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A time sequence of approximately monthly estimates of the Earth's gravity field, derived from the Gravity Recovery And Climate Mission (GRACE) science data, have been recently made available to the user community. In addition to these monthly estimates, a long-term mean gravity field has also been made available. These gravity field products are generated by the GRACE Science Data System team elements at the UT-CSR, Jet Propulsion Laboratory and at GFZ-Potsdam. In this presentation, we briefly describe the gravity field processing standards and methodology in use at UT-CSR. The traditional linearized least-squares implementation of gravity field determination from GRACE tracking data is reviewed with particular attention the to a-priori gravitational force models in use. The evolution of GRACE mission since its launch in March 2002 is then discussed. The main mission events, and the flight dynamic profile (pointing, inter-satellite separation, ground-track evolution, etc) are presented - with the purpose of aiding the interpretation and assessment of the gravity field product quality. The presentation closes with the description of the likely future evolution of the flight profile.

URL: http://www.csr.utexas.edu/grace

G31A-04 0845h

Static and time-variable Earth gravity fields from CHAMP and GRACE

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We investigate the use of CHAMP observations for Earth's mean and time-varying gravity solutions and their geophysical interpretation. 1.5 years of CHAMP data (dynamic RSO orbits and accelerometer) were processed for monthly gravity solutions in spherical harmonics complete to degree 90, using the energy conservation principle and an efficient conjugate gradient inversion with an approximate error covariance matrix. With the exception of several months (because of the bad ground track coverage), monthly gravity solutions are computed for the time period from May 2001 through February 2003. The mean CHAMP gravity field solution (including 1 year of data) is evaluated using other gravity field solutions and various data. The estimated 2nd and 3rd degree/order of the time-varying components of the CHAMP gravity field are modeled with secular, annual, and semi-annual parameters, and compared with available solutions using satellite laser ranging (SLR). Although the second tesseral and the third zonal coefficient observed by CHAMP show unrealistically large variations, other estimates agree well with SLR solutions. The temporal geoid changes from the CHAMP solutions have correlations of 0.6 0.8 and RMS differences of 0.8 0.7 mm, when compared with the CSR's SLR solutions. The CHAMP temporal gravity field solutions are compared with combinations of various geophysical fluid models, including atmosphere, hydrology, ocean, cryosphere, and in situ data. Finally, we investigate some local methods to recover the continental surface water from GRACE mission. Our proposed methods are basically based on the local modeling of the water contents using GRACE potential difference [Jekeli, 1999 and Han, 2003]. They will enhance the spatial resolution as well as the accuracy of the estimates. The results based on the one year simulation of GRACE orbit and range-rate indicate that the local method can improve higher degree/order spectral contents compared to the global spherical harmonic approach.

G31A-05 0900h

An Initial Look at GRACE Time-Variable Gravity Results

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The GRACE satellite mission, launched in March, 2002, will deliver regular, monthly estimates of the Earth's gravity field during its 5-year lifetime. The time-variable gravity fields derived from these estimates 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 presentation we compare results obtained using the initial time-variable GRACE gravity solutions, with estimates of what the signal is expected to look like as inferred from independent hydrological, oceanographic, etc models. We use this comparison to help assess both the GRACE data and the models.

G31A-06 0915h

Combining sea surface and terrestrial gravity data for global geopotential modeling and geoid determination

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We present a method for combining sea surface and terrestrial gravity data with the new precise GRACE gravity data into a global geopotential model solution. Traditional methods typically require density and height assignments, gridding, and downward continuation in the case of terrestrial gravity data, and dynamic topography models for sea surface data. Our method allows different types of data, at different altitudes, of varying quality, and with incomplete to redundant coverage, to be combined rigorously with spaced based observations to produce a full covariance least squares fit to high degrees without patching. Combined with the latest in high performance computers, as well as a new least-squares algorithm designed to handle extremely large data sets, results from the terrestrial data are shown for models up to spherical harmonic degree 360.

G31A-07 0930h

Temporal Variations in the Earth's Gravitational Field: Modeling Results from a New Generation of GIA Models

