2004 ANNUAL MEETING

FEBRUARY 25-27, 2004
HOTEL BOULDERADO, BOULDER, COLORADO
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MEETING AGENDA

Wednesday, February 25
5:00 - 8:00  Meeting Registration / Reception  Mezzanine
Poster room available for set-up  Executive Board Room / Foyer

Thursday, February 26
7:30  Continental Breakfast  Meeting Foyer
8:15  Welcome, Introductions and Overview  Ballroom
- Will Prescott, UNAVCO, Inc.
- Eric Calais, Purdue University
- Herb Dragert, Geological Survey of Canada
8:30  Recent advances in GPS technology and data processing  Ballroom
- Tom Herring, MIT
9:30  Loading effects and reference frame definition  Ballroom
- Geoffrey Blewitt, University of Nevada, Reno
10:30  Break  Meeting Foyer
11:00  Breakout Sessions  Alpine/Balsam
- Seismic imaging of strain transients  Columbine
  - Paul Silver, Carnegie Institute of Washington
  - Western GPS Networks  Columbine
  - Fred Blume / Will Prescott, UNAVCO, Inc.
12:00  Lunch  Mezzanine
1:30  Recent advances in InSAR  Ballroom
- Mark Simons, CALTECH
2:30  Time-dependent modeling of geodetic time series  Ballroom
- Paul Segall, Stanford University
3:30  Break  Meeting Foyer
4:00  Breakout Sessions  Alpine/Balsam
- High rate GPS applications  Columbine
  - Kristine Larson, University of Colorado, Boulder
  - Before PBO: Opportunities for Research with Borehole Strainmeter Data
  - Evelyn Roeloffs, USGS Vancouver
5:00  Poster Session  Executive Board Room / Foyer
6:00  Dinner  Mezzanine
7:30 - 8:30  UNAVCO Business Meeting  Alpine/Balsam
Poster Session continues  Executive Board Room / Foyer

Friday, February 27
7:30  Continental Breakfast  Meeting Foyer
8:30  Continental deformation: blocks or flow?  Ballroom
- Wayne Thatcher, USGS Menlo Park
9:30  GPS measurements of active deformation in New-Zealand  Ballroom
- John Beavan, Institute of Geological and Nuclear Sciences
10:30  Break  Meeting Foyer
11:00  PBO with summary of NA reference frame working group activities  Ballroom
- Mike Jackson, UNAVCO, Inc.
- Geoffrey Blewitt, University of Nevada, Reno
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<th>Time</th>
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<tr>
<td>12:00</td>
<td>Annual Meeting Ends</td>
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<tr>
<td>12:15</td>
<td>Transfer to UNAVCO, Inc. for Open House</td>
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<td>1:00</td>
<td>UNAVCO, Inc. Open House Reception</td>
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<td>2:00</td>
<td>Presentations</td>
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<td>3:00</td>
<td>Building Tours</td>
<td>UNAVCO, Inc.</td>
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<tr>
<td>5:00</td>
<td>Open House ends</td>
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From: Hotel Boulderado, 2115 13th Street, Boulder, CO 80302-4801 US
To: UNAVCO, Inc., 6350 Nautilus Drive, Boulder, CO 80301-5553 US

Driving Directions
Start out going South on 13TH STREET toward SPRUCE STREET
Turn RIGHT onto SPRUCE STREET
Turn LEFT onto BROADWAY/CO-7. Continue to follow BROADWAY
Turn LEFT onto 28TH STREET
Turn RIGHT onto IRIS AVENUE/DIAGONAL HIGHWAY
Turn RIGHT onto JAY RD/CR-44.
Turn LEFT onto N 63RD STREET/CR-39
Turn RIGHT onto NAUTILUS DRIVE
UNAVCO, Inc. is located on the corner of N 63RD and NAUTILUS DRIVE
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ABSTRACTS
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Time series of permanent GPS stations are usually shown as variations in station positions. Such series usually show correlations between stations in a region; these correlations are often removed using regional filtering. Another useful mode of analysis, most applicable to small networks, is to solve for changes in the strain across the network (as well as a mean displacement) from the series of station displacements. This automatically removes common-mode signals, and produces an output (strain change) of immediate geophysical relevance. Applying this method to the SOPAC time series for small (10-20 km span) subnetworks of the SCIGN and BARGEN networks shows that the resulting strain series have substantial variations in the amount of day-to-day scatter seen in the estimated strain, with larger variations for subnetworks in more coastal areas, and much smaller ones for subnetworks further inland. This difference in noise level will be important for the application of GPS to measuring time variations in strain, as planned by the PBO.
PLATE BOUNDARY OBSERVATORY DATA AND DATA PRODUCTS: AN OVERVIEW

GREG ANDERSON

The Plate Boundary Observatory (PBO) will give an unprecedented four-dimensional view of active plate boundary deformation across the western United States and Alaska, using a network of 875 continuous GPS (CGPS) sites, 175 borehole strainmeter (BSM) stations, and five long-baseline laser strainmeters (LSM), all installed over the next five years. My main job as PBO Data Products Manager is to ensure the EarthScope community has the data and data products they need; this abstract gives an overview of our plan to make that possible.

PBO CGPS data will be sampled at 15 seconds/sample (15-sec) and 1 sample/second (1-Hz), with one year and two weeks of on-receiver storage, respectively. Except for manual download sites, all receivers will broadcast 15-sec BINE X data streams; 1-Hz data will be retrieved on an as-needed basis, with a limited number of sites perhaps streaming 1-Hz data. PBO BSM stations will broadcast real-time streams of strain, seismic, and auxiliary channels at a nominal sample rate of 20-Hz, limited by the strainmeter design; data will be buffered on-site as well. PBO LSM data streams will be sampled once every 300 seconds. When the network is complete, these data rates will add up to at least 550 GB/yr of CGPS, 3700 GB/yr of BSM, and 12 MB/yr of LSM data.

All PBO data and metadata will be collected at the PBO Headquarters in Boulder and a redundant offsite backup facility operated by PBO staff. LSM data will also flow to the Agnew/Wyatt (AW) group at UC San Diego for initial quality checks and processing. PBO data will flow to Boulder through a variety of paths, including direct Internet access, cellular modems, satellite telemetry, and manual downloads. Once there, automated systems overseen by PBO staff will check data quality, convert data as necessary, and distribute data to PBO archives and analysis centers using a system built on the Unidata Local Data Manager software.

Collecting PBO data is only one part of the process; EarthScope users also need higher-level data products created from PBO data. The lowest level, zero-order PBO data products are raw data and station metadata from each site. First-order GPS products include daily SINEX files, simplified position time series, and information on outliers, offsets, and common-mode noise; first-order strain products include time series in natural strain units with and without earth tides removed, as well as scale factors from counts to strain units. Second-order products from PBO include long-term GPS station velocity estimates, strain rates, and network strain maps. PBO may also create higher-level products, including estimates of coseismic offsets from and postseismic decay following large earthquakes, but at that point, PBO operations meet the research boundary, and where to draw the line is unclear.

