

gravity mission and terrestrial GPS stations, respectively.

G41B-04 0830h POSTER

Glacier Demise in Patagonia and Predictions of the Solid Earth's Geodetic Response

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Examinations of "glacier health" in southernmost Patagonia during the past two decades have converged on a very pessimistic diagnosis: the glacier systems are presently wasting away at a rate of more than 40 km³ per year [Rignot, Rivera and Casassa, *Science*, 302, 2003]. The mass loss during the last 7-8 years is equivalent to a sea-level rise contribution of $\dot{\xi} \approx 1$ mm per decade. The vertical stress release may be the largest ongoing surface load change anywhere on our planet. Consequently, the geodetic response measured at both short and long wavelengths is of interest, as it offers a unique opportunity to sample broadscale crustal, lithospheric and mantle rheological properties. Using both spherical and planar geometries, conventional self-gravitational Maxwell viscoelastic modeling shows that the vertical crustal motion response should be substantial, probably at the cm/yr level, or larger. The rate is highly sensitive to asthenospheric viscosity, while the pattern is more dependent upon both load history and effective surface "lid" thickness. We explore the types of data (gravity, lake tilts and GPS surveys), and the error budgets in such data, that would allow isolation of the short term rheological response of the crust, lithosphere and asthenosphere in light of Patagonian volcanic and tectonic evolution over the past 10 million years

G41B-05 0830h POSTER

Numerical Predictions of GIA Based on a New Generalized Sea-Level Theory

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The calculation of gravitationally self-consistent sea level changes driven by the melting of ice sheets is a classic problem in geophysics. Since the redistribution of ocean mass, together with the ice load, constitutes the total surface mass load in such applications, a robust prediction of any related observable (3-D crustal motions, rotational anomalies, etc.) requires an accurate prediction of the sea level (ocean load) change. Although the Farrell & Clark [1976] sea level equation remains a standard pillar of modern research in glacial isostatic adjustment (GIA), their approach assumes a non-rotating Earth and shorelines that remain fixed as sea level rises and falls through the glacial cycle. Over the last decade, numerous efforts have been made to extend sea level predictions based on the Farrell & Clark [1976] theory to incorporate both rotation effects and an evolving shoreline geometry, where the latter arises from local ocean transgression/regression or from the growth/ablation of grounded marine-based ice. Recently, a generalized sea-level theory has been described which is based on an exact relationship between GIA-induced global sea level variations and ocean height changes [Mitrovica & Milne, 2003]. We outline this theory, which holds for arbitrary 3-D viscoelastic Earth models, and present a suite of results from its application to spherically symmetric Earth models. In particular, we present differences in predictions based on the old and new sea-level theory in order to highlight cases where the former is no longer sufficiently accurate for modern GIA analyses.

G41B-06 0830h POSTER

Dynamic Ellipticity and Paleoclimate Time Scales

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It has been known since SPECMAP that paleoclimate age-scales derived from "tuning" against astronomically derived obliquity and precession curves are mildly inconsistent. Specifically, those derived from tuning to precession differ systematically from those tuned to obliquity. In 1990, I suggested that this discrepancy was a consequence of changes in the earth's moments-of-inertia from glaciation. In the last few years several cores and composites with good time resolution over the last several million years have become available, and this time span is long enough to allow tuning against eccentricity. In this talk I examine Shackleton's six-million year v677846 composite of V 19-30, ODP 677, and ODP 846 benthic ¹⁸O against Laskar's orbital elements. Because the different sinusoidal components making up the various orbital elements are too closely spaced to be resolved on time segments of less than about 2.4-million years duration, I computed coherences between the data and the different orbital elements. This shows that the basic tuning is very good. Nonetheless, the phase of the coherence again shows that one cannot maintain consistent phases between the different elements given the present value of $(C - A)/C$. Comparisons of the data and Laskar's La93 program output run with varying values of γ suggests that the late Miocene figure of the earth was approximately hydrostatic with a gradual transition from that to present average values.

