

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 indicates a 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 King¹ (626-583-7815; nking@usgs.gov);

Michael Heflin² (Michael.B.Heflin@jpl.nasa.gov);
Thomas Herring³ (tah@chandler.mit.edu);
Kenneth Hurst² (hurst@cobra.jpl.nasa.gov);
Sharon Kedar² (sharon@cobra.jpl.nasa.gov); John
Langbein⁴ (langbein@shasta.wr.usgs.gov); Linette
Prawirodirdjo⁵ (linette@josh.ucsd.edu)

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

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

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

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

⁵Scripps 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 Langbein¹ (langbein@usgs.gov); Michael B

Heflin² (Michael.B.Heflin@jpl.nasa.gov); Ken
Hurst² (hurst@cobra.jpl.nasa.gov); Sharon
Kedar² (sharon@cobra.jpl.nasa.gov); Thomas
Herring³ (tah@chandler.mit.edu); Nancy E King⁴
(nking@usgs.gov); Linette Prawirodirdjo⁵
(linette@ucsd.edu)

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

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

³MIT, 77 Massachusetts Ave, Cambridge, MA 02139, United States

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

⁵UCSD, 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 Craymer¹ (613-947-1829; craymer@nrcan.gc.ca)

Mike Piraszewski¹

¹Natural 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 addition, we have been receiving regional weekly solutions for two other continuous GPS arrays in North America: 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.

G21A-0955 0830h POSTER

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

Pedro Elósegui¹ (617-496-7645; pelosegui@cfa.harvard.edu)

James L Davis¹ (617-496-7640; jdavis@cfa.harvard.edu)

Jerry X Mitrovica² (416-978-4946; jxm@physics.utoronto.ca)

Brian P Wernicke³ (626-395-6192; brian@gps.caltech.edu)

Richard A Bennett¹ (617-495-7453; rbennett@cfa.harvard.edu)

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

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

³California 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.

G21A-0956 0830h POSTER

Re-examination of the postseismic deformation following the 2000 Western Tottori Earthquake, Southwest Japan

Manabu Hashimoto¹ (+81-774-38-4191; hashimoto@rcep.dpri.kyoto-u.ac.jp)

Ito Takeo¹ (+81-774-4188; ito@rcep.dpri.kyoto-u.ac.jp)

¹RCEP, Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

Previously, we presented the results of the dual frequency observations following the Western Tottori earthquake of Oct. 6, 2000 and interpretations in terms of afterslip on the source fault. In this study, we report the results of a re-examination of the above data using a logarithmic decay function based on the rate-state dependent friction law.

The 2000 Western Tottori earthquake is a typical inland earthquake in Japan with left-lateral strike-slip faulting on a NNW-SSE trending vertical fault plane. The Japanese University Consortium for GPS Research (JUNCO) studied the postseismic deformation immediately after the mainshock with a dense GPS network surrounding the source region. Most observations were carried out continuously until the end of October 2000, and some sites equipped with dual frequency receivers were reoccupied in March 2001. JUNCO observed a slowly decaying movement at every site. The spatial pattern shows left lateral motion across the source fault, similar to the coseismic displacements. We derived the amount of afterslip on a shallow part of the source fault from this spatial pattern. We fit exponentially decaying functions to the data from the sites occupied in March 2001 and obtained time constants of 20 to 40 days. However, this may be inconsistent with the idea of afterslip on the source fault or its extension, since an exponential decay function is closely related to the relaxation of stress in a viscoelastic layer.

Here we fit the temporal variation with the following logarithmic decay function proposed by Marone et al. (1991)

$$U_p(t) = \alpha \ln\left\{\frac{\beta}{\alpha} t + 1\right\} + V_0 t + U_{ref},$$

where $U_p(t)$ is the displacement, t is time in days, α is the fault constitutive parameter in the velocity-strengthening layer, β is the coseismic velocity, V_0 is the steady state velocity and U_{ref} is the offset at the start of observation. In this nonlinear fitting, we assume a non-negative constraint on V_0 . We obtained positive α at 6 of 12 sites. The estimated α ranges from 0.07 to 1.07 cm. This estimate gives a value of (a-b) consistent with laboratory data for a velocity-strengthening layer at a shallow depth. Mainly because of the lack of data between October 2000 and March 2001, appropriate values could not be obtained at other sites.

