model with a mantle viscosity of about 10^{19} Pa s. Contemporary crustal deformation of the Cascadia forearc, 300 years after a great earthquake, can be explained by the viscoelastic model. The observation that GPS sites 300-400 km landward of the rupture region of the 1960 great Chile earthquake are presently moving seaward, opposite to the motion of the coastal sites, can be explained by stress relaxation. Elastic models can also fit most of the observations by assuming that all deformation is due to fault motion. The fault motion thus determined effectively includes contribution from stress relaxation.

G22E-03 1630h

Long-term Postseismic Deformation Following the 1964 Alaska Earthquake

Jeffrey T Freymueller[1] (jeff@giseis.alaska.edu)

Steven C. Cohen[2] (Steven.C.Cohen@nasa.gov)

Sigrún Hreinsdóttir[1] (sigrun@giseis.alaska.edu)

Hisashi Suito[1] (suito@giseis.alaska.edu)

[1]Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99709, United States

[2]Goddard Space Flight Center, Geodynamics Branch, Code 921, Greenbelt, MD 20771, United States

Geodetic data provide a rich data set describing the postseismic deformation that followed the 1964 Alaska earthquake (Mw 9.2). This is particularly true for vertical deformation, since tide gauges and leveling surveys provide extensive spatial coverage. Leveling was carried out over all of the major roads of Alaska in 1964-65, and over the last several years we have resurveyed an extensive data set using GPS. Along Turnagain Arm of Cook Inlet, south of Anchorage, a trench-normal profile was surveyed repeatedly over the first decade after the earthquake, and many of these sites have been surveyed with GPS. After using a geoid model to correct for the difference between geometric and orthometric heights, the leveling+GPS surveys reveal up to 1.25 meters of uplift since 1964. The largest uplifts are concentrated in the northern part of the Kenai Peninsula, SW of Turnagain Arm. In some places, steep gradients in the cumulative uplift measurements point to a very shallow source for the deformation. The average 1964-late 1990s uplift rates were substantially higher than the present-day uplift rates, which rarely exceed 10 mm/yr. Both leveling and tide gauge data document a decay in uplift rate over time as the postseismic signal decreases. However, even today the postseismic deformation represents a substantial portion of the total observe deformation signal, illustrating that very long-lived postseismic deformation is an important element of the subduction zone earthquake cycle for the very largest earthquakes. This is in contrast to much smaller events, such as M 8 earthquakes, for which postseismic deformation in many cases decays within a few years. This suggests that the very largest earthquakes may excite different processes than smaller events.

G22E-04 1645h INVITED

Relative land/sea-level movements and great Holocene earthquakes, Alaska

Ian Shennan[1] (ian.shennan@durham.ac.uk)

Sarah Hamilton[1] (s.l.hamilton@durham.ac.uk)

[1]Department of Geography, University of Durham, South Road, Durham DH1 3LE, United Kingdom

The “earthquake deformation cycle” (EDC) model describes relative sea-level (RSL) movements associated with large plate boundary earthquakes. On March 27, 1964, an earthquake of magnitude 9.2 occurred along the south coast of Alaska, USA. By applying quantitative transfer functions to microfossil data collected from contemporary tidal flats, marshes and wetlands together with observational data from 1964 we can calibrate models of Holocene environmental change represented by fossil assemblages in sediment sequences. We use the transfer function models to quantify relative sea-level changes through multiple Holocene EDCs in Alaska and separate co-seismic from non-seismic events. Geological evidence from four sites around the Cook Inlet - Girdwood, Ocean View (Anchorage), Kenai and Kasilof, support a four phase EDC model that in the zone of co-seismic submergence comprises: (1) Relatively rapid land uplift and sedimentation immediately after an earthquake, i.e. the post-seismic period; (2) Centuries-long inter-seismic period of slower relative land uplift caused by strain accumulation along the locked portion of the Alaska-Aleutian subduction zone; (3) A pre-seismic period of relative sea-level rise (relative land subsidence) lasting approximately a decade; (4) Rapid co-seismic land subsidence during a great (Mw > 8) earthquake. The four sites record evidence of Holocene co-seismic submergence in the form of multiple peat-mud couplets. Not all events are recorded at each site, the interval between events is variable and the magnitude of submergence varies from less than 0.5 m to greater than 2.0 m. A unique finding is the identification and quantification of pre-seismic RSL rise prior to each co-seismic event. Biostratigraphic changes that reveal a pre-seismic RSL rise typically occur over 1 to 5 cm of sediment, are dated at Kenai and Girdwood (for the 1964 earthquake) to start approximately 10 years before the event and indicate pre-seismic RSL rise up to 0.2 m. This is strong evidence to suggest that pre-seismic movements may represent a precursor to a great earthquake. Independent work based on twentieth century observations and limited to only parts of an EDC describe possible mechanisms for this phenomenon. This has potential implications for other subduction zone locations including Chile, Japan and the Pacific Northwest of the USA and Canada.