The AW group will produce first-order LSM data products, while Kathleen Hodgkinson, PBO Strainmeter Data Analyst, will produce all other strainmeter data products. GPS data will be analyzed in a similar fashion to the IGS model. There will be two independent Analysis Centers, each producing its own products using different software, whose work will be supervised by an independent Analysis Center Coordinator (ACC); the ACC will also create the official combined PBO GPS data products.

Gathering and analyzing data is not worthwhile if the resulting products are not available to the user community; that is the job of the PBO Archives. PBO will have two GPS archives, at the UNAVCO Boulder Facility and the Scripps Orbit and Permanent Array Center, and two
strainmeter archives, at the UC Berkeley Seismological Laboratory and the IRIS Data Management Center. These archives will warehouse PBO data and data products and distribute them to end users through a modified GPS Seamless Archive System (GSAC). Users will retrieve data from the archives using a single, uniform PBO web portal system, and ultimately, through the EarthScope web portal.

This outline is fleshed out in the PBO Data Plan, which I will post on the UNAVCO web site as soon as possible; a general UNAVCO e-mail will announce when the plan is online. After a period of public comment, the PBO Data Products Advisory Committee (DPAC) will meet to recommend changes based on community input. The DPAC will also review PBO data operations annually to ensure PBO data meet EarthScope needs. I urge all community members to read the data plan once it is available and suggest enhancements; this is a community effort, and we cannot make PBO a success without community feedback.
LONG-TERM POST-SEISMIC RATES FOLLOWING THE 1999 HECTOR MINE EARTHQUAKE USING CONTINUOUS GPS

KENNETH E. AUSTIN AND SUSAN E. OWEN

The 16 October 1999 Mw7.1 Hector Mine earthquake was one of the best geodetically recorded earthquakes in recent history. Continuous GPS observations have shown a distinct short term transient, spanning roughly the 10 days following the earthquake. Longer term observations are complicated by annual and seasonal signals, as well as the long term motions caused by coupling of the plate boundary. In order to better understand the influence of these processes on the post seismic signals, we analyze the time-series for regional continuous stations in the SCIGN network from the regional processing centers. We begin by removing outliers and observations with large errors in the raw datasets, followed by a common mode bias filter to remove reference frame and regional noise from the time-series. Data gaps are filled via interpolation in order to create a continuous data set. We use a principal component analysis approach to the regionally filtered time-series in order to break down the signal into it's main components, and identify the tectonic signal. The time series are then compared to currently available models to determine the likely processes that drive the deformation. Identification of these longer term postseismic rates and their spatial patterns is key to helping to resolve the processes which drive the post-seismic deformation.
During the 2002/03 and 2003/04 Antarctic field seasons, we deployed and maintained a network of five stations consisting of various sensors, data acquisition, and telemetry hardware on Mount Erebus, Antarctica. Sensors include dual-frequency GPS, broadband seismometers, infrasonic microphones, infrared radiometers, tiltmeters, gas sensors, weather sensors (temperature, wind speed/direction, humidity, barometric pressure), and system monitors: temperature (instrument and battery), current (amps), and voltages. The stations can deliver real-time, year-round data streams to McMurdo and to the U.S. while augmenting a pre-existing year-round network of short period FM-telemetered seismic stations and continuous single-frequency GPS receivers. The program objective is to acquire diverse multiyear data about the physical conditions of Erebus while developing suitable instrumentation for general volcano deployments.

Mt. Erebus contains a persistent, actively convecting anorthoclase phonolite lava lake. Until recently, small strombolian eruptions occurred daily from the lake and adjacent vents within the centrally-located summit crater. Decline in Strombolian activity in early 2003 is probably due to a change in the plumbing. The first 5.5 months of data from the new continuous dual-frequency GPS network reveal small but variable motions of the five GPS sites, consistent with results from campaign and continuous data collected since 1999/2000. We observe average horizontal motions of $1.2 \pm 0.8 \text{mm/yr}$ to $4.7 \pm 1.1 \text{mm/yr}$ and average vertical motions from $7.9 \pm 1.0 \text{mm/yr}$ to $25.0 \pm 0.9 \text{mm/yr}$. However, we observed a 12 mm horizontal and 80 mm vertical transient in the time series of station NAUS, with disturbances noted at three other sites as well. The transient at NAUS was characterized by three days of northwestward motion (away from the volcano’s crater) followed by approximately 12 days of southeastward motion to return NAUS to its pre-transient position. The transient corresponds to a temperature increase during a wind storm, a condition which favors rime ice formation. The direction of apparent motion is parallel to dominant wind direction, away from the side of the antenna on which rime ice would form. Rime ice on the antenna at NAUS is likely responsible for the January transient, indicating that the effects of rime ice on GPS solutions can be significant and should be taken into consideration when interpreting GPS data in similar cold-weather environments.
USING GPS TO ASSESS EARTHQUAKE POTENTIAL IN FRIULI (NE ITALY)

MAURIZIO BATTAGLIA, UC BERKELEY SEISMOLOGICAL LABORATORY, BERKELEY, CA USA
DAVID ZULIANI, CENTRO RICERCHE SISMOLOGICHE, OGS, UDINE, ITALY
MARK H. MURRAY, UC BERKELEY SEISMOLOGICAL LABORATORY, BERKELEY, CA USA
ROLAND BÜRGMANN, UC BERKELEY SEISMOLOGICAL LABORATORY, BERKELEY, CA USA
ENRICO PRIOLO, CENTRO RICERCHE SISMOLOGICHE, OGS, UDINE, ITALY

On 6 May 1976, a magnitude 6.4 earthquake struck the Friuli region of northeastern Italy near the towns of Gemona and Venzone. Although it was not as large as some previous earthquakes in Italy, its severe ground motion (up to 0.36 g) affected an area with numerous historical towns, resulting in 989 fatalities and 45,000 people left homeless. At least four other destructive earthquakes with epicentral intensity greater than or equal to IX on the Mercalli-Cancani-Sieberg scale have occurred in the Friuli region in the last 5 centuries (1511, 1700, 1794, and 1928).

Seismicity in the Friuli-Venezia Giulia region (NE Italy) demarcates the boundary between a proposed Adria microplate and the Eurasian plate. The observed thrust and strike-slip earthquake focal mechanisms suggest that seismotectonic characteristics of the region are not homogeneous, and that the contemporary seismic deformation pattern is likely to be complex. We have initiated geodetic studies to better characterize and monitor deformation along the NE edge of the Adria microplate. The major objectives of the Friuli Deformation project are:

To measure crustal movements throughout NE Italy to better assess earthquake potential.
To identify active blind thrust faults and test models of tectonics in the Friuli and Adriatic region.
To measure local variations in strain rate that might reveal the mechanical properties of earthquake faults.

In the event of an earthquake, to measure permanent crustal deformation to improve estimates of the extent and magnitude of slip on the fault, strong ground motions, and possible changes in stress on nearby major faults.

