G31C-07 1150h

Recent Small Glacier Mass Balance Signatures in Time-Variable Gravity

Mark E Tamisiea[1] (303-492-4060; tamisiea@colorado.edu)

Jerry X Mitrovica[2] (jxm@physics.utoronto.ca)

Jim L Davis[3] (jdavis@cfa.harvard.edu)

[1]University of Colorado, CB 440, Boulder, CO 80309, United States

[2]University of Toronto, Department of Physics, 60 St. George St., Toronto, ON M5S 1A7, Canada

[3]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, United States

The global reservoir of small (or mountain) glaciers may be experiencing an accelerated phase of net melting. Estimates of the recent mass balance of large systems of such glaciers using point measurements of accumulation and discharge rates or changes in ice sheet height along profiles obtained from altimetry are subject to biases associated with incomplete sampling. Integrated measurements, such as changes in sea level and the geoid (or sea surface) are more robust in this specific sense. However, these variations may be contaminated by signals from past (i.e., Pleistocene to Late Holocene) glacial fluctuations. As an example, in regions with low asthenospheric viscosity, such as Alaska and Patagonia, predictions of radial crustal motion (and thus sea level) are known to be highly sensitive to the local glacier history over the last few thousand years [e.g., Ivins and James, 1999, Larsen et al., 2003; Tamisiea et al., 2003]. In contrast, the predicted geoid (sea surface) variation in the same regions is insensitive to this aspect of the loading history [Tamisiea et al., 2003]. In this talk we extend this work to consider predictions of present-day geoid patterns arising from past glacial fluctuations of various time scales. We demonstrate that measurements of geoid variations in the vicinity of small glacier systems provide a remarkably robust (i.e., uncontaminated) measure of the ongoing mass balance of these systems. We conclude that such measurements should be a key target of existing and future satellite gravity missions.

G31C-08 1205h

Mantle Lateral Variations and Earth Tides

Laurent Metivier[1] (lalmetiv@ipgp.jussieu.fr)

Marianne Greff-Lefftz[1] (greff@ipgp.jussieu.fr)

Michel Diament[1] (diament@ipgp.jussieu.fr)

[1]Institut de Physique du Globe de Paris, 4, place Jussieu, Paris 75005, France

Earth strain and gravity responses to tides or atmospheric loads, are generally calculated assuming radially stratified earth models, and at hydrostatic equilibrium. However, some local observations show unexplained perturbations on the tidal gravity signal. A possible cause for those perturbations may be the neglect of rheology and density lateral variations as well as the non hydrostaticity of the Earth. We have investigated a non radially symmetrical earth numerical model with the intent to study the earth response to low frequency forcings. This model uses a finite element method (spectral elements) developed on the cubed sphere mesh (Chaljub et al., 2003 ; Ronchi et al., 1996), and has resolved the static gravito-elasticity equations. The non-hydrostaticity has been taken into consideration by a first order perturbation theory. As a first validation of our model, we computed the M2 and M3 tidal earth response for a radially stratified model: the Preliminary Referential Earth Model. We obtained, as expected, PREM Love numbers with a very good accuracy. As a second validation, we calculated the effect of ellipticity of the Earth and compared, for homogeneous model or for PREM, our numerical results with analytical solutions (using Maple computations), or literature solutions. Finally, as first applications, we have investigated the influence of the lateral variations induced by oceanic -continental crust distribution, and the possible influence of a mega-plume on gravity tide.

In the future, we also intend to extend our approach to more local studies, for features affected by other forces than Earth tides.

G32A MCC: Level 2 Wednesday 1330h

Gravity Posters

Presiding: **M M Watkins,** Jet Propulsion Laboratory, California Institute of Technology**; R S Nerem,** University of Colorado

G32A-0720 1330h POSTER

GRACE Level-1 Processing Status

Gerhard L Kruizinga[1] (818 354 7060; Gerhard.L.Kruizinga@jpl.nasa.gov); William I Bertiger[1] (818 354 4990; William.I.Bertiger@jpl.nasa.gov); Kelley E Case[1] (818 345 5870; Kelley.E.Case@jpl.nasa.gov); Christopher J Finch[1] (818 354 2390; Christopher.J.Finch@jpl.nasa.gov); Frank Flechtner[2] ((+49) 8153-28-1297; flechtne@gfz-potsdam.de); Larry J Romans[1] (818 354 5809; Larry.J.Romans@jpl.nasa.gov); Michael M Watkins[1] (818 354 7514; Michael.M.Watkins@jpl.nasa.gov); Sien C Wu[1] (818 354 4937; Sien-Chong.Wu@jpl.nasa.gov)

[1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, United States

[2]GeoForschungsZentrum Potsdam, Department 1: Geodesy and Remote Sensing c/o DLR Oberpfaffenhofen, Wessling D-82230, Germany

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, GeoForschungs Zentrum, Potsdam and JPL. Furthermore, a quality control assessment for the Level-1 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

G32A-0721 1330h POSTER

Integrated Sensor Analysis for GRACE

Bjoern Frommknecht (+49-89-23185; frommknecht@bv.tum.de)

Institute for Astronomical and Physical Geodesy, TU Munich, Arcisstrasse 21, Munich D-80333, Germany

GRACE measures the Earth's gravity field with great precision and detail. The gravity signal is deduced from the measured relative motion between the two satellites, corrected for all non-gravitational forces acting on the two satellites. Thus, a very sophisticated system of sensors with K-Band microwave inter-satellite ranging, GPS, micro-accelerometry, star-tracking and angular control together forms the gravimetric system. A simulator of this integrated sensor system has been constructed. Employing realistic models for gravitational as well as non-gravitational forces, satellite geometry and attitude, the expected GRACE signal can be simulated realistically. The noise modelling of the sensors is based on performance specifications. The simulator serves three purposes: (1) to deliver a thorough understanding of the sensor system, as well as its signal and noise behavior, (2) to compare anticipated and real system performance by analysis of real data and simulated data, (3) to identify processing errors and possible malfunctions. Based on a three day test data set K-Band and differential mode accelerometry have been analyzed in detail. Signal characteristics, the noise level as well as signal-to-noise behavior of the K-Band system are close to the anticipated performance. More complex is the situation for the differential accelerometry signal where actual, simulated and predicted performance show some disagreement that needs explanation.

