In this paper, certain aspects of the ongoing work of the multi-national GRACE project team is encapsulated into a description of the mission profile and its relationship to the science goals. The areas of focus include the orbit & station-keeping activities; the attitude pointing performance; the thermal stability performance; instrument configuration; and the status of the key in-flight verifications of alignments & center-of-mass calibrations. Along with a description of the importance of each such focus area on science data quality, the current in-flight performance relative to the pre-flight goals will be presented. Arising from these considerations, the talk will conclude with an outline of the science mission plan for the near future.

G12C MCC: 123 Monday 1530h

Crustal Deformation II *(joint with S, T)*

Presiding: **M J Johnston,** U.S. Geological Survey**; T Árnadóttir,** Nordic Volcanological Institute

G12C-01 1530h

Comparisons Between the ITRF97, IGS97 and IGS00 Pure GPS Reference Frames: Implications for Precise Velocity Estimations

Shimon Wdowinski[1] (shimonw@rsmas.miami.edu)

Giovanni F Sella[2] (sella@earth.northwestern.edu)

Timothy H Dixon[1] (tdixon@rsmas.miami.edu)

[1]RSMAS-MGG, University of Miami, Miami, FL 34199, United States

[2]Deparment of Geological Sciences, Northwestern University, Evanston, IL 60208, United States

Use of a global reference frame is essential to many geodetic applications and critical to velocity estimates for space geodetic sites. The most commonly used reference frame is the International Terrestrial Reference Frame which uses different collocated space-based techniques. We present results of a comparison of three pure GPS reference frames that are in current use and that have been aligned by different groups to published ITRF multi-techinque frames. These are ITRF97 as defined by ITRF (ITRF97), ITRF97 as defined by IGS (IGS97) and ITRF2000 as defined by IGS (IGS00). We compare the three reference frames over the time interval 1993 to 2002 and look at 600 time-series. Observed differences may reflect a number of factors most importantly: (1) the number of available sites and their location at a give epoch, (2) the epoch of alignment of the reference frame and (3) the length of the time-series. We observe a decrease in scatter over time in the WRMS of all the reference frames, which undoubtedly reflects the increased number of sites and robustness of position estimates for each site. WRMS differences are greatest $<$ 1996 between ITRF97 and IGS00. The velocity components in north, east and vertical show a small but significant bias depending on the reference frame in all three components. Differences in velocities between IGS97 and IGS00 are upto 2 mm/yr. These differences have important implications for geodetic studies that aim to resolve $<$ 1 mm/yr of motion.

G12C-02 1545h

Crustal Deformation in Central Asia From GPS Measurements, 1994-2002

Mathilde Vergnolle[1] (33-4-92-94-26-06; vergno@geoazur.unice.fr); Eric Calais[2]; Jacques Déverchère[1]; Vladimir San'kov[3]; Andrei Lukhnev[3]; Andrei Miroschnitchenko[3]; Sharav Amarjargal[4]

[1]Géosciences Azur UMR 6529, CNRS/UNSA/UMPC, 250 rue A. Einstein, Valbonne 06560, France

[2]Dept. of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907-1397, United States

[3]Institute of Earth's Crust, Russian Academy of Sciences, Siberian branch, 128 Lermontov St., Irkustk 664033, Russian Federation

[4]Research Center for Astronomy and Geophysics, x, Ulaan Baatar 210351, Mongolia

We present Global Positionning System (GPS) measurements of crustal motions at ∼50 sites in central Asia (Mongolia-Baikal) for the 1994-2002 period. We investigate the effect of the definition of rigid Eurasia in the implementation of the reference frame and analyze the kinematics of deformation in the northern part of Asia, in particular the motion of north China with respect to Eurasia and south China.

In Mongolia, we find rapid spatial changes in strain regime, from NS shortening and right-lateral shear in the Altay, to left-lateral shear in central Mongolia, and to NW-SE extension in Eastern Mongolia and the Baikal rift zone. We find that extension is not limited to the Baikal rift zone, currently opening at 4 mm/yr in a NW-SE direction, but affects a much broader area encompassing most of Eastern Mongolia and, possibly, part of north China.

