displacements induced by the hector mine earthquake are measured from USGS airborne imagery and satellite optical imagery and the potential of those measurements is discussed.

G31C MCC: 2010 Wednesday 1020h

Satellite Measurements of Temporal Gravity Variations II

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

G31C-01 1020h INVITED

Time-Variable Gravity From Satellite-Laser-Ranging and Doppler Measurements: An Update on the Low-Degree Components as Well as the Connections With Geophysical/Climatic Processes

Christopher M Cox[1] (301-614-6094; ccox@stokes.gsfc.nasa.gov)

Benjamin F Chao[2] (301-614-6104; chao@bowie.gsfc.nasa.gov)

Andrew Y Au[1] (301-614-6114; aau@bowie.gsfc.nasa.gov)

Jean-Paul Boy[2] (301-614-6777; boy@bowie.gsfc.nasa.gov)

[1]Raytheon ITSS Company, NASA GSFC Mailstop 926.0, Greenbelt, MD 20771, United States

[2]NASA GSFC Space Geodesy Branch, Code 926, Greenbelt, MD 20771, United States

The oblateness of the Earth's gravity field, J2, has long been observed to undergo a slight decrease due to post-glacial rebound of the mantle. Sometime around 1998 this trend reversed quite suddenly. This reversal persisted until 2001, at which point the atmosphere-corrected time series appears to have reversed yet again. Presently, the time series appears to be returning to the value that would nominally have been reached had the anomaly not occurred. This anomaly signifies a large interannual change in global mass distribution whose J2 effect overshadows that of the post-glacial rebound over such timescales. A number of possible causes have been considered, with oceanic mass redistribution as the leading candidate although other effects, such as glacial melting and core effects may be contributing. The amount by which J2 returns to it's nominal value provides a valuable constraint on the separation of the causes, and will be considered. We will present our latest Satellite Laser Ranging and DORIS Doppler derived time series for J2, and various other low-degree harmonic terms, as well as our investigations into the causes. In addition, we will show the comparison of the J2 results with those derived from CHAMP, as computed at NASA GSFC, and the recently released GRACE gravity model.

G31C-02 1035h

Variations in the Earth's Oblateness During the Past 26 years

Minkang Cheng[1] (512-471-7818; cheng@csr.utexas.edu)

Byron D. Tapley[1] (512-471-5573; tapley@csr.utexas.edu)

[1]Center for Space Research, UT at Austin, 3925 W. Braker Ln. #200, Austin, TX 78759-5321

Analysis of Satellite Laser Ranging (SLR) data from multiple satellites over 26 years from 1976 to 2002 indicate that the Earth?—s dynamic oblateness, as represented by the J2 coefficient, undergoes both seasonal and long-term variations. The dominant signatures in the observed variations in J2 are (1) a secular decrease with a rate of -2.75x1.0e-11/year, which is mostly due to postglacial rebound, (2) seasonal variations, which have a mean amplitude of 2.9x1.0e-10, associated with the Earth?—s annual mass redistribution and (3) significant interannual variations with time scales of 4-6 years. Two large interannual variations in J2 can be related to the strongest El Ni?o-Southern Oscillation (ENSO) during the periods of 1986-1991 and 1996-2002. The ENSO related large fluctuations cannot be explained by current models since the interannual mass redistributions within the atmosphere, ocean and continental hydrology contain significant uncertainties. The observed fluctuations with 4-6 year time scale indicate the impact of the ENSO phenomenon on the large-scale global mass redistributions within Earth?—s system components.