We also estimate the distribution of afterslip using a multi-segment fault model and obtain the largest slip of about 4cm near the epicenter of the mainshock, while the northernmost segment appears to have the smallest slip of about 2cm.

G21A-0957 0830h POSTER

Deformation in the New Madrid Seismic Zone from Continuous GPS Geodesy

Victor M. Santillan¹ (9016784809; santillan@ceri.memphis.edu)

Robert, Jr. Smalley¹ (9016784929; smalley@ceri.memphis.edu)

Michael Ellis¹ (9016784980; ellis@ceri.memphis.edu)

¹Center for Earthquake Research and Information, University of Memphis, 3890 Central Ave., Memphis, TN 38152, United States

A key question for the cause of the New Madrid earthquakes is what is driving the earthquakes? In order to address this question, several ongoing GPS based geodetic projects are being performed in the New Madrid seismic zone. Initial results from campaign style GPS networks in the New Madrid area reported deformation rates suggestive of plate boundary zones, but refined estimates of the deformation rate determined after additional GPS campaigns, are much lower and may not be statistically distinguishable from zero. We report here on the preliminary results from the GPS array for Mid-America (GAMA), an 11 station, continuous GPS network that began operation four years ago and has been in full operation for the last two years. To establish a reference frame for North America, we processed over four years of continuous GPS data from a set of stations in cratonic North America. These sites have a mean residual rms motion with respect to a stable North America of slightly less than 1 mm/yr, which is in agreement with previous GPS determinations of the stability of North America. This defines our lower limit for detection of deformation with respect to North America. The mean residual rms motion of the GAMA sites, with respect to the reference frame, is about 1.5 to 2 mm/yr, which is near the limit of detectability

for 2 years of data. The results from the continuous GPS network contributes to a better identification of zones with possible crustal strain accumulation as well as improving our ability to constrain geodynamic models that have been proposed for the New Madrid seismic zone.

G21A-0958 0830h POSTER

FReDNet: A CONTINUOUS GPS GEODETIC NETWORK MONITORING CRUSTAL DEFORMATION IN NE ITALY

David Zuliani¹ (390432522433; dzuliani@inogs.it);

Maurizio Battaglia² ((510) 642-8314;

battag@seismo.berkeley.edu); Mark Murray² ((510) 642-2601; mhmurray@seismo.berkeley.edu);

Alberto Michelini¹ (390432522433;

amichelini@inogs.it); Roland Burgmann³ ((510) 643-9545; burgmann@seismo.berkeley.edu);

Ignio Marson¹ (imarson@inogs.it)

¹Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Centro Ricerche Sismologiche, Via Trevisio 55, Udine 33100, Italy

²UC Berkeley Seismological Laboratory, 215 McCone Hall, Berkeley, CA 94720-4760, United States

³Dept of Earth and Planetary Science, UC Berkeley, 385 McCone Hall, Berkeley, CA 94720-4760, United States

The Friuli Regional Deformation network (FReD-Net) of continuously operating Global Positioning System (GPS) receivers monitors crustal deformation in the Friuli area and the northeast boundary of the Adriatic microplate. The Friuli area, located within the active collision zone between Eurasia and the Adriatic block, is characterized by one of the strongest clusters of seismic activity in the Adriatic microplate. Relative motions of the Adriatic block and deformation across the Friuli region are on the order of 5 mm/yr. The principal goals of the FReDNet program are to determine the distribution of deformation in this region and to estimate interseismic strain accumulation on its active faults to better assess seismic hazards. FReDNet is operated by the Centro Ricerche Sismologiche (CRS) of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS. We began to install the initial 6 stations of FReDNet in the summer of 2002. To integrate geodetic and seismic data, we plan to collocate some GPS stations with broadband seismometers maintained by the OGS. FReDNet is part of a larger program of geodetic monitoring of the Adriatic microplate that includes repeating episodic measurements of geodetic points (e.g., points of the IGM95 geodetic network). The data and experience acquired through the FReDNet program will allow the OGS to monitor hazardous faults for emergency response management, and provide infrastructures for geodetic data management and processing.

