

GIA. Finally, we compare our predictions with different types of observational constraint from Canada and Fennoscandia.

G12A-1060 1330h POSTER

Inverting the Fennoscandian Relaxation-Time Spectrum in Terms of a 2D Viscosity Structure With a Cratonic Lithosphere

Zdenek Martinec¹ (+49-331-288-1103; zdenek@gfz-potsdam.de)

Detlef Wolf¹ (+49-331-288-1140; dasca@gfz-potsdam.de)

¹GeoForschungsZentrum Potsdam, Telegrafenberg, Potsdam 14473, Germany

The Fennoscandian relaxation-time spectrum (RTS), recently revised by Wiczerkowski et al. (1999), is a classical data set used in studies of glacial-isostatic adjustment (GIA). We interpret these data in terms of a 2D viscosity structure with a thick cratonic lithosphere below the former Fennoscandian ice sheet and a much thinner lithosphere underlain by an asthenosphere in the peripheral regions. The forward modelling of GIA is implemented in the time domain using the spectral-finite element approach developed by Martinec (2000). The computed vertical displacement for individual spherical harmonics is fitted by a single exponential function and the relaxation time is determined. The synthetic RTS for degrees 10 to 40 is then compared with the observational RTS and the acceptability of the underlying earth model is evaluated. The free parameters for the inverse modelling are either the thickness of the cratonic lithosphere and the upper-mantle viscosity or the thickness of the peripheral lithosphere and the asthenosphere viscosity. We show that a 2D viscosity structure with a cratonic lithosphere of 200 km thickness satisfies the observational Fennoscandian RTS as good as a conventional spherically symmetric earth model with a 95 km thick lithosphere.

G12B MCC: 123 Monday 1330h

New Results From the GRACE Mission (joint with H, OS)

Presiding: M M Watkins, Jet Propulsion Laboratory; B D Tapley, University of Texas; J M Wahr, University of Colorado

G12B-01 1330h

The GRACE Mission: Status and Performance Assessment

Byron D Tapley (512-471-5573; tapley@csr.utexas.edu)

Center for Space Research, The University of Texas at Austin, R1000, Austin, TX 78759, United States

The Gravity Recovery and Climate Experiment (GRACE) was selected under the NASA Earth System Science Pathfinder (ESSP) program with the goal of observing the static and time-variable gravity field with an unprecedented level of accuracy over the course of the five-year mission. The GRACE mission, successfully launched on March 17, 2002, consists of two satellites, co-orbiting in a polar orbit and separated by 200 km. Each satellite carries a microwave, dual frequency one-way ranging system, which is providing measurements of the differential satellite perturbations due to variations in the gravity field. Each satellite carries a high precision accelerometer and a GPS receiver to aid in the recovery of the gravity field from the observational data. The extended mission life coupled with the precision of the measurements is expected to provide a static gravity field model which is several orders of magnitude more accurate than current models and will provide measurements of the temporal variations which will provide new insight into mass and momentum transport among the Earth's atmosphere, ocean and land components. The mission, which is one of the first NASA Earth System Pathfinder Missions, is implemented through a collaborative arrangement by NASA and DLR. The presentation will summarize the mission status and will describe some of the preliminary analysis results.

URL: <http://www.csr.utexas.edu/grace/>

G12B-02 1345h

GRACE Gravity Field Results from JPL

Michael M. Watkins¹ (818-354-7514; michael.watkins@jpl.nasa.gov); Dah-Ning Yuan¹ (818-354-7549; dah-ning.yuan@jpl.nasa.gov); Willy Bertiger¹ (willy.bertiger@jpl.nasa.gov); Gerhard Kruizinga¹ (gerhard.kruizinga@jpl.nasa.gov); Larry Romans¹ (larry.romans@jpl.nasa.gov); Sien Wu¹ (sien.wu@jpl.nasa.gov)

