

G21A-0962 0830h POSTER

Stress Inversion Analysis Based on Velocity Field of the Japanese Islands

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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

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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

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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

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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

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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

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The Nicoya peninsula, in NW Costa Rica, sits over the seismogenic portion of the Cocos-Caribbean interphase. This makes the peninsula an ideal place to record and study both, the elastic deformation associated with the earthquake cycle, as well as the viscoelastic deformation resulted from failure. An additional temporal advantage of the Nicoya peninsula is that this subduction segment is near the end of a seismic cycle (it ruptured in 1853, 1900 and 1950) and it is deforming rapidly.

As a joint cooperation effort between the Costa Rica Volcanological and Seismological Observatory, at the National University (OVSICORI-UNA) and the Japan Marine Science and Technology Center (JAMSTEC), with funding from the Japan International Cooperation Agency (JICA), a dense (5-10 km spacing) transect of GPS sites was constructed and occupied in the fall of 2001. This GPS transect, which consists of 10 sites that cover from the updip portion of the locked zone to beyond its downdip extend, complements a more regional network of nearly 25 sites in and around the Nicoya peninsula, occupied several times by OVSICORI-UNA, the Jet Propulsion Laboratory, the University of Miami and the University of California at Santa Cruz.

Early in 2002 JICA donated the equipment for three continuous recording GPS stations to be installed on the peninsula at three sites of the transect. The installation of the continuous sites and reoccupation of the transect will be carry out by OVSICORI-UNA and the Earthquake Research Institute (ERI) of Tokyo University, in the fall of 2002. Also as part of this new joint cooperation initiative, JICA, ERI and JAMSTEC will build up at OVSICORI-UNA the capability to process the GPS data in Costa Rica. We will be presenting preliminary results from both the campaign-style transect as well as the continuous sites.

G22A-04 1415h

In Search of the Adriatic Microplate

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The Adriatic region (a broad area of deformation in the central Mediterranean within the Eurasian-African plate boundary zone) is an ideal natural laboratory for studying plate boundaries because of the wide variety of tectonic processes it displays (e.g., continental collision, subduction of continental and oceanic lithosphere, major continental faults). The Adriatic block moves relative to the Eurasian plate at between 1 and 6 mm/yr. This motion generates moderate to large earthquake in many areas, some of which are highly populated. However, the region has been investigated mainly at a local scale, so we have only a limited understanding of the deformation field. Considerable uncertainty surrounds the present kinematics of this region (e.g., is the Adriatic block still closely connected with the African continent, does it behave as an independent microplate or is it an area of continuous deformation?).

To determine the behavior of the Adriatic block, we analyze continuous GPS data from 30 stations of the EUREF and ASI network along the border of the Adriatic region (the majority of the GPS stations are located along the Italian peninsula, a smaller number along the Slovenian and Croatian coast). To assess the overall quality of the analysis (e.g., to identify those stations with a discontinuous or inconsistent data set), we compute time series of station positions.

We use the estimated GPS horizontal velocities to impose constraints on the kinematics of the Adriatic region.

URL: <http://seismo.berkeley.edu/~battag>

G22A-05 1430h

Continuous GPS Measurements in Iceland 1999 - 2002

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The Icelandic Meteorological Office operates a network of continuous GPS stations (ISGPS). The network was initiated as a collaborative project in 1999, to monitor crustal movements in active tectonic and volcanic areas in Iceland. There are presently 17 continuous GPS stations in Iceland, of which 14 belong to the ISGPS network, two are IGS stations and one is operated by the National Land Survey of Iceland. The design of the ISGPS network is aimed towards simplicity, robustness and cost-efficiency. The number of electric components in the field is minimized and we use a stainless steel quadrupod monument design to achieve high monument stability. Data from the ISGPS stations are automatically downloaded and processed on a daily basis. We use the Bernese V4.2 software to process the data. The data are initially processed using predicted satellite orbits, and then reprocessed with CODE final orbits.