G22F MCC: 2010 Tuesday 1710h

Bowie Lecture

Presiding: **V Dehant,** Royal Observatory of Belgium**; J T Freymueller,** University of Alaska, Fairbanks

G22F-01 1715h INVITED

Episodic Tremor and Slip in the Cascadia Subduction Zone: A Story of Discovery

Herb Dragert (250-363-6447; dragert@pgc.nrcan.gc.ca)

Geological Survey of Canada, Pacific Geoscience Centre, 9860 West Saanich Rd., Sidney, BC V8L 4B2, Canada

For more than two decades, seismologists at the Pacific Geoscience Centre puzzled over the episodic appearance of simultaneous "noise" on seismographs from stations located over the Cascadia subduction zone in southwestern British Columbia. With the 1992 initiation of continuous GPS monitoring in Victoria, B.C., another puzzle presented itself in an inexplicable 5-mm westward displacement of the then solitary regional continuous GPS monument over a period of about a week in October 1994. These observations remained unexplained (and unrelated) until recently. Beginning in 1996, as a result of improvements in GPS orbits and regional densification of continuous GPS networks, transient aseismic crustal motions lasting from periods of a few days to over a year were starting to be recognized. For the Pacific Northwest, detailed analyses of continuous GPS data successfully resolved a spatially coherent, transient signal that occurred in August 1999. Unrelated to after-slip that can follow great thrust earthquakes or to shallow slow-slip "tsunami" earthquakes, this signal, detected at 7 contiguous GPS sites, was characterized by a change in site positions ranging from 2 to 5 mm over a period of 6 to 15 days in a direction opposite to long-term deformation motions. This brief reversal was modeled by ∼2 cm of slip on the plate interface, providing the first evidence for discrete "silent" slip events occurring on the deeper Cascadia subduction zone. In early 2002, researchers at Central Washington University established the surprising regularity of Cascadia slip events on the plate interface underlying southern Vancouver Is. and northwestern Washington State. Eight slip events were identified between 1992 and 2002, with a recurrence interval of 14.5 ±2 months. Next, Japanese scientists discovered the episodic occurrence of unique, non-volcanic tremors at average depths of about 30 km along the Nankai Subduction Zone. The similarity of the average depth of slip and the migration velocity of slip for the GPS-determined Cascadia slip events, to the depth and migration velocity of the Japanese tremors triggered the search for seismic signatures for the Cascadia slip events. An examination of seismic records from 1996 to 2002 for sites on Vancouver Is. revealed that what had previously been deemed surface noise was signal from seismic tremors that accompanied slip events. The Cascadia tremors were found to be similar in character to the Japanese deep tremors. In addition, their source region was found to coincide with, or directly overlie, the region of the subducting slab interface where transient slip occurs. The close correlation of tremors with slip coined the naming of the phenomenon as Episodic Tremor and Slip (ETS). The physical processes which give rise to this dynamic behavior on the deeper plate interface are not yet well understood. To date, only the Nankai and Cascadia subduction zones have been observed to share aspects of this behavior, suggesting that this phenomenon may be restricted to young subduction zones. The release of fluids, contact with a hydrated mantle wedge, and episodic changes in shear strength or mechanical coupling may all play a part in governing this behavior. Possible connections of ETS with the development of "E-zone" reflector bands, basal erosion, and pulsating metamorphism await further research. In the context of seismic hazard, the ETS zone may mark the down-dip limit of coseismic rupture of the next megathrust earthquake. Also, since it is conceivable for a slip event to trigger a large subduction thrust earthquake, the onset of ETS activity could identify times of higher probability for the occurrence of megathrust earthquakes.

G31A MCC: 2010 Wednesday 0800h

Satellite Measurements of Temporal Gravity Variations I

Presiding: **M M Watkins,** Jet Propulsion Laboratory, California Institute of Technology**; R S Nerem,** University of Colorado

G31A-01 0800h

GRACE Gravity Field Analysis Results from JPL

Michael Watkins[1] (Michael.Watkins@jpl.nasa.gov); Dah-Ning Yuan[1] (Dah-Ning.Yuan@jpl.nasa.gov); Willy C Bertiger[1] (willy.bertiger@jpl.nasa.gov); Gerhard Kruizinga[1] (Gerhard.Kruizinga@jpl.nasa.gov); Larry C Romans[1] (Larry.Romans@jpl.nasa.gov); Sien Wu[1] (Sien.Wu@jpl.nasa.gov)

[1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

The Jet Propulsion Laboratory serves as the GRACE gravity field analysis verification center, generating independent gravity solutions for assessing the error characteristics of the fields through comparison with the other centers (UTCSR and GFZ), and performing studies to develop optimal parameterizations which may improve the field quality. In addition, we provide a quick gravity solution turnaround capability to assess the utility of alternate Level-1 algorithm implementations. In this presentation, we will present the most recent gravity field results from GRACE, with special attention to summarizing our best understanding of the Level-1 data quality and influence on the field characteristics, and the effects on the fields of varying parameterizations (orbital arc lengths, nuisance parameterization and sub-arc lengths, etc) in the Level-2 analysis.