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Predictions of ongoing glacial isostatic adjustment (GIA) have played a central role in the interpretation of temporal variations in the Earth's gravitational field. Analyses of the spherical harmonic (zonal and nonzonal Stokes) coefficients of the secular change have, for example, followed two rather distinct philosophies: First, if all other contributions to satellite-derived observations are assumed to be known, then GIA predictions can be used to constrain Earth rheology or Late Pleistocene ice histories; Alternatively, observations may be corrected for the GIA signal and the residual signal used in some other geophysical analysis (e.g., constraining mass variations associated with ongoing hydrological, oceanographic and crysospheric processes). Previous predictions of the GIA signal have been based on simple, spherically symmetric (i.e., radially stratified) Earth models. With the initiation of a new set of gravity missions, the accuracy of the constraints on the Stokes coeficients will be significantly improved, and GIA models must evolve to incorporate the full complexity of the Earth system. In this talk, we present predictions of temporal gravity variations derived from a new generation of finite element models of the GIA process. Our models incorporate 3-D variations in mantle viscosity inferred (indirectly) from recent global seismic tomographic models as well as realistic lithospheric structures (including plate boundaries and regional thickness variations). We demonstrate the extent to which previous GIA predictions adopted in analyses extending over two decades have been biased by the assumption of spherical symmetry in mantle structure.

G31A-08 0945h

Evaluating Available Mean Sea Surfaces and Geoid Models at High Latitudes Within the GOCINA Project.

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A major goal of the EU project GOCINA (Geoid and Ocean Circulation in the North Atlantic Ocean) is to determine an accurate geoid in the region between Greenland and the UK and, thereby, create a platform for validation of future GOCE Level 2 data and higher order scientific products. The central quantity bridging the geoid and the ocean circulation is the mean dynamic topography, which is the difference between the mean sea surface and the geoid. The best available geoid models (EGM96, GRACE, CHAMP, GOCINA03) will be evaluated against present mean sea surface models (i.e. CLS01, GSFC00, KMS03) comparing the differences with state of the art Mean Dynamic Topography models. An extended comparison in the Arctic Ocean will also be presented to demonstrate the impact of improved geoid and mean sea surface modelling. Particularly using the GRACE derived geoid models, and the KMS03 mean sea surface

URL: http://www.gocina.dk

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G31B MCC: Level 2 Wednesday 0830h

Before PBO: What Do We Know? I Posters *(joint with S, T)*

Presiding: **H Dragert,** Geological Survey of Canada; **B R Smith,** Scripps Institution of Oceanography

G31B-0701 0830h POSTER

Analysis of Nine Years of North American CORS Data

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Data from a network of 350 Continuously Operating GPS Reference Stations (CORS) located across the U.S. were homogeneously analyzed together with about 130 globally distributed stations for the period from 1994 through 2002. Every third day was included for computational efficiency. The final orbits of the International GPS Service (IGS) were used without adjustment, after applying transformations to a consistent IGS00 reference frame (closely aligned to ITRF2000); the reported satellite accuracy codes were applied for each day. Our double-differenced carrier phase analysis methods are generally consistent with the IERS 1996 Conventions, using 30-second sampling and a 15-degree elevation cutoff. Data for each day were processed in three interlocking subnetworks that were combined at the normal equations level, then the days were combined to determine the station coordinates and linear velocities of all stations. Results were carefully edited to delete spans of bad data and to introduce position

discontinuities where necessary, usually due to equipment changes or nearby earthquakes. The combined solution was aligned to the IGS00 reference frame by minimizing the differences for 53 of the 54 IGS fiducial stations. To determine the daily station repeatabilities, we re-solved each day using a subset of constrained coordinates taken from the overall 9-year solution. Using the global solution and the station repeatabilities, we plan to examine the intra-plate stability of N. America and to assess the feasibility of realizing a horizontal reference frame for eastern N. America stable at the 1-mm level or better. This work anticipates the requirements of the Plate Boundary Observatory (PBO) currently under construction. This solution will also improve our understanding of local and regional vertical motions across N. America. In the future, PBO will dramatically improve the spatial resolution of long-term GPS solutions of this type, at least in the western U.S.

G31B-0702 0830h POSTER

Using Internet-Based Automated Software to Process GPS Data at Michigan Tech University

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The Michigan Tech University GPS monument was made operational in October of 2002. The monument, which consists of a concrete pillar extending approximately 10 feet below the surface and protrudes 5 feet above ground, is located at the Houghton County Memorial Airport (47.171803°N, 88.498361°W). The primary purpose of the monument is to measure the velocity of the North American Plate at this location. A Trimble 4000ssi geodetic receiver with a Trimble Zephyr antenna is used to collect GPS data. The data are sent to a PC where they are processed using Auto-GIPSY, an internet-based GPS processing utility, which makes it possible to process GPS data, via email, without having knowledge of how the software works. Two Perl scripts were written to facilitate automation and to simplify processing of the GPS data even further. Twelve months of GPS data were processed, using Auto-GIPSY, which produced a velocity of -24 ± 5 mm/yr and -4 ± 6 mm/yr for the X and Y components respectively with an azimuth of 261° with respect to the ITRF2000. This calculated result compares well with the NNR-NUVEL1A velocity of -17 mm/yr and -1 mm/yr for the X and Y components respectively with an azimuth of 267°. The results from an alternative online processing service, the Scripps Coordinate Update Tool (SCOUT) that uses GAMIT, will also be presented as a comparative method.

