U32A-05 1130h

Interannual Variations in Earth's Low-Degree Gravity Field and the Connections With Geophysical/Climatic Changes

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Long-wavelength time-variable gravity recently derived from satellite laser ranging (SLR) analysis have focused to a large extent on the effects of the recent (since 1998) large anomalous change in J2, or the Earth's oblateness, and the potential causes. However, it is relatively more difficult to determine whether there are corresponding signals in the shorter wavelength zonal harmonics from the existing SLR-derived time variable gravity results, although it appears that geophysical fluid mass transport is being observed. For example, the recovered J3 time series shows remarkable agreement with NCEP-derived estimates of atmospheric gravity variations. Likewise, some of the nonzonal spherical harmonic components have significant interannual signal that appears to be related to mass transport. The non-zonal degree-2 components show reasonable temporal correlation with atmospheric signals, as well as climatic effects such as El Nino Southern Oscillation. We will present recent updates on the J2 evolution, as well as a look at other low-degree components of the interannual variations of gravity, complete through degree 4. We will examine the possible geophysical and climatic causes of these low-degree time-variable gravity related to oceanic and hydrological mass transports, for example some anomalous but prominent signals found in the extratropic Pacific ocean related to the Pacific Decadal Oscillation.

U32A-06 1145h INVITED

Geoide Height Time Dependence and Global Glacial Isostasy: The ICE-5G(VM2) Model and GRACE

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Interpretation of the global field of geoide height secular variation that will be obtained once the GRACE observations have been filtered to remove the influence of the tides and various contributions from the seasonal climate cycle will require a high quality model of the process of glacial isostatic adjustment(GIA). Since this process continues to contribute significantly to the secular change of sea level everywhere on Earth's surface, it constitutes a severe contamination of the signal associated with modern climate change that it is the goal of GRACE to more accurately define. A recently developed new model of the global GIA process(Ann. Rev. Earth PLanet. Sci. 32, 111-149,2004) will be described that is expected to constitute a high quality filter of the GRACE observations. The ICE-5G(VM2) model embodies a deglaciation component that is significantly different from it's ICE-4G(VM2) precursor, although the net eustatic rise across the glacial-interglacial transition is almost identical and very close to the oxygen isotope constrained value of 120m. The new data that have been invoked to develop this refined model include absolute gravity, VLBI and GPS observations from the interior of the North American continent where the GIA process is unconstrained by 14C dated relative sea level histories. The model also incorporates important modifications to the ice unloading histories of Greenland, the British Isles and Eurasia.

U33A CC: 517 A Wednesday 1330h

Time-Variable Gravity: Observation, Modeling, and Interpretation III

Presiding: **E R Ivins,** Jet Propulsion Laboratory, California Institute of Technology; **D J Crossley,** Saint Louis University

U33A-01 1330h

Dynamic Circum-Antarctic Ocean and the Search for a Crustal Rebound Signal in Satellite Gravity Data

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During the next few years the NASA-DRL and NASA-CNES satellite missions shall detect gravity change (Gravity Recovery and Climate Experiment, or 'GRACE') and continue to map dynamic ocean topography (JASON). The data retrieved from these missions contribute to a legacy of remote sensing data that coalesce in the late 1970's when both global gravity change and sea surface temperature, for example, began to be routinely archived. These formed an invaluable multi-decadal geophysical time-series. The series brings together some powerful information bearing on the causes of present-day climate variability. Quite independently, space-based radar and laser altimetry,onice GPS, speckle tracking of ice flow by remote sensing, in-situ ocean temperature and salinity measurements, passive microwave monitoring from space, ice core data, and InSAR-based grounding line migration information provide a wealth of data from which the mass balance of the principal ice drainage basins of Antarctica can be quantified. There is error in such estimates, and GRACE gravity change data, coupled with bedrock surface motion data, could provide a means of independently constraining cryospheric mass changes [Wu et al., 2002; Velicogna and Wahr, 2002]. The signal associated with ongoing ice mass change during 1990-2004 [Rignot and Thomas, 2002] must be separated from that associated with past deglaciation. Such separation demands that an additional, and very serious, error source be removed: the ocean mass related signature. Strong spatio-temporal variability in salinity, mass flux, and/or temperature occurs south of 40 S latitude, is, however, predictable. Here we use the ECCO model to aid in quantifying the geodetic signals observed on bedrock in Antarctica and in southernmost South America. Terrestrial gravity experiments are likely detecting a dynamic ocean signal that is at a microgal/yr level.