Between the summer of 2002 and the winter of 2003, we installed the initial 7 continuous GPS stations of the Friuli Deformation Network (FReDNet) to provide regional crustal deformation data and support for survey-mode GPS operations. We are currently planning local geodetic networks for survey-mode GPS measurements to provide a detailed picture of the local deformation in areas of particular interest (i.e., location of seismic gaps). Beginning this summer, these networks will surveyed once every two years over the next five years. Finally, we plan to use the geodetic data to improve our understanding of the kinematics, tectonics, and earthquake cycle in Friuli. We are currently using continuous GPS measurements and block modeling to investigate the active present-day deformation of the Adria microplate, whose kinematics is not well constrained and remain controversial.
GPS IN NEW ZEALAND – RESULTS AND NEW DEVELOPMENTS

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SCHOOL OF SURVEYING, UNIVERSITY OF OTAGO
PO BOX 56, DUNEDIN, NEW ZEALAND

Tectonically, New Zealand’s North Island contains subduction, forearc, back-arc rifting, volcanic, and strike-slip environments, while the South Island includes continental collision, networks of sub-parallel strike slip faults, and subduction. This wide range of tectonic environments within a small area makes New Zealand an excellent target for geophysical and geological studies, but the juxtaposition of different environments means that one-dimensional interpretations of field data have to be treated with care.

Campaign GPS began in New Zealand in 1990 and expanded greatly from 1994 onwards. Three continuous stations were installed in 1995 and the network was expanded modestly until 2002 when a major upgrade began. The campaign data have been used in coseismic and postseismic studies of earthquakes in 1994, 1995 and 2003. However, the period 1995-2003 was remarkably free of earthquakes, enabling a detailed interseismic velocity field to be developed from repeated campaign observations.

The velocity field has been used in the new "semi-dynamic" geodetic datum of the country, NZGD2000, and has been converted to a strain-rate field that, among other things, can be compared with probabilistic seismic hazard models developed from geological and seismic data. The velocity field has more recently been interpreted in terms of a model consisting of rotating tectonic blocks with variable inter-block coupling along the block-bounding faults. This has proved to have predictive power: in order to match both the present-day velocity field and known geological slip rates along North Island faults the model predicts slip rates on other known faults whose rates have not yet been measured paleoseismically. The locations of the relative poles of rotation between the rotating forearc blocks also indicate that this rotation and the development of the North Island back-arc rifting are a result of the resistance to subduction of the Hikurangi Plateau (an oceanic plateau) and the Campbell Plateau (continental crust).

A 30-station nationwide CGPS network has been under construction by LINZ and GNS since late 2001, and will be completed this year. In addition, as part of the New Zealand GeoNet project, some 60 CGPS stations are being installed along the North Island (Hikurangi) subduction forearc, and some 20 stations within the back-arc volcanic region. The GeoNet project is a 10-year integrated upgrade and deployment of seismic, strong-motion, geodetic and geochemical monitoring. GeoNet has many aims in common with the U.S. Earthscope program, although its funding is largely from the Earthquake Commission (a geohazards insurance company set up by the government) rather than from a research foundation.

A large (25 mm) aseismic deformation event was observed on two CGPS stations over a 10-day period in October 2002 in the northern Hikurangi margin, and smaller events have been observed at other times and places. These events are tentatively interpreted as resulting from slow slip on the subduction interface. Because of the continuous station distribution at the time
we have no information on the lateral extent of the October 2002 event. Analysis of regional campaign data from 1995, 1997 and 2001 indicates that no similarly large events occurred during this time interval. A forthcoming campaign (March 2004) may therefore help to delineate the lateral extent of the 2002 event.

A joint US-NZ project has been running since 2000 to measure and model the vertical deformation rates across the Southern Alps in the central part of the continental collision zone. This consists of 11 sites with a mix of continuous and semi-continuous GPS. After 3.5 years relative vertical rates of up to 7 mm/yr have been measured to better than 1 mm/yr precision (with realistic noise modelling), and a future challenge is to understand these rates in terms of continental collision and mountain building processes.
FIRST REPORT OF THE
STABLE NORTH AMERICA REFERENCE FRAME (SNARF)
WORKING GROUP

GEOFF BLEWITT, KRISTINE LARSON, RICK BENNETT, ERIC CALAIS, MIKE CRAYMER, TOM HERRING, MEGHAN MILLER, GIOVANNI SELLA, RICHARD SNAY, AND MARK TAMISIEA

Here we present a report of the first workshop of the Stable North America Reference Frame (SNARF) Working Group, which was held on January 27, 2004 at UNAVCO, attended by the co-authors of this poster. At that workshop, the SNARF WG discussed various technical aspects that must be considered toward the development of a reference frame attached to stable North America. Here we summarize the outcomes of those discussions and a list of initial recommendations as to how this work should proceed. The long term outcome of this work will be a reference frame that can be used by the Plate Boundary Observatory. This will ensure consistency between the various analysis groups, and will provide well-defined frame parameters that will assist the interpretation of station coordinate time series in terms of geophysical models.
LOADING EFFECTS AND REFERENCE FRAME DEFINITION

GEOFF BLEWITT

Redistribution of mass on the Earth's surface causes changes in the Earth's geometrical shape, gravity field, and orientation in space (the "three pillars of geodesy"), each of which are fundamental considerations for global reference frame definition. On seasonal to several-year time scales, surface mass redistribution is believed to dominate changes in Earth's shape, as measured by stations coordinates of the IGS network. Dynamic models connect this change in Earth's shape to variations in the geocenter (net movement of the solid Earth relative to the center of mass of the whole Earth system), and to Earth rotation. In this lecture I review recent progress in probing these interconnections by analysis of GPS station coordinate time series. The longer term outcome of this new development in geodesy is likely to be a better understanding of connections in the entire Earth system. It will also provide a new approach to comparing different geodetic techniques for consistency through the dynamic models, and it will suggest new ways to combine different geodetic data types for more optimal inversion of Earth models.
SEMI-PERMANENT GPS STATION DESIGN FOR HIGH RESOLUTION, HIGH ACCURACY STRAIN MONITORING IN THE BASIN AND RANGE

GEOFF BLEWITT
MACKAY SCHOOL OF EARTH SCIENCES AND ENGINEERING
UNIVERSITY OF NEVADA, RENO

The Basin and Range (B&R) is an example of a tectonic province which is characterized by slow secular deformations of a spatial complexity that can only be fully revealed by sufficiently high resolution (~20 km) geodetic measurements over a large area (10^6 km^2). Furthermore, an important requirement for unbiased estimation of secular strain is to adequately sample seasonal variation in station position, which implies a required temporal resolution of ~0.1 yr. It is therefore likely that, in provinces such as the B&R, the temporal resolution of <<0.01 yr provided by continuous GPS can be relaxed in favor of providing enhanced spatial resolution. For example, if each GPS receiver shares its tracking time between a pair of stations every few weeks, the spatial resolution can be doubled, at the acceptable cost of decreasing the temporal resolution. Apart from increasing the spatial resolution of secular signals, this strategy also creates a possible opportunity to capture co-seismic signals with high spatial resolution, by providing a dense GPS network with accurate pre-seismic coordinates in the earthquake region. The response to potential earthquakes would be rapid and vastly simplified.