G32A-0722 1330h POSTER

Comparison of three techniques for modeling the Earth's gravity field on the basis of a satellite orbit

Pavel Ditmar[1] (+31-15-2782501; ditmar@geo.tudelft.nl)

A. A. Van Eck van der Sluijs[1] (+31-15-2782501; S.vanEck@citg.tudelft.nl)

[1]Dept. of Physical, Geometrical and Space Geodesy (FMR), Delft University of Technology, Kluyverweg 1, Delft 2629 HS, Netherlands

At present, there are three techniques for the computation of the Earth's gravity field from a satellite orbit: (i) the "classical" approach based on the integration of variational equations (IVEA); (ii) the energy balance approach (EBA); (iii) the acceleration approach (AA), which directly relates the satellite accelerations to the gravity field in accordance with Newton's second law. Most of the results have been obtained so far with the IVEA and EBA. The AA is believed to be inferior because the double differentiation needed to convert the satellite orbit into the satellite accelerations amplifies data noise dramatically. We show that that a poor performance of the AA is a myth. One can easily prove that the solution of an inverse problem is invariant with respect to the linear transformation of the data vector of the kind **d' = B d** (where **d** is the original data vector, **d'** is the transformed data vector, and **B** is the transformation matrix) provided that the matrix **B** is square and invertible. The only pre-requisite is that the optimal estimation procedure is followed, including the usage of the properly transformed covariance matrix: $\mathbf{C}_{d'} = \mathbf{B}\,\mathbf{C}_d\,\mathbf{B}^T$. In other words, such data vectors **d'** and **d** are equivalent. It is easy to show that the satellite positions and satellite accelerations are two nearly equivalent data sets (in order to reach a strict equivalence, the latter can be supplied, e.g., with the initial state vector). Therefore, these data sets may result in nearly the same gravity field model. A decision which technique is preferable should be made on the basis of practical considerations, e.g. the numerical efficiency. According to our experience, the AA leads to a much faster computational scheme than the IVEA. Furthermore, we have considered the EBA. It is easy to show that a set of kinetic energy measurements is nearly equivalent to a set of along-track satellite accelerations. The other two components of the acceleration vectors are ignored by the EBA. Therefore, one can expect that this technique is about $\sqrt{3}$ times less accurate than the IVEA and AA (provided that all 3 acceleration components are equally informative and accurate). This conclusion can also be justified from the physical point of view. The cross-track and the radial components of the of the gravitational forces, which are responsible for corresponding accelerations, are always directed normally to the elementary path. Therefore, they do no work and are not perceptible in terms of the energy balance. Our theoretical findings are supported by a numerical example. A 10-day drag-free repeat satellite orbit of 246-km altitude with 1-s sampling is considered; the orbit corresponds to the EGM96 gravity field model truncated at degree and order 80. The satellite positions are artificially contaminated with 1-cm white noise, after which satellite accelerations are derived. Then, the gravity field model is computed with the AA and EBA. The accuracy of the results obtained, expressed in terms of average geoid height errors (in the latitudinal band $\pm 80^\circ$), turns out to be the following: AA (all three acceleration components are considered): 29.7 cm; AA (only the along-track component is considered): 50.3 cm; EBA: 52.1 cm. In order to compare the AA and the IVEA, we have considered a similar data set but with 15-s sampling. The models obtained are characterized by the following accuracy: IVEA: 111 cm; AA: 114 cm. These results agree very well with the theoretical expectations.

G32A-0723 1330h POSTER

The Effect of Arc Length on GRACE Gravity Models

Brian Gunter[1] (512-471-6728; gunter@csr.utexas.edu)

Zhigui Kang[1] (512-471-0163; kang@csr.utexas.edu)

John Ries[1] (512-471-7486; ries@csr.utexas.edu)

[1]The University of Texas at Austin Center for Space Research , 3925 West Braker Lane Suite 200, Austin, TX 78759-5321, United States

Conventional modeling techniques often make use of a one day integration period (arc) in order to recover as much of the gravity field signal as possible. This one day arc length has served as a reasonable compromise between the ability to resolve the long period orbit perturbations from the gravity field and the growth of various modeling errors due to the extended integration time. The nature of the observables from the GRACE mission, however, may make it more effective to use a shorter arc length (i.e., less than one day). The data gathered by the GRACE mission differs from classical

methods by relying principally on the high precision measurement of the short-period, differential perturbations of the two GRACE satellites. As a result, a shorter arc length should still be able to resolve the long wavelength components of the gravity field effectively without suffering from the longer period modeling errors associated with the longer arc lengths. Using data from the GRACE mission, this study will present results from a series of experiments designed to test the influence of both short and long arc lengths on the estimation of the gravity field.

G32A-0724 1330h POSTER

Terrestrial Water Storage Variations From GRACE: Estimation, Validation and Uncertainty

James Famiglietti[1] (jfamigli@uci.edu)

Jianli Chen[2] (chen@csr.utexas.edu)

Matthew Rodell[3] (Matthew.Rodell@nasa.gov)

Ki-Weon Seo[4] (kiweon@speer.geo.utexas.edu)

Clark Wilson[4] (crwilson@mail.utexas.edu)

[1]Dept. of Earth System Science, University of California, Irvine, Irvine, CA 92612, United States

[2]Center for Space Research, University of Texas at Austin, Austin, TX 78759, United States

[3]Hydrological Science Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States

[4]Dept. of Geological Sciences, University of Texas at Austin, Austin, TX 78712, United States

In this presentation we discuss our plans for producing monthly estimates of basin-scale changes in total water storage from GRACE observations of the time-variable gravity field. Monthly changes in total water storage (snow, surface waters, soil water and groundwater) will be estimated for several large (>200,000 km^2) watersheds around the globe. Water storage change estimates will be compared to those derived from observations as well as to those produced from assimilating land models such as the Global Land Data Assimilation System (GLDAS). Uncertainty estimates will incorporate errors due to instrument limitations, atmospheric mass removal, post-glacial rebound, basin leakage and aliasing of high-frequency hydrologic signals. The importance of GRACE-derived water storage changes in hydrology and Earth system science will be highlighted.

G32A-0725 1330h POSTER

Global time-variations of hydrological signals from GRACE satellite gravimetry

Olivier BRUNAU[1] (brunau@pinot.cst.cnes.fr)

Guillaume Ramillien[1] ((+33) 05 61 33 29 30; Guillaume.Ramillien@cnes.fr)

Anny Cazenave[1] ((+33) 61 33 29 22; Anny.Cazenave@cnes.fr)

[1]LEGOS-GRGS/CNES, 18, Avenue Edouard Belin 31055 Toulouse cedex 01 FRANCE, Toulouse 31055, France, Metropolitan

Successfully launched in mid-March 2002, the goal of the GRACE (Gravity Recovery & Climate Experiment) satellite mission is to measure the spatio-temporal variations of the Earth's gravity field with high accuracy (1 cm in terms of geoid height) and a spatial resolution of 200-300 km for a nominal period of five years. The unprecedented precision of the GRACE mission will enable us to detect tiny time-variations of the gravity field related to global redistributions of fluid masses at the surface of the Earth. We preent here a new approach based on the generalized least-squares inverse method to unravel the different contributions of the main surface water reservoirs (atmosphere, oceans, total continental water storage) from time-series of monthly-mean GRACE geoids. The synthetic GRACE geoids were computed from outputs of global models of different climatic fields. Because of the non-uniqueness of the classical inverse problemes in gravity, independant information were added before inversion. In dividual geoid components of each hydrological contribution obtained as a solution of the inversion was then converted into a map of equivalent-water thickness using a linear filtering of the spherical harmonics of the geoid solutions. Validation consisted of comparing the soil moisture solutions with independent information of in situ soil moisture time-series from Robock's database (Robock, 2002). Analysis of the errors after "de-correlation" suggests that the proposed inverse approach is able to recover global changes of water mass at time scales of at least a few weeks and accuracy of a few millimeters in water thickness.