G21A-0959 0830h POSTER

Strain rate vs. seismicity and structural geology in Italy inferred from a permanent GPS network

Matteo Massironi¹ (matteo.massironi@unipd.it)

Alessandro Caporali¹ (alessandro.caporali@unipd.it)

Silvana Martin² (silvana@ux1.unipd.it)

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

²Dept. of Chemistry, Physics and Mathematics, University of Insubria, Via Lucini 3, Como 20100, Italy

High quality, weekly solutions for the coordinates of 45 permanent GPS stations spanning one to six years and covering the Alpine Mediterranean area are used to estimate a horizontal velocity field aligned with the ITRF2000 velocity datum, with 1 sigma uncertainties typically below 0.5 mm yr⁻¹. After subtracting model velocities for the Eurasian plate, we show that the residual velocity field North of the Apennines, in the Adriatic/Dinaric region, describes a NNE-trending tectonic flow with a negative velocity gradient, from 6 mm yr⁻¹ NE of the Apennines to virtually zero NE of the Dinarids. In the Calabria region we observe a divergent pattern, with NNW orientation, which turns to West as one moves North, towards Tuscany. Very small residual velocities are observed for stations in the Sardinia Corsica block, Spain, Southern France and North of the Alps. This regional pattern of velocities defines areas of intraplate strain. On the basis of good station coverage and of a strain rate value above a threshold, we define five provinces: Calabria, Central Apennines, both in extensional regime, and North Adriatic, Eastern Alps and South Adriatic, under compression. We show that the orientations of the principal strain rate axes agree with the stress pattern which is inferred from local seismicity. A comparison of the geodetically determined

strain rate with the strain rate associated to seismic moment of earthquakes in the past 20 years shows that each province may differ considerably from the others in the amount of seismic moment which is accommodated by surface strain. For example, the Umbria seismic sequence of 1997 seems to have released a seismic moment not exceptionally large, but concentrated in a short time interval, so that the equivalent coseismic strain rate is larger than the value which is observed geodetically. On average, depending on the assumptions on the seismogenic volume and time span, 70% to 100% of the surface strain seems to be accommodated by the release of seismic moment in the upper Italian crust.

G21A-0960 0830h POSTER

Detection of Large-Scale Troposphere Solitons Using Data from Continuous GPS Arrays

Jan S Krynski¹ (48-22-828-0269ext113; krynski@igik.edu.pl)

Yevgen M Zanimonskiy¹ (48-22-828-0269ext121; astro@igik.edu.pl)

¹Institute of Geodesy and Cartography, Jasna 2-4, Warsaw 00-950, Poland

Networks of continuously operating GPS receivers are set up by geodesists, geophysicists, government and military agencies to implement a wide range of positioning capabilities and atmospheric investigations. Microwave radio signals transmitted by GPS satellites are delayed by atmosphere. An improvement in modelling atmosphere is needed for developing and spatial extension of real time GPS positioning technology. It might also be useful for precise processing of GPS data. Complexity of spatial and temporal dynamics of tropospheric processes makes them difficult to model. The irregular effects of troposphere on GPS solutions can be substantially reduced by applying statistical methods to the analysis of data from continuous GPS arrays. Tropospheric delay data obtained for Central and East European permanent EPN stations was analyzed. The structure of atmospheric variations above the region along 50 parallel in that part of Europe is quite specific. The atmospheric fronts that pass from west to east keep frequently the same structure when moving along 1-2 thousand kilometres during one or two days. Relatively simple structure of motion of such atmospheric fronts as compared with West European fronts allows their effective investigation. Processes of forming and moving of solitary tropospheric waves were qualitatively modelled similarly to soliton modelling in water.

G21A-0961 0830h POSTER

Use of Southern California Integrated GPS Network (SCIGN) to image post-seismic perturbations of the ionosphere.