G41C CC: 220 C-E Thursday 0830h

New Sensors of Our Planet: Modern Geodesy and New Insights in Earth Science I Posters (joint with OS, P, S, T, C, GC)

Presiding: N Sneeuw, University of Calgary; H Dragert, Geological Survey of Canada

G41C-01 0830h POSTER

Mean Sea Surfaces - and inter-annual ocean variability

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In a comparison between hydrodynamic derived mean dynamic topography (MDT) and synthetic derived MDT (derived from the difference between the MSS and the geoid), the results depends on the quality of the MSS and geoid, but also on the inter-annual ocean variability. In principle the MSS used to derive the synthetic MDT should be averaged over the same period in time as used to average the hydrodynamic derived MDT to avoid leakage of inter-annual ocean variability on the result. Different global mean sea surfaces (CSR98, GSFC00, CLS-SHOM98, CLS01, KMS01) are based on limited T/P time-epoch used in their derivation. Consequently, inter-annual ocean variability (like the major El-Nino event in 1997-1998) will be visible to a larger or smaller extend in these different MSS (the MSS are actually quasi-stationary MSS). In our new mean sea surface (KMS03) we have included a method to account for the inter-annual ocean variability. By investigating the inter-annual ocean variability from T/P the MSS can be made to include the inter-annual variability over a specific period in time. From the 9.9 years of T/P altimetry the inter-annual ocean variability for each year have been modeled using the annual mean sea level height once the "intra"-annual ocean variability have been removed. The "intra"-annual variability was initially removed by removing the mean monthly value of all months from the 9.9 year period. Evaluation of the available mean sea surfaces will be carried out in the GOCINA study region (www.gocina.dk) in the Northern Atlantic region. An extended comparison will also be presented in the Arctic Ocean to demonstrate the impact of improved geoid and mean sea surface modeling to derived reliable synthetic MDT. Particularly using the GRACE derived geoid models (GGM01), and the KMS03 mean sea surface.

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

G41C-02 0830h POSTER

CHAMP Gravity Results Using the Energy Integral Approach with Emphasis on Algorithmic Aspects

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The usage of the principle of energy conservation for gravity field determination from satellite observation has been considered since the early years of the satellite era. Now that CHAMP provides near-continuous tracking by GPS, aided by accelerometry this method can be applied and it has been successfully tested by various groups. The basic characteristic is the use of GPS derived position and velocity data and the correction for non-gravitational forces derived from accelerometer data. New calculations make now use of purely kinematic CHAMP orbits which avoids the introduction of a priori gravity field information. The disadvantage is that kinematic orbit determination yields only position and the velocity has to be derived numerically. In the data processing a calibration of the accelerometer data is necessary to account for the bias of the accelerometer. For this purpose the implemented method is the cross-over analysis which consists of an adjustment of cross-over points under the assumption that the potential in the Earth-fixed frame is constant. After bias and scale estimation, global geoid determination down to dm accuracy seems possible for the spectral range covered by CHAMP. However, the approach is based on the assumption of a constant energy. Therefore, any known time variable changes in the gravity field must be modelled properly and subtracted in order to reveal new unknown time variable effects. Current results do not reveal new features which means data processing has to be improved. Different approaches for certain data processing steps will be presented and test results discussed. The obtained knowledge can be transferred to the data processing of GRACE-data.

G41C-03 0830h POSTER

Investigations on Orbit Modeling for Producing the UT1-like Quantity UTGPS

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The Earth Orientation Department of the US Naval Observatory produces a UT1-like product UTGPS each day. UTGPS is used in the Department's daily determination of UT1, but first must be calibrated. Calibration of UTGPS uses almost entirely UT1 estimates from VLBI solutions produced at several analysis centers, one of which is in the Astrometry Department of the US Naval Observatory. The standard deviation of the calibrated UTGPS is about 0.015 millisecond, smaller than that for 1-hour observations with two VLBI antennas. The determination of UTGPS requires modelling radiation-pressure perturbations of GPS orbit planes. The model assumes the orbit-normal acceleration to be the orbit-normal component of radiation pressure for a perfectly-absorbing sphere plus a once-per-revolution acceleration. This last acceleration can be specified by giving the corresponding rates of motion of the angular momentum in two directions: first, along the projection of the Sun direction on the orbit plane and second, in the perpendicular direction in the orbit plane. The model specifies these rates as functions only of the elevation of the Sun direction above the satellite's orbit plane. The rates are determined empirically many months before they are to be used in determining UTGPS. We will discuss deviations of the actual motions of orbital-angular-momentum vectors from modelled motions. The rate deviations are small, frequently under 0.02 millisecond per day. Measuring these rate deviations has required integration of orbit planes. Several different integration techniques have been used—one of these is the integrator used in producing UTGPS, an integrator of the orbit plane alone, and another comes from software performing a least-squares solution for accelerations on GPS satellites. We discuss the properties of the deviation rates determined by each technique. In the case of the integrator used to produce UTGPS, the determined rates have two different values for each elevation of the Sun above the orbit plane, one when the Sun direction is moving toward the orbit pole and one when the Sun direction is moving away.