G32A-0726 1330h POSTER

Temporal mass variability in the Earth's systems and its impact on GRACE science

Paul F. Thompson[1] (512-471-5573; thompson@csr.utexas.edu)

Byron D. Tapley[1] (tapley@csr.utexas.edu)

Srinivas V. Bettadpur[1] (srinivas@csr.utexas.edu)

[1]The University of Texas at Austin, Center for Space Research, 3925 W. Braker Ln Suite 200, Austin, TX 78759-5321, United States

The GRACE mission, which was launched in March of 2002, should have orbit coverage nominally sufficient to estimate the gravity field as a piecewise mean every 30 days with a spatial resolution on the order of 400 km. Due to the nature of this orbital the orbit sampling, short period mass variability will not be completely observable. This short period variability can alias into the longer period gravity estimates at a variety of spatial scales, affecting the accuracy of the gravity results. Perfect knowledge of the short period (primarily daily) mass variability of the Earth would be required to remove the aliasing effects completely. Since the true variability is not known, simulations are used to estimate the aliasing error that may be present in the GRACE gravity estimates. Contemporary atmospheric, ocean, and hydrology models are used to approximate the variability present in the Earth's dynamical system. Different combinations of these models will be used to construct an estimate of the unmodeled signal present during GRACE gravity recovery. The aliasing error determined from these simulations will be described. GRACE data processing has adopted an atmosphere-ocean de-aliasing (AOD) model provided by GeoForschungsZentrum Potsdam (GFZ). The AOD product is based on six hour global data from the ECMWF combined with a barotropic ocean model. The time series of geopotential coefficients from this product is used in order to remove some of the short period variability due to the atmosphere and oceans. At a minimum, the impact of using an AOD model will need to show no degradation in the orbit determination, measurement residuals, or covariance of the gravity fields. We will discuss the implementation of the AOD model in the GRACE data processing and compare the resulting gravity estimates with gravity estimates that did not use an AOD model. Furthermore, the GRACE solution perturbation due to using or not using the AOD model will be contrasted with corresponding aliasing simulations.

G32A-0727 1330h POSTER

Geoid change about Greenland resulting from past and present-day changes in the Greenland Ice Sheet

Kevin M Fleming[1] (+49 331 288 1449; kevin@gfz-potsdam.de)

Zdeněk Martinec (+49 331 288 1103; zdenek@gfz-potsdam.de)

Jan Hagedoorn (+49 331 288 1750; jan@gfz-potsdam.de)

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

[1]Department 1: Geodesy and Remote Sensing GeoForschungsZentrum Potsdam, Telegrafenberg, Potsdam 14473, Germany

We have produced predictions of contempory spatial and temporal changes in the geoid about Greenland arising from glacial-isostatic adjustment, with the aim of resolving to what degree such changes may be detectable by gravity space missions (CHAMP, GRACE). These geoid changes may be divided into those resulting from the ongoing effect of the deglaciation following the Last Glacial Maximum, and those from present-day variations in the global ice regime. We will focus on the Greenland Ice Sheet, making use of two mass-balance models that have been derived from independent sources.

G32A-0728 1330h POSTER

Geoid, its Temporal Variation and Dynamic Topography as Constraints in Global Geodynamics

Karen Niehuus[1] (niehuus@geophysik.uni-frankfurt.de)

Harro Schmeling[1] (schmelin@geophysik.uni-frankfurt.de)

[1]Institute of Meteorology and Geophysics Goethe-University, Feldbergstr. 47, Frankfurt am Main 60323, Germany

Introduction Density distributions derived from highly resolved seismic tomography and viscosity models of Earth's mantle are investigated in analytical and numerical flow models. The aim of this project is to fit the models' predicted observables to the GRACE satellite-mission's gravity and geoid measurements and the field's variation with time and to reproduce estimates of dynamic topography as an additional constraint. Advection of a given density field yields temporal variations in the geoid and dynamic topography. In order to investigate whether identifiers of such mantledynamic processes may be discerned from other signals contained in GRACE-data, these quantities will be analyzed in the spatial and spectral domain. This permits predictions for regional mantledynamic contributions and renders variations of the harmonic coefficients with time, thus providing corrective fields to apply to GRACE-data. **Modelling** Advection of mantle density distributions derived from seismic tomography drives a flow. The variables of the governing flow equations are expressed in terms of products of radial functions and scalar spherical harmonics, yielding a set of coupled first order differential equations. Spheroidal and toroidal terms decouple, the initial solutions for a set of boundary conditions are propagated through a series of shells of constant values for the sought variables by the propagator matrix [Panasyuk and Hager, 1996]. This in turn yields solutions in the form of boundary vectors that give the fluid velocities, stresses, gravitational potential and its radial derivative at any radial level in the earth. **Results** We reproduce 70 % of the observed long-wavelength geoid corrected for isostatically compensated crust and oceanic lithosphere. Gravity field measurements and estimates of dynamic topography [Panasyuk and Hager, 2000] serve to further constrain the range of acceptable models. Advection of density distributions of best-fitting models permits first estimates of the magnitude of temporal geoid variations. According to our preliminary results, the time-dependent geoid signals produced by mantle-dynamic processes may reach or exceede the expected resolution limits for temporal geoid changes of the 5 - year GRACE mission. An iterative search of the parameter space should yield models of improved fit to the observables and its variations. **References** S.V. Panasyuk and B.H. Hager. Understanding the effects of mantle compressibility on geoid kernels. *Geophysical Journal International*, 124:121-133, 1996. S.V. Panasyuk and B.H. Hager. Models of isostatic and dynamic topography, geoid anomalies, and their uncertainties. *Journal of Geophysical Research*, 105:28,199-28,209, 2000.

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G32A-0729 1330h POSTER

Independent Determination of Low Degree Gravitational Changes From Earth Rotation and Geophysical Models

Jianli Chen[1] (chen@csr.utexas.edu)

Clark Wilson[1,2] (clarkw@maestro.geo.utexas.edu)

[1]Center for Space Research, University of Texas at Austin, 3925 W. Braker Lane, #200, Austin, TX 78759, United States

[2]Department of Geological Sciences, University of Texas at Austin, 1 University Station C1100, Austin, TX 78712, United States

Changes in the Earth's rotation are caused by mass redistribution and movement within the Earth system (i.e. mass and motion effects). The successful separation of mass and motion excitations of the Earth's rotation provide people a unique opportunity to independently determine the degree 2 gravitational changes. These results can serve as observational constraints to the GRACE observation. In this study, we estimate atmospheric wind and oceanic current effects on the Earth's rotation using NCEP reanalysis atmospheric model and the ECCO data assimilating ocean general circulation model developed at NASA JPL. After these two kinds of effects are removed from the Earth's rotational observation, the remaining excitations are used to infer the degree 2 spherical harmonic change. We will compare these preliminary solutions with geophysical model predictions and satellite laser ranging observations, and estimate uncertainties of these solutions.