G31C-03 1050h

Contributions of surface fluid reservoirs of the late 90's anomaly of the Earth's oblateness

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

Priscillia Soudant[1] (soudant@notos.cst.cnes.fr)

Anny Cazenave[1] ((+33) 05 61 33 29 22; Anny.Cazenave@cnes.fr)

[1]LEGOS-GRGS/CNES, 18, Avenue Edouard Belin 31 055 Toulouse Cedex 01 FRANCE, Toulouse 31400, France, Metropolitan

Recent satellite measurements have revealed a sudden change in the behaviour of the J2 (i.e. Earth's oblateness) time-series (Cox and Chao, 2002). Such an anomaly suggests an important redistribution of mass at the surface of the Earth from the high-latitude to the equatorial regions. In particular, air and water masse inside surface reservoirs (atmosphere, oceans, continental water storage -soil moisture, ground water, snow depth and ice reservoirs- (Cox and Chao, 2002, Dickey et al., 2002, Nerem et al., 2002, 2003, Chao et al., 2003)). In this study, we have reconsidered the long time-seriesof each fluid contribution using outputs of global atmosphere, ocean and hydrology models (ECMWF and NCEP for atmospheric surface pressure; POCM, OPA, MIT simulations and ECCO assimilation for ocean bottom pressure; LaD model for continental waters -soil moisture, groundwater,and snow cover-). We have also considered the contribution of mountain glaciers melting using data from NSIDC. We show that the J2 anomaly bulge of 1998-2000 coincides with a significant increase of the degree-2 zonal harmonic of the oceans. Empirical Orthogonal Functions (EOF) analyses of the atmospheric, oceanic and hydrological fields allow us to better understand the importance of each contribution.

G31C-04 1105h

Ocean Bottom Pressure Measurements Off Sanriku, Japan

Tadahiro Sato[1] (tsato@miz.nao.ac.jp); Hiromi Fujimoto[2] (fujimoto@aob.geophys.tohoku.ac.jp); Koji Matsumoto[1] (matumoto@miz.nao.ac.jp); Yoshiaki Tamura[1] (tamura@miz.nao.ac.jp); Toshihiro Higashi[3] (higashi@kugi.kyoto-u.ac.jp); Minoru Nishino[2] (nishino@aob.geophys.tohoku.ac.jp); Ryota Hino[2] (hino@aob.geophys.tohoku.ac.jp); Toshihiko Kanazawa[4] (kanazawa@eri.u-tokyo.ac.jp)

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

[2]Graduate School of Science, Tohoku University, Aramaki, Aoba-ku, Sendai 980-8578, Japan

[3]Graduate School of Science, Kyoto University, Oiwakecho, Kitashirakawa, Sakyoku, Kyoto 606-8502, Japan

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

Variable motions of the ocean are changing the Earth's gravity field. For example, mass exchange in the Pacific Ocean is considered to be the most probable source of the recent rapid and large change in the J2 term, which may be related to the ENSO event in 1997 (Cox and Chao, 2002). The actual ocean mass exchange related to that event was also observed from ocean bottom pressure records (OBPRs) offshore of Peru (Fujimoto et al., 2003). On the other hand, satellite altimetry measurements, such as TOPEX/Poseidon (T/P), enable us to estimate the oceanic effect on gravity observations using globally-gridded data for sea surface height (SSH) variability. However, the altimeter data are affected by steric changes in the ocean, which should not contribute to the observed gravity changes (for example, Sato et al., 2001). In order to examine the relation among the mass exchange in the oceans, SSH variation, and gravity changes, we began a three-year observation project in 2001 to measure the ocean bottom pressure changes at the three crossover points of the T/P satellite off Sanriku, Japan: 143.1E, 39.2N (Point-A); 146.0E, 39.2N (Point-B); and 144.6E, 41.5N (Point-N). The data are sampled at an interval of one minute. Here, we will report the analysis results for the OBPR data for the two years since the beginning of the observations. Although the records at Point-N show a peculiar time variation, we obtained clear tidal signals at Point-A and Point-B. We compared the tidal analysis results with a global ocean tide model, NAO99b (Matsumoto et al., 2000), and we confirmed that, at both Point-A and Point-B, the predicted tides agree to the actual observations within the difference of 1 % in amplitude for the four major tidal waves: M2, S2, K1 and O1. This suggests that it may be possible to correct the tidal effect on the satellite gravity data with an accuracy of about 1 % by using recent global tide models. We also compared residuals of the OBPR data, which were obtained by subtracting the tides and long-term trend, with the T/P data. Two corrections were applied to the T/P data: one for the tide and one for the inverted barometer (IB) response of the ocean to air pressure changes. We found that at Point-B (about 350 km from the nearest coast) the corrected T/P data show temporal variations well correlated with the pressure observations. However, at Point-A (about 110 km from the coast), no meaningful correlation is observed. Our results suggest the possibility that the SSH variations observed from T/P may exhibit the barotropic component in the open ocean distant from coastal regions where western boundary currents are dominant. For the two-year observations at Point-B, the barotropic signals have a magnitude of about 7 cm in the peak-to-peak amplitude and show four dominant peaks at periods of 205, 128, 50, and 28 days.

