mined by means of the Liouville equation. For predicting the GIA-induced sea-level change, three different global models of the Pleistocene deglaciation and several viscosity stratifications are used. We compare the predicted postglacial sea-level change induced by the Pleistocene deglaciation with a set of globally distributed sea-level index points and evaluate the acceptability of the underlying earth and ice models. The best-fitting models are employed to remove the GIA-induced contribution to the recent sea-level change recorded by a set of Fennoscandian tide-gauge stations. In future studies, the reduced tide-gauge trends may serve as a datum when studying the relation between recent ice-mass change and absolute sea-level rise. Martinec,Z., 2000. Spectral-finite element method approach to three-dimensional viscoelstic relaxation in a spherical earth. Geophys. J. Int., 142, 117-141.

G41A-03 0830h POSTER

Using Fuzzy-Set Classification to Analyse Sea-Level Indicators With Respect to Glacial-Isostatic Adjustment

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The intepretation of sea-level indicators (SLIs) in terms of glacial-isostatic adjustment (GIA) has usually been based on neighbouring SLIs grouped into a single sea-level curve, which is then assumed to represent the Holocene sea-level change in that region. In this method, the nominal height and age of a particular SLI are the only characteristics considered in the inference of the former sea-level height. However, only isolation basins yield a narrow range for sea level, whereas SLIs based on samples, such as flotsam, shells or peat, only allow the determination of an upper or lower bound or a range for it. To use also these types of sample properly, we have developed a classification scheme based on Fuzzy logic. After the defintion of appropriate membership functions, this method leads to a more systematic and realistic interpretation of the large amount of SLIs available. We apply this method to SLIs from several regions in Canada and demonstrate how it modifies the inference of GIA for a particular region and, thus, the determination of mantle viscosity.

G41A-04 0830h POSTER

A Reanalysis and Reinterpretation of Geodetic and Geomorphologic Evidence of Glacial-Isostatic Uplift in the Churchill Region, Manitoba

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We review the history of analyses of the tide-gauge record for Churchill, Manitoba, and advance a new analysis of the record using a longer time series than that available to Tushingham (1992). The sensitivity of the mean rate of relative sea-level change obtained to the averaging procedure employed is demonstrated by calculating rates for sliding observation intervals of variable widths. After that, the 'best' mean rate of relative sea-level rise is compared with estimates of the mean rate of land uplift and the mean rate of gravity change based on GPS and absolute gravimetry data, respectively. As an additional type of observation, the postglacial relative sea-level change obtained from paleo-shoreline evidence in the Churchill region is also included. Assuming that the governing process is glacial-isostatic adjustment, a joint inversion of the four types of data return upper- and lower-mantle viscosities of about 3×10^{20} Pa s and $> 5 \times 10^{21}$ Pa s, respectively.

G41A-05 0830h POSTER

Viscoelastic Relation of Multi-layered Half-space Models

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The response of viscoelastic (VE) half-space models to time dependent surface loading was analyzed using both a semi-analytical and numerical approachs. The models solved were (1) an elastic layer resting on a VE half-space and (2) a three layer lithosphere, containing a crustal low viscosity zone, resting on a half-space mantle. First, the corresponding elastic problems were solved using Propagator Matrix methods (an exact analytical approach) or shooting methods (using an ODE solver). Then, the Correspondence Principle was employed to transform the elastic solutions into their corresponding VE solutions for a given model rheology. The Correspondence Principle involves inverting the Laplace Transform of the time domain solution using the calculus of residues. In the first model, a comparison was made between Maxwell and Burgers Body rheologies for the VE half space. The poles were investigated to determine their characteristics in the wavenumber domain and under what conditions they have imaginary parts. In the second model, the effects of the crustal low viscosity zone on the ratio of the vertical to horizontal displacements was investigated in an attempt to reconcile the difference between observations and current model predictions.