G32A-0730 1330h POSTER

Gravity models from CHAMP and other satellite data

F G Lemoine[1,2] (301-614-6109; Frank.G.Lemoine@nasa.gov); C M Cox[1,2]; N P Zelensky[1,2]; S B Luthcke[1]; B F Thompson[3]; D D Rowlands[1]; D S Chinn[1,2]; R S Nerem[3]

[1]Laboratory for Terrestrial Physics, Code 926, NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States

[2]Raytheon ITSS, 1616 McCormick Drive, Upper Marlboro, MD 20774

[3]Dept. of Aerospace Engineering Sciences, CB 431, University of Colorado, Boulder, Boulder, CO 80309-0431, United States

CHAMP spacecraft is the first of a series of new spacecraft missions that are revolutionizing our ability to model the Earth's geopotential. We report on the analysis of over 100 days of CHAMP data in 2001 and 2002, merged with tracking data of other satellites such as Jason, Topex, GFO, Starlette, Stella, Spot-2, as well as satellite altimetry. We find that the CHAMP-only component of these solutions is a significant improvement over pre-CHAMP satellite only models with respect to the high degree information expressed by the geopotential model coefficients. For example, the variance of the differences with altimeter-derived anomalies through degree 70 is 2.80 $mGal^2$ for the CHAMP-only solution based on 87 days of data vs. 10.19 $mGal^2$ for EGM96S. Nonetheless, in order to model properly the various resonances to which different satellites are sensitive, we must include other satellite data. We compare the performance of these new CHAMP derived solutions with EGM96 and the EIGEN series of solutions. We review carefully the performance of these models for altimetric satellites.

G32A-0731 1330h POSTER

KMS2002 Global Marine Gravity Field, Bathymetry And Mean Sea Surface

Ole B. Andersen[1] (+45 3587 5255; oa@kms.dk)

Per Knudsen (+45 3587 5318; pk@kms.dk)

[1]National Survey (KMS), Rentemestervej 8, Copenhagen NV 2400, Denmark

During the last three years the KMS global marine gravity field has been improved in corporation with National Imaginary and Mapping Agency (NIMA). These improvements have resulted in a release of KMS99 and KMS2001 gravity fields. Especially, the KMS99 gravity field presented a significant improvement in comparisons with marine observations, as well as global coverage within the 82 degree parallels by adding the ERS-ERM data. The subsequent, KMS2001 only resulted in minor improved gravity field modelling. A new revised global high resolution marine gravity field KMS2002 is presented in this Combining this finetuning with careful edition of data are expected to improve the KMS2002 gravity field, in particularly coastal regions. Improved resolution and data coverage in particularly ice-covered regions are other improvements, which is currently under investigation. The KMS gravity field modelling approach uses the observed sea surface height anomalies relative to EGM96 and converts these into gravity using FFT techniques. For the KMS2002 focus has been on improved mapping of the intermediate wavelength (100-250 km) of the gravity field using the exact repeat mission data from the TOPEX/POSEIDON and ERS-2 satellite missions. The KMS2002 gravity field is accompanied with a high-resolution bathymetry model and a high resolution mean sea surface.

URL: http://research.kms.dk/GRAVITY

G32A-0732 1330h POSTER

Asymptotic Theory for Calculating Geoid Change Caused by Dislocations Buried in a Spherical Earth

Wenke Sun (81-3-5841-5721; sunw@eri.u-tokyo.ac.jp)

Earthquake Research Institute, University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo 113-0032, Japan

Space techniques, e.g., altimetry and gravity missions, become powerful tools in modern geodesy. They can be widely applied in geodetic, oceanographic and geodynamic studies. As a potential application, they provide us with powerful means to detect geoid (or sea level) change caused by earthquake due to their nearly continuous measurements of sea level and geoid over repeat period intervals. To investigate co-seismic geoid (sea level) change or to interpret observed geoid changes by altimetry or gravity missions, theoretical work on co-seismic deformation is also necessary. Dislocation problem for a half-space was studied by many scientists. They presented analytical expressions for calculating surface displacement, tilt, and strain due to various dislocations buried in semi-infinite medium. Especially, Okada (1985) summarized previous studies and presented a complete set of analytical formulae for calculating these geodetic deformations. Okubo (1991, 1992) proposed expressions in closed form to describe potential and gravity changes due to dislocations. Due to their mathematical simplicity, these dislocation theories have been widely applied up to the present day to study or invert seismic faults. However, validity of these theories is strictly limited to a near field because Earth's curvature and radial heterogeneity are ignored. Therefore, a dislocation theory for a more realistic earth model is demanded to interpret far field deformation. A homogeneous or stratified sphere should be considered for this purpose. A homogeneous sphere model is obviously superior to half-space since it includes earth curvature. Efforts to develop formulations for such an earth model were advanced through numerous studies. These studies revealed that earth's curvature effect is negligible for shallow events, while vertical layering may have considerable effects on deformation fields. However, Sun and Okubo's (2002) recent study indicates that both curvature and vertical layering have significant effects on co-seismic deformation. Compared to the half space and homogeneous sphere models, a stratified sphere is the most realistic; they reflect both sphericity and stratified structure of the earth. Sun and Okubo (1993, 1998) and Sun et al. (1996) presented theories to calculate coseismic displacements and gravity changes in spherically symmetric earth models. Okubo (1993) proposed a reciprocity theorem for connecting solutions of dislocation and tidal, shear and load deformations. This theoretic result provides a useful tool for the current study. The above studies concerning different earth models indicate that different theories have different advantages and disadvantages. For the half-space earth model, corresponding theories are mathematically simple and can be used easily in an application. However, the disadvantage of the theories is that the earth model is physically too simple to reflect sphericity and stratified structure of the earth. On the other hand, theories for spherical earth models are physically better, but are mathematically tedious due to numerical integration and summations (Sun and Okubo 1993, 1998; Sun et al., 1996). Therefore, to overcome the disadvantages of the two cases, in this study, we present a new asymptotic theory as an approximation of the dislocation theory. The co-seismic geoid (sea level) change is investigated and a set of asymptotic expressions is presented for calculating potential and geoid changes caused by four independent seismic sources. This theory is valid in near and regional areas. Note that although geoid and sea level are different physical concepts, their coseismic changes are considered to be the same.

