GRACE since (1) these models may provide improved atmospheric de-aliasing when compared to ECMWF, (2) they inherit high temporal resolution from the NWP models, (3) efforts are directed towards improving the land surface component and coupling groundwater models; this provides hydrological mass estimates at sub-diurnal resolution, (4) re-analyses provide consistent long time series, (5) GRACE data can help validating model outputs. A coupled atmosphere - land surface - groundwater modelling system is currently being implemented for the European CORDEX region at 12.5 km resolution, based on the TerrSysMP platform (COSMO-EU NWP, CLM land surface and ParFlow groundwater models). We report results from Springer et al. (J. Hydromet.) validating the water cycle in COSMO-EU using GRACE and P, ET and R data. We show that after GRACE bias correction, hydrological conditions prior to 2002 can be reconstructed. Comparing GRACE with CLM allows identifying processes needing improvement. Finally, we compare COSMO-EU surface pressure with ERA-I at timescales < and > 1 month and spatial scales below/above the resolution of global models. We find differences with magnitude 1-3 hPa (1-3 cm EWH); relevant for post-GRACE mission concepts.

B.4 Talk

J. Huang , G. Pavlic , A. Rivera

Presenter Jianliang Huang

How well can synoptic groundwater storage variation be mapped from GRACE? - A case study in Alberta, Canada

In Canada, groundwater levels are monitored by recording water table changes at wells However, the distribution of the wells is uneven across the country. Volume changes in groundwater storage can only be estimated with large uncertainties because specific yields are usually poorly known or inexistent.
The GRACE measurements can provide the total water storage (TWS) variations at a large scale and have been successfully used to study groundwater depletion trends in large water basins worldwide. In this study, we chose the province of Alberta, Canada, for a pilot study as a first step to assessing national-scale GWS variations using GRACE. The province operates a provincial-wide groundwater observation well network. Wells are equipped with data loggers and sensors that continually record groundwater levels. These wells provide in situ data for the validation of GRACE.
The objective of this study is to map GWS variations in Alberta, using the Release 5-monthly Earth gravity models derived from GRACE observation and the land surface model (LSM). We try to derive the seasonal GWS variation as 12-monthly maps from averaged over 2003-2013; a synoptic trend map of GWS variation; and the GWS time series over the study region to find seasonal and inter-annual patterns of groundwater storage variations.

B.4 Poster

Leonid Zotov, Viktor Yushkin, Jaakko Makinen, Mirjam Bilker-Koivula,
Roman Sermyagin, Natalya Frolova

Presenter L. Zotov

Mass changes over Russia from GRACE and absolute gravimetry

We extract the mass changes in the hydrological basins of large Russian rivers by applying MSSA (Multichannel Singular Spectrum Analysis) filtering technique to GRACE data. Separation of annual cycles and trends into different PCs allows studying regional hydrological changes, climate-induced variations in precipitation, floods, etc. We also compare regional changes with gravity changes obtained in particular regions by absolute gravimeters.