¹Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

The GRACE team at the Jet Propulsion Laboratory have over the past few years adapted the MIRAGE software used for deep space tracking data analysis and determination of the gravity field of planetary bodies such as Mars, Venus, the Moon, and 433 Eros, for GRACE applications. We have used this software to produce Earth gravity fields of unprecedented quality from a combination of the first GRACE K/Ka-band intersatellite tracking, GPS, accelerometer, and star camera data. In this paper we will present the results of that gravity field analysis, including the parameterization used, the spectral content of the residuals, the calibrated covariance, and performance in external tests such as orbit fits and sea surface topography. In addition, since the software and parameterization are independent of that used at the University of Texas and GFZ Potsdam, it provides a type of verification of the fields, and we will discuss the results of the intercomparison of the available gravity solutions.

G12B-03 1400h INVITED

GRACE Orbit and Gravity Field Recovery at GFZ Potsdam - First Experiences and Perspectives

Christoph Reigber¹ (49-331-288-1100; reigber@gfz-potsdam.de); Frank Flechtner¹ (flechtne@gfz-potsdam.de); Rolf Koenig¹ (koenigr@gfz-potsdam.de); Ulrich Meyer¹ (meyeru@gfz-potsdam.de); Karl-Hans Neumayer¹ (neumayer@gfz-potsdam.de); Roland Schmidt¹ (rschmidt@gfz-potsdam.de); Peter Schwintzer¹ (psch@gfz-potsdam.de); Sheng Yuan Zhu¹ (zhu@gfz-potsdam.de)

¹GeoForschungsZentrum Potsdam Division 1: Kinematics and Dynamics of the Earth, Telegrafenberg A 17, Potsdam 14473, Germany

Since the launch of the two GRACE satellites on March 17, 2002, both satellites follow each other in a distance of about 220 km in an almost polar, circular and 500 km high orbit. For orbit and long-wavelength gravity field recovery the GRACE mission concept follows CHAMP's configuration, i.e., GPS satellite-to-satellite tracking and accelerometry on each of the two satellites. The essentially new element is the K-band microwave link measuring the relative distance of one satellite with respect to the other in both directions with an ultra-high precision (few m). To fully exploit this high precision, the requirements on the performance and precision of the accelerometers to measure non-gravitational orbit perturbations are one order of magnitude more stringent than on CHAMP. The goal of GRACE is a distinct progress in global gravity field recovery from space with respect to accuracy and spatial as well as temporal resolution. First experiences of the GFZ project team with the instrument and sensor performance on the GRACE satellites, the parameterization of the data in precise orbit determination and first tentative gravity field solutions are discussed and compared with CHAMP related results. GRACE data processing at GFZ Potsdam is part of the GRACE level-2 product generation and validation, which is shared with UTEX/CSR and NASA/JPL. On level-1, GFZ Potsdam is responsible for providing high frequency atmosphere and ocean mass variation models to avoid alias effects in GRACE's envisaged sequence of monthly gravity field solutions. Gravity de-aliasing products quality will be discussed.

G12B-04 1415h INVITED

GRACE Level-1 Data Processing

Gerhard L. Kruizinga¹ (818 354 7060; Gerhard.L.Kruizinga@jpl.nasa.gov); William I Bertiger¹ (William.I.Bertiger@jpl.nasa.gov); Christopher J Finch¹ (Christopher.J.Finch@jpl.nasa.gov); Larry J Romans¹ (Larry.J.Romans@jpl.nasa.gov); Michael M Watkins¹ (Michael.M.Watkins@jpl.nasa.gov); Sien C Wu¹ (Sien-Chong.Wu@jpl.nasa.gov)

¹Jet Propulsion Laboratory California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

The beginning of the science processing for the GRACE mission, called Level-1 processing, consists of data reformatting, data compression, editing, and precise time tag alignment based on GPS precise orbit determination for the formation of the dual one way range. This task is performed at the Jet Propulsion Laboratory, California Institute of Technology (JPL) GRACE Science Data System team working in cooperation with the Physical Oceanography Data Active Archive Center (PO-DAAC). In this talk an overview will be given of the data flow from raw telemetry (Level-0) to Level-1 data which is used to estimate gravity fields by the Level-2 processing centers at the Center for Space Research, University of Texas at Austin, Geo Forschungs Zentrum, Potsdam and JPL.