G31C-05 1120h

Earth Tides, Mantle Anelasticity, and the Post-1998 Change in the Earth's Oblateness

David Benjamin[1] (David.Benjamin@colorado.edu)

John Wahr[1] (wahr@lemond.colorado.edu)

Shailen Desai[2] (Shailen.D.Desai@jpl.nasa.gov)

[1]Dept. of Physics and CIRES, U of Colorado, Boulder, CO 80302, United States

[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, United States

G

A large change in the Earth's oblateness that apparently began in 1998, was recently detected using satellite laser ranging data (Cox and Chao, 2002). The characteristics of this anomaly, though, are sensitive to the way in which the 18.6-year tidal contributions are modeled. Results obtained by fitting and removing inphase and out-of-phase 18.6 year terms, suggest that the anomaly could, instead, be part of a quasi-periodic perturbation with an approximately 10-year cycle. The results we obtain for the 18.6 year tide, combined with other earth tide and earth rotation estimates, are consistent with an anelastic model of the Earth that assumes a frequency-dependence for Q that is in rough agreement with that inferred from laboratory measurements.

G31C-06 1135h

An Investigation of Recent Gravity Variations Using Geophysical "Fingerprints"

R. Steven Nerem[1] (303-492-6721; nerem@colorado.edu)

Christopher M. Cox[2] (301-614-6094; ccox@stokes.gsfc.nasa.gov)

Eric W. Leuliette[1] (303-492-4584; Eric.Leuliette@colorado.edu)

Blair F. Thompson[1] (Blair.Thompson@colorado.edu)

[1]Colorado Center for Astrodynamics Research, University of Colorado, UCB431, Boulder, CO 80309-0431, United States

[2]Raytheon ITSS, NASA/GSFC, Code 926, Greenbelt, MD 20771, United States

Recently, Satellite Laser Ranging (SLR) data have been used to detect a large change in the Earth's oblateness during 1998-2002 [Cox and Chao, 2002]. The leading candidates for the cause of this change are mass redistribution in the oceans and the melting of mountain glaciers [Dickey et al., 2002]. Most studies of this phenomena have employed estimates of the low-degree spherical harmonic coefficients in comparisons of the observations and the models. Here, we present preliminary results using the same SLR observations to estimate the amplitude of geophysical "fingerprints" describing mass redistribution in different components of the Earth system (Antarctica, Greenland, post-glacial rebound, ocean-continent mass exchange, mountain glaciers, etc.). We take spherical harmonic expansions of these fingerprints, and use them to linearly transform the SLR spherical harmonic solutions into a set of new parameters that describes the estimated amplitude of each of the fingerprints. This is done on a monthly basis from 1980-2002 (bimonthly before 1992) so that the time variation of the amplitude coefficients may be studied. We will present an interpretation of these results in the context of investigation the anomalous gravity variations during 1998-2002. While this technique is particularly useful for a spatially sparse dataset such as is provided by SLR, we will also discuss the benefit of analyzing data from the CHAMP and GRACE missions using this same technique.

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