G31A-02 0815h INVITED

Low-degree temporal gravity field variations using CHAMP data

Christoph Reigber[1] (49-331-288-1100; reigber@gfz-potsdam.de); Horst Jochmann[1]; Johann Wünsch[1]; Svetozar Petrovic[1]; Peter Schwintzer[1]; Franz Barthelmes[1]; Christoph Forste[1]; Karl-Hans Neumayer[1]

[1]GeoForschungsZentrum Potsdam, Dept. 1 "Geodesy & Remote Sensing" Telegrafenberg A 17, Potsdam 14473, Germany

The ability to recover with CHAMP the Earth's gravity field homogeneously and precisely from only a few weeks' worth of GPS satellite-to-satellite tracking data stimulates the investigation of temporal gravity field variations as seen by CHAMP. From a multi-annual exploitation of CHAMP data, time series of low degree spherical harmonic gravitational coefficients are derived and evaluated in the spatial and spectral domain by comparison with geophysical data and models covering atmospheric, oceanic and hydrologic mass redistributions. The space/time resolution and stability obtainable with a mission like CHAMP in recovering short-term environmentally induced gravity field variations were estimated. From experience gained up to now with the CHAMP data processing, the investigations are restricted to spherical harmonics up to degree/order 4, i.e. spatial wavelengths not shorter than 10000 km. The coefficients' time series are simultaneously derived in a comprehensive global gravity field solution with the higher-degree terms kept time-invariant. Results from both CHAMP-only and CHAMP combined with selected Laser satellite solutions are studied.

G31A-03 0830h

GRACE Gravity Field Product Description and Mission Profile

Srinivas Bettadpur[1] (1-512-471-7587; srinivas@csr.utexas.edu)

Frank Flechtner[2] ((+49) 8153-28-1297; flechtne@gfz-potsdam.de)

Michael M. Watkins[3] (1-818-354-7514; michael.m.watkins@jpl.nasa.gov)

[1]Center for Space Research, The University of Texas at Austin, 3925 W. Braker Lane, Suite 200, Austin, TX 78759, United States

[2]GeoForschungsZentrum Potsdam, Department 1: Geodesy and Remote Sensing c/o DLR Oberpfaffenhofen, Wessling D-82230, Germany

[3]Jet Propulsion Laboratory, 4800 Oak Grove Drive, M/S 301-125L, Pasadena, CA 91109, United States

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

Shin-Chan Han[1] (han.104@osu.edu)

C.K. Shum[1] (ckshum@osu.edu)

Christopher Jekeli[1] (jekeli.1@osu.edu)

Chung-Yen Kuo[1] (kuo.70@osu.edu)

Alexander Braun[2] (braun.118@osu.edu)

[1]Laboratory for Space Geodesy and Remote Sensing Research, The Ohio State University, 2070 Neil Avenue, Columbus, OH 43210-1275, United States

[2]Byrd Polar Research Center, The Ohio State University, 1090 Carmack Rd, Scott Hall, Columbus, OH 43210-1002

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

John Wahr[1] (303-492-8349; wahr@lemond.colorado.edu)

Sean Swenson[1] (swensosc@lemond.colorado.edu)

Isabella Velicogna[1] (isabella@lemond.colorado.edu)

[1]Department of Physics and CIRES, Campus Box 390, University of Colorado, Boulder, CO 80309, United States

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

Francis Condi[1] (fcondi@csr.utexas.edu)

Brian Gunter[1] (gunter@csr.utexas.edu)

John Ries[1] (ries@csr.utexas.edu)

Byron Tapley[1] (tapley@csr.utexas.edu)

[1]Center for Space Research, University of Texas at Austin, 3925 W. Braker Lane, Suite 200, Austin, TX 78759-5321, United States

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

Konstantin Latychev[1] (416 946 8129; latychev@physics.utoronto.ca)

Mark Tamisiea[2]

Jerry X. Mitrovica[1]

Jeroen Tromp[3]

[1]University of Toronto, Dept. of Physics, 60 St. George Street, Toronto, ONT M5S 1A7, Canada

[2]University of Colorado, 440 UCB, Boulder, CO 80309, United States

[3]California Institute of Technology, Seismological Laboratory, 1200 E. California Blvd., Pasadena, CA 91125, United States

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.

Per Knudsen[1] (+45 3587 5318; pk@kms.dk)

Ole B. Andersen (+45 3587 5318; oa@kms.dk)

Anne L. Vest (+45 3587 5264; alv@kms.dk)

[1]National survey - KMS, Rentemestervej 8, Copenhagen NV 2400, Denmark

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

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

William Dillinger[1] ((301)713-2851; William.H.Dillinger@noaa.gov); Michael Cline[1] ((301)713-3202; Mike.Cline@noaa.gov); Richard Foote[1] ((301)713-3205; Rick.Foote@noaa.gov); Stephen Hilla[1] ((301)713-2851; Steve.Hilla@noaa.gov); Jim Ray[1] ((301)713-2850; Jim.Ray@noaa.gov); Richard Snay[1] ((301)713-3202; Richard.Snay@noaa.gov); Tomas Soler[1] ((301)713-3205; Tom.Soler@noaa.gov)

[1]National Geodetic Survey, NOAA, 1315 East-West Highway, N/NGS6, Silver Spring, MD 20910, United States

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