The time series from most ISGPS stations are dominated by motion caused by plate spreading, in general agreement with the NUVEL-1A plate motion model. Discrepancies are observed at stations which are within the plate boundary deformation zone or close to volcanic deformation sources. Transient signals attributed to an eruption in Hekla in February 2000, are observed. The nearest station, located 50 km from Hekla, recorded 7 mm horizontal motion towards Hekla during the eruption. Time series from stations located near Katla volcano indicate there is a slow pressure increase beneath the volcano. Two magnitude $M_W=6.5$ and $M_W=6.4$ earthquakes spaced 17 km apart occurred on June 17 and June 21, 2000, in the South Iceland Seismic Zone. Although most of the ISGPS stations were not located close to the epicenters, a clear deformation signal was detected at all operational stations. The co-seismic displacements for the June 21 event fit well to a source model based on network GPS measurements. The observed displacements for the June 17 event include deformation from triggered events on Reykjanes Peninsula.

The ISGPS network has proven a valuable tool to monitor crustal deformation and timing deformation events.

URL: <http://hraun.vedur.is/ja/englishweb/gps.html>

G22A-06 1445h

SNR-Based Multipath Corrections to GPS Phase Measurements: Improving the Accuracy of Permanent GPS Stations

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Despite advances in permanent station monumentation and site selection, multipath at geodetic GPS stations still remains a major source of error. Geophysicists use the GPS phase observable to obtain millimeter positioning results, yet multipath phase errors can easily be on the centimeter level in some cases. A method to remove phase multipath errors without expensive equipment changes or extensive computing time would be of great benefit to the geodetic community.

We present here a method to evaluate phase multipath errors and correct for these errors using the signal-to-noise ratio (SNR) recorded by GPS receivers. Although the SNR observable is not routinely reported in RINEX files at this time, the SNR can be easily extracted from most raw GPS data files. A reflected (multipathed) signal can interfere constructively or destructively with the direct signal, yet the GPS receiver will observe and record only the composite (direct + reflected) signal. SNR serves as a measure of the degree of constructive and destructive interference. With adaptive signal processing techniques, measures of the direct and reflected signal phase, amplitude, and frequency can be extracted from the SNR. Using these measures, an effective reflector (horizontal surface under the antenna or an adjacent building, for example) with a certain distance and orientation relative to the antenna can be determined. The spatially correlated nature of multipath errors is then used to generate phase corrections based on any appropriate receiver/satellite geometry where reflections would take place.

SNR-based corrections were applied to a large number of continuous GPS stations, where the corrections

used depended on the degree of multipath severity. Results from point-positioning and network solutions for several stations before and after SNR-based corrections are given here.

G22A-07 1520h

Five Years of GPS Observations Along the Length of the Cascadia Margin: Fate of the Eastern California Shear Zone and Entrainment of the Cascadia Fore-arc in Oblique Subduction

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High-precision, continuous GPS geodesy in the Pacific Northwest provides a synoptic view of the along-strike variation in Cascadia margin kinematics. We present an updated and denser PANGA (Pacific Northwest Geodetic Array) GPS velocity field with improvements in systematic noise reduction, uncertainty modeling, and longer observation intervals. Common stations in this and our previously published solution [Miller et al., 2001] demonstrate agreement in the velocity field and stable continent reference frame at better than the 95% confidence. Nevertheless, improvements in analysis reveal detailed structure of the time series and better precision. The velocity field and its temporal variations constrain the interfering patterns of deformation that affect the Cascadia convergent margin on decadal time scales. Coastal stations in the northern and central parts of the margin are strongly entrained in the Juan de Fuca/North America convergence direction. This pattern is overlain on the transition from the inland penetration of the transform margin, the Eastern California shear zone and NW-migrating Sierra Nevada block, to fore-arc entrainment and geotectonically modest back-arc deformation. These results reveal the break-up of the Sierra Nevada block at its northern end, the transfer of NW-directed transform motion south of and across the Klamath Mountains province, the northward migration of the fore-arc along a boundary that lies close to or within the Oregon Cascades magmatic axis. Inland stations have lesser motions, consistent with their structural domains from south to north: the Canada and northern Washington back arc experiences slow convergence parallel motion, the Yakima fold belt actively contracts, and southeastern Oregon shows integrated Basin and Range extension. The magnitude of northward fore-arc motion relative to North America decreases northward from northern and central Oregon (7-8 mm/yr) to western Washington (5-7 mm/yr) to Vancouver Island (2 mm/yr), consistent with oblique convergence and geologic constraints on permanent deformation. The margin-parallel strain gradient, concentrated in western Washington across the populated Puget Lowlands, compares in magnitude to shortening across the Los Angeles Basin.