G41C-04 0830h POSTER

Satellite Formation Flying for Geodetic Applications: Analysis of J2-Disturbed Orbits

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Future geodetic satellite missions will most probably make use of the concepts of satellite formation flying. Most studies use Hill equations (HE) to describe the relative motion of the chief satellite and deputy satellite. Some underlying assumptions limit the applicability of HE: (1) the Earth is spherically symmetric; (2) the orbit of the Hill frame is rigorously a circle; (3) the relative distance between the satellites is small compared with the radius of the Earth. Under these assumptions, the homogeneous solutions of HE describe relative orbit motion very well. In reality, the situation is much more complicated. The second zonal spherical harmonic of the Earth, J_2 , produces the primary gravitational perturbations. This J_2 force includes secular, long-periodic, and short-periodic components, which consequently will perturb the satellite orbits. Our objective in this presentation is to study the relative motion between arbitrary chief and deputy satellite configurations due to J_2 disturbance for geodetic applications. Four different methods, (1) numerical integration of Newton equations; (2) numerical integration of Lagrange Planetary Equations (LPE) in Gauss form; (3) numerical integration of HE; and (4) nontrivial analytical solutions of HE, will be used to analyze the relative motions in the Hill rotating frame. Since this J_2 perturbation has a two cycle per revolution (CPR) frequency component, we developed a complementary analytical solutions for the non-homogeneous HE, which combine the homogeneous, resonant and non-resonant solution. Our preliminary results show that numerical integration of Newton equations and LPE can capture all disturbance characteristics, while the numerical or analytical method of HE perform relatively well in the differential mode. Furthermore, one can get any designed shapes of the relative motion by setting specific initial positions and velocities, e.g. 2 by 1 elliptic motion in the orbital plane.

G41C-05 0830h POSTER

Analysis of Spatial and Temporal Stability of Airborne Laser Swath Mapping Data using Mutual Information

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Airborne laser swath mapping (ALSM) is capable of measuring ranges and intensities of thousands of laser returns per second. This capability allows ALSM to not only create accurate maps of large areas but also to remotely sense the area as it is surveying. Two classes of objects which appear frequently in ALSM data are buildings and trees. These classes are often difficult to separate because their elevations and local gradients can be quite similar. They are also often found in close proximity. In order to determine the remote sensing capability of ALSM, a more complete set of features is explored to determine the separability of these two classes across geographically and temporally diverse data sets. Mutual information provides a means to quantify the separability of the classes using the different features. This information provides new insight into the spatial and temporal stability of ALSM features. Mean intensities and standard deviation of intensities are found to be features which provide the ability to discriminate between the building and tree classes. The features appear to be quite stable over geographically diverse data sets. Although the ALSM data are not temporally invariant, it is still possible to discriminate between the two classes. Mutual information also quantifies the ability to discern between buildings and trees using only ALSM data. Using the features that have the highest ranking according to mutual information, a classification accuracy of better than 90% can be achieved across dissimilar geographical areas.

G41C-06 0830h POSTER

Absolute Gravity Measurements And GPS Observations Along A Profile Crossing The Rhine Graben From The Vosges To The Black Forest.

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The Alsatian plain is located in the Rhine graben limited by the Vosges Mountains (France) and the Black Forest (Germany). The present-day tectonic evolution of this system is not totally clear: is the graben subsiding, are the mountains uplifting, what is the relative behaviour of the 3 different geological components? In attempting to answer these questions, we compare for the first time in this region time series of absolute gravity (AG) measurements at different sites to the available GPS observations. We consider 3 AG sites: our reference station is the gravimetric Observatory Strasbourg J9, located in the Rhine plain where AG measurements are regularly performed since 1997 and where superconducting gravimeter (SG) observations are available almost continuously for 17 years; the satellite sites are the Welschbruch station in the Vosges, where 5 AG measurements have been conducted since 1997 and the Black Forest Observatory (BFO) where 2 AG measurements are available. GPS permanent receivers are collocated at the Strasbourg-J9 site (since 1999) and at the Welschbruch station (since 2000); GPS permanent receivers are located in the surroundings of the BFO. We will compare the long term content of these two types of geodetic measurements with special emphasis on the trend; we will discuss in particular the admittance value for the ratio gravity change/vertical displacement change and its link to different physical processes.