G31B-0703 0830h POSTER

Testing intraplate deformation in the North American plate interior from a combined geodetic solution: implication for strain accumulation on potentially seismogenic faults in the central and eastern U.S.

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Large earthquakes within stable plate interiors, such as the 1811-1812 New Madrid events in the Mississippi valley, are direct evidence that significant levels of strain can accumulate along geologic structures far from plate boundary faults. However, direct geodetic measurement of present-day horizontal strain in the Central and Eastern US is challenging because of the low strain rate relative to the underlying geodetic noise and difficulties in accurately estimating geodetic site velocity uncertainties. In an attempt to rigorously assess crustal strain rates in the central and eastern United States, we combined independent geodetic solutions based on 300 continuous geodetic stations covering the stable interior of the North American plate. The combination includes daily GPS solutions computed at Univ. Wisconsin with GIPSY-OASIS and at Purdue University with GAMIT that range from 1996 to 2003, as well as IGS weekly combined solutions, and the full ITRF2000 solution, which also serves as reference frame. We emphasize realistic assessments of velocity uncertainties through a variety of techniques, including use of the full covariance matrix of the geodetic solutions in the combination and assorted statistical tests meant to detect regionally coherent departures from plate rigidity. We present our most recent horizontal velocity field and vertical rates for the central and eastern US, including a comparison of the 3D velocity fields defined independently from the GIPSY and GAMIT analyses. Preliminary conclusions regarding upper bounds on deformation in this region will be presented, as will residual site velocities as a function of the type of antenna mounting structure.

G31B-0704 0830h POSTER

Block model of western US kinematics from inversion of geodetic, fault slip, and earthquake data

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The active deformation of the southwestern US (30° to 41°N) is represented by a finite number of rotating, elastic spherical caps. Horizontal GPS velocities (1583), fault slip rates (94), and earthquake slip vectors (116) are inverted for block angular velocities, locking on block-bounding faults, and the rotation of individual GPS velocity fields relative to North America. GPS velocities are modeled as a combination of rigid block rotations and elastic strain rates resulting from interactions of adjacent blocks across bounding faults. The resulting Pacific - North America pole is indistinguishable from that of Beavan et al. (2001) and satisfies spreading in the Gulf of California and earthquake slip vectors in addition to GPS. The largest blocks, the Sierra Nevada - Great Valley and the eastern Basin and Range, show internal strain rates, after removing the elastic component, of only a few nanostrain/a, demonstrating long term approximately rigid behavior. Most fault slip data are satisfied except that the San Jacinto fault appears to be significantly faster than inferred from geology while the Coachella and San Bernardino segments of the San Andreas fault are slower, suggesting the San Andreas system is straightening out in Southern California. Vertical axis rotation rates for most blocks are clockwise and in magnitude more like the Pacific than North America. One exception is the eastern Basin and Range (242°E to 248°E) which rotates slowly anticlockwise about a pole offshore Baja.

G31B-0705 0830h POSTER

Effects of Lateral Heterogeneity on Strain Accumulation Across the Carrizo Plain Segment of the San Andreas Fault

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Changes in lithology, elastic properties or rheology on either side of a fault can influence the pattern of surface strain accumulation and release. Large offset strike-slip faults are likely to juxtapose terrain with different mechanical properties. The central section of the San Andreas Fault exemplifies this behavior by juxtaposing different lithologies and elastic properties on opposite sides of the fault. Lisowski et al. (1991) showed that the San Andreas Fault, south of Cholame and north of the big bend, has an asymmetric strain accumulation pattern. This area is appropriate for detailed study because deformation is dominated by a single strike-slip fault, and geophysical and geologic studies provide constraints on elastic thickness, rheology, fault kinematics and earthquake history. A well defined velocity profile is also available (SCEC v.3.0). Using these data, we analyze the effect of laterally varying mechanical properties on interseismic strain accumulation and the earthquake cycle using the finite element model TECTON. Lisowski, M., J.C. Savage, and W.H. Prescott, The velocity field along the San Andreas fault in central and southern California, J. Geophys. Res., 96, 8369-8389, 1991.