G32A-0733 1330h POSTER

Satellites Seek Gravity Signals for Remote Sensing the Seismotectonic Stresses in Earth

Han-Shou Liu[1] (301-614-6505; Han-Shou.Liu-1@nasa.gov)

Jizhong Chen[2] (301-614-6742; chenj@pop900.gsfc.nasa.gov)

Jinling Li[3] (jll@center.shao.ac.cn)

[1]NASA Goddard Space Flight Center, Code 921, Greenbelt, MD 20771, United States

[2]Sigma Space Corporation, Code 924, NASA/Goddard, Greenbelt, MD 20771, United States

[3]Shanghai Astronomical Observatory National Academy of Sciences, 80 Nandan Road, Shanghai 200030, China

The ability of the mantle to withstand stress-difference due to superimposed loads would appear to argue against flow in the Earth′s mantle, but the ironic fact is that the satellite determined gravity variations are the evidence of density differences associated with mantle flow. The type of flow which is most likely to be involved concerns convection currents. For the past 4 decades, models of mantle convection have made remarkable advancements. Although a large body of evidence regarding the seafloor depth, heat flow, lithospheric strength and forces of slab-pull and swell-push has been obtained, the global seismotectonic stresses in the Earth are yet to be determined. The problem is that no one has been able to come up with a satisfactory scenario that must characterize the stresses in the Earth which cause earthquakes and create tectonic features. The stress generated by mantle convection under the crust are inferable from high degree ($n \geq 13$) spherical harmonics of the geopotential. Therefore, satellite gravity missions may be able to seek the Earth's gravity signals for investigating the seismotectonic effect of these subcrustal stresses. It is well known that subcrustal stress patterns for ($13 \leq n \leq 25$) are applicable to identify the forcing mechanisms for uplift, depression, rifting, volcanism, seismicity, plate motion, kimberlite magmatism, ore formation and hot spots distributions on the surface of the Earth. However, in order to provide significant insights into the origin of earthquakes and the formation of tectonic features, subcrustal stress patterns for ($13 \leq n \leq 150$) are required. To meet this requirement, satellite gravity missions during the past 40 years have improved and extended the spherical harmonic model of the Earth's gravitational potential up to degree and order 360. This gravity model can be used to compute the stresses under the crust accurate enough to identify stress concentrations for earthquakes and realize tectonic features in the crust. In this paper, we have stiched together the satellite gravity data with a single thread of mantle convection. In this way, we have obtained a series of subcrustal stress patterns up to harmonic degree 150 from which 10 stress patterns are selected and displayed. Subcrustal stress maps for n=13 through n=150 illustrate the recognition progress of the modern world. A map of earthquakes for Ms>7.0 from 1976 to 2000 is also given for reference. The intense seismicity in the subcrustal stress concentration belt (the ring of fire around the Pacific) is expected. A broad band of seismicity extends from southern Europe to southeast Europe to southeast Asia; this is associated with the subcrustal stress concentration belts in Europe, Africa, Arabian, and Asia. These results seem to provide significant insights into the origin of the earthquakes and formation of the world.

G32A-0734 1330h POSTER

Collocated Observations with a Superconducting Gravimeter and an Absolute Gravimeter FG5 at Esashi Station

Yoshiaki Tamura[1] (+81-197-227131; tamura@miz.nao.ac.jp)

Tadahiro Sato[1] (tsato@miz.nao.ac.jp)

Yoichi Fukuda[2] (fukuda@kugi.kyoto-u.ac.jp)

Toshihiro Higashi[2] (higashi@kugi.kyoto-u.ac.jp)

[1]National Astronomical Observatory, Mizusawa, 2-12 Hoshigaoka, Mizusawa 023-0861, Japan

[2]Graduate School of Science, Kyoto University, Oiwake Kitashirakawa Sakyo-ku, Kyoto 606-8502, Japan

Continuous gravity change observations with a superconducting gravimeter (SG) are carried out for more than 12 years at Esashi Earth Tides Station, NAO, Japan. The objects of the observations are the studies of earth tide, core dynamics, secular change of gravity, and so on. Collocated absolute gravity measurements with an FG5 gravimeter of Kyoto University are regularly carried out once a year since 2000. The purposes of the collocated observations are, 1) to determine the scale factor of the SG at Esashi Station, 2) to constraint secular gravity change at the Station, and 3) to monitor long term stability of the SG. The SG has a high resolution in gravity changes, but it has a drift (even it is small) in the long term phenomena. The collocated observations of SG and FG5 reinforce their capabilities each other, and enable high resolution and long term stable gravity change observations. About the determination of the scale factor of the SG, it was estimated within the accuracy of 0.07%. The accuracy of at least 0.1% is required to compare observed tidal factors with theoretical ones. About the long term phenomena, annual change and pole tide are discussed already until now. The absolute gravity measurements give more constraint in the studies of such long term gravity changes.

G32A-0735 1330h POSTER

Gravity Effects of Solar Eclipse and Inducted Gravitational Field

Keyun Tang[1,2] (8610- 62007408; kytang@mail.igcas.ac.cn); Qianshen Wang[1]; Hongqi Zhang[2]; Changcai Hua[3]; Fenglin Peng[1]; Keliang Hu[2]

[1]Institute of Geology and Geophysics, Chinese Academy of Sciences, No.1, North Tucheng Xi Road Chaoyang District, Beijing 100029, China

[2]National Astronomy Observatory, 20A, Datun Road Chaoyang District, Beijing 100012, China

[3]Institute of Geophysics,China Seismological Bureau, No.5, Min Yuan South Road Haidian District, Beijing 100086, China

During solar eclipses in recent decades, gravity anomalies were observed and difficult to be explained by Newton's gravitational theory. During the solar eclipse of 1995, India scientists Mishra et al. recorded a gravity valley in amplitude of 12 μGal; they interpreted that qualitatively as atmospheric effects. During the total solar eclipse of March 1997, we conducted a comprehensive geophysical observation at Mohe geophysical observatory of China (with latitude of $53.49^0 N$ and longitude of $122.34^0 E$. From the data we recorded, we found two valleys about 5 to 7 μGal. Unnikrishnan et al. inferred this gravity anomaly was caused by the environment changes. We know that the observation had been conducting in a room inside a small building with a stable coal heating system; the temperature variation inside the experimental room was less $1^0 C$ during the eclipse. Moreover, the measured atmospheric pressure change was less 1hPa during the eclipse. It is reasonable to believe that surrounding environment of the observatory excluded the significant gravity variations caused by temperature, pressure variation and local moving of persons and vehicles. To further study the gravity effects related to solar eclipses, our scientific team took more observations during Zambia total solar eclipse of June 2001 and Australia total solar eclipse of December 2002. After data corrections, we found respectively two gravity anomalies, with 3 to 4μGal for Zambia eclipse and 1.5μGal for Australia eclipse. As many scientists have pointed out that pressure-gravity factor is lower than 0.3μGal/hPa, it means that any

gravity anomaly great than 0.5μGal could not be inferred as the results of atmospheric pressure change. The two more gravity anomalies recorded during the solar eclipses provided us strong evidences that some gravity anomalies could not simply be inferred as atmospheric pressure change. We have tried to explain those anomalies by the induced gravitational field.