G41B CC: 220 C-E Thursday 0830h

Observations of Glacial Isostatic Adjustment and Contemporary Ice-Ocean-Mantle Mass Redistribution II Posters *(joint with H, OS, S, T, C, GC, PP, SEDI)*

Presiding: **H Scherneck,** Chalmers University of Technology**; J A Henton,** Natural Resources Canada**; A Capra,** University of Bologna

G41B-01 0830h POSTER

Observing Fennoscandian Geoid Change

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Tide gauge records, multi-epoch precise levelling, and time series of GPS data have revealed both vertical and horizontal movements of the Fennoscandian crust due to glacial isostatic adjustment. The oval-shaped uplift area has an extension of 1750 by 1000 km with the major axis oriented approximately northeast. Maximum uplift (1 cm/yr) is observed in the northern part of the Bothnian Bay, reducing to less than 1 mm/yr at the western coastline of Norway Denmark and Baltic countries. Existing time series of relative and absolute gravity for a few sites and GIA model calculations indicate an annual gravity change of -2 μgal/yr in the central uplift area. Detection of this phenomenon is within reach of FG-5 absolute gravimeters, but may require a time series of 5 years or more. Similarly the geoid rate eexpected to peak at 0.6 mm/yr may be determined by gravimetric satellite missions. Cross-validation of the space and terrestrial observations will play a central role in the project. Initiated by Institut für Erdmessung, a multi-national cooperation has been set up for frequent collection of absolute gravity data in a dense Fennoscandian network. Three recently acquired FG-5 absolute gravimeters (by the University of Hannover, the Finnish Geodetic Institute, and the Agricultural University of Norway) will visit 30 sites annually in Denmark, Finland, Norway, and Sweden, some by several instruments for comparison purposes. The first observing run was carried out in 2003, which also included the participation of BKG, Germany. The national mapping agencies in all four countries have made observing sites available to the project, and even prepared new sites. This poster describes the present status of the project.

G41B-02 0830h POSTER

Absolute Gravity and Global Positioning System Measurements of Glacial Isostatic Adjustment in Eastern Canada

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The Nouveau Quebec-Labrador region was the site of one of the major ice domes of the Laurentide Ice Sheet and is currently experiencing postglacial rebound. For this region the highest observed uplift rates are in the vicinity of James Bay through to southwestern Labrador; the rates then decrease to the south and towards the coastal Atlantic margins. High-precision geodetic observations are providing a useful and accurate method of measuring the pattern and rates of contemporary uplift in this area. In order to monitor the temporal variations in gravitational potential resulting from regional glacial isostatic adjustment, an array of absolute gravity (AG) sites have been established in northern Quebec. Acquired in late 1985, the JILA-2 absolute gravimeter operates by using the free-fall method. This instrument has been continually upgraded since its acquisition with new computer control, new lasers, GPS clock, new timing electronics, and ancillary equipment. These upgrades were necessary in order to make it more efficient, field-worthy, lighter and easier to use. Indeed for the sites of the James Bay/Nouvelle Quebec Region, JILA-2 is generally operated within a tent in an often challenging environment. Absolute-gravity field stations are all co-located with sites of the Canadian Base Network (CBN). Initiated in 1994, the CBN is a network of pillar monuments with forced-centering plates for Global Positioning System (GPS) receiver antennae. Accurately positioned three-dimensionally with GPS, the CBN can serve as a monitoring network for deformation studies of the Canadian landmass. Issues such as mass redistribution or changes in density contrasts within the Earth may be better addressed by monitoring positional changes (*i.e.*, primarily height changes) and integrating these observations with gravitational variations. The comparison of the temporal rate of change of gravity with the GPS height rate is thus highly desirable. Recent velocity estimates based on both the multiple-epoch GPS network surveys as well as the preliminary results from absolute-gravity trends indicate regional uplift. These preliminary results also exhibit general agreement among the uplift rates for GPS radial velocities, gravity trends, and predictions of vertical crustal motion from postglacial rebound models. Finally, in order to densify the array of AG stations and facilitate comparisons with GPS-determined rates, planning is now underway for the occupation of all suitable CBN sites with an A-10 (*Micro-g Solutions*) absolute gravimeter.

G41B-03 0830h POSTER

Geoid-height Change and Vertical Crustal Motion due to Present and Past Glacial Changes in Antarctica

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We present results based on forward modelling of signatures related to present and past variations of the Antarctic Ice Sheet. Our calculations are organized according to the time scale of the ice-mass change. First, we implement seasonal and secular ice-mass imbalances acting on an elastic earth. Then, the elastic earth is replaced by a viscoelastic earth, and the glacial-isostatic adjustment due to global Pleistocene deglaciation scenarios is calculated. We predict the resulting geoid-height change and vertical crustal motion for Antarctica and discuss whether the signals generated are sufficiently large to be detected by the GRACE satellite

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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 km^3 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 rhelogical 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 ^{18}O 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 resuls 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 Ap- proach 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.