G31B-0706 0830h POSTER

Analysis of data from multiple geodetic networks for a spatio-temporal fault slip history at Parkfield, CA during the 1990s

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Transitions from creeping to locked portions of the San Andreas fault have been seen to experience transient deformation. One such transition zone occurs at Parkfield, CA, a locale well-known for its history of M6 earthquakes. Despite a prediction that another M6 earthquake would take place in 1988 ± 5 years, the most recent such event at Parkfield was in 1966. In the early 1990s, however, rate changes were observed in data from the permanent two-color geodimeter network and tensor strain meters. There was a general increase in seismic moment release, and three M∼4.5 earthquakes nucleated near the inferred hypocenter of previous Parkfield M6 earthquakes. More recently a concurrent magnetic field anomaly was identified. These observations have been interpreted to result from a transient increase in fault slip-rate on the San Andreas. However, to date analyses of the geodetic data have been limited to forward models and inversions for instantaneous rate changes. Here we present results of a time-dependent inversion using data from the permanent two-color network, two portable two-color networks, and GPS surveys in the Parkfield area. Our analysis uses an efficient nonlinear Kalman filtering technique well-suited to inferring slip-rate changes from data contaminated by random walk and white noise. This method exploits the fact that, unlike local benchmark noise, a deformation signal is spatially coherent. We have also explored means for simultaneously estimating the seasonal noise that is common in geodetic time-series. This type of analysis enables estimation of fault slip at every epoch for which there are data, resulting in a time-history of slip rather than a single rate change. Results to date show an increase in slip-rate on the upper ∼6 km of the fault near Middle Mountain between 1993 and 1995 followed by a decrease to the background rate by 1998. The Parkfield two-color network, established in 1984, provides a long baseline of temporally dense measurements. Thus, the analysis methods we discuss are applicable to modeling data from continuous GPS networks like PBO. While large deformation events are easily observed; here we demonstrate the potential for highlighting subtle slip-rate transients with continuous geodetic monitoring.

G31B-0707 0830h POSTER

A New Approach to Time-Dependent Inversion of Geodetic Data Using Monte Carlo Mixture Kalman Filter

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It is important to precisely clarify time history of transient fault slip or magma intrusion (hereafter we simply call them fault slip) from surface deformation measurements to understand the physical processes of earthquake generation and volcano eruption. We have developed a new time dependent inversion method for imaging detailed time history of fault slip from geodetic data. We employed a stochastic model that enables non-parametric description of fault slip evolution. In this framework, temporal smoothness of slip is determined by a scaling parameter (temporal smoothing parameter). In order to reconstruct detailed time history of fault slip, we assumed that the temporal smoothing parameter is variable in space and time. In this case, Kalman filter that has been used in past studies cannot be used because spatio-temporal distribution of the temporal smoothing parameter is unknown. In order to estimate slip history under this condition, we have developed a new filtering technique, Monte Carlo mixture Kalman filter (MCMKF), and applied it to the time dependent inversion. The validity of the MCMKF based inversion scheme is investigated through numerical experiments. In the numerical experiments, the MCMKF based inversion scheme is applied to the simulated displacement time series generated by 4 sources:

1 Mogi source, 2 tensile faults, and 1 shear fault. In a source, the temporal smoothing parameter and the slip are assumed to be temporally variable and spatially uniform, and the temporal evolutions of the temporal smoothing parameter and the slip are allowed to take different values in respective sources. Then results are compared with those obtained by the conventional Kalman filter based scheme. The results show that the MCMKF based method is capable of imaging spatio-temporal variation of fault slip together with the temporal smoothing parameter that is variable in space and time. We also find that the MCMKF is able to image whole time history of transient slip events more precisely than Kalman filter. Especially, the MCMKF is superior to Kalman filter in precisely reproducing slip rate changes and propagating slip. Furthermore, the MCMKF gives significantly smaller AIC (Akaike information criterion) values than Kalman filter. These results indicate that the MCMKF yields better slip estimates than Kalman filter.

G31B-0708 0830h POSTER

Time-Dependent Coulomb Stres along the San Andreas Fault System

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Many questions remain regarding the evolution of stress along the San Andreas Fault System: Which segments of the San Andreas System are approaching failure? What is the stress interaction along different fault segments for likely slip scenarios? To what extent does locking depth influence the regional stress field? To better address these questions, we have developed and tested a semi-analytic, time-dependent model for 3-D displacement and stress caused by a dislocation in an elastic layer over a viscoelastic half-space. Our model is remarkably efficient: a single time-step computation of 2048 by 2048 horizontal grid cells, containing over 400 fault elements within a 900 x 1700 km fault zone, requires approximately 1 minute of CPU time on an ordinary workstation. This speed enables us to rapidly explore various full 3-D viscoelastic models with realistic 1000-year faulting scenarios. Our approach for investigating time-dependent deformation and stress evolution of the San Andreas Fault System is as follows: We represent far-field plate motion by continuous slip in the lower portion of a 50 km thick elastic layer. Earthquakes are modeled by episodic slip along individual faults using spatially-variable locking depth and geologically-estimated recurrence intervals. Each co-seismic event results in an instantaneous change of stress within the viscoelastic half-space that slowly relaxes with time and is coupled with the evolution of stresses within the elastic plate. We investigate such evolving stresses by computing time-dependent Coulomb stress within the seismogenic zone. We find that the evolving stress field is sensitive to plate thickness, half-space viscosity, and faulting scenario. We are currently establishing a suite of models, consistent with both geodetic and geological observations, that will increase our understanding of how temporal plate-boundary deformation and stress variations within the seismogenic crust can result from different tectonic settings throughout the earthquake cycle.