G32A-0736 1330h POSTER

Improved United States Gravimetric and Hybrid Geoids for 2003

Daniel R Roman (301-713-3202 x161; dan.roman@noaa.gov)

U.S. National Goedetic Survey Commerce/NOAA/NOS, 1315 East-West Highway SSMC 3, room 9317 N/NGS6, Silver Spring, MD 20910, United States

A new gravimetric geoid, USGG2003, and a new hybrid geoid, USHG2003, were developed to replace the existing models (G99SSS and GEOID99, respectively) for the United States. USGG2003 was developed from much the same gravity data, however, significant improvements were made regarding the quality and use of DEM's in the remove-compute-restore technique. This one-arcminute model is in the ITRF00 reference frame, refers to a GRS-80 ellipsoid, and models the geopotential surface with W_0 = 62636856.88 m^2/s^2. A comparison was made between geoid heights derived from USGG2003 and more than 11,000 GPS/leveling data in the Fall of 2003. The GPS/leveling data were from NOAA's National Geodetic Survey database and provided GPS-derived ellipsoidal heights (above NAD 83) on leveled bench marks (above NAVD 88). Due to the varying quality and distribution of the GPS/leveling data and systematic errors is USGG2003, significant differences occurred at short (100 km) and long (650 km) wavelengths. The complicated relationship between data of varying quality generated an empirical "curve" that could no longer be accurately fit by means of a single positive-definite matrix in Least Squares Collocation. An improved LSC methodology that used a combination of positive-definite matrices generated a mathematical model that better followed the empirical data. USHG2003 was created from a conversion surface developed from this improved LSC methodology using USGG2003 and the GPS/leveling from Fall 2003. Both GEOID99 and USHG2003 were compared to the GPS/leveling data from which they were respectively derived to check for any remaining signal or misfit. This misfit lowered from 4.6 cm (1σ) for GEOID99 to about 2.8 cm (1σ) for USHG2003. The misfit derived from both an uncorrelated signal (thought to derive from the random error in the GPS observations) and a correlated component (which could derive from any either the GPS or leveling adjustments as well as USGG2003). The correlated signal was about 2.5 cm (1σ) with a 20 km correlation length for GEOID99, while it was less than 1.7 centimeter at 6 km for USHG2003. This improvement does not necessarily imply that more "noise" was incorporated into USHG2003. The shortest correlation length used in the improved LSC method was only 100 km, which is still a significant scale. Hence, USHG2003 is a better model for converting between the NAVD 88 and NAD 83 datums.

G32A-0737 1330h POSTER

Gravity Within the Topographic Masses - Case Study Over Australia

Michael Kuhn[1] (+61-8-92667603; M.Kuhn@curtin.edu.au)

Sten Claessens[1] (+61-8-92662218; claesses@vesta.curtin.edu.au)

[1]Curtin University of Technology Western Australian Centre for Geodesy, GPO Box U1987, Perth, WA 6845, Australia

The behaviour of gravity within the topographic masses needs to be known for the determination of different gravity field parameters such as geoid height or orthometric height. For example, geoid determination by Stokes's formula requires downward continuation of gravity data to the geoid and the orthometric height is defined by the mean gravity along the plumb line between the Earth's surface and the geoid. In the past, different approximations (hypotheses for the topographic masses) have been used in order to derive gravity along the plumb line from the measured gravity at the Earth's surface. In this study a remove-restore technique based on the Poincaré and Prey reduction is used to determine gravity within the topographic masses. The actual free-air gradient in the reduced field is derived from the generalized Poisson's equation. From the gravity values given along the plumb line mean gravity as well as the mean gravity gradient are computed and compared with different (approximated) values used in the past. The results for mean gravity and the mean gravity gradient can be used in gravimetric geoid computation to realize an improved downward continuation as well as improved computation of orthometric heights from levelling and gravity measurements. Numerical results for mean gravity and the mean gravity gradient are given for two sample areas in Australia representing an area with a large range of topographic mass-density values and a mountainous area. Furthermore, the mean gravity values computed from different methods are used to estimate the effect on the orthometric height.

G32A-0738 1330h POSTER

Improved Gravimetric Geoid Model for Japan From Terrestrial Data and Altimetric Gravity Model

Yuki Kuroishi (81-29-864-6280; yuki@gsi.go.jp)

Geographical Survey Institute, Space Geodesy Laboratory, 1 Kitasato, Tsukuba 305-0811, Japan

An improved gravimetric geoid model for Japan is developed by combining an altimetric gravity model, KMS02 with terrestrial gravity data. Additional terrestrial gravity data were newly obtained in some data gaps for previous geoid models: ship data in the western part of Seto Inland Sea and land gravity data in south and east Hokkaido, where the latest gravimetric geoid model for Japan, JGEOID2000 shows relatively large errors at short wavelengths. In addition, medium wavelength signals of gravity from KMS02 are retrieved and combined by filtering based on wavelets. The combination significantly reduces systematic errors of JGEOID2000 gravity/geoid models derived from ship data, at medium wavelengths around Hokkaido Island. Moreover, recently-released global geopotential models from the GRACE mission, EIGEN-GRACE01S by GFZ and GGM01 by CSR are used as a foundation for 1D-FFT computation of Stokes integral in a remove-restore manner. Those models themselves show improved performance over the Japanese islands in terms of geoid heights when compared with GPS/leveling geoid heights throughout the islands. When we change the maximum degree of the spherical harmonics used and merge them with higher degree harmonics of EGM96 (up to degree and order 360), those geopotential models seem to work best at degree 90. Resulting geoid models are compared and evaluated with GPS/leveling geoid heights.

G32A-0739 1330h POSTER

Constrained 3-D Linear Inversion of Geoid Anomalies

Emilson Pereira Leite[1] (51-3091-4753; emilson@iag.usp.br)

Naomi Ussami[1] (51-3091-4787; naomi@iag.usp.br)

Spiros Pagiatakis[2] (1-416-736-2100; spiros@yorku.ca)

[1]Department of Geophysics, Astronomical and Geophysical Institute, University of Sao Paulo., Rua do Matao, 1226, Sao Paulo, SP 05508-900, Brazil

[2]Department of Earth and Atmospheric Science, Faculty of Pure and Applied Science, York University., 4700 Keele Street, Toronto, ON M3J 1P3, Canada

Lithospheric-scale geoid anomalies with wavelength of $<$ 1000 km may provide independent geophysical evidence of mantle thermal state. In order to estimate the density distribution within the lithosphere from geoid anomalies, a constrained linear inversion technique is proposed for an arbitrarily shaped 3-D body by approximating it by a set of right-rectangular prisms. The forward problem is expressed by the gravitational potential given by Nagy et al. (2000). The geoid anomaly at each point on the surface of the Earth is the sum of the gravitational potential of all prisms, divided by the normal gravity. We take the first derivative of the gravitational potential with respect to density in order to compute the system sensitivity matrix (G), which is used in the inversion procedure. Non-uniqueness and instability problems are solved by minimizing two functionals that represent absolute and relative constraints, so that the absolute value of the difference between observed and calculated geoid anomalies is minimum in the least-squares sense. Inequality constraints are also introduced to represent lower and upper bounds for the densities. This method with the current computing capability allows us to invert large data sets with a sizable model space. Other advantages of this approach include: 1) geological and geophysical information can be incorporated to constrain the solution 2) it avoids problems related to wavenumber domain transforms, and 3) it is possible to analyse the solution in terms of resolution and variance. The algorithm was tested on synthetic models and a discussion of the potentialities of the method to solve real problems are also presented using as an example the case of a 8-meter amplitude positive geoid anomaly observed along the Eastern Brazilian continental margin.