Furthermore, the quality control assessment for all data products will be discussed as well as experience gained by processing the GRACE data set. Finally an overview will be given of all science data products to be distributed to the science community and the method of distribution.

URL: <http://www.csr.utexas.edu/grace>

G12B-05 1430h INVITED

Validation of GRACE Time Variable Gravity Against Atmospheric Mass Variations

Isabella Velicogna¹ (303-492-5141; isabella@colorado.edu)

John Wahr¹ (wahr@colorado.edu)

¹Department of Physics and CIRES, CAMPUS BOX 390, University of Colorado, BOULDER, CO 80309-0390, United States

GRACE will resolve temporal variations in gravity at length scales of a few hundred km and larger, and produce a complete global map once every 30 days. The data delivered by GRACE will need to be calibrated and validated in order to ensure their quality and reliability. The Calibration/Validation (Cal/Val) phase will validate the data collected during the on-orbit checkout phase and verify the quality of the data for the entire life span of the mission. In order to Cal/Val GRACE data, we must select an area of greater than 2×10^5 km² where the integral of all surface mass changes can be constrained with an accuracy better than 1 cm of water thickness equivalent. As it would be difficult to constrain the hydrology and precipitation signals in a typical region with sufficient accuracy, we Cal/Val GRACE in relatively water-free areas where the atmospheric pressure can be well constrained. We present the results of the Cal/Val of GRACE satellite data in the desert of southwestern Egypt. This extremely dry region has several barometers and rain gauges within or nearby. The gravity variation measured by GRACE in the selected area will be the sum of contributions from the GRACE measurement error, the error in removing the atmospheric mass variation using geopotential heights from an ECMWF global circulation model, the fluctuation of water mass in the Nile river and Lake Nasser, aquifer depletion, and sea surface variations in surrounding seas. In general, only the atmospheric mass variation will be significant at the 1 cm level of water thickness equivalent within the Cal/Val area. Simulations indicate that the other signals besides the atmosphere should contribute negligibly to the time variable gravity measured by GRACE. To approximate the error in removing atmospheric mass distribution from GRACE data, we calculate the difference between surface pressure from barometer measurements and modeled surface pressure from ECMWF, averaged over periods of GRACE monthly estimates of geoid. We will compare residual differences with the signal measured by GRACE. If the two signals are significantly different we will investigate if the fluctuation of water mass in the area can be responsible for the observed discrepancy.

G12B-06 1445h INVITED

GRACE: Mission Profile and its Relation to Science Goals

Srinivas V Bettadpur (+1-512-471-7587; srinivas@csr.utexas.edu)

University of Texas Center for Space Research, 3925 W. Braker Lane, Suite 200, Austin, TX 78759-5321, United States

On March 17, 2002, the twin GRACE satellites were successfully launched, with the purpose of collecting data leading to dramatic improvements in the estimates of the long-term mean and temporal variability of the Earth gravity field. The gravity information from GRACE is contained within the inter-satellite (microwave) range-change measurements, supported by measurements of the non-gravitational accelerations, the attitude and the GPS tracking data. Ensuring sufficient quality of these measurements to meet the science goals had led to unique requirements on the precision of the GRACE attitude pointing system, its dimensional stability & precision of instrument accommodation, as well as on other aspects of the flight system & mission design.

In this paper, certain aspects of the ongoing work of the multi-national GRACE project team is encapsulated into a description of the mission profile and its relationship to the science goals. The areas of focus include the orbit & station-keeping activities; the attitude pointing performance; the thermal stability performance; instrument configuration; and the status of the key in-flight verifications of alignments & center-of-mass calibrations. Along with a description of the importance of each such focus area on science data quality, the current in-flight performance relative to the pre-flight goals will be presented. Arising from these considerations, the talk will conclude with an outline of the science mission plan for the near future.