Here I present the design of a recently installed network of 30 stations serviced by 17 receivers in the B&R province (funded by the DOE Geothermal Program). The GPS stations are entirely mobile except for a rock-bolt monument, which has such low environmental impact that permitting process is radically simplified (or not deemed necessary). Key design features include ability to rapidly redeploy the GPS systems, the requirement that the antenna phase center be repeatable to << 1 mm, and that theft or vandalism is deterred. A potential side-benefit of such a design is reduced multipathing due to the lack of large metallic structures around and under the antenna, such as the reinforced monuments and chain link fences often associated with permanent GPS stations. Also, such a design allows for the purchase of 2 or 3 GPS stations sets (serving 4-6 stations) for the price of just one permanent GPS station.
HIGH-RATE (1-2 Hz) REAL-TIME CGPS IN CENTRAL AND SOUTHERN CALIFORNIA: DISPLACEMENT WAVEFORMS FROM THE SAN SIMEON EARTHQUAKE

YEHUDA BOCK, FRANK VERNON, JOHN LANGBEIN, GLEN OFFIELD

We are in the process of upgrading CGPS sites in California to high-rate (1-2 Hz), low latency (<1 s) operations, and integration of these data with seismic data in the region. So far 40 sites have been upgraded including the "Parkfield", "Orange County", and "Diamond Valley Lake" networks, and a concerted effort is underway to upgrade 30 more sites in Riverside County. Here we describe:

Displacement waveforms from the San Simeon earthquake measured in real-time by sites in the Parkfield network. These are the first near-field measurements of a large earthquake with a high-rate GPS network.

Noise characteristics and offset and rate sensitivity of 1 Hz GPS position data on medium scales (10's of kilometers) and 2 Hz data on the 50 m baseline at Pinon Flat Observatory. Communications, hardware, and data handling infrastructure developed to accommodate these and future upgrades.
GEOSPATIAL DATA AND WEB APPLICATIONS TO SUPPORT THE SITING, RECONNAISSANCE, AND PERMITTING OF PLATE BOUNDARY OBSERVATORY GPS AND STRAINMETER SITES

KYLE R. BOHNENSTIEHL
UNAVCO, INC.

Given the large geographic area that the Plate Boundary Observatory (PBO) covers, the number of stations, and the wide geographic distribution of PBO staff, a method to help PBO staff locate potential sites for instrument installation was required. The frontline reconnaissance tool for PBO is an Internet Map Server (IMS), available using any web browser application, that provides LANDSAT satellite imagery at a resolution of 28.5m, political boundary maps, road maps, Verizon cell phone coverage maps, historical earthquake information, Federal land ownership information, and in some areas 1m resolution aerial photography. PBO site locations, proposed sites from the public and PBO staff, permitted sites, and installed sites are also visible in the IMS. Attributes about the sites can be queried and displayed using the IMS tools. Additional reconnaissance tools include Delorme road atlas overlays printed on clear acetate and GIS maps that include more detailed, site specific data. Custom GIS analysis for viewshed, incoming solar radiation, and telecommunications coverage can also be performed. Office reconnaissance and siting analysis should eliminate wasted time in the field and result in cost savings over the length of the five year build out phase of PBO. UNAVCO/PBO also provides an online siting form that the scientific community and public can use to suggest potential PBO site locations. This information is available in the IMS and is also linked to PBO Operations database.
GIBBS SAMPLING INVERSION
APPLIED TO THE COSEISMIC GEODETIC PROBLEM

BENJAMIN A. BROOKS
SCHOOL OF OCEAN EARTH SCIENCE AND TECHNOLOGY
UNIVERSITY OF HAWAII

Gibbs sampling falls within a widely used class of Monte Carlo-based sampling inversion algorithms of which simulated annealing is perhaps the best known. In contrast to simulated annealing which only attempts to find the peak of the multidimensional posterior distribution, Gibbs sampling collects samples that are then used to compute whatever marginal distributions or statistics are desired. Here, we extend Gibbs sampling to a larger class of unnormalized, non-linear, multidimensional probability functions. Our development removes a source of subjectivity from this technique by making the results independent of critical temperature, although is still important as the temperature for most efficient sampling. Additionally, we use samples gathered in the course of estimating to generate intersample distance distributions that characterize an inverse problem’s modality and indicate whether less computationally expensive methods might be adequate. For the coseismic geodetic problem our experiments with synthetic data suggest a general inverse relationship between and signal-to-noise ratio: as data become less noisy, increases, and our correction to the Gibbs sampling technique is needed to assure properly scaled posterior distributions. Inversion of surface displacement data from the 1994 Northridge earthquake confirms coseismic source parameters from other methods while providing extra information in the form of properly scaled marginal, posterior distribution functions.
TRANSIENT GROUND DEFORMATION FOLLOWING THE 30 JANUARY 1997 DIKE INTRUSION AT KILAUEA VOLCANO, HAWAII

EMILY DESMARIAIS AND PAUL SEGALL
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On 30 January 1997 an East Rift Zone (ERZ) intrusion opened a new fissure within the Kilauea Volcano permanent GPS network at Napau Crater, 3km uprift from the ongoing eruptions at Pu'u O'o. The fissure eruption lasted for two days and opened a nearly vertical dike 1.96m wide by 5.15km long that extended from the surface to a depth of 2.4km (Owen et al., 1997). During the fissure eruption, the lava pond at Pu'u O'o drained pausing the eruptions there for nearly a month until it eventually refilled in late February and eruptions resumed 28 March 1997.

The GPS timeseries show a transient following the dike intrusion in the ERZ. In the 120 days following the event the closest station to the fissure, KTPM, moved an additional 7 cm to the South. We invert continuous and campaign GPS data using a non linear least squares method with an extended Kalman filter (McGuire and Segall, in press) for the time dependent volume change of a Mogi source under Kilauea's summit, opening of a nearly vertical dike in the ERZ and slip on a decollement 10km under the South flank. The extended Kalman filter allows simultaneous estimation of slip rate with temporal smoothing, spatial smoothing, positivity, random walk and data error scale parameters resulting in improved spatial and temporal resolution over previous filters (Segall and Matthews, 1997). This study models post eruptive deformation as the crust accommodates the opening of the dike to gain understanding about the relaxation time of the Hawaiian crust and the potential for catastrophic failure of the South flank.