U33A-02 1345h

Time Variable Gravity Observations From Superconducting Gravimeters and Their Relation to the Earth's Dynamics and Structure

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The first term (1997-2003) of the GGP (Global Geodynamics Project) of a worldwide network of superconducting gravimeters (SGs) ended recently. Thanks to a special effort of all the participants, high quality records of time-varying gravity (and pressure) were collected from about 15 stations with a cluster in Europe and Japan, and individual stations in Canada, United States, Australia, South Africa, Indonesia, Antarctica and in the Arctic (Svalbard). A second term (2003-2007) of GGP is presently ongoing with additional stations in Europe and in South America (Chile). We try here to review the main scientific results obtained from time-varying gravity observations with SGs. We first emphasize the seismic frequency band (periods below 54 min) with significant contributions such as the splitting analysis of 0S2 or the first discovery of 2S1 in a stack of low noise SGs after the Peru earthquake of magnitude 8.4 in 2001. A noise comparison from all the stations shows that these instruments are uniquely suited to study in optimal conditions the sub-seismic band (periods above 54 min and below the tides) where it is predicted there should be the core modes and the Slichter triplet of the solid inner core. New results related to the tidal signature in gravity are presented: zonal long-period components, ocean loading, detection of non-linear tides, and Free Core Nutation resonance effects. We will also show the interest of SGs to investigate low frequency phenomena thanks to their extremely low instrumental drift: seasonal changes due to various loading effects (hydrological, non-tidal oceanic, atmospheric), as well as the contribution from the pole motion at the Chandler period. Finally we will discuss the possibility to validate time-varying satellite gravity data from the new space missions CHAMP and GRACE by using a regional network of SGs like the one currently operating in Europe.

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U33A-03 1400h INVITED

Absolute Gravimetry and Its Application to Time-Variable Gravity

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Measurements of absolute gravity are becoming increasingly important today in measuring the time-varying gravity that results from tectonic dislocations (earthquakes), vertical crustal motions (postglacial rebound) and the monitoring of magma motions (volcanology). Almost since the beginnings of scientific inquiry, absolute and relative gravityusing the then-available parts in 10^5 to parts in 10^6 level of precision and (sometimes) accuracywere successfully used to study the shape of the earth. Today's parts in 10^9 absolute gravimeters permit the study, though the associated gravity changes, of a number of geophysical processes at the centimeter level of sensitivity. The "hows," the "where-froms," and also the "limitations" of both today's and tomorrow's absolute gravimeters will be discussed. Finally our recent development of a truly portable absolute gravimeter will be described and (somehow) demonstrated. [This latter development will be reported on in considerable detail during the session G09: New Sensors of Our Planet.]

U33A-04 1415h INVITED

Magnetohydrodynamic Convection in the Outer Core and its Geodynamic Consequences

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The Earth's fluid outer core is in vigorous convection through much of the Earth's history. In addition to generating and maintaining Earth's time-varying magnetic field (geodynamo), the core convection also generates mass redistribution in the core and a dynamical pressure field on the core-mantle boundary (CMB). All these shall result in various core-mantle interactions, and contribute to surface geodynamic observables. For example, electromagnetic core-mantle coupling arises from finite electrically conducting lower mantle; gravitational interaction occurs between the cores and the heterogeneous mantle; mechanical coupling may also occur when the CMB topography is aspherical. Besides changing the mantle rotation via the coupling torques, the mass-redistribution in the core shall produce a spatial-temporal gravity anomaly. Numerical modeling of the core dynamical processes contributes in several geophysical disciplines. It helps explain the physical causes of surface geodynamic observables via space geodetic techniques and other means, e.g. Earth's rotation variation on decadal time scales, and secular time-variable gravity. Conversely, identification of the sources of the observables can provide additional insights on the dynamics of the fluid core, leading to better constraints on the physics in the numerical modeling. In the past few years, our core dynamics modeling efforts, with respect to our MoSST model, have made significant progress in understanding individual geophysical consequences. However, integrated studies are desirable, not only because of more mature numerical core dynamics models, but also because of inter-correlation among the geophysical phenomena, e.g. mass redistribution in the outer core pro-

duces not only time-variable gravity, but also gravitational core-mantle coupling and thus the Earth's rotation variation. They are expected to further facilitate multidisciplinary studies of core dynamics and interactions of the core with other components of the Earth.