G32A-0740 1330h POSTER

Gravity study in the Taipei Basin

Hsien-Hsiang Hsieh[1] (alvo@escc.gep.ncu.edu.tw)

Horng-Yuan Yen[1] (yenhy@earth.sinica.edu.tw)

Ming-Tar Lu[2]

Chien-Ying Wang[1] (wangcy@earth.ncu.edu.tw)

[1]Institute of Geophysics, National Central University, NO.300, Jung-da Rd., Jung-li 320, Taiwan

[2]Chinese Petroleum Corporation, 3, SUNGREN ROAD, SHINYI CHIU, Taipei 110, Taiwan

Taipei City is a metropolis in northern Taiwan, which is located on a triangle-shaped alluvium basin. Gravity measurement and analysis are particularly useful as a reconnaissance tool for an urban region. A higher resolution gravity map over the Taipei Basin is required to help understand its tectonic signature. There is, therefore, a need to compile a gravity map that encompasses the entire basin region. In this study, we have compiled the gravity data (roughly 36 km x 36 km) of the Taipei Basin and its surrounding area. After gravity reductions, the Bouguer anomaly map was constructed. The general trend of the Bouguer values decreases from west to east, but does not reflection the basement structure of the Taipei Basin. The residual anomaly is obtained by using Griffin method to investigate the shallower structure. We also calculate the derivative anomaly map to analyze some high frequency signal of the Taipei Basin. The shallower sedimentary layer is almost flat referred from above both maps. To illustrate how the gravity data constrain subsurface density structures, a two-dimensional gravity analysis will be performed with the gravity profile across the geological strike taken from the Bouguer anomaly map. In the modeling, available seismic, drilling, and other data are used wherever possible to constrain the geometries and/or densities. Preliminary results of the modeling and their geological significance will be presented.

G

G32A-0741 1330h POSTER

Sub-Decimeter Local Geoid Model in Taiwan Mountain Belt

Din-Yao Jeng[1] (l4890105@ccmail.ncku.edu.tw)

Kwo-Hwa Chen[2]

Ching-Liang Tseng[1]

[1]Department of Earth Sciences, National Cheng Kung University, No.1, Ta-Hsueh Road, Tainan 701, Taiwan

[2]Department of Surveying and Geoinfomatics, National Cheng Kung University, No.1, Ta-Hsueh Road, Tainan 701, Taiwan

A first-order leveling network of 4500-km leveling lines, including 2065 benchmarks, with 2.5$K^{1/2}$ mm accuracy around Taiwan island has been established by MOI(Ministry Of the Interior) in 1998-2003. GPS measurement and gravity data were collected at each benchmark. Existing local geoid model with accuracy of 10-20 cm was calculated with observations of sea surface gradients derived from satellite altimetry, land gravity anomalies, ship gravity anomalies and the EGM96 model in Taiwan. In this paper, we combine GPS and leveling measurements described above and undulation data estimated using existing local geoid model to improve the accuracy of local geoid model of Taiwan with the least squares collocation technique. A correction signal with variance-covariance matrix related to distance between benchmarks is added into the observation equation. Correction signals of benchmarks are separated into three part: GPS height, leveling height and the undulation, by their variance-covariance matrix. The result shows that the mean difference of ΔN(undulation difference) derived from our new local geoid model and GPS/leveling is 4.1cm. Our new local geoid model in the mountainous Taiwan area has an accuracy of about $\pm$3.3 cm, which is close to the accuracy of GPS, while comparing with independent near-fault GPS/leveling data.

G32A-0742 1330h POSTER

Web tools for ingest, quality control, and dissemination of Gravity Metadata

David Dater[1] (303-497-6120; David.T.Dater@noaa.gov)

Travis Stevens[1] (303-497-6607; Travis.Stevens@noaa.gov)

[1]National Geophysical Data Center, NOAA E/GC1 325 Broadway, Boulder, CO 80305, United States

NOAA's National Geophysical Data Center (NGDC) is developing and using an integrated system of Web-based tools for receipt, ingest, quality review, and dissemination of metadata and data. These tools are being used to improve the quality and content of gravity data as part of the North American Gravity Database. Using these tools, scientists will be able to submit data and metadata information on-line. After verification and ingest, these and other data can be compared and viewed with other data This poster describes the metadata component of the integrated system and introduces the Web-based tools for browse, subset, overlay, and delivery of data on-line using Oracle spatially enabled database, ArcIMS, and Web browsers.

URL: http://www.ngdc.noaa.gov/seg/potfld/gravity/welcome.shtml

G32A-0743 1330h POSTER

Earth-model discrimination via gravimetric terrestrial spectroscopy

Mensur Omerbashich[1] (omerbasic@unb.ca)

Petr Vanîèek[1] (vanicek@unb.ca)

[1]Department of Geodesy and Geomatics Engineering, University of New Brunswick, PO Box 4400, Fredericton, NB E3B 5A3, Canada

We devised a method for Earth-model discrimination, of potentially general interest to geophysics. Based on Jeffreys's rule of thumb, it is claimed that the last decade's mean-diurnal free oscillation magnitudes (MDOM) of the Earth's gravity field linearly correlate with seismic energies and seismic magnitudes of 381 earthquakes larger than M = 6.3 found in the record. Here the oscillation of the gravity field is caused by the seismic waves generated by these medium-to-large earthquakes. Oscillation magnitudes are taken at the discrete values predicted by the individual model's long eigen-periods; we take all modes between 12 min - 2 hrs. Using the correlation coefficients computed from variance-spectra between the MDOM and $M > 6.3$ global seismicity, which in some cases reach up to 0.97, we subsequently propose a general method for Earth-model discrimination: if a model yields high correlations of the MDOM with Earth's seismicity on the day of the large earthquake, that model is to be considered successful. Various criteria for model discrimination could then be derived from this observation. Gaps are normally present in the record of temporal gravity variations obtained by a seismically excited gravimeter. We thus start the data processing for our technique by applying a non-equidistant Gaussian filter with 4sigma-width, to the last decade's one second step record collected by the Canadian superconducting gravimeter (SG) that operates at Cantley, Quebec. Thus the original one-second data are transformed to records with steps 8 and 32 sec. The non-equidistancy feature of our filter means that one-second gaps in the record are properly accounted for and gaps larger than the filtering steps set at 8 and 32 sec remain in the series. We then perform the least squares spectral analysis (LSSA) of so filtered a record, without any further preprocessing of the data so as to satisfy the rigour requirement. The LSSA seems suitable for our purpose due to its ability to handle gaps in data, unlike other spectral analyses. We obtain power- and variance-spectra of the record (including noise), and using three different geophysical models we look into the free oscillation of the Earth at the periods predicted by these models; we compute respectively the mean-diurnal and mean-weekly gravity oscillation magnitudes (MWOM). For all three models the correlations are higher when seismic energies are used rather than seismic magnitudes, as well as when variance-spectra are used rather than power-spectra. As deduced from the variance-spectra (but not the power spectra) of gravity, the correlation is maximum for eigen-periods of around 821 sec. When a depth-of-earthquake separation is performed, the best correlation between the MDOM series and the deep ($d > 400$ km) earthquakes shows a curious delay of three days, for all the models. For this we have no physical explanation. Finally, the series of MDOM values of the Earth's gravity field appears periodic over the studied decade: a synodic semi-monthly and solar semi-annual periods show up as the only two significant periods from the one-day to ten-years period interval. Various researchers in the area of earthquake prediction and "tidal triggering" have in the past pointed their finger at the same periods. We know where these periods come from but we have no physical explanation as to why they should trigger the characteristic oscillations.