Results show that most dike opening is accommodated in the top ~2-3 km of with a maximum velocity 8 mm/day. Every model shows Mogi source under Kilauea rapidly inflating after months of gradual pre-fissure eruption deflation. The decollement slips gradually seaward during the first month after the eruption.
PBO OPERATIONS: BUILDING THE NETWORK

KARL FEAX

The Plate Boundary Observatory (PBO), part of the Earthscope project, will study the three-dimensional strain field resulting from active plate boundary deformation across the Western United States. PBO is a large construction project involving the reconnaissance, permitting, installation, documentation, and maintenance of 875 permanent GPS stations and 175 strainmeter stations in five years. In order to meet this demanding project installation schedule, PBO operations must immediately begin the reconnaissance, permitting, and installation activities simultaneously in each of the six PBO regions. In addition to meeting the installation production goals of the first year, the PBO operations must complete various project startup activities, including developing and implementing policies and procedures to streamline the remote office operations. Critical PBO personnel must be hired in order to staff, locate, and setup the regional offices. The GPS and strainmeter station final design specifications and site construction specifications will be completed leading to system hardware procurements. A PBO construction safety plan must be developed and implemented to ensure safe PBO worksites. A process for hardware receiving, tracking, testing, packaging, and shipping must be developed to reduce in-field construction time and hardware failures. Finally, a robust database and other web-based tools must be designed and developed to facilitate the data entry, documentation, and reporting of all the reconnaissance, permitting, and installation activities. The completion of these tasks is necessary to achieve the project mission on schedule and under budget.
HOW WELL CAN GPS DATA CONSTRAIN VARIATIONS IN LITHOSPHERIC RHEOLOGY? A BASIN AND RANGE CASE STUDY

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Elevated strain rates measured by a GPS transect across the entire Basin and Range near latitude 39°N suggest that its westernmost 200 km has a lithosphere that is rheologically weaker than the rest of the Basin and Range. In this presentation I use a simplified two-dimensional realization of the thin viscous sheet model to characterize the ability of GPS velocities to distinguish between localized and gradual horizontal variations in the Basin and Range lithospheric viscosity. I show that if the lithosphere can be described as a thin viscous sheet, then narrow localization of lower viscosities in the vicinity of the highest strain rates is not required to concentrate strain rates. If the lowest depth-averaged viscosity is focused in a narrow zone, then the result is that strain rates are elevated between the zones of relatively greater viscosity. However, if the viscosity varies gradually across a wide zone (hundreds to thousands of kilometers across), then the strain rates vary with a $1/x$ pattern where $x$ is the distance normal to the Basin and Range structure. The result is an effectively concentrated deformation that may be difficult to distinguish from deformation owing to more abrupt changes in lithospheric properties. To distinguish between various models for lithospheric viscosity variations, time dependent signals owing to postseismic relaxation must be removed from deformation data (in this case the GPS velocity data). I subtract the GPS velocities predicted by a model of viscoelastic relaxation following the historic earthquakes of the Central Nevada Seismic Zone (Hetland and Hagar, 2003). The remaining velocities, although possibly containing additional signals from other (possibly pre-historic) earthquakes, are taken to approximate the secular pattern. This pattern is spatially smoother and consistent with a more gradual decrease in lithospheric viscosity from east to west.
RECENT ADVANCES IN GPS TECHNOLOGY AND DATA PROCESSING

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Analysis of GPS data by multiple analysis centers from regional GPS networks such as the Southern California Integrated GPS Network (SCIGN) are now routinely yielding sub-millimeter horizontal and few millimeter vertical scatter and agreement between independent analyzes of these data. These results are achieved when the coordinate systems from the two analyzes are realized over a ~600 km-size region using the same methodology for the two analysis centers. Both analyzes use bias-fixing and hence the north and east coordinate estimates are of similar quality. In this talk, we focus on advances that might allow similar quality results to be obtained on much larger sized networks. Global analyzes of GPS data typically have 2-mm horizontal and 5-mm vertical scatters that are spatially correlated. Some part of this spatial correlation is due to signal (such as fluid loading) and some part is due to noise (such as orbit errors). The precise separation of these two types of contributions is not yet clear. Issues to be addressed include the accuracy of pseudo-range measurements from modern receivers and how this accuracy affects bias fixing on long baselines. We also consider the impact of the third GPS frequency on bias fixing. Other topics to be addressed is how other measurements from the GPS receiver, such as signal-to-noise ratio, might be used to provide quality checking on results and hence more robust isolation of transient events in GPS results.
To interpret data from strainmeters the raw instrument output must be converted from volts to units of strain. It is also important to know how sensitive the instruments are to changes in vertical strain. The Earth tides (body tide plus ocean load tide) provide a known strain signal against which strainmeters can be calibrated and the sensitivity to vertical strain can be assessed by calculating the change in dilatational strain produced by changes in atmospheric pressure.

In this study we investigate how well the predicted tides compare with the measured tides and calculate the pressure response for 16 currently active volumetric dilatometers located along the western US plate boundary. The phase and amplitudes of the M2 and O1 tides and pressure response are calculated for 2-month segments of data over the lifetime of each instrument.

We find that the phase of the measured tide does not vary significantly over the lifetime of most instruments and the measured M2 phase is within 10° of that predicted for 12 instruments. However, for many instruments the amplitude of the M2 tide changes monotonically with time, with net increases or decreases of typically 5%, but in some cases 15% or more. These tidal amplitude changes stabilize 5 to 10 years after the instrument installation and may be due to rock modulus changes near the borehole wall. We also find that the pressure response can vary from 4 to 50 nanostrain per millibar change in pressure at instruments located within the same region and that sites with high pressure response exhibit the largest variation in tidal amplitudes with time.

The December 22, 2003 M6.5 San Simeon, California earthquake produced coseismic offsets recorded by dilatometers in the Parkfield area, as well as transient strain signals at all other California dilatometers. All nonzero coseismic steps agreed in direction with the calculated strain field of the earthquake based on a dislocation model; however, amplitudes of steps recorded by two instruments were larger than expected and are being investigated further. The possible role of fluid flow in controlling rapid recovery of recorded strain at one Parkfield dilatometer is also being evaluated.
VOLCANO DEFORMATION ANALYSIS USING PERSISTENT SCATTERERS IN DIFFERENTIAL SAR INTERFEROMETRY

ANDREW HOOPER, PAUL SEGALL AND HOWARD ZEBKER

Much progress has been made in our ability to detect deformation on volcanoes using differential SAR interferometry (DInSAR), however significant problems with the technique remain. These include temporal decorrelation and the inability to interfere SAR images gathered on repeat satellite tracks more than a few hundred meters apart. One method for avoiding both temporal and spatial decorrelation is to identify persistent scatterers (PS) in the images. Their persistence means they do not decorrelate significantly with time, while their pointwise nature means that speckle is not an issue.

Other PS systems have been developed on the assumption that, to first order, the deformation is steady in time. While they can easily be adapted to include a non-steady model of deformation, they are limited to cases where the function of deformation with time can be simply parameterized, e.g. a polynomial. Volcano deformation however, tends to be non-steady and not readily parameterized. We have therefore developed a system that generates a time series of deformation for each PS with no prior assumptions about the temporal nature of this deformation. An appropriate model of deformation can then be selected and solved for. This technique has been verified using synthetic data representing a non-steady, inflationary/deflationary Mogi source.
APPARENT ANNUAL GPS SCALE VARIATION MAY REPRESENT DEGREE-ONE EARTH DEFORMATION