URL: http://topex.ucsd.edu

G31B-0709 0830h POSTER

Transient rheology of the uppermost mantle in the epicentral region of the 1999 M7.1 Hector Mine earthquake, California

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Elevated strain rates are often observed after large strike-slip earthquakes. A current challenge is to discriminate among models capable of explaining rapid postseismic deformation at various spatial scales: poroelastic rebound (e.g., Peltzer et al., 1998), afterslip (e.g., Hearn et al., 2002), and postseismic relaxation governed by a Maxwell rheology, nonlinear rheology or transient rheology (Ivins, 1996). At the small strains and timescales involved in postseismic relaxation, a transient response is expected (Minster and Anderson, 1981) . Observations of postseismic deformation following major earthquakes have high potential to constrain the properties of transient rheology because of the good time coverage and spatial sampling of geodetic measurements. Continuous GPS data from the Southern California Integrated GPS Network and campaign GPS data from the U.S. Geological Survey define the postseismic surface deformation field for the first 2.5 years following the 1999 M7.1 Hector Mine earthquake. We consider four classes of postseismic deformation models, including two transient rheology models represented by a Burgers body (a combination of Maxwell and Kelvin elements with viscosities η_1 and η_2, respectively) and conclude that the data are best explained with dominantly postseismic flow of the upper mantle governed by a a transient rheology. The upper mantle is characterized by two material relaxation times 0.07 years and 2 years with associated viscosities $\eta_2 = 1.7 \times 10^{17}$ Pa s and $\eta_1 = 4.6 \times 10^{18}$ Pa s. The Kelvin element is presumably one of several relaxation elements that compose an absorption band model of seismic wave attenuation. These results carry implications for the transition from anelastic to viscous behavior in Earth's upper mantle.

G31B-0710 0830h POSTER

Anomalous Crustal Deformation in the Central Nevada Seismic Belt Detected by InSAR.

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The Central Nevada Seimic Belt (CNSB) is one of the tectonically most active areas in North America. The CNSB was the location of major normal and strike-slip earthquakes in 1915 (Pleasant Valley M7.5) and in 1953 (four Magnitude 6.8-7.2 during 6 month). GPS measurements have shown ongoing crustal deformation at rates of 5 to 10 mm/yr across the CNSB. Those geodetic estimates of deformation are by a factor of 3-4 higher than geologic fault slip rates derived by paleoseismology. A possible explanation for this discrepancy between geodetic and geologic rates of deformation is that the geodetic measurements do not reflect long-term strain accumulation but transients such as post-seismic relaxation following the 1915-1954 earthquakes. We measure crustal deformation in the CNSB using Interferometric Synthetic Aperture Radar (InSAR). We obtained 9 independent interferograms each covering four adjacent frames (400 km in along-track direction) spanning 4-7 years using ERS SAR imagery acquired between 1992 and 2001. A precise displacement map obtained by stacking (averaging) the interferograms shows shortening of the distance between the ground and the satellite at a rate of 2mm/yr (range change). The maximum range change occurs in the epicentral area of the 1954 Dixie Valley and 1915 Pleasant Valley earthquakes. This suggest that we may see post-seismic deformation caused by these normal events. We discuss models of post-seismic deformation to explain the observed deformation.

G31B-0711 0830h POSTER

Quaternary Fault Database for the Basin and Range Province of Nevada and Utah: Fodder for PBO's Gristmill

