the geographic patterns and sizes of the geoid height errors are contrasted with the variability evident in the sequence of monthly gravity estimates. For the low degree spherical harmonics, the relative significance of errors in background gravitational force models used in GRACE data processing is discussed in relation to the size of the signal from monthly fields. These results should aid in geophysical interpretation of the GRACE data products, and in its comparison to results from other geodetic techniques.

U31A-04 0915h INVITED

Hydrological Information Inferred From GRACE Estimates OF Time-Variable Gravity

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Data from the GRACE satellite mission are now being used to generate regular, monthly solutions for the Earth's gravity field. The time-variable gravity fields derived from these solutions can be used to study such things as changes in the large-scale distribution of water stored on land and in the ocean, mass variations of the polar ice sheets, and post-glacial-rebound in the solid Earth. In this talk we discuss the quality of these initial GRACE fields, and we use the time-variable results inferred from these fields to estimate hydrological signals over large regions. We compare these estimates with the output of independent hydrological models, to help assess both the GRACE data and the models.

U31A-05 0930h

Water Storage Variations and Associated Errors Estimates from GRACE

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Four different basin functions are designed to estimate water storage variations from GRACE, and associated errors (measurement, leakage and atmospheric pressure errors) are evaluated: one of the basin functions is changed monthly using knowledge of true load variation. To test basin functions performance, Stokes coefficient variation from land and oceans models are synthesized, and error levels 50 and 100 times greater than the nominal GRACE error estimate are used to corrupt the Stokes coefficients. Five different basins (Amazon, Mississippi, Lena, Huang He and Oranje) are selected in this experiment representing a variety of basin sizes, locations and signal variance. In the large basins (Amazon, Mississippi and Lena), water storage variations are recovered successfully with the two error levels. As error level changes from 50 to 100 times, the shapes of basin functions are changed, yielding less atmospheric pressure error and more leakage error. Amplitude spectra of measurement and atmospheric pressure errors have different shapes but the best results are obtained when both are used.

U31A-06 0945h

Annual Gravity Field Variation from GRACE - Initial Analysis.

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GRACE is currently mapping the Earth's gravity field in space and time with un-precedented resolution and accuracy. The first 11 monthly global gravity fields solutions, recently being released to the GRACE science working team, have been used to study the long wavelength component of the annual gravity variation (Spherical harmonic deg. 10). The GRACE data shows an annual component in the gravity field peaking at 7.1 microGal over the Amazon Basin. Over the central southern Africa amplitudes peaks at 4.2 microGal and over Bangladesh at 3.4 microGal. The peaks follow the solar Equinoxes being in opposite phase on the two hemispheres. The annual component in the gravity field is compared with gravity changes due to a simple water storage model based on simultaneous hydrological NCEP reanalysis data. This model peaks at 6.6 microGal over the Amazon Basin. Comparisons with other models and in-situ data have also been performed to validate the findings. The spatial correlation between the amplitude of the annual gravity signal in GRACE and hydrology computed over 10 degree zonal latitude bands is higher than 80 percent everywhere.

U32A CC: 517 A Wednesday 1030h

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

Presiding: **B F Chao,** NASA Goddard Space Flight Center**; J Hinderer,** Ecole et Observatoire des Sciences de la Terre

U32A-01 1030h

First Results From GRACE Time Variable Gravity Field in Europe: a Comparison With Surface Gravity Changes Observed by Superconducting Gravimeters and With Hydrology Model Predictions