URL: <http://www.geodesy.cwu.edu>

G22A-08 1535h

Observation of Geodetic and Seismic Deformation with 11 Years of Continuous GPS: Horizontal and Vertical Deformation in Southern California

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Time series of daily GPS positions from the SCIGN and its predecessor, the PGGA, arrays are analyzed for geodetic signal and noise content. The eleven year analysis interval, January 20, 1991 - January 12, 2002, spans 4 earthquakes that produced measurable crustal deformation. A site motion model is developed to simultaneously estimate linear trends, nuisance offsets, annual and semi-annual oscillations, along with the crustal deformation. Deformation model parameters include coseismic offsets from the M_W 6.1 Joshua Tree, M_W 7.3 Landers/ M_W 6.2 Big Bear, M_W 6.7 Northridge, and M_W 7.1 Hector Mine earthquakes, as well as postseismic rate changes and exponential decays following the Landers and Hector Mine earthquakes. Model parameters are estimated using weighted least squares with full data covariances that account for the white and flicker noise present in each time series. Position noise is reduced by a factor of 2 in each coordinate direction by removing orbital and global reference frame errors that have a common affect over the region.

After removing the common mode noise, the scatter of daily position residuals is about 1.1 mm horizontally and 3.5 mm vertically. Horizontal postseismic deformation was modeled as a short-term relaxation that decays exponentially superimposed on a longer-term signal that, at time scales of a several years, resembles a rate change. Vertical postseismic deformation was modeled only as a rate change.

Resulting horizontal coseismic displacements compare fairly well with published fault dislocation models for the earlier Joshua Tree, Landers, and Northridge earthquakes. For the later Hector Mine earthquake, estimated coseismic offsets show good agreement with modeled displacements in both horizontal and vertical directions. Between the Landers and Hector Mine earthquakes, linear site rates were estimated with formal uncertainties (using the white+flicker data noise model) of <0.5 mm/yr horizontally and <2 mm/yr vertically. As expected, the direction of horizontal postseismic deformation from the Landers and Hector Mine earthquakes largely coincides with the direction of coseismic displacement. Best-fit time constants for estimated exponential decays were somewhat variable from site-to-site, ranging from 2 to 5 months. In the vertical direction, the post-Hector Mine rate change between the Elsinore and San Jacinto faults acts in the direction that reduces absolute vertical motion, so that postseismic rates in this area are negligible. Postseismic uplift is occurring to the south of the rupture, with rates up to several mm/yr. The region of postseismic uplift is bounded to the southeast by the San Jacinto fault.

URL: <http://sopac.ucsd.edu/other/personnel/niko.html>

G22A-09 1550h

Assessing the Effect of Aquifers and Oil Fields on the Interseismic Velocity Field Across Metropolitan Los Angeles

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GPS observations made from 1994 to 1998 suggest contractional strain to be biggest across the northern half of the metropolis [Argus et al. 1999]. SAR interferometry shows aquifer and oil fields in the metropolis to be rising and falling [Bawden et al. 2001]. If such subsidence and uplift made by man were to accumulate over several years, then horizontal motions accompanying the vertical motions could bias the interseismic velocity field determined from GPS.

We assess the size of horizontal motions accompanying the rise and fall of aquifers and oil fields using both GPS geodesy and synthetic aperture radar (SAR) interferometry. We find horizontal oscillations (observed with GPS) of the Santa Ana aquifer to be biggest where vertical oscillations (observed with SAR) change in size most quickly with distance. Using 10 GPS sites in and around the aquifer and 3 seasonal interferograms, we find the horizontal oscillation (in mm) roughly equals 1000 m times the vertical gradient (in mm/m).

We next use this empirical relationship to remove from the interseismic velocity field the effect of aquifers and oil fields: we take the horizontal velocity (in mm/year) made by man to be 1000 m times the vertical gradient (in mm/year per m) observed with SAR over several years. Removing motions made by man reduces variations in velocities across the metropolis, allowing the velocity field to be evaluated more instructively for seismic hazard.

We then determine the residual velocity field removing both motions made by man and elastic right shear that will be released in great earthquakes along the San Andreas. Contractional strain is observed to be directed north-northeast and to be bigger across the northern half and smaller across the southern half of greater Los Angeles New GPS sites define the spatial variation in contraction much better than before. Relative to the San Gabriel mountains USC is moving at 4.5 ± 1.5 mm/year toward the north-northeast and Palos Verdes is moving at 6 ± 1.5 mm/year toward the north-northeast. (The values following the \pm are 95% conf. limits excluding uncertainty in motions made by man.)