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The USGS has nearly completed a comprehensive compilation of Quaternary faults and folds that could be potential seismic sources for large surface-rupturing earthquakes throughout the U.S. The compilation consists of GIS-based maps of Quaternary faults and folds and a robust (i.e., >7,500 p.) database that will be accessible via the Internet. The data for the Basin and Range (B&R) province will prove very useful for comparing Quaternary geologic deformation rates with GPS-derived geodetic strain rates (i.e., Earthscope/PBO). This poster focuses on the B&R province of Nevada and Utah and features a new map of Quaternary faults and folds, as well as GPS stations (USGS and Cal Tech) and paleoseismic study sites. Current campaign-style and continuous GPS stations are well distributed across the northern B&R, whereas paleoseismic studies have been concentrated mainly along the Intermountain and Central Nevada Seismic belts and the Yucca Mountain area. The Quaternary fault and fold map shows the time of most recent fault (or fold) movement, sense of movement, slip (or uplift) rate category, and a numeric identifier. GIS data are maintained in ArcInfo on a Unix server and linked to a File Maker Pro web database that contains comprehensive written descriptions, several of which are displayed on this poster. More than 1,000 Quaternary faults are shown on the map, the majority of which are within the highly extended B&R terrain of Nevada and western Utah. To visually depict potential earthquake sources, we categorized the time of most recent movement (surface rupture) on the faults as <1.6 Ma, (black), <750 ka (blue), <130 ka (green), <15 ka (orange), and historic (<200 yrs, red). The <130,000 year time frame is probably the most relevant for seismic-hazards assessments because it encompass multiple earthquake cycles on most B&R faults. The slip-rate categories (in mm/yr) are binned to separate relatively inactive faults (<0.2, thin lines) from active normal faults (0.2-1, medium lines) and moderately (0.2-1) to quite active (>1 thick lines) oblique- and strike-slip faults. With few exceptions, the only faults that exceed >2 mm/yr are the Holocene strike- or oblique-slip faults in the western B&R province.

G31B-0712 0830h POSTER

Block Interactions in Southern Oregon, Northern California, and Northwestern Nevada

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Southern Oregon, northern California, and northwestern Nevada is an area of plate tectonic interest due to the surrounding complex interactions between the Pacific plate, Sierra Nevada block, western Basin and Range, California Coast Range, Mendocino Transform, Juan de Fuca plate and the San Andreas fault. The overall net effects from these interactions on the tri-state area are unknown and constitute the focus of our research. Over a two week period in June and July of 2003, GPS data were collected at approximately 100 sites between 40 - 45 degrees N. and 235 - 245 degrees E. Most of the sites were first occupied as part of National Geodetic Survey HARN surveys in 1998 and 1999. These data are currently being processed and the resulting velocity vectors will be analyzed to ascertain block interactions in the region of interest.

G31B-0713 0830h POSTER

Cascadia Episodic Tremor and Slip: An Ideal Target for PBO Studies

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One of the most intriguing recent findings made possible by high-precision geodesy is the discovery of "Episodic Tremor and Slip" (ETS) along the northern Cascadia Margin. Analyses of continuous GPS data from both the Western Canada Deformation Array (WCDA) and the Pacific Northwest Geodetic Array (PANGA) have resolved transient horizontal surface displacements of 2 to 5 mm occurring over a period of 6 to 15 days in a direction opposite to long-term deformation motions. These brief reversals of motion are accompanied by unique low-frequency (1 to 5 Hz) tremors that have a source region which coincides with, or directly overlies, the region of the subducting slab interface where transient slip occurs. Furthermore, for the plate interface underlying southern Vancouver Island and northwestern Washington State, ETS events appear to occur with surprising regularity, having a recurrence interval of 14.5 ±2 months. For ETS events which involved larger areas, both tremor activity and slip displacements have been observed to migrate in northwest and southeast directions, parallel to the strike of the subduction zone, at rates of 5 to 15 km per day. The physical processes which give rise to this dynamic behavior on the deeper subduction interface are not yet understood. More detailed seismic, GPS, and strainmeter observations are required along the full length of the Cascadia Margin to map the exact aerial extent and depth range of ETS events and to monitor the temporal evolution of individual events. Such detailed observations will allow correlations with structure, rheology, and thermal regimes, and provide critical data for modeling and understanding this phenomena and evaluating its role in seismic hazard estimates in the Pacific Northwest.

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G31B-0714 0830h POSTER

Stress Transfer, Thermal Unrest, and Implications for Seismic Hazards Associated with the Norris Uplift Anomaly in Yellowstone National Park