We find that central Mongolia (western part of Amurian-North China block) is moving to the east to southeast at 3-6 mm/yr w.r.t. Eurasia. This is significantly faster than proposed by most deformation models of Asia and 90 degrees off in azimuth, but consistent with other geodetic results in northern China. We model the postseismic effects of four M8 and greater earthquakes that occurred in Mongolia between 1905 and 1957 and show that the present-day contribution of viscoelastic relaxation is less than 3 mm/yr.

The discrepancy between GPS observations in Mongolia and model predictions must be sought in processes not accounted for in most of these models, such as the far-field contribution of the Pacific subduction zones and/or the effect of gravitational forces on intracontinental deformation.

G12C-03 1600h

Crustal Deformation Measured by GPS on Reykjanes Peninsula due to Triggered Earthquakes on June 17, 2000

Thóra Árnadóttir[1] (+354-5254488; thora@norvol.hi.is); Halldór Geirsson[2] (+354-5226000; dori@vedur.is); Erik Sturkell[2] (+354-5226000; erik@vedur.is); Kristín S Vogfjörd[2] (+354-5226000; kristinv@vedur.is); Páll Einarsson[3] (+354-5254816; palli@raunvis.hi.is); Sigrún Hreinsdóttir[4] (sigrun@giseis.alaska.edu)

[1]Nordic Volcanological Institute, Grensasvegur 50, Reykjavik 108, Iceland

[2]Icelandic Meteorological Office, Bustadavegur 9, Reykjavik 150, Iceland

[3]Science Institute, University of Iceland, Dunhagi 3, Reykjavik, ISL 107

[4]Geophysical Institute, University of Alaska, PO Box 757320, Faribanks, AK 99775, United States

The South Iceland Seismic Zone (SISZ) experienced the largest earthquake for 88 years on June 17, 2000 (M_W=6.5). The event occurred at 15:40:41 UT, and was caused by right–lateral strike slip on a N–S fault at 63.98°N, 20.37°W. The main shock triggered seismicity over a large area in South Iceland, and significant slip on three faults on Reykjanes Peninsula, up to 85 km away from the main shock epicenter. The first event on Reykjanes Peninsula occurred near the Hvalhnúkur fault (63.951°N, 21.689°W), at 15:41:07 UT, with an estimated moment magnitude of M_W=5.3. The second event occurred near lake Kleifarvatn (63.937°N, 21.940°W) at 15:41:11 UT. The magnitude for this event is difficult to determine because nearby stations were saturated and the seismic signal is also hidden in the coda of the main shock and the first triggered event. The third event located near Núpshlídarháls (63.902°N, 22.124°W) occurred at 15:45:27 UT, and had an estimated M_W=4.8. The locations and timing of the events on Reykjanes suggest that the first two were triggered by surface waves from the main shock. A second large (M_W=6.4) earthquake in the SISZ occurred on June 21, 2000. This event does not appear to have triggered as much activity on Reykjanes Peninsula, as the earlier one, although the epicenter was closer.

An extensive GPS network, previously measured in 1993 and 1998, was remeasured in 2000 following the earthquakes and again in 2001. The observations show deformation due to the June 2000 earthquake sequence, motion caused by plate spreading across Reykjanes Peninsula, as well as subsidence at the Svartsengi geothermal area and inflation in the Hengill volcanic area. The largest coseismic motion was observed near lake Kleifarvatn, indicating that this event was the largest of the three. Repeated lake levelling shows that the east side of the lake subsided by about 7 cm, relative to the west side, between 1994 and 2001. Crustal deformation due to the events was also observed with InSAR and continuous GPS. We model the surface deformation observed with network and continuous GPS, caused by the three events on Reykjanes Peninsula, after correcting for plate motion, using rectangular dislocations in an elastic half space. We also model subsidence due to geothermal exploitation at Svartsengi by a deflating point source. Best fit uniform slip models indicate that faulting occurred on N–S to NNE–SSW striking planes with primarily right–lateral strike slip.