Juliette Artru¹ (626-395-6950; juliette@gps.caltech.edu)

Vesna Ducic² (+33-1-4511-4123; ducic@ippg.jussieu.fr)

Philippe Lognonné² (+33-1-4511-4251; lognonne@ippg.jussieu.fr)

¹Seismo Lab, California Institute of Technology, 1200 E California Blvd, Pasadena, CA 91125, United States

²Institut de Physique du Globe de Paris, 4 avenue de Neptune, SAINT MAUR 91104, France

Post-seismic perturbations in the atmosphere and ionosphere are induced by solid earth-atmosphere coupling, and can be monitored systematically after large earthquakes, e.g. using Doppler sounding. We will focus here on the capacity of short-scale imagery of the ionosphere offered by dense GPS networks. SCIGN is composed of 250 receivers in Southern California that provide continuous measurements of Total Electron Content along each receiver-satellite. A reconstruction of 2-D vertical electron content maps is performed, with a special attention paid on the accuracy and resolution achieved. We applied our technique to the detection of post-seismic ionospheric perturbations by the Hector Mine Earthquake in Southern California on October 16th, 1999. Two regimes of seismic perturbations are found, the first one related to seismic waves traveling in the ionosphere at about 3 km/s whereas the second regime would be induced by the onset of a gravity wave.

G21A-0962 0830h POSTER

Stress Inversion Analysis Based on Velocity Field of the Japanese Islands

Takeshi Iinuma¹ (81-3-5841-5736; iinuma@eri.u-tokyo.ac.jp)

Teruyuki Kato¹ (81-3-5841-5730; teru@eri.u-tokyo.ac.jp)

Muneo Hori¹ (81-3-5841-5740; hori@eri.u-tokyo.ac.jp)

¹Earthquake Research Institute, University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan

In order to estimate stress change within the crust from the observed displacement rates, we have devised a new stress inversion method, which uses Airy's stress function. The merit of this stress inversion method is that we can estimate stress field without full knowledge of elastic property of the object and without taking high order derivatives of the observed quantity. We assumed that the strain within the crust is the summation of elastic strain and non-elastic strain and further assumed that the volumetric strain does not include non-elastic deformation. This is equivalent that the crust is composed of elasto-plastic material. We examined this method for simple cases assuming different rigidities. Solutions showed mostly identical stress distributions with analytical solutions no matter what the values of rigidity are. Thus the method can estimate stress within the crust without knowing rigidity.

Then we applied this stress inversion method to the Japanese Islands where Geographical Survey Institute has been operating a nationwide GPS array named "GEONET". We used velocity data estimated from three years of observations of GEONET. For applying this method to the Japanese Islands, we need to estimate boundary traction around the Japanese islands. We used two different approaches for this purpose; one is using the average stress change derived from simple average strain change and the other is using stress drop data of large earthquakes that have occurred at the plate boundaries around the Japanese Islands. Though results showed slightly different stress distributions especially in the inland area, they did not look like significant difference. Thus we used the result of latter case for further discussion because it uses geophysically more meaningful assumptions than the former case.

In order to examine if the obtained stress is appropriate or not, we compared observed "total" strain and estimated "elastic" strain assuming an arbitrary value of rigidity in the whole area. Results suggest that the estimated strain looks generally larger than the observed one, which indicates that the given uniform value of rigidity might not be appropriate. Thus in return, we could estimate the distribution of rigidity by this comparison. Comparison of this result with seismicity data suggests that inland shallow earthquakes seem to occur where rigidity is lower.

Although the method shown here have to be improved for further applications such as for 3D material and for better estimation of boundary tractions, the method may be used for monitoring stress changes in the Japanese Islands from the dense GPS array.

G21A-0963 0830h POSTER

Space-Time Inversion of Geodetic Data for Fault Slip by Monte Carlo Mixture Kalman Filter Approach

Junichi Fukuda¹ (fukuda@eri.u-tokyo.ac.jp)

Tomoyuki Higuchi² (higuchi@ism.ac.jp)

Shinichi Miyazaki¹ (miyazaki@eri.u-tokyo.ac.jp)

Teruyuki Kato¹ (teru@eri.u-tokyo.ac.jp)

¹Earthquake Research Institute, University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo 113-0032, Japan

²The Institute of Statistical Mathematics, 4-6-7 Minami-Azabu, Minato-ku, Tokyo 106-8569, Japan