U33A-05 1430h INVITED

Geodetic Implications of Mass Transfer in the Deep Earth

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We review a variety of possible mass motions within the Earth that might have observable geodetic consequences. Of the wide range of possible motions, there are some with well-modeled and observed effects, e.g. the rotational wobble of the fluid core (the Free Core Nutation). Many others, e.g. the translational triplet of the inner core, rotational wobbles of the inner core (the Free Inner Core Nutation and Inner Core Wobble), and effects due to wave motions within the fluid core, have uncertain periods and marginal possibilities of being observed. This paper will present the current situation with respect to all mass changes that have been proposed, and provide estimates of the surface effects that appear either as changes in gravity or in rotational angular velocity of the Earth. Of particular interest are the inner core motions, high frequency internal gravity waves, and exchanges of angular momentum between the mantle and the inner core (due to its triaxiality). All these have periods in the range of days to a few years, and thus observable in principle both through gravity and rotation. At longer periods, gravity loses its observational power in favor of measurements of Earth rotation. The challenge is not only observational but also theoretical, because of uncertainty in properties such as the radial density profile and lateral density changes below the core mantle boundary.

U33A-06 1445h INVITED

Hydromagnetic Oscillations of the Earth's Core on Decadal and Interannual Timescales

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All observations of the properties and dynamics of the Earth's core are, by necessity, indirect. Useful sources of data include geomagnetic variations arising from flow within the fluid core, variations in the length of day, and changes in the gravity field. Interpreting this information relies on models to relate the observations to physical processes in the core. We address the need for better models by developing a new theoretical framework to describe hydromagnetic waves in the core (torsional oscillations) and the accompanying motion of the mantle and inner core. The coupled motion of the core and mantle can be decomposed into an infinite set of normal modes. The frequency and spatial form of the normal modes depend on the physical properties of the core (including the internal structure of the magnetic field), whereas the modal amplitudes are related to the excitation source (which depends on the dynamics of the convective geodynamo). The model can thus be used to constrain both physical properties and dynamics of the core-mantle system. For example, the gravitational coupling that arises from the aspherical core-mantle and inner-core boundaries is found to be capable of explaining core-mantle angular momentum transfer observed as decadal and interannual length-of-day variations.

U41A CC: 517 A Thursday 0830h

Union Frontier Lectures II

Presiding: **S King,** Purdue University; **W R Peltier,** University of Toronto

U41A-01 0830h

Advances and Challenges in Hydrogeophysics

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It is widely recognized that natural heterogeneity of hydrogeological parameters control the infiltration and spread of water and contaminants in the subsurface, and that the range of spatial scales associated with heterogeneity is typically great. Conventional wellbore sampling methods, which are used to characterize heterogeneity, are invasive and often reflect only very localized conditions, which may not capture key information about field-scale heterogeneity. Similar to how medical imaging procedures have reduced the need for invasive surgery, geophysical methods hold promise for improved and minimally invasive characterization of the subsurface. The field of hydrogeophysics has developed in recent years to investigate the potential that geophysical methods hold for providing quantitative information about subsurface parameters or processes. Geophysical methods entail the measurement of subsurface properties or contrasts of properties; from these measurements, the nature and distribution of subsurface materials can often be deduced. Many advances in the last decade have illustrated the promise that geophysical methods have for providing subsurface stratigraphic information, for estimating hydrogeological properties, and for monitoring hydrological processes. Such advances include: an improved understanding geophysical responses in the 'softer' sediments characteristic of many near subsurface environments, improved digital technology for acquisition, improvements of many geophysical methods for near-surface data acquisition and processing, and improved computational speed and capabilities associated with processing, inversion, modeling and visualization of geophysical data. However, there are many obstacles that still hinder the routine use of geophysics for hydrogeological characterization. Some of the key hydrogeophysical challenges include the integration of geophysical and hydrological measurements, development of relationships to link the geophysical and hydrogeological parameters, and associated scale and uncertainty issues. This talk, presented on behalf of the AGU Hydrogeophysics Technical Committee and collaborators, will focus on illustrating the benefit of including geophysical data into the subsurface characterization and monitoring process, and on discussing current limitations and future trends in the emerging discipline of hydrogeophysics.