G12C MCC: 123 Monday 1530h

Crustal Deformation II (joint with S, T)

Presiding: M J Johnston, U.S.

Geological Survey; T Árnadóttir,
Nordic Volcanological Institute

G12C-01 1530h

Comparisons Between the ITRF97, IGS97 and IGS00 Pure GPS Reference Frames: Implications for Precise Velocity Estimations

Shimon Wdowinski¹ (shimonw@rsmas.miami.edu)

Giovanni F Sella² (sella@earth.northwestern.edu)

Timothy H Dixon¹ (tdixon@rsmas.miami.edu)

¹RSMAS-MGG, University of Miami, Miami, FL 34199, United States

²Department of Geological Sciences, Northwestern University, Evanston, IL 60208, United States

Use of a global reference frame is essential to many geodetic applications and critical to velocity estimates for space geodetic sites. The most commonly used reference frame is the International Terrestrial Reference Frame which uses different collocated space-based techniques. We present results of a comparison of three pure GPS reference frames that are in current use and that have been aligned by different groups to published ITRF multi-technique frames. These are ITRF97 as defined by ITRF (ITRF97), ITRF97 as defined by IGS (IGS97) and ITRF2000 as defined by IGS (IGS00). We compare the three reference frames over the time interval 1993 to 2002 and look at 600 time-series. Observed differences may reflect a number of factors most importantly: (1) the number of available sites and their location at a give epoch, (2) the epoch of alignment of the reference frame and (3) the length of the time-series. We observe a decrease in scatter over time in the WRMS of all the reference frames, which undoubtedly reflects the increased number of sites and robustness of position estimates for each site. WRMS differences are greatest < 1996 between ITRF97 and IGS00. The velocity components in north, east and vertical show a small but significant bias depending on the reference frame in all three components. Differences in velocities between IGS97 and IGS00 are up to 2 mm/yr. These differences have important implications for geodetic studies that aim to resolve < 1 mm/yr of motion.

G12C-02 1545h

Crustal Deformation in Central Asia From GPS Measurements, 1994-2002

Mathilde Vergnolle¹ (33-4-92-94-26-06;

vergnol@geoazur.unice.fr); Eric Calais²; Jacques

Déverchère¹; Vladimir San'kov³; Andrei

Lukhnev³; Andrei Miroshnichenko³; Sharav

Amarjargal⁴

¹Géosciences Azur UMR 6529, CNRS/UNSA/UMPC, 250 rue A. Einstein, Valbonne 06560, France

²Dept. of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907-1397, United States

³Institute of Earth's Crust, Russian Academy of Sciences, Siberian branch, 128 Lermontov St., Irkutsk 664033, Russian Federation

⁴Research Center for Astronomy and Geophysics, x, Ulaan Baatar 210351, Mongolia

We present Global Positioning System (GPS) measurements of crustal motions at ~50 sites in central Asia (Mongolia-Baikal) for the 1994-2002 period. We investigate the effect of the definition of rigid Eurasia in the implementation of the reference frame and analyze the kinematics of deformation in the northern part of Asia, in particular the motion of north China with respect to Eurasia and south China.

In Mongolia, we find rapid spatial changes in strain regime, from NS shortening and right-lateral shear in the Altay, to left-lateral shear in central Mongolia, and to NW-SE extension in Eastern Mongolia and the Baikal rift zone. We find that extension is not limited to the Baikal rift zone, currently opening at 4 mm/yr in a NW-SE direction, but affects a much broader area encompassing most of Eastern Mongolia and, possibly, part of north China.

We find that central Mongolia (western part of Amurian-North China block) is moving to the east to southeast at 3-6 mm/yr w.r.t. Eurasia. This is significantly faster than proposed by most deformation models of Asia and 90 degrees off in azimuth, but consistent with other geodetic results in northern China. We model the postseismic effects of four M8 and greater earthquakes that occurred in Mongolia between 1905 and 1957 and show that the present-day contribution of viscoelastic relaxation is less than 3 mm/yr.