DANIEL J. JOHNSON

Over 100 globally distributed GPS sites have been analyzed here using GIPSY/OASIS II in a fiducial-free reference frame. Seasonal deformation cycles related to degree-one loading are poorly managed by typical linear reference frame constraints. With a linear reference frame model, seasonal patterns that deviate from linearity will be removed if they are coherent over the entire network. Because degree-one deformation is regionally extensive and coherent (within hemispheres), some degree-one deformation may be absorbed by the scale parameter. Due to imbalances in the distribution of GPS sites between hemispheres and larger degree-one amplitudes in the northern hemisphere, amplitudes of annual vertical motion related to degree-one deformation are reduced in the northern hemisphere and enhanced in the southern hemisphere as a result of typical reference frame realizations.
L1 GPS MONITORING OF DEFORMATION ASSOCIATED WITH KILAUEA’S ONGOING EFFUSIVE ERUPTION

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Active volcanoes are a harsh, high-risk environment for monitoring instruments. Compounding this risk, instruments used to track shallow magmatic activity must be installed near the source. With NASA funding, UNAVCO developed a low-cost and robust continuous L1 GPS volcano deformation monitoring system. The system features real-time data telemetry through redundant repeaters to a single master radio. In July 1999, with help from USGS Hawaiian Volcano Observatory (HVO), 13 L1 GPS stations were installed in Kilauea’s summit caldera, its east rift zone, and on the active Pu`u `O`o vent. The L1 network supplements the existing 20-station (HVO/Stanford University/University of Hawaii) dual-frequency GPS network. Bernese 4.2 daily GPS solutions use the dual-frequency network as a backbone, forming L1 baselines to the nearest station. Although scatter in the L1 station positions is several times that of dual-frequency stations, this simple data reduction strategy coupled with data editing during extreme ionospheric activity provides precise L1 station positions. Many shallow magmatic events have occurred since the installation of the L1 GPS network. In the September 1999 simultaneous dike inflation, Kilauea caldera subsidence and contraction, and subsidence of Pu`u `O`o was observed. Large displacements of the L1 station on Pu`u `O`o cone occur during two periods of long-term (several months) magmatic inflation, which both ended in rapid deflation accompanying the formation of new vents at Pu`u `O`o. Ongoing subsidence of Pu`u `O`o at varying rates (average of 10 cm/yr) is observed during the entire record. Relative position change between the Pu`u `O`o L1 station and another L1 station located 1.5 km distant on relatively stable ground provides temporal details of deformation not resolved in the times series of individual station positions. These two L1 stations are located near tiltmeters, which further improve temporal details of short-term deformation fluctuations. Robust, but expendable, L1 GPS stations enhance monitoring of deformation associated with shallow magmatic activity and the GPS data complement that from tiltmeters.
PACIFIC NORTHWEST VELOCITY FIELD: CONSTRAINTS ON FAULT COUPLING AND BLOCK MOTIONS IN CASCADIA

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We have computed a velocity field for the Pacific Northwest covering Oregon and Washington in the US and SW British Columbia in Canada. The velocities are based on GPS measurements made between 1991 and 2003 and include both survey mode and continuous stations. Survey mode data were taken from numerous occupations by the US Geological Survey, Cascades Volcano Observatory, University of Washington, Rensselaer Polytechnic Institute, Geodetic Survey of Canada, and others. Continuous data were taken from the Western Canada Deformation Array, Pacific Northwest Geodetic Array, National Geodetic Survey CORS sites, and others. Processing was done with the GAMIT/GLOBK software package.

The velocity field comprises 305 velocities with standard errors of 1.0 mm/yr or less and 422 with standard errors of 2.0 mm/yr or less. The uncertainties were verified by checking the distribution of residuals relative to a simple model that includes rotation of Oregon and locking at the Cascadia subduction thrust.

The degree of coupling on the Cascadia subduction zone and on upper plate faults and the motions of the surrounding plates, large and small, were inferred by simultaneous inversion of these GPS velocities supplemented with surface tilt rates, surface uplift rates, seafloor spreading rates, slip vectors, and transform fault azimuths. Angular velocities of the Pacific (Pac) and Juan de Fuca (JdF) plates relative to North America (NAm) were estimated from a combination of GPS, spreading rates, and transform fault azimuth data. In addition, we examined the possibility of independent motions of several smaller continental blocks (micro-plates) in the region. The distribution of fault locking on the subduction thrust was estimated as part of the inversion using a 3D elastic halfspace dislocation model. Along the Cascadia subduction zone, the slip deficit rate (the rate of fault slip not taken up by steady slip), appears to be predominantly offshore. In current models, the offshore coupled zone south of 45N and 46N is only partially (50%) locked while in the north the offshore section of the thrust is fully locked. The Oregon crustal block, including most of Oregon and SW Washington, rotates clockwise relative to North America at about 1 degree/Myr around a pole in NE Oregon. Vancouver Island, SW British Columbia, and eastern Washington appear to be part of the North American plate. The GPS data show clearly that the southern Cascade volcanic arc does not localize slip or produce a forearc ‘sliver’, as often occurs in oblique subduction zones. Instead the rotation of most of Oregon as a large elastic block, probably driven by Basin and Range extension, removes most of the obliquity of the convergence at the Cascadia subduction zone. The angular velocity of the Oregon block estimated from GPS data in Oregon indicates an overall rate of convergence of the Oregon block with North America of 6.6 ± 0.7 mm/yr near Seattle (at 47.6N, 237.7E).
PBO PERMANENT GPS SITE: CONCEPTUAL DESIGN

DAVID MENCIN AND STEVE BORENSTEIN

A major component of the Plate Boundary Observatory (PBO) is an array of 875 permanent GPS stations that cover the Western Conterminous United States and Alaska. These sites will use both Short Drill Braced Monuments (SDBM) and Deep Drill Braced Monuments (DDBM), modular solar and AC power systems, and next generation IP based GPS receivers with embedded Linux operating systems, advanced communication systems for always on diagnostics and data retrieval.

Monumentation is based on previous community experiences through UNAVCO and SCIGN. The DDBM is the primary choice for PBO, deeply anchored (10m) and isolated from the surface. The SDBM is meant for exposed bedrock and sites that are logistically difficult for the heavy drilling equipment required for a DDBM. Power systems and enclosures are designed to be secure and modular for rapid and easy deployment. Standardized configurations and parts are kept to a minimum to reduce variations in system configurations.

The heart of the system is an IP based GPS receiver with an embedded Linux operating system. All equipment at the site will be IP based and remotely controlled and monitored from the operations center. These technologies will enable real time data streaming based on TCP or UDP protocols and simultaneous file based data collection for FTP based access, all at different sample rates and configurations. This will also enable advanced diagnostics of the PBO GPS network.
INFERENCES OF TRANSIENT FAULT SLIP FROM GEODETIC DATA AND THE RELATION TO MODERATE SEISMICITY

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A major objective of expanding continuous GPS networks is to enable observation of time-varying deformation. Transient displacements have been observed in data from several existing networks, largely in subduction zone settings, and have been used to infer the spatio-temporal slip-rate history on faults. Implementation of the Plate Boundary Observatory will soon provide a much larger dataset, motivating the development of increasingly sophisticated analyses both in terms of the models employed and the interpretation of results. Questions remain, however, regarding 1) proper characterization of noise, 2) the variety of transient deformation events that may be imaged (for instance in terms of tectonic setting, magnitude, and duration), and 3) how inferences of slip-rate history may be used to better understand mechanisms of fault slip in different settings. Here we present a study that begins to address these issues.