G41C-07 0830h POSTER

Investigation of the Deep Earth's Interior with Superconducting Gravimeters: Study of the Gravest Seismic and Subseismic Modes

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Superconducting gravimeters (SGs) show extremely low drift (a few $\mu\text{gal yr}^{-1}$) and very high sensitivity in the long period seismic band. Below 1 mHz many SGs can achieve lower noise levels than the best long period seismometers (and spring gravimeters) and are thus well suited for the study of the gravest seismic modes. We demonstrate this by analysing SG series observed after the 2001 Mw = 8.4 Peru event in the normal mode band. The high resolution, seen for example in the splitting of ${}_0S_2$, contributes significant information to long-period normal mode seismology. The low noise level of SGs has led to the first detection of the degree one seismic mode ${}_2S_1$ (first elastic overtone of the Slichter translation of the solid inner core). The study of these long period seismic normal modes is of major interest as it leads to valuable constraints for the density structure in the mantle and core. The improvement of Earth's models needs observations of the splitting of the gravest modes, a task that is uniquely suited to SGs. Besides, SG data are most appropriate for the study of subseismic modes including the Slichter triplet of the inner core. The detection of that translational motion is primordial to provide some information on the density jump and probably on the viscosity at the inner core boundary, as well as on the stratification of the liquid outer core. We consider a possible seismic excitation of the Slichter triplet by looking for the optimal source parameters necessary to produce a sufficient surface gravity effect to be observed with a superconducting gravimeter.

G43A CC: 220 C-E Thursday 1330h

Computations in Geodesy and Geosciences II Posters (joint with OS, GC)

Presiding: R Blais, University of Calgary; M Soofi, University of Calgary

G43A-01 1330h POSTER

Quality Control Of Geodetic Networks Through Robustness Analysis

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After geodetic networks (e.g., horizontal control, leveling, GPS etc.) are monumented, relevant measurements are made and point coordinates for the control points are estimated by the method of least-squares, and the goodness of the network is measured by a precision analysis making use of the covariance matrix of the estimated parameters. When such a network is designed, traditionally this again uses measures derived from the covariance matrix of the estimated parameters. This traditional approach is based upon propagation of random errors. Reliability of geodetic control networks (the detection of outliers/gross errors/blunders among the observations) has been measured using a technique pioneered by the geodesist Baarda. In Baarda's method a statistical test (data-snooping) is used to detect outliers. What happens if one or more observations are burdened with an outlier? It is clear that these outliers will affect the observations and produce incorrect estimates of the parameters. If the outliers are detected by a statistical test then those contaminated observations are removed, the network is re-adjusted, and we obtain the final results. In the approach described here, traditional reliability analysis (Baarda's approach) has been augmented with geometrical strength analysis using strain in a technique called robustness analysis. In statistical literature robustness is insensitivity to outliers in the data. Robustness analysis is a natural merger of reliability and strain and is defined as the ability to resist deformations induced by the largest undetectable outliers as determined from internal reliability analysis. This paper addresses the consequences of outliers not being detected by Baarda's test. This failure may happen for two reasons (i) the observation is not sufficiently checked by other independent observations or (ii) the test does not recognize the gross error (type II error). By how much can these undetected errors influence the network? If the influence of the undetected errors is small the network is called robust; if it is not it is called a weak network. In this study, the computational process to determine threshold values for robustness primitives is discussed and some results are presented.

G43A-02 1330h POSTER

A Critique on the Logic of the Least-Squares Principle for the Estimation of Geodetic Parameters

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Within the standard formalism of least-squares estimation there are several paradoxical and curious questions which are seldom explicitly formulated. The study of such questions is valuable not only from a theoretical point of view, but also from a practical perspective since it can contribute to a stronger comprehension of the potential drawbacks associated with the use of least-squares techniques in data analysis problems. Along these lines, the aim of this paper is to present an alternative viewpoint of the optimal statistical principles that are traditionally linked to least-squares estimation. Specifically, it is shown that the well known property of unbiasedness for the least-squares estimators can be replaced with a different, yet equivalent, constraint which implies that the numerical range of the unknown parameters is boundless. The consequences that arise from this strange dualism in the context of geodetic parameter estimation are discussed, and a short critique on the statistical foundations of the least-squares method is also made. In order to facilitate the above investigation, the shortcomings of the least-squares estimators are further exposed from