The discrepancy between GPS observations in Mongolia and model predictions must be sought in processes not accounted for in most of these models, such as the far-field contribution of the Pacific subduction zones and/or the effect of gravitational forces on intracontinental deformation.

G12C-03 1600h

Crustal Deformation Measured by GPS on Reykjanes Peninsula due to Triggered Earthquakes on June 17, 2000

Thóra Árnadóttir¹ (+354-5254488;

thora@norvol.hi.is); Halldór Geirsson²

(+354-5226000; dori@vedur.is); Erik Sturkell²

(+354-5226000; erik@vedur.is); Kristín S

Vogfjörd² (+354-5226000; kristinv@vedur.is); Páll

Einarsson³ (+354-5254816; palli@raunvis.hi.is);

Sigrún Hreinsdóttir⁴ (sigrun@giseis.alaska.edu)

¹Nordic Volcanological Institute, Grensasvegur 50, Reykjavik 108, Iceland

²Icelandic Meteorological Office, Bustadavegur 9, Reykjavik 150, Iceland

³Science Institute, University of Iceland, Dunhagi 3, Reykjavik, ISL 107

⁴Geophysical Institute, University of Alaska, PO Box 757320, Fairbanks, AK 99775, United States

The South Iceland Seismic Zone (SISZ) experienced the largest earthquake for 88 years on June 17, 2000 ($M_W=6.5$). The event occurred at 15:40:41 UT, and was caused by right-lateral strike slip on a N-S fault at 63.98°N, 20.37°W. The main shock triggered seismicity over a large area in South Iceland, and significant slip on three faults on Reykjanes Peninsula, up to 85 km away from the main shock epicenter. The first event on Reykjanes Peninsula occurred near the Hvalhnjúkur fault (63.951°N, 21.689°W), at 15:41:07 UT, with an estimated moment magnitude of $M_W=5.3$. The second event occurred near lake Kleifarvatn (63.937°N, 21.940°W) at 15:41:11 UT. The magnitude for this event is difficult to determine because nearby stations were saturated and the seismic signal is also hidden in the coda of the main shock and the first triggered event. The third event located near Núpshlíðarháls (63.902°N, 22.124°W) occurred at 15:45:27 UT, and had an estimated $M_W=4.8$. The locations and timing of the events on Reykjanes suggest that the first two were triggered by surface waves from the main shock. A second large ($M_W=6.4$) earthquake in the SISZ occurred on June 21, 2000. This event does not appear to have triggered as much activity on Reykjanes Peninsula, as the earlier one, although the epicenter was closer.

An extensive GPS network, previously measured in 1993 and 1998, was remeasured in 2000 following the earthquakes and again in 2001. The observations show deformation due to the June 2000 earthquake sequence, motion caused by plate spreading across Reykjanes Peninsula, as well as subsidence at the Svartsengi geothermal area and inflation in the Hengill volcanic area. The largest coseismic motion was observed near lake Kleifarvatn, indicating that this event was the largest of the three. Repeated lake levelling shows that the east side of the lake subsided by about 7 cm, relative to the west side, between 1994 and 2001. Crustal deformation due to the events was also observed with InSAR and continuous GPS. We model the surface deformation observed with network and continuous GPS, caused by the three events on Reykjanes Peninsula, after correcting for plate motion, using rectangular dislocations in an elastic half space. We also model subsidence due to geothermal exploitation at Svartsengi by a deflating point source. Best fit uniform slip models indicate that faulting occurred on N-S to NNE-SSW striking planes with primarily right-lateral strike slip.

The sequence of events on Reykjanes Peninsula following the main shock on June 17 2000, demonstrates dynamic triggering of earthquakes and interaction between parallel faults in Southwest Iceland.