The sequence of events on Reykjanes Peninsula following the main shock on June 17 2000, demonstrates dynamic triggering of earthquakes and interaction between parallel faults in Southwest Iceland.

G12C-04 1615h

Transient Postseismic Relaxation With Burger's Body Viscoelasticity

Eric A Hetland[1] (617-253-8872; eah@mit.edu)

Bradford H Hager[1] (brad@chandler.mit.edu)

Richard J O'Connell[2] (oconnell@geophysics.harvard.edu)

[1]Dept. of Earth, Atmos. and Planetary Sciences, Massachusetts Institute of Technology 77 Massachusetts Ave., Cambridge, MA 02139, United States

[2]Dept. Earth Planetary Sciences , Harvard University 20 Oxford St., Cambridge, MA 02138, United States

Typical models used to investigate postseismic deformation are composed of an elastic layer over a Maxwell viscoelastic region. Geodetic observations made after a number of large earthquakes show a rapid exponential decay in postseismic velocity immediately after the rupture, followed by a more slowly decaying (or constant) velocity at a later time. Models of a Maxwell viscoelastic interior predict a single exponential postseismic velocity relaxation. To account for observed rapid, short-term relaxation decay, surprisingly low viscosities in the lower-crust or upper-mantle have been proposed. To model the difference in short and long time decay rates, the Maxwell element is sometimes modified to have a non-linear rheology, which results in a lower effective viscosity immediately after the rupture, evolving to a higher effective viscosity as the co-seismic stresses relax. Incorporation of models of after-slip in the lower crust on a down-dip extension of the fault have also had some success at modeling the above observations.

When real rocks are subjected to a sudden change in stress or strain, e.g., that caused by an earthquake, they exhibit a transient response. The transient deformation is typically accommodated by grain boundary sliding and the longer-time deformation is accommodated by motion of dislocations. Both a short-term transient response and long-term steady creep are exhibited by a Burger's body, a Maxwell element (a spring in series with a viscous dash-pot) in series with a Voigt element (a spring in parallel with a viscous dash-pot). Typically the (transient) viscosity of the Voigt element is 10 - 100 times less than the (steady) viscosity of the Maxwell element. Thus, with a Burger's body, stress relaxation is a superposition of two exponential decays.

For a model composed of an elastic layer over a viscoelastic region, the coseismic changes in stress (and strain) depend only on the elastic moduli, and are independent of the description of the viscous component of the rheology. In a Burger's body model of viscoelasticity, if the viscosity of the Voigt element is much less than that of the Maxwell element, the initial relaxation time is given by the decay time $\tau = \eta_{\mathrm{Voigt}}/G_{\mathrm{Maxwell}}$. Whereas, for a Maxwell rheology, the initial relaxation time is given by $\tau = \eta_{\mathrm{Maxwell}}/G_{\mathrm{Maxwell}}$. For both models, the initial spatial distribution of stresses is the same, which results in identical initial spatial distribution of velocities. Thus it is easy to mistake the transient response of a Burger's body for that of a Maxwell rheology with unrealistically low viscosity. Only later in the seismic cycle do the spatial patterns of velocity differ for the two rheologies.

G12C-05 1630h

Tectonomagnetic Anomaly Observed at Parkfield, California, from 1993 to the Present - Correspondence to Increased Shear Strain-Rate during the Same Period.

Malcolm J. S. Johnston[1] (650 3294812; mal@usgs.gov)

Robert J. Mueller[1] (650 3294857; rmueller@usgs.gov)

[1]US Geol. Surv., 345 Middlefield Rd., MS977, Menlo Park, CA 94025, United States