URL: http://einstein.gge.unb.ca

G32B MCC: 2010 Wednesday 1340h

Before PBO: What Do We Know? II *(joint with S, T)*

Presiding: **R A Bennett,** Harvard-Smithsonian Center for Astrophysics**; K W Hudnut,** U.S. Geological Survey

G32B-01 1340h

The Plate Boundary Observatory Component of the EarthScope Facility

Mike Jackson[1] (303 497 8008; mikej@unavco.ucar.edu)

Will Prescott[2] (720 565 5973; prescott@unavco.org)

Paul Silver (202 478 8834; silver@dtm.ciw.edu)

[1]UNAVCO, Inc., 3360 Mitchell Lane Suite C, Boulder, CO 80301

[2]Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015

The Plate Boundary Observatory (PBO), one of the core components of EarthScope, is a geodetic observatory designed to study the three-dimensional strain field resulting from plate boundary deformation in the western US including Alaska. The science goals of PBO require that plate boundary deformation be adequately characterized over the wide range of temporal and spatial scales common to active continental tectonic processes. To meet these goals, PBO will install a core of geodetic instruments that possess excellent sensitivity over this broad temporal spectrum, with a deployment configuration that will dramatically increases the spatial scale and density of stations. The PBO Facility will consist of 891 permanently-installed GPS stations, 175 borehole strainmeters, five laser strainmeters, and a pool of 100 portable GPS receivers for temporary deployment and rapid response for volcanic and seismic crises. PBO will provide a range of data and data products for scientific investigations and for education and outreach activities. Congress has provided funding for EarthScope to the National Science Foundation and a proposal to construct EarthScope has received approval from the National Science Board. Construction is expected to commence in September or October 2003.

URL: http://www.unavco.org/PBO/PBO.html

G32B-02 1355h INVITED

A Reference Frame for PBO: What do we Have; What do we Need?

Geoffrey Blewitt (1-775-784-6691 x 171; gblewitt@unr.edu)

Nevada Bureau of Mines and Geology, and Seismological Laboratory, University of Nevada Mail Stop 178, Reno, NV 89557, United States

By definition, the Plate Boundary Observatory (PBO) will investigate the mechanics associated with the boundary between the North America and Pacific plates. A natural frame of reference to describe crustal deformation between these two plates would be one in which the far field appears to be stationary, which leads to two possibilities: the "stable North America frame" or the "stable Pacific frame." The theory of plate tectonics pre-supposes the existence of such entities. Within such a framework the sum of deformations across contiguous regions of the plate boundary zone are constrained by the known relative far-field plate motion. However both theory and observation complicate this simplified framework. Are "stable plate interiors" a meaningful concept at the level of anticipated geodetic accuracy? Observational evidence suggests that most of the North America and Pacific Plates appear to be horizontally stable at the level of 1–2 mm/yr over plate-wide distance scales, which is not a very stringent constraint given current and anticipated station velocity accuracies at <1 mm/yr. Where do these stable plate interiors end, and the plate boundary zones begin? The Pacific-North America plate boundary zone is so broad that gravitational potential energy and mantle dynamics must play an important role - how deep into the plates do these dynamics have a measurable effect? How should we account for glacial isostatic adjustment in the definition of a plate-fixed frame? How should we define a "vertical datum" that is theoretically useful and can be realized in practice? In this presentation I review the current status of reference frame theory and actual practice, and I outline current thinking on the reference frame needs for PBO that derives from the working group on the "Stable North America Reference Frame" (SNARF), recently formed under the auspices of UNAVCO and the IAG sub-commission on the North America Reference Frame (NAREF).

G32B-03 1410h

GPS Lessons Learned

Michael Heflin (mbh@cobra.jpl.nasa.gov)

Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

Global geodesy has improved dramatically over the past decade starting with the GPS for IERS and Geodynamics demonstration compaign in 1991 (GIG 91). At that time it took over a week of CPU time to process a network solution based on 21 global receivers and orbit overlaps were in the 40 cm range. Today it is possible to process a network solution based on 80 global receivers in less than one day of CPU time and orbit overlaps are in the 4 cm range. Special methods are under development for efficient processing of increasingly large regional networks which may contain hundreds or thousands of GPS receivers. Along the way there have been many lessons learned about GPS satellites, receivers, monuments, antennas, radomes, analysis, reference frames, error sources, and interpretation. A wide range of scientific disciplines have been impacted including studies of plate motion, post-glacial rebound, seasonal loading, deformation in plate boundary zones, coseismic displacements due to major earthquakes, postseismic relaxation, and interseismic strain accumulation related to assessment of seismic hazards. Lessons learned will be presented in the context of new dense networks such as the Plate Boundary Observatory (PBO).

G32B-04 1425h INVITED

Results and Comparisions from the Southern California Integrated and other arrays

Thomas A Herring (1-617-2535941; tah@mit.edu)

EAPS MIT, 77 Massachusetts Av, Cambridge, MA 02139, United States

The Southern California Integrated GPS Network (SCIGN) was established after the 1994 Northridge Earthquake near Los Angeles, California. The SCIGN array is the largest integrated array in North America and was largely completed in July 2001. Currently the array has about 250 continuously operating GPS receivers. The current operation of SCIGN shares many of the characteristics sought for the operation of the plate boundary observatory. All of the data from SCIGN are freely available. SCIGN operates three analysis centers, one for near-real time processing and two for final post processing. There is also an analysis committee that compares and combines the results from the two post processing centers. This analysis committee makes available results in the form of time series, 3-dimensional velocity vectors, and postseismic deformation parameters from a uniform analysis of loosely constrained solution vectors with full covariance matrix information and from analyses preformed at the two post processing centers at Jet Propulsion Laboratory (JPL) and the Scripps Institution of Oceanography (SIO). (http://chandler.mit.edu/ tah/SCIGN). We present here comparisons of uniform processing of the solutions from JPL and SIO with the processing results presented by the two centers (http://sideshow.jpl.nasa.gov/mbh/series.html and http://sopac.ucsd.edu/cgi-bin/dbShowArraySitesMap .cgi?array=SCIGN). From these comparisons, the robustness of signals seen in strain field in the region and non-linear temporal variations in the time series can be assessed. The RMS difference of the 3-D velocities from the uniform analysis is 0.6 mm/yr, and for horizontal 2-D velocities 0.5 mm/yr. We will examine those sites where the two analysis centers do not agree well. In these cases, the differences arise from site characteristics such as the effects of snow, multipath, subtle instrument failures, and loading processes when different lengths of data are used. We will also examine results from other networks around the world where some of the effects discussed above are even more pronounced.

URL: http://chandler.mit.edu/~tah/SCIGN

G32B-05 1440h

Broadband Deformation in the San Francisco Bay Area