Parkfield, CA, a locale well-known for its history of M6 earthquakes, lies at the transition between creeping and locked segments of the San Andreas fault. In the early 1990s, rate changes were observed in data from several monitoring networks at Parkfield and were accompanied by three moderate earthquakes (approximately M4.5) which nucleated near the inferred hypocenter of previous Parkfield M6 earthquakes.

We have analyzed data from the permanent two-color EDM network using a nonlinear Kalman filtering technique. This method is well-suited to inferring slip-rate changes from data contaminated by random walk and white noise. Furthermore we have implemented a means for simultaneous estimation of the seasonal noise that is common in geodetic time-series. This type of analysis provides a fault slip estimate at every epoch for which there are data, resulting in a time-history of slip rather than a single rate change.

Our results show that fault slip-rate on the San Andreas between Middle Mountain and Parkfield increased following the three moderate earthquakes, perhaps as a response to these events. Similarly, a slow earthquake has been inferred from strainmeter data following a Mw 5.1 earthquake in 1998 at San Juan Bautista, site of another transition between creeping and locked behavior on the San Andreas. The setting of the inferred time-varying slip at Parkfield is clearly different from that of many recently observed transients in subduction zones, although it is as yet unknown whether the underlying mechanisms are similar. To better understand the relation between seismic and aseismic slip we consider the effect of stress changes imposed by the three earthquakes and explore the evolution of shear stress on the fault during the transient event.
We report on 5 borehole stations installed in the San Francisco Bay area with strainmeters, seismometers, pore pressure monitors, tilt sensors, GPS, and high-frequency 24-bit recording systems. These Mini-PBO stations are part of an NSF-funded project to develop a pilot system for the study of transient plate boundary deformation from fractions of seconds to years in central California. We are currently resolving interaction problems, such as electrical grounding, that are typically encountered during the hookup of such complex systems, and are in the initial stages of assessing the data quality of the instrumentation. The tensor strainmeters, installed at about 200-m depth, use the CIW hydraulic system to measure the volume change in 3 sensing volumes that form 120-degree sectors of an annulus, allowing the 3-component horizontal strain tensor to be determined. The 3-component 2-Hz velocity borehole seismic packages are located just above the strainmeters to improve signal strength, particularly at the high end of the frequency band for the analysis of small earthquakes and their relation to transient deformation. The GPS antennas are mounted at the top of the borehole casings in an experimental approach to achieve inexpensive yet stable monuments. The tensor strainmeters, pore pressure monitors, and tiltmeters appear to reliably measure tidal strain, and local and teleseismic earthquake deformation. We will present noise and deformation results from strain, seismic, and GPS instrumentation. The lessons learned from the analysis and integration of the different data types produced by the Mini-PBO project should pave the way for users of the more extensive data sets that will be acquired through the dense instrumentation deployments planned under PBO.
ACTIVE TRANSTENSIONAL BOUNDARY ZONE BETWEEN THE WESTERN GREAT BASIN AND SIERRA NEVADA BLOCK, WESTERN U.S. CORDILLERA

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The Walker Lane and northern part of the eastern California shear zone form a boundary zone accommodating differential motion between the Sierra Nevada and western Great Basin. Within the boundary zone, Global Positioning System (GPS) velocities show a westward increase from 2-3 mm/yr in the central Great Basin to ~14 mm/yr in the Sierra Nevada and a concomitant clockwise rotation from west-northwest to northwest. In the same region, incremental extensional strain-axes recorded by earthquake focal-mechanisms and fault-slip inversion show an east to west anticlockwise rotation of 50°; from parallel with the velocity field in the central Great Basin to nearly orthogonal to the velocity field along the eastern flank of the Sierra Nevada. Unlike the plane-strain deformation conditions in the central Great Basin, progressive divergence between the incremental extension axes and velocity field within the boundary zone indicates nonplane strain deformation. The boundary zone records active constriction formed in conditions varying from wrench-dominated to extension-dominated transtension from the eastern margin, westward toward the Sierra Nevada.
DEFORMATION IN LONG VALLEY AND THE HILTON BLOCK, SIERRA NEVADA, CA FROM GPS STUDIES

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Long Valley caldera, California, is a "natural laboratory" for the study of interaction between volcanism and tectonics. The Hilton Block area south of Long Valley caldera has been one of the most seismically active regions in California. Understanding the connections between volcanism and tectonics in this region will require a better understanding of both the kinematics of the Hilton Block and the mechanics of stress transfer within the caldera system. Annual GPS measurements have been made from 1999 through 2002 on a network of over 35 sites designed to better characterize both the regional strain rates and the strain rates within the Hilton Block. Our network includes data from 10 recently installed benchmarks and 10 benchmarks without a prior history of survey-mode GPS measurements. We combine our observations with GPS data collected by the U.S.G.S.. Between the 1999 and 2001 surveys, there was no significant deformation of the resurgent dome; the dome resumed its inflation around January 2002. Since there were no significant earthquakes or intrusive events in the region between 1999 and 2002, our results give an estimate of the 'background' strain rates.
GPS MEASUREMENTS FOLLOWING THE DECEMBER 22 2003 M 6.5 SAN SIMEON EARTHQUAKE ALONG THE CREEPING SEGMENT OF THE SAN ANDREAS FAULT

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Following the December 22 M 6.5 San Simeon earthquake, we resurveyed 6 GPS stations along the creeping segment of the San Andreas fault, north-east of the mainshock. Preliminary models indicate estimated values of coseismic displacements at these sites as large as 4 cm. We previously collected GPS data at 11 stations along the creeping segment of the San Andreas, from San Juan Bautista to Parkfield, in January 2003 as part of a project to characterize the patterns of aseismic fault slip in space and time along the central aseismically-slipping segment of the San Andreas fault. We will present the coseismic displacements from the M 6.5 San Simeon earthquake for these stations in addition to existing permanent GPS stations in the area. The data will be used to constrain the geometry and slip of the coseismic rupture. We will also evaluate if the San Andreas fault experienced any triggered slip that can be resolved by the GPS data.
PBO NETWORK PERFORMANCE FOR CASCADEIA

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The geodetic community has begun the 5-year initiative to instrument North America as part of the Plate Boundary Observatory (PBO). GPS and strainmeters are currently being distributed across the western United States in a manner designed to target specific scientific objectives. While a blueprint for the placement of stations is already established, there exists a window of opportunity to optimize the network design and aid the site selection committees with site prioritization. We will provide an update on our ongoing efforts to evaluate the performance of the proposed network through numerical simulations. For this meeting, our analysis will focus on transient source events in Cascadia. Results describe the PBO network performance as a function of the magnitude and duration of a slow slip event on the subduction interface and provide insight into the expected level of resolution. Simulations are designed to mimic the slow slip events that have been observed near Vancouver Island using a dislocation rise time of 15 days and an along-strike propagation rate of 2800 km/yr. For each simulation, 3-component synthetic GPS are created that include white noise and a random walk component. Most recently we have included synthetic tensor strain data into the analysis. The Extended Network Inversion Filter [McGuire and Segall, Geophys. J. Int., 2003] is used to infer the original source parameters from synthetic time series given the proposed station distribution. The Extended Network Inversion Filter is an implementation of a Kalman filter that is well suited to extract a time-dependent signal from noisy data and is efficient at analyzing large time series. Resolution of the source process is evaluated by comparing the synthetic input model with the inferred source model estimated by the filter. We report the network’s ability to detect and resolve propagating slow slip events both along-strike and down-dip. Initial results suggest that slow slip in the transition zone off of the Oregon coast would be difficult to resolve. Further north along the subduction interface, a slip magnitude of several centimeters in the transition zone represents a resolvability threshold, although smaller events may still be detectable.
EASTERN NORTH AMERICAN POSTGLACIAL UPLIFT FROM CONTINUOUS AND EPISODIC GPS