U41A-02 0915h INVITED

Recent Changes in Canada's Arctic Glaciers

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Canada's Arctic islands contain over 110,000 km2 of ice caps and glaciers, the largest area of land ice in the world outside Antarctica and Greenland. This region is projected to experience summer warming of 1-4°C over the next century due to the build-up of greenhouse gases in the atmosphere. The small ice masses in this region are likely to respond more rapidly to this warming than the larger Greenland ice sheet, and they may contribute appreciably to sea level changes over the next century. Glacier mass balance in the region has been persistently negative over the past 40 years. On Devon ice cap, the mass balance of the accumulation zone has become progressively more positive over that period, while that of the ablation zone has become progressively more negative. This suggests that the hydrological cycle in this part of the Arctic has become more vigorous over time. Balance fluxes computed for Devon ice cap were compared with observed fluxes (determined from ice thickness and surface velocity measurements derived from airborne radio echo sounding and SAR interferometry respectively). This comparison suggests that, over most of the ice cap, accumulation areas are thickening at rates of up to 0.15 m a-1, while ablation areas are thinning at rates of up to 0.8 m a-1. The exception is the southeast sector of the ice cap where accumulation areas appear to be thinning at up to 0.3 m a-1. Since 1960, the extent of land ice cover in the Arctic islands has decreased by around 1.8%. Rates of change are largest along the northern and southern coastal fringes of the Arctic Archipelago and lowest in interior regions. The margins of larger ice caps and glaciers terminating on land show little change. Small ice caps and tidewater-terminating outlet glaciers are most strongly affected. This suggests that iceberg calving may have contributed significantly to mass loss in some regions. For Devon ice cap, the calving contribution may be as large as 35%. Volume-area scaling techniques have been used to make a preliminary estimate of the ice volume loss associated with the reduction in ice-covered area. The potential contribution to global sea level is on the order of 1.5mm for the period 1960-2000. A significant number of glaciers show evidence of changes in flow regime, and such changes have resulted in both advances and retreats of glacier margins. Whether these flow regime changes represent normal surge-type behaviour or a response to climate forcing is not yet clear.

U42A CC: 517 A Thursday 1030h

Union Frontier Lectures III

Presiding: **S King,** Purdue University; **W R Peltier,** University of Toronto

U42A-01 1030h

Cycles, Cycles Everywhere - Corals, Coccoliths, and Climate

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Critical to our understanding of both past and future climate change is the biogeochemcial cycle of carbon on Earth. This is popularly recognized in the context of the creation and destruction of solid organic matter such as vegetation and fossil fuels, which has a clear and intuitive relationship to the amount of carbon dioxide in the atmosphere. Less widely recognized is the cycling which involves solid inorganic carbon as carbonate minerals - the most abundant form of carbon present at or near the surface of the Earth, and one with a distinctly counter-intuitive relationship with atmospheric CO2. For instance, changes in the rate of production of coral skeletons may have played a role in Holocene climate change, but with increased carbonate carbon removal driving atmospheric CO2 higher and not lower. The carbonate skeletons produced by some species of plankton in the open ocean are also critical to the climate system. The sinking of these skeletal parts is currently suspected to be important in helping to transport organic matter to depth and thus temporarily isolating this carbon from the atmosphere. The deposition of plankton-derived carbonate to the sediments of the deep-sea also helps regulate atmospheric CO2 but on thousand year time-scales, and will play a key role in the eventual removal of fossil fuel carbon from the atmosphere. However, there is a growing awareness that carbonate production by plankton may be severely diminished in the future. Maybe the cycle of carbonate on Earth could be re-set to how it operated over two hundred million years ago. Here I review some of the current areas of interest in global carbonate cycling, particularly its relationship to climate change and to fundamental moments in the evolution of life.

U42A-02 1115h

From Core to Solar Wind: Studying the Space Environment of Planets

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Space physics permeates studies of the planets - from the magnetic field generated in a planetary core, through the charged particle bombardment of surfaces, the heating, excitation and ionization of an atmosphere or corona, to the acceleration of ions and electrons trapped in a planet's magnetosphere. This presentation provides an introductory overview of the space environment of planetary objects - from giant planets to tiny comets. The talk highlights three cases that illustrate the range of issues and applications of planetary space physics. (1) How has the solar wind interaction with Mars' strong, patchy remnant magnetization affected the loss of water? (2) How does the activity of volcanoes on Io trigger dynamics of the vast magnetosphere of Jupiter? (3) How could measurements of particles and fields by the Galileo spacecraft as it flew past Ganymede and Europa tell us that former has a liquid iron core and the latter a layer of liquid water?