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We investigate the time-variable gravity changes in Europe retrieved from 11 initial GRACE monthly solutions provided by UT-CSR, ranging from April 2002 to October 2003. We first infer from each of the satellite solutions (expressed in spherical harmonics to degree 120) gravity anomaly maps according to various truncation levels. An empirical orthogonal function (EOF) decomposition of the time-variable gravity field is done to exhibit the main spatial and temporal characteristics. We show that the dominant signal is found to be annual with an amplitude and a phase both in agreement with predictions in Europe using snow and soil-moisture variations from recent hydrology models. We compare these GRACE gravity field changes to surface gravity observations from superconducting gravimeters of the GGP (Global Geodynamics Project) European sub-network, with a special attention to loading corrections. Initial results suggest that all 3 data sets (GRACE, hydrology and GGP) are responding to annual changes in near-surface water of a few microGal (at length scales of 1000 km) that show a high value in winter and a summer minimum. To this level of accuracy, and noting we have as yet insufficient data to support a strong conclusion, the calibration and validation aspects of the GRACE data processing would appear to be tentatively confirmed.

U32A-02 1045h

Variation of Ocean Bottom Pressure in Global Ocean Models, and Compared with Satellite Measurements of Dynamic Oblateness J_2

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The time series of J_2 produced from Lageos measurements by Cox and Chao is a measure of fluctuations in the mass distribution of the earth-ocean-atmosphere-hydrosphere-cryosphere system. At periods shorter than annual, after subtraction of the atmospheric contribution, the ocean is expected to be a significant contributor to this signal. We show here, using a global barotropic ocean model, that a significant part of the observed J_2 signal is due to the ocean, and is related to coherent circumpolar modes in both the Arctic and Antarctic. At periods shorter than about 7 days we also show that ocean loading and self-attraction effects have a significant impact on predictions of non-tidal ocean pressure fluctuations, although the absolute value of these fluctuations is generally small (less than 1 cm of water). At longer timescales, we use diagnostics from the HADCM3 climate simulation to identify the major global ocean modes of pressure fluctuation, identifying in particular a long period mode in which water moves between the Atlantic and Pacific oceans, which shows correlations with both model J_2 and El Niño time series.

U32A-03 1100h

Global Ocean Mass Variations from GRACE Gravity Fields

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A time-series of mean water mass variations over the ocean is computed from the initial release of monthly GRACE gravity field models, using an optimal averaging kernel. The time-series is used to study non-steric global mean sea level variations and is compared to a time-series constructed from altimetry corrected with a climatological steric signal. Seasonal signals are clearly apparent in both time-series, with similar amplitudes and phases. Although the time-span of the GRACE measurements is only slightly longer than one yearly cycle, we will also examine residuals in order to quantify a bound on the non-seasonal ocean mass signals during the time period.

U32A-04 1115h

Decadal Ocean Bottom Pressure Variability and its Associated Gravitational Effects in a Coupled Ocean-Atmosphere Model

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The launch of the GRACE satellite mission in March 2002 has made timely the study of geophysical processes that redistribute the Earth's mass. This study uses the Hadley Centre coupled ocean-atmosphere model HadCM3 to examine the ocean's role in mass redistribution. This state-of-the-art model simulates a realistic present day climate, and both the thermohaline circulation and El Nino are well represented. From the model output we derive a one-hundred year time-series of global ocean bottom pressure. The length of this time-series makes it well suited to the study of low-frequency bottom pressure variability. After removal of the mean seasonal cycle, the leading empirical orthogonal function of bottom pressure is a striking, basin-wide, oscillation between the Atlantic and Pacific Oceans. Statistical analysis of the forcing fields suggest that this mode is primarily a wind driven phenomenon. This was confirmed by performing experiments in which an ocean-only model was forced by anomalous winds from HadCM3. Next, the gravitational effects of this mode are considered. A surprising result is that oceanic mass redistribution can lead to decadal linear trends in the zonal harmonic J_2, with a slope of approximately one-third that observed in geodetic measurements of J_2, and which is thought to be due, primarily, to post glacial rebound. Although there is tantalising evidence that such a low-frequency mode of variability may actually occur in the physical ocean, the indirect nature of the evidence means no certain conclusions can yet be drawn. Thus, we consider the potential of GRACE to detect this low-frequency oceanic mass redistribution amongst the many other factors affecting the Earth's gravitational field.

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 non-zonal 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,on-ice 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.

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-