G22A-10 1605h

Southern California regional earthquake probability estimated from continuous GPS geodetic data

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Current seismic hazard estimates are primarily based on seismic and geologic data, but geodetic measurements from large, dense arrays such as the Southern California Integrated GPS Network (SCIGN) can also be used to estimate earthquake probabilities and seismic hazard. Geodetically-derived earthquake probability estimates are particularly important in regions with poorly-constrained fault slip rates. In addition, they are useful because such estimates come with well-determined error bounds. Long-term planning is underway to incorporate geodetic data in the next generation of United States national seismic hazard maps, and techniques for doing so need further development.

I present a new method for estimating the expected rates of earthquakes using strain rates derived from geodetic station velocities. I compute the strain rates using a new technique devised by Y. Hsu and M. Simons [Y. Hsu and M. Simons, pers. comm.], which computes the horizontal strain rate tensor ($\dot{\epsilon}$) at each node of a pre-defined regular grid, using all geodetic velocities in the data set weighted by distance and estimated uncertainty. In addition, they use a novel weighting to handle the effects of station distribution: they divide the region covered by the geodetic network into Voronoi cells using the station locations and weight each station's contribution to $\dot{\epsilon}$ by the area of the Voronoi cell centered at that station. I convert $\dot{\epsilon}$ into the equivalent seismic moment rate density (\dot{M}) using the method of Savage and Simpson [1997] and maximum seismicogenic depths estimated from regional seismicity; \dot{M} gives the expected rate of seismic moment release in a region, based on the geodetic strain rates. Assuming the seismicity in the given region follows a Gutenberg-Richter relationship, I convert \dot{M} to an expected rate of earthquakes of a given magnitude. I will present results of a study applying this method to data from the SCIGN array to estimate earthquake rates in southern California, but my technique is generally applicable to any region with a sufficiently dense geodetic array and well-located seismicity.

Savage, J. C. and R. W. Simpson, Surface strain accumulation and the seismic moment tensor, *Bull. Seismol. Soc. Am.*, 87, 1345-1353, 1997.

G22A-11 1620h

Optimizing GPS arrays to image both tectonic and anthropogenic deformation

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The design and development of the next generation of continuous GPS arrays can be optimized to measure both tectonic and ground water-induced surface deformation, by minimizing the number of GPS sites located on the margins of pumped aquifers. Ground water pumping and hydrocarbon production throughout southern California cause vertical and horizontal deformation that are evident in Interferometric Synthetic Aperture Radar (InSAR) imagery and continuous GPS measurements. For instance, multi-year InSAR imagery show that portions of metropolitan Los Angeles are subsiding at rates of more than 20 mm/yr and seasonal InSAR imagery show vertical oscillations of as much as 110 mm, from late summer to early fall. GPS sites located on the margins of these basins have as much as 15 mm of seasonal horizontal motion in their time-series and are pulled towards the basins with annual subsidence.

Establishing GPS arrays that attempt to avoid anthropogenic deformation signals altogether will leave significant gaps in the network that would be ineffective for resolving slip on targeted faults. In addition, changes in ground water pumping patterns may encroach on the tectonic geodetic network. However, since most tectonic studies heavily rely on horizontal GPS components to model fault slip at depth and most ground water subsidence modeling studies use only vertical elevation changes, then locating GPS sites in regions with small InSAR gradients will satisfy both modeling needs. Therefore, GPS sites located well within or outside of ground water basins will have significantly smaller horizontal motion than sites located on basin margins and can be utilized by both science communities.

URL: <http://quake.wr.usgs.gov/research/deformation/modeling/socal/1a.html>

G22A-12 1635h

Modeling small spatial and temporal variations in slip-rate using geodetic data

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A large investment has been made in regional continuous GPS networks in the western United States and abroad. One of the strengths of these networks is that they produce measurements with sufficient temporal density to image subtle time-varying deformation. In order to use the networks to their full potential it is necessary to both mine the established baseline of data for evidence of previously unidentified slip transients and to implement a means for using the continuous data stream in ongoing monitoring for transient deformation. These applications require the ability to separate small transient signals from ongoing steady-state deformation.