Precise measurements of local magnetic fields have been obtained with a differentially connected array of seven synchronized proton magnetometers in the Parkfield region since 1984. The magnetometers are located along 60 km of the transition region of the San Andreas fault where fault creep changes from zero to about 15 mm/yr. To the south the fault last ruptured with a M8 earthquake in 1857. The central region has ruptured with M6 earthquakes in quasi-periodic manner from 1881 to 1966. Between 1992 and 1994, a significant increase in shear strain was observed on the 2-color geodimeter network and a small network of borehole tensor strainmeters in the central region. This strain change was accompanied by three M4.5-5 earthquakes roughly a year apart in 1992, 1993 and 1994 near the suspected nucleation point of M6+ earthquakes in this region. After correction for secular variation, it is apparent that an anomalous 0.2 nT/yr increase in the magnetic field has occurred from mid-1993 to the present on several magnetometers on the southeast side of the San Andreas Fault and smaller increases are observed on the northeast side of the fault. The strain

data are consistent with increased slip in the central region near the hypocenters of the M5 earthquakes. The magnetic field data indicate that this change in slip occurred in a region larger than indicated by the 2-color EDM data. Magnetic field steps were not expected, nor were they observed, to accompany the M5 earthquakes. A simple rectangular-source piezomagnetic model with a width W of 6 km, a length L of 20 km, a depth of 3 km and variable slip change of up to 5 cm generates magnetic field perturbations of the same signs and amplitudes as those observed. If correct, this increased slip distribution indicatesa changing stress state in the region which may increase the likelihood of moderate magnitude earthquakes in the near future.

G21A MCC: Hall C Tuesday 0830h

Continuous GPS Arrays: Results and Data Scrutiny I Posters *(joint with S, T)*

Presiding: **K W Hudnut,** U.S. Geological Survey**; N E King,** U.S. Geological Survey

G21A-0951 0830h POSTER

Toward an ITRF2000 Combined Solution for the Southern California Integrated GPS Network

Nancy E King[1] (626-583-7815; nking@usgs.gov); Michael Heflin[2] (Michael.B.Heflin@jpl.nasa.gov); Thomas Herring[3] (tah@chandler.mit.edu); Kenneth Hurst[2] (hurst@cobra.jpl.nasa.gov); Sharon Kedar[2] (sharon@cobra.jpl.nasa.gov); John Langbein[4] (langbein@shasta.wr.usgs.gov); Linette Prawirodirdjo[5] (linette@josh.ucsd.edu)

[1]U.S. Geological Survey, Pasadena, 525 S. Wilson Ave., Pasadena, CA 91106, United States

[2]Jet Propulsion Laboratory, 4800 Oak Grove Ave., Pasadena, CA 91109, United States

[3]Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, United States

[4]U.S. Geological Survey, Menlo Park, 345 Middlefield Rd., Menlo Park, CA 94025, United States

[5]Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093, United States

The Southern California Integrated GPS Network (SCIGN) has two independent centers for precise processing of data from 250 stations. The Jet Propulsion Laboratory (JPL) uses the GIPSY-OASIS II processing software and the Scripps Institution of Oceanography (SIO) uses the GAMIT/GLOBK/GLORG software. The first comparison of JPL and SIO results revealed discrepancies of several mm in station position and several mm/yr in station velocity; these differences were the result of inconsistent antenna heights, different methods of estimating velocity, and, especially, different reference frames. To combine JPL and SIO solutions in a consistent reference frame, we chose 75 stations with at least 500 days of data and horizontal RMS of 1 mm or less. Rotating and translating the frames to align these 75 stations generates 0.5 mm/yr horizontal RMS velocity difference. Adding the vertical component, the 3-dimensional RMS velocity difference is 1.2 mm/yr. In a consistent reference frame the SIO and JPL horizontal RMS position difference is less than 1 mm. Vertical differences, due to antenna height discrepancies, still have to be resolved. Current combinations are in a North American reference frame, but using stations from the global network will allow us to align the SCIGN stations in the ITRF2000 reference frame.

G21A-0952 0830h POSTER

Noise levels in Southern California Integrated GPS Network (SCIGN) data; Preliminary results

John Langbein[1] (langbein@usgs.gov); Michael B Heflin[2] (Michael.B.Heflin@jpl.nasa.gov); Ken Hurst[2] (hurst@cobra.jpl.nasa.gov); Sharon Kedar[2] (sharon@cobra.jpl.nasa.gov); Thomas Herring[3] (tah@chandler.mit.edu); Nancy E King[4] (nking@usgs.gov); Linette Prawirodirdjo[5] (linette@ucsd.edu)