We develop a new method for space-time imaging of fault slip or dike intrusion from geodetic data. Segall and Matthews (1997) first presented a Kalman filter (KF) based method to infer spatio-temporal distribution of fault slip from geodetic data and it has been applied to several transient phenomena. In KF, observation noise and system noise are assumed to follow stationary Gaussian distributions, and this assumption has made it difficult for us to identify small variation of signals and to trace rapidly accelerating signals or coseismic signals. In order to overcome this difficulties, we develop a new algorithm for state estimation, which we call Monte Carlo mixture Kalman filter (MCMKF). MCMKF can be applied to conditional dynamic linear model in which system model and observation model are variable in time. This feature enables us to construct more flexible models than conventional state space model. We apply this space-time inversion method to simulated data which are generated by an infinitely long strike slip fault. In order to separate tectonic signal from local station motion, we take random walk noise component into account following Segall and Matthews (1997). Results show that

the proposed method can reproduce rapidly accelerating and decelerating fault slip and coseismic slip as well as low variation of fault slip rate, even in a case that noise level is so high that signal is invisible. Comparison of results obtained by MCMKF and KF indicate that the likelihood obtained by the MCMKF approach is significantly larger than that obtained by the KF approach especially when deformation rate varies rapidly or coseismic deformation exists, and signal-to-noise ratio is low.

G21A-0964 0830h POSTER

Inversion of GPS Data Using Spectral Decomposition of a Green Function

Honglin Jin¹ (+81-3-5841-5736; jhl@eri.u-tokyo.ac.jp)

Teruyuki Kato¹ (teru@eri.u-tokyo.ac.jp)

Shin'ichi Miyazaki¹ (miyazaki@eri.u-tokyo.ac.jp)

Muneo Hori¹ (hori@eri.u-tokyo.ac.jp)

¹Earthquake Research Institute, the University of Tokyo, 1-1, Yayoi 1, Bunkyo-ku, Tokyo 113-0032, Japan

The Japanese Islands are located at the boundaries among Eurasia, Pacific, North America and Philippine Sea plates. Collision and subduction of these plates cause overall crustal deformation in the islands. Recent studies of geodetic distribution of dense GPS array data have shown that the distribution of inter-plate coupling is not homogeneous along the subducting plate boundaries. It is important to elucidate the distribution of rates of coupling along the boundaries for understanding subduction process and nature of slow slip episodes as well as for earthquake prediction studies.

In the conventional inversion scheme, all physical processes involved (surface measurements due to fault dislocation, in this case) are represented by Green's function. Therefore, the nature of Green's function determined the ill-posedness of inverse problem. In order to solve this problem, Hori (2001) introduced a new approach of inversion, in which inversion operator (Green function as an operator) is determined without considering the method of measurement by introducing the spectral decomposition of Green function. The operator can be computed if Green's function and domains are given, no matter how actual measurements are conducted. Since inverse operator is obtained through numerical spectral decomposition of Green's function, it clarifies the mathematical reason of the ill-posedness of the inverse problem. Deformation function at surface can be estimated from measured data using least square method and then the deformation function is used for solving the inverse problem to predict slip function at the plate boundary using inverse operator.

We have applied this new inversion method to the Japanese GPS data and estimated the distribution of back-slip (or coupling) on a subducting Philippine Sea plate. Before applying the method, we considered that the vertical component of GPS data is important in estimating distribution of coupling along the plate boundary. For this purpose, first, we reduced the noise in the vertical components of GPS time series by removing correlated scatter among neighboring stations.

The calculated slip distribution on the Philippine Sea plate indicates that the slip generally directs to the northwest with the maximum speed of about 8 cm/yr, consistent with motion of the Philippine Sea plate, though some improvements may be necessary for more conclusive results.

G22A MCC: 106 Tuesday 1330h

Continuous GPS Arrays: Results and Data Scrutiny II (joint with S, T)

Presiding: K W Hudnut, U.S.

Geological Survey; N E King, U.S.

Geological Survey

G22A-01 1330h

Seasonal Crustal Deformation in Japan, Revisited

Kosuke Heki (+81-197-22-7139; heki@miz.nao.ac.jp)

Earth Rotation Division, National Astronomical Observatory, 2-12 Hoshigaoka, Mizusawa, Iwate 023-0861, Japan