An example of the type of transient deformation described above may be found in several studies that have inferred transient slip events at the transitions between locked and creeping sections of the San Andreas fault. Such processes, if present, would have an important impact on the cycle of strain accumulation and release on a major strike-slip plate-bounding fault, and understanding them may shed light on the conditions which favor aseismic slip over unstable failure. Langbein et al. (1999) used two-color EDM and strainmeter data to model one such event. They estimated the secular slip-rate on the San Andreas near Parkfield, CA prior to 1993 and a post-1993 rate change. For the latter period they imaged a slip-rate increase extending over ~ 25 km² with a peak value of ~ 6 mm/yr.

An adaptation of the Kalman filter called the Extended Network Inversion Filter (ENIF, Segall and Matthews, 1997; McGuire and Segall, in review), developed to analyze transient deformation using geodetic data, is capable of simultaneously imaging the spatial and temporal slip history of a fault. Here we present the results of simulations designed to assess the feasibility of using the ENIF to model transients with low signal to noise ratio using existing station distributions. We also explore to what extent current GPS networks would have to be expanded in order to image transients of a given amplitude and duration. To simulate a case with low signal-to-noise ratio, we generated synthetic data for the existing Parkfield continuous GPS and two-color laser networks, as well as yearly observations of Parkfield area campaign stations using a transient slip event of the magnitude and duration inferred by Langbein et al. (1999). For a high signal-to-noise ratio comparison we also analyzed synthetic data generated from a transient slip event with moment equivalent to that of a M_w 6 earthquake released over five years. We find that even in the low signal-to-noise ratio case it is possible to recover the moment of the transient event, although the peak transient slip tends to be underestimated in all cases and the initiation time of the modeled transient is not always accurate.

G22A-13 1650h

Sub-millimeter Signal Detection by GPS: Cross Validation using GIPSY and GAMIT Solutions for the Yucca Mountain Network

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A continuous and densely spaced GPS network has been installed at Yucca Mountain, southern Nevada, as part of the BARGEN array. It was funded by the Department of Energy to characterize strain at the proposed nuclear waste repository. Each GPS antenna is deep-mounted into solid bedrock and atmospheric effects in the desert climate of the region are relatively low, making this an ideal network to explore the potential precision of GPS. Due to the importance of obtaining an accurate and reliable set of velocity mea-

surements at Yucca Mountain, two separate groups using entirely different methods have independently processed the GPS data from this network. The UNR group has utilized JPL's GIPSY-OASIS II, employing a precise point positioning technique, whereas the Cfa group has used MIT's GAMIT software and a double-differencing approach. Comparison of the two sets of results for 28 stations and 2.8 years of data has revealed only small differences in horizontal velocity estimates, with formal errors for both groups less than 0.17 mm/yr and an RMS of residual velocity differences of 0.23 mm/yr. The two solutions are consistent with one another at the two sigma level. Relative horizontal velocities at stations within 40 km of Yucca Mountain itself are on the order of <0.5 mm/yr, with

a smooth pattern of NNW shear. In order to obtain negligible differences in results both groups had to account for coseismic offsets caused by the 1999 Hector Mine earthquake. It was also necessary to perform ambiguity resolution in GIPSY. Without ambiguity resolution, the GIPSY results were significantly different to those produced by GAMIT. The data was processed in GIPSY on a line-by-line basis, relative to a station in the center of the Yucca Mountain network, to produce a regionally-referenced solution free of common mode signals. It was evident in both solutions that radome changes produce a measurable effect in the vertical component, giving an apparent vertical swell of approximately 2 mm/yr in the Yucca Mountain region if left unaccounted for. With the radome effect re-

moved, vertical velocities within 40 km of Yucca Mountain are minimal, with an RMS of 0.56 mm/yr, which also suggests a high degree of precision. This study has not only given us a high degree of confidence in our estimated velocities for the Yucca Mountain area, but also indicates a measure of the success of both GIPSY and GAMIT. We have shown that solutions produced through these different GPS processing packages, each containing over 1 million lines of code, can produce accurate and virtually identical results at the level of <0.5 mm/yr, and have demonstrated that it is possible to confidently detect sub-millimeter per year signals over an approximately 200 km wide area using GPS.

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Pan, C., The rotation of non-rigid Earth, *Eos Trans. AGU*, 83(47), Fall Meet. Suppl., Abstract U41A-05, 2002.