[1]US Geological Survey, 345 Middlefield RD, Menlo Park, CA 94025, United States

[2]JPL, 4800 Oak Grove Dr, Pasadena, CA 91109, United States

[3]MIT, 77 Massachuetts Ave, Cambridge, MA 02139, United States

[4]US Geological Survey, 525 South Wilson Ave, Pasadena, CA 91106, United States

[5]UCSD, 9500 Gilman Dr, La Jolla, CA 92093, United States

Quantifying the noise levels in GPS data is a necessary for estimating station velocities and their uncertainties. The estimate of velocity uncertainty is particularly sensitive to the noise model used to characterize the time-series at its lowest frequencies. Previous published analysis (Zhang et. al, 1997 and Mao et. al, 1999) of noise levels in GPS data indicated that the flicker noise ($1/f$ where f is frequency) best represent the temporal correlations at low frequencies in GPS station position time-series. On the other hand, analysis of high precision EDM data (Langbein and Johnson, 1995) show temporal correlations at low frequencies that is consistent with a random-walk ($1/f^2$). It is believed that localized monument wobble is the cause for the random-walk. With the more recent GPS solutions that use data from a regional network and, as a consequence of resolving the ambiguity in GPS phase data, these solutions have better precision than those used in the published results. To test whether random-walk could be a component of the GPS data, time series of GPS data processed by JPL using GIPSY-OASIS II are examined. These data are from a subset of SCIGN for which the ambiguities have been resolved and a local reference frame has been defined. Preliminary analysis indicates that either flicker or a wide-band, seasonal noise is present. In addition, it is possible to place an upper bound on the amount of random-walk noise in the SCIGN data since these data span enough time and the recent data have less flicker noise than the published solutions.

G21A-0953 0830h POSTER

Canadian Contributions to the NAREF Initiative to Densify the ITRF in North America

Mike Craymer[1] (613-947-1829; craymer@nrcan.gc.ca)

Mike Piraszewski[1]

[1]Natural Resources Canada, Geodetic Survey Division 615 Booth St., Ottawa, ON K1A 0E9, Canada

In an effort to densify the ITRF in North America, the IGS initiated a program of distributed regional processing to better manage the computational effort. Under the auspices of the North American Reference Frame (NAREF) Working Group, the Geodetic Survey Division (GSD) has been contributing to this initiative on two fronts: the provision of weekly regional GPS solutions for continuous GPS arrays in Canada and the combination and integration of regional solutions for other arrays across North America.

Since the beginning of 2001, GSD has been computing two independent Canada-wide weekly solutions using GIPSY-OASIS II and the Bernese GPS Software. These solutions include all known geodetic-quality, continuous GPS stations across Canada as well as stations from neighboring arrays in the U.S. In additional, we have been receiving regional weekly solutions for two other continuous GPS arrays in North American: the Western Canada Deformation Array from the Geological Survey of Canada - Pacific Division and the Plate Boundary Observatory from the Scripps Institution of Oceanography. The later covers most of the western seaboard of the U.S. Most recently, we have also been receiving weekly solutions from the U.S. National Geodetic Survey for their entire national CORS network. This contribution now makes NAREF truly North American in scope.

GSD has also been combining these regional solutions into weekly NAREF combinations in order to provide a time series of consistent, high accuracy coordinates for continuous GPS stations in North America. Overlap among these regional arrays provide redundancy checks and allow for the determination of correct relative weighting of different solutions and a more realistic assessment of accuracy. The agreement among the regional solutions is generally less than a couple of mm horizontally and about 4 mm vertically. Agreement of the minimally constrained NAREF combinations with the IGS weekly combinations is of the order of 1-3 mm horizontally and 3-6 mm vertically. These combinations have been integrated into the IGS global network using a combination of Helmert transformation and a priori weighting of IGS global stations. Agreement of these integrated NAREF combinations with the IGS solutions is about 1 mm horizontally and 3 mm vertically.