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Deformation maps of Yellowstone, inferred from satellite interferometric synthetic aperture radar (InSAR), delineate a large area of uplift (30 by 40 km) centered under the north rim of the Yellowstone caldera. Since this area is nearly centered on the Norris Geyser Basin (NGB), we call it the Norris Uplift Anomaly (NUA). The NUA began inflating in 1997, and had inflated a maximum of ∼125 mm through the summer of 2002 (the latest InSAR data available). This inflation has led to dilatation of the surface above the uplift of an estimated 8.5 microstrain. The pressure decrease from this dilatation, concentrated in the depth interval 0-2 km, could lead to an increase in advective heat transported to the surface, producing the currently observed thermal unrest. The spring and summer of 2003 has been a time of vigorous thermal unrest in the NGB of Yellowstone National Park. Unrest began with the eruption of Steamboat Geyser in May 2000, and has intensified this spring and summer with the eruption of Porkchop Geyser (dormant since 1989), the formation of a 75 m line of fumaroles just north of NGB, and a general trend of increasing spring and ground temperatures in NGB. The National Park Service has closed some footpaths in the geyser basin owing to near-boiling ground temperatures. The uplift has also led to an increase in seismic hazard potential in the area of uplift. The calculated stress field from the modeled shallow dipping dike that best fits the InSAR observations through 2002 is over 0.4 MPa at a normal fault that slipped during (and at the 4 km hypocentral depth of) a nearby M_L 6.1 earthquake in 1975. Stress changes an order of magnitude less may be responsible for triggering normal-faulting earthquakes.

G31B-0715 0830h POSTER

Isla Guadalupe, a Plate Boundary Observatory Remote GPS System: What's Next in PBO-Mexico?

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As a join project between scientific and technical personnel from Southern California Integrated GPS Network, the University NAVSTAR Consortium, Nanometrics Inc, and CICESE, we installed a VSAT remote communications on Isla Guadalupe in support of data telemetry from a cluster of GPS, meteorological and seismic instrumentation. This Mexican island located between 28° 53' and 29° 11'N and 118° 13' to 118° 22'W, lies too far from the main land to allow regular radio link. The station now in operation (GUAX) is near of the early GEOMEX site (GUAD), which recent GPS survey mode result show, is fully located on the Pacific plate within the prediction (1 mm/yr N and 2 mm/yr E) of both the geophysical (NNR-NUVEL1-A) and geodetic (ITRF2000) Plate Tectonic models. Thus, GUAX serve as an important clue to accurately monitor the plate's motion, as well as a reference for studies of California Borderland deformation. During the last 5 years we have built two more sites in northern Baja California: SPMX (1998) and CORX (2000); these together with the IGS station in Ensenada (CICE established in 1995 and replaced by CIC1 in 1999), became part of SCIGN-SOPAC (http://sopac.ucsd.edu, www.scign.org). In Mexico the major organizations working with GPS are INEGI (15 sites) and UNAM (different groups: 20-25 sites). Other State Universities and agencies are increasingly using permanent GPS stations for diverse purposes. It seems that in order to achieve our commitment for PBO-Mexico we must to follow the PGGA/SCIGN/CSRC waybill.

G31B-0716 0830h POSTER

Plate Boundary Observatory in Taiwan

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The island of Taiwan is situated in the plate boundary zone between the Eurasian and the Philippine Sea plates. The Philippine Sea plate is subducting northwestward underneath the Eurasian plate along the Ryukyu Trench in the north, while the Eurasian plate underthrusts the Philippine Sea plate along the Manila Trench in the south. Taking advantage of the extremely high strain rate in the Taiwan area, an integrated National Science Council project, Plate Boundary Observatory in Taiwan (PBOT), was initiated following the idea of US PBO. The scientific goal of PBOT is to observe the crustal deformation on various temporal and spatial scales in the Taiwan plate boundary zone employing available state of the art techniques for measuring crustal strain. The techniques include seismology, Global Positioning System (GPS), Interferometric Synthetic Aperture Radar (InSAR), borehole strainmeter, and earthquake geology. They are complementary to each other and form a complete spectrum of measuring various periods of crustal strain. The process of crustal deformation is generally quite slow. To obtain a reliable result, we usually need to persist in the observations for several years or even decades. Thus the PBOT should be a long-term project. In the first phase of 3 years period from 2003 to 2006, we will focus on the two areas, i.e. the plate suture zone in the Longitudinal Valley area and the western Taiwan where the higher seismic hazard is expected. A five-year national program, entitled Program for Earthquake and Active-fault Research (PEAR) was initiated after the disastrous 1999 Chi-Chi earthquake (Mw 7.6). As part of the PEAR, a dense continuous GPS array consisting of 150 new and about 50 pre-existing stations will be completed in the Taiwan area by the end of 2005 through a joint effort by the Central Weather Bureau and the Institute of Earth Sciences, Academia Sinica. The 50 new stations are going to be evenly distributed around the Taiwan Island. The other 100 stations will be densely deployed near the major active faults and potential earthquake source areas. The enormous continuous GPS data collected by the array will give us the unprecedented opportunity to study the crustal deformation in Taiwan. The near real time spatial and temporal variations of crustal strain can be realized and their correlation with seismic activity will be studied. Using GPS data from the dense array, the slow slip events related to fault-creep and subduction may be detected. In the event of a major earthquake, the continuous GPS array provides the precise measurements of preseismic, coseismic, and postseismic deformations. It may shed light on the process of strain accumulation and energy release through an earthquake cycle. The present-day fault-slip rates of major active faults in Taiwan will be estimated. These results provide the important information for seismic risk analysis and lead to the effective reduction of earthquake disaster