G12C-04 1615h

Transient Postseismic Relaxation With Burger's Body Viscoelasticity

Eric A Hetland¹ (617-253-8872; eah@mit.edu)

Bradford H Hager¹ (brad@chandler.mit.edu)

Richard J O'Connell²
(oconnell@geophysics.harvard.edu)

¹Dept. of Earth, Atmos. and Planetary Sciences, Massachusetts Institute of Technology 77 Massachusetts Ave., Cambridge, MA 02139, United States

²Dept. Earth Planetary Sciences, Harvard University 20 Oxford St., Cambridge, MA 02138, United States

Typical models used to investigate postseismic deformation are composed of an elastic layer over a Maxwell viscoelastic region. Geodetic observations made after a number of large earthquakes show a rapid exponential decay in postseismic velocity immediately after the rupture, followed by a more slowly decaying (or constant) velocity at a later time. Models of a Maxwell viscoelastic interior predict a single exponential postseismic velocity relaxation. To account for observed rapid, short-term relaxation decay, surprisingly low viscosities in the lower-crust or upper-mantle have been proposed. To model the difference in short and long time decay rates, the Maxwell element is sometimes modified to have a non-linear rheology, which results in a lower effective viscosity immediately after the rupture, evolving to a higher effective viscosity as the co-seismic stresses relax. Incorporation of models of after-slip in the lower crust on a down-dip extension of the fault have also had some success at modeling the above observations.

When real rocks are subjected to a sudden change in stress or strain, e.g., that caused by an earthquake, they exhibit a transient response. The transient deformation is typically accommodated by grain boundary sliding and the longer-time deformation is accommodated by motion of dislocations. Both a short-term transient response and long-term steady creep are exhibited by a Burger's body, a Maxwell element (a spring in series with a viscous dash-pot) in series with a Voigt element (a spring in parallel with a viscous dash-pot). Typically the (transient) viscosity of the Voigt element is 10 - 100 times less than the (steady) viscosity of the Maxwell element. Thus, with a Burger's body, stress relaxation is a superposition of two exponential decays.

For a model composed of an elastic layer over a viscoelastic region, the coseismic changes in stress (and strain) depend only on the elastic moduli, and are independent of the description of the viscous component of the rheology. In a Burger's body model of viscoelasticity, if the viscosity of the Voigt element is much less than that of the Maxwell element, the initial relaxation time is given by the decay time $\tau = \eta_{\text{Voigt}}/G_{\text{Maxwell}}$. Whereas, for a Maxwell rheology, the initial relaxation time is given by $\tau = \eta_{\text{Maxwell}}/G_{\text{Maxwell}}$. For both models, the initial spatial distribution of stresses is the same, which results in identical initial spatial distribution of velocities. Thus it is easy to mistake the transient response of a Burger's body for that of a Maxwell rheology with unrealistically low viscosity. Only later in the seismic cycle do the spatial patterns of velocity differ for the two rheologies.

G12C-05 1630h

Tectonomagnetic Anomaly Observed at Parkfield, California, from 1993 to the Present - Correspondence to Increased Shear Strain-Rate during the Same Period.

Malcolm J. S. Johnston¹ (650 3294812; mal@usgs.gov)

Robert J. Mueller¹ (650 3294857; rmueller@usgs.gov)

¹US Geol. Surv., 345 Middlefield Rd., MS977, Menlo Park, CA 94025, United States

Precise measurements of local magnetic fields have been obtained with a differentially connected array of seven synchronized proton magnetometers in the Parkfield region since 1984. The magnetometers are located along 60 km of the transition region of the San Andreas fault where fault creep changes from zero to about 15 mm/yr. To the south the fault last ruptured with a M8 earthquake in 1857. The central region has ruptured with M6 earthquakes in quasi-periodic manner from 1881 to 1966. Between 1992 and 1994, a significant increase in shear strain was observed on the 2-color geodimeter network and a small network of borehole tensor strainmeters in the central region. This strain change was accompanied by three M4.5-5 earthquakes roughly a year apart in 1992, 1993 and 1994 near the suspected nucleation point of M6+ earthquakes in this region. After correction for secular variation, it is apparent that an anomalous 0.2 nT/yr increase in the magnetic field has occurred from mid-1993 to the present on several magnetometers on the southeast side of the San Andreas Fault and smaller increases are observed on the northeast side of the fault. The strain