URL: http://www.naref.org

G21A-0954 0830h POSTER

Statistical analysis of the time series of permanent GPS stations

Alessandro Caporali (+39 49 8272052; alessandro.caporali@unipd.it)

University of Padova, Dept. of Geology, Paleontology and Geophysics, Via Giotto 1, Padova 35137, Italy

Time series of the horizontal coordinates of 21 GPS stations of the EUREF Permanent Network in the Alpine Mediterranean area with three or more years of continuous tracking have been computed with the intent of estimating velocities and their uncertainties, taking into account the detailed structure of their noise. The power spectral densities demonstrate that colored noise, mostly flicker (1/f) noise, can be present at frequencies below six cycles per year, while at higher frequencies the spectrum tends to a regime of white (i.e. frequency independent) noise. This statistical information is used to obtain more accurate estimates of station velocities and of their uncertainties than by standard least squares. Following an approach well known in the analysis of time series of frequency standards, the stability of each time series is computed as a function of time, in the sense of a two-samples Allan variance. Taking into account the correct correlations of pairs of samples as a function of their lag, the slope of each time series is estimated by least squares, with a non-diagonal weight-matrix. We show that in all the examined cases the uncertainties in the velocities computed taking into account the detailed noise spectrum are larger by a factor of 4 +/-1 than the formal uncertainties obtained by least squares under the assumption of pure white noise. Estimating the slope of a time series taking into account the autocorrelation of the samples yields velocities not significantly different from those obtained assuming uncorrelated samples. We conclude that the reason for the velocity uncertainty estimated by standard least squares being unrealistically small is the neglect of the cumulative effect of uncorrelated and correlated noise. Neglecting the correlated noise does not, however, affect the velocity. When analyzed in the space domain, the time series decorrelate already at very short distances (< 100 km), suggesting that random errors affecting the coordinates of clusters of stations such as, for example, atmospheric refraction or mismodeling of the orbits are negligible.

G

G21A-0955 0830h POSTER

Measurement of Great Salt Lake Loading by the BARGEN Continuous GPS Network

Pedro Elósegui[1] (617-496-7645; pelosegui@cfa.harvard.edu)

James L Davis[1] (617-496-7640; jdavis@cfa.harvard.edu)

Jerry X Mitrovica[2] (416-978-4946; jxm@physics.utoronto.ca)

Brian P Wernicke[3] (626-395-6192; brian@gps.caltech.edu)

Richard A Bennett[1] (617-495-7453; rbennett@cfa.harvard.edu)

[1]Harvard-Smithsonian Center for Astrophysics, 60 Garden Street MS 42, Cambridge, MA 02138, United States

[2]University of Toronto, Department of Physics 60 St. George Street, Toronto, ON M5S 1A7, Canada

[3]California Institute of Technology, Division of Geological and Planetary Sciences Mail Stop 100-23, Pasadena, CA 91125, United States

The northernmost segment of the Basin and Range Geodetic network (BARGEN) forms an east-west transect from western Utah to eastern California between the latitudes of N 40° and N 41°. Two of our GPS sites, COON and CEDA, are located within 20 km south of the Great Salt Lake (GSL), which extends NNW for a length of ∼100 km. Lake level records for GSL during the period of the operation of BARGEN (mid-1996 to present) indicate seasonal elevation variations of ∼0.5 m amplitude superimposed on a roughly "decadal" feature of amplitude ∼1 m. Using an elastic Green's function based on PREM and a simplified load geometry for GSL, we calculate that these elevation variations translate into vertical crustal loading signals of ±0.5 mm (seasonal) and ±1 mm (decadal). The calculated maximum horizontal loading signals are roughly a factor of two smaller. Despite the small size of the expected loading signals, we conclude that we can observe them using time series for the three-dimensional coordinates of COON and CEDA. For CEDA, the variations in the time series are in phase with, and the same magnitude as, both the predicted seasonal and decadal variations. For COON, we obtain a similar match for the decadal variations, but the observed seasonal variations, although in-phase with the predicted variations, are a factor of 3–4 larger. We speculate that this difference may be caused by some combination of local precipitation-induced site motion, unmodeled loading from other nearby sources, errors in the GSL load geometry, and atmospheric errors. We will present these results, and also discuss the loading effect as an error source for estimates of long-term site velocity.