G31B-0717 0830h POSTER

Local fluid flow and borehole strain in the South Iceland Seismic Zone

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Installation of 175 borehole strainmeters is planned for PBO. It is therefore vital to understand the behavior of existing strainmeter installations. We investigate signals recorded by three borehole dilatometers in the south Iceland seismic zone following two M_w 6.5 earthquakes in June 2000. Poroelastic relaxation has been documented following these events based on InSAR and water level data [*Jónsson et al., 2003, Nature*]. According to poroelastic theory for a homogeneous isotropic (unfractured) medium, the anticipated post-seismic volumetric strain has the same sign as the coseismic strain step. For example, coseismic compression results in pore-pressure increases; post-earthquake fluid drainage causes additional compression. However, we find that observed strain changes vary considerably between different instruments after the earthquakes. One instrument (HEL) behaves as expected with transient strain increasing with the same sign as the coseismic strain step. Another instrument (SAU) shows partial strain relaxation, opposite in sign to the coseismic signal. The third (BUR) exhibits complete strain relaxation by 3-4 days after the earthquakes (*i.e.,* BUR does not record any permanent strain). BUR has responded in the same fashion to three different earthquakes and two volcanic eruptions, demonstrating conclusively that the transient response is due to processes local to the borehole. Fluid drainage from cracks can explain these observations. Rapid straining results in compression (extension) of the rock and strainmeter. Fluid filled fractures near the borehole transmit normal stress, due to the relative incompressibility of water. Thus, at short time scales the instrument records a coseismic strain step. With time, however, fluid flows out of (in to) the fractures, and the normal stress transmitted across the fractures decreases (increases). As the stress relaxes the strainmeter expands (contracts), reversing the coseismic strain. Barometric responses are consistent with this model. HEL shows shows high coherence and zero phase lag at periods of 1-8 days. SAU and especially BUR show substantial phase lags at periods longer than 4 days. Our results highlight the need to limit (or at least calibrate the effects of) fracture dominated flow in the near field of borehole strainmeters.

G31B-0718 0830h POSTER

A large scale velocity inversion for slip rates on South Island, New Zealand Faults

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This paper presents a velocities for 411 points distributed over the South Island, New Zealand which show the interseismic velocity field for this part of the Pacific Australian plate boundary in significantly higher resolution than previous studies. The velocities were determined by analysis of data observed 15 GPS surveys from 1992 till 2001 and three major triangulation surveys conducted between 1939 and 1982. The velocity field reveals a fairly uniform pattern of velocities across the New Zealand plate boundary in which the velocity is negligible (within errors) in the eastern part of the South Island and increases to up to 85% of the Pacific-Australia relative plate velocity on the west coast. An exception of this pattern is found in the far south of the South Island where the velocities are negligible except for a narrow zone along the west coast where the velocities reach a maximum value of about 45% of the relative plate velocity rate. The velocity field was inverted using a three dimensional model composed of 42 dislocations which model the effects of the Puysegur Trench, The Alpine Fault and the Marlborough Faults. In order to prevent edge effects in the model, the Marlborough Faults and Puysegur plate boundary thrusts were extended a minimum of 500 km north and south of the limit of New Zealand. Inverting the velocity vectors using a dislocation model containing the major faults on the plate boundary zone produces a reasonable match to known slip rates. An exception to this is the Alpine Fault where the calculated dip slip are clearly greater than paleoseismic estimates. This discrepancy may indicate deformation on unmodeled structures within and east of the Southern Alps.

G31B-0719 0830h POSTER

Remote Sensing of Strain Accumulation and Near Fault Coseismic Displacements

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1) we analysed the ERS archive spanning a 10 years period over le libanese part of the levantine fault. 43 derived differential interferograms depend on troposhere, ionosphere, ground deformation and uncertainties on data(including errors on orbits). Static and dynamic tropospheric patterns where best estimated from standard atmosphere models and available meteorological data. troposphere correction from MERIS data are shown consistant with meteological data. TEC maps where derived from GPS measurements. Analysis of trade-off between the parameters yields estimate of the spatial frequency dependant limitation of ERS insar. Map showing a possible strain accumulation rate of few millimeters per year is presented. Results derived from the permanent scatters procedure are consistant with the interferograms. 2) close-up views of the fault

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

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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

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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

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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

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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

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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"

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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.