Regarding the seasonal crustal deformation found in the nationwide GPS array (GEONET) data [Murakami and Miyazaki, 2001], Heki [2001] analyzed two-year data in Northeast Japan and attributed it to seasonal loading by snow along the western flank of the backbone range. Recently, the whole GEONET data set was reanalyzed by the Geographical Survey Institute using an improved software system. Here I report results of

the investigation of the mechanisms of seasonal crustal deformation over the entire Japan with a method similar to my past study [Heki, 2001]. I modeled site coordinates time series 1996-2002 with linear, annual and semiannual functions. By rejecting sites with parameter uncertainties and residuals larger than thresholds, I automatically excluded sites with insufficient temporal coverage and sites that experienced transient deformation due to (slow) earthquakes. Although not clear in the local analysis of Northeast Japan [Heki, 2001], uniform seasonal expansion/contraction for the entire country is significant in addition to the snow loading signals. By using the 3D site displacements in winter relative to those in summer, I estimated the load distribution (water column heights for blocks as large as 50km x 50km), as well as the scale change as an additional parameter. We obtained the scale of 5.7E-9 (contraction in winter) and the load distribution which largely coincides with the snow depth distribution observed by AMeDAS (Automated Meteorological Data Acquisition System). However, significant loads are often estimated in snow-free regions and further investigation is needed for other loading mechanisms such as atmosphere, non-tidal ocean loading, and soil moisture. It is difficult to identify the origin of the scale change, but real deformation (e.g. global contraction of the northern hemisphere in winter [Blewitt et al., 2001]) would be minor in comparison with artificial changes stemming from atmosphere, etc.

G22A-02 1345h

Interseismic deformation in Shikoku and western Honshu, Japan

Christopher H Scholz¹ ((845)365-8360; scholz@ldeo.columbia.edu)

Yosuke Aoki¹ ((845)365-8422; aoki@ldeo.columbia.edu)

¹Lamont-Doherty Earth Observatory of Columbia University, P.O. Box 1000, Route 9W, Palisades, NY 10964, United States

Crustal deformation in Shikoku and western Honshu, Japan, is dominated by 1) interplate coupling along the Nankai trough, 2) strike slip faulting at the Median Tectonic Line (MTL), and 3) rigid plate motion. However, the interplate coupling effect and rigid plate motion have not been well separated in previous studies because they are based on horizontal velocities only and the reference frame was ambiguous. Also, the slip rate of MTL was not well constrained because of the sparsity of geodetic data, although geological estimates have been available. Thus we tried to separate these effects by using horizontal and vertical GPS velocities and a refined kinematic reference frame.

We first obtained the depth variation of the interplate coupling from vertical velocities of GPS sites, based on the idea that vertical velocities are not contaminated by rigid plate motion or the MTL motion. The result shows that the seismic coupling decreases gradually from 27km to 40km depth, consistent with the deep slip model, in which the fault is extended to the ductile shear zone, as an interseismic strain accumulation model. The shallower part (< 15km) of the plate interface is not likely to be fully coupled, but the resolution is poor because of the lack of GPS sites near the trench.

Next, given the depth variation of the interplate coupling, we estimated the slip rate of the MTL and rigid plate motion from horizontal GPS velocities according to the new reference frame with respect to the stable Eurasian craton by Kogan et al. (to be submitted to J. Geophys. Res.). The slip rate of the MTL is estimated to be 2.28 ± 1.06 mm/yr. Although the estimated rate is smaller than the geological estimate (7mm/yr), the MTL must have accumulated 2m of slip because no large earthquake have occurred in the last, at least, 1000 years. Rigid plate motion of the area is 1.50 ± 0.62 mm/yr westward with respect to the stable Eurasian craton, indicating that western Japan is likely to be on the Eurasian plate and the general assumption that western Japan is on the Amurian plate moving 5 - 10mm/yr eastward with respect to the Eurasian plate is not likely to be true.

G22A-03 1400h

A Continuous GPS Transect over the Locked Portion of the Nicoya, Costa Rica, Underthrust Seismogenic Zone

Marino Protti¹ ((506) 261-0781; jprotti@una.ac.cr);

Koichiro Obana² (obanak@jamstec.go.jp); Takeshi

Iinuma³ (iinuma@eri.u-tokyo.ac.jp); Shin'ichi

Miyazaki³ (miyazaki@eri.u-tokyo.ac.jp); Teruyuki

Kato³ (teru@eri.u-tokyo.ac.jp); Yoshiyuki

Kaneda² (kaneday@jamstec.go.jp)

¹Observatorio Vulcanologico y Sismologico de Costa Rica, Universidad Nacional (OVSI-CORI-UNA), Apartado 2346-3000, Heredia, Her 3000, Costa Rica