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We use continuous and episodic Global Positioning System (GPS) data to measure the movement caused by glacial isostatic adjustment (GIA) due to glacial unloading in eastern North America. At present it is challenging to quantify GIA motion in North America because of the limited distribution of continuous GPS sites in and around Hudson Bay, the area of maximum glacial loading. In the last two years new continuous GPS (CGPS) sites have been established in Canada. Episodic GPS (EGPS) sites provide a low cost and higher density alternative, but often have large errors, especially in the vertical. However, the large vertical signal due to GIA (>10mm/yr) in the area of maximum uplift permits this motion to be resolved, even with EGPS data. We present data from 130 CGPS sites throughout North America and almost 100 EGPS sites of the Canadian Base Network (CBN). The CBN sites are located across central and southern Canada and have been episodically occupied between 1994 and 2002. We detect a coherent pattern of vertical motions around the area of maximum glacial loading, Hudson Bay. The observed velocities are initially large and upward, and decrease southward from Hudson Bay to zero, delineating the hinge line near the Great Lakes. The position of the hinge line is in agreement with some numerical GIA predictions. The horizontal residual velocities after removing the motion of the rigid North American plate also show a consistent, but more complex pattern than the vertical velocities. A three-dimensional site velocity distribution may permit assessment of the role of GIA in the seismicity of eastern North America.
NOAA's National Geodetic Survey (NGS) manages the National and Cooperative CORS (Continuously Operating Reference Station) program. CORS comprises a nationwide network of ground-based GPS receivers. NGS provides access to GPS data from this network via the Internet with no direct cost to users. The program's primary objective is to enable GPS users to determine precise positional coordinates.

Users can achieve centimeter- or decimeter-level accuracy by postprocessing several hours or minutes, respectively, of their GPS data with data from the CORS network. Users can also determine the travel path of a moving platform--like an aircraft, a boat, or a land vehicle--with decimeter-level accuracy by postprocessing GPS data from a receiver mounted on this platform with data from the CORS network.

Additionally, CORS data are used by:

Earth scientists to monitor crustal motion,
Meteorologists to monitor the distribution of moisture in the atmosphere, and
Atmospheric scientists to monitor the distribution of free electrons in the ionosphere.

The CORS network currently (January 2004) contains more than 800 stations and is growing at a rate of about eight new stations per month. These stations are operated by a collection of more than 110 organizations representing various federal, state, and local government agencies, as well as various academic and commercial institutions. CORS information is available both via the Web (http://www.ngs.noaa.gov/CORS/) and via anonymous file transfer protocol (ftp://www.ngs.noaa.gov/cors/).
IDENTIFICATION OF SLOW EARTHQUAKE ONSET TIME WITH THE CONTINUOUS WAVELET TRANSFORM

WALTER MICHAEL SZELIGA AND TIMOTHY IAN MELBOURNE

In the Pacific Northwest, continuous GPS has detected nine slow earthquakes occurring at 14.5±1 month intervals within the northern Cascadia plate interface (Dragert et al., 2001; Miller et al., 2002). Recent investigation by the authors has revealed the possibility that slow earthquakes also occur within the Southern Cascadia plate interface (Szeliga et al. AGU Fall meeting). With the upcoming installation of 875 new continuous Global Positioning System stations associated with the Plate Boundary Observatory, a systematic methodology for the determination of the onset time of slow earthquakes becomes necessary. Precise determination of Slow Earthquake onset time is necessary for accurate time-dependent slip inversion models. Utilizing the time and frequency localization properties of the Continuous Wavelet Transform, it becomes possible to identify onset times for transient behavior in continuous GPS timeseries. Temporal correlation of transients with transients at nearby continuous GPS stations indicates the presence of a spatially and temporally correlated signal. Automation of this method would assist researchers in identifying transient events in large continuous GPS catalogs.
NEW CONSTRAINTS ON THE ACTIVE DEFORMATION OF THE CONTINENTS

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How continents deform has been hotly debated without definitive resolution since the earliest
days of the development of the plate tectonic model. The evident wide distribution of seismicity,
active faulting, and tectonically generated topography have suggested that active continental
deformation takes place over broad regions and differs fundamentally from the narrowly focused
straining occurring between plates of oceanic lithosphere. End-member models have postulated
this deformation is either quasi-continuous or due to the relative motions of a small number of
rigid blocks (‘microplates’).

The absence of precise quantitative measures of regional continental deformation has been the
chief obstacle in determining which, if either, description is correct. However, GPS methods
have the singular capability of providing the necessary quantification, permitting accurate
mapping of site velocities across deforming zones in a common reference frame. GPS is
therefore increasingly being applied to define patterns of movement in the western U. S.,
Mediterranean, central Asia, Japan, South America and New Zealand. Common features of the
kinematics are now emerging.

The GPS measurements suggest present-day continental tectonics can be economically
described by the motions of a relatively small number of microplates. Deformation is typically
focused in narrow zones whose extent is much smaller than the intervening largely inactive
regions. I will show that large GPS data sets from the western U. S. and the Aegean can be
matched well by models with a small number of adjustable parameters that account for rigid
block rotations and earthquake-related strain accumulation effects near block boundaries.
However, occasional systematic misfits between model-predicted and observed GPS velocities
reveal the existence of intraplate deforming zones or smaller microplates not resolved by the
data. Other intraplate faults and earthquakes as large as M~7 attest to additional departures
from rigidity that are below current GPS detection thresholds. Nonetheless, despite the detailed
complexity of active continental deformation revealed by seismicity, active faulting, fault
geomorphology and earthquake fault plane solutions, GPS results show that continental
tectonics, at least in the some regions, is to first order very similar to global plate tectonics and
obeys the same simple kinematic rules.

Plate kinematics is unlikely to be as generally useful on the continents as it has been on a
global scale. The degree to which it can be applied depends largely on the long-term rigidity of
continental microplates and the persistence (or not) of their boundaries. Heterogeneities in
strength and internal buoyancy of continental lithosphere and the complex structural histories of
deforming regions suggest more complicated behavior. However, initial attempts to extrapolate
the present-day, GPS-based Aegean microplate model backward in time to better understand
late Cenozoic tectonic evolution in the North Aegean are encouraging. Furthermore, since rigid
block motions successfully describe present-day continental deformation, this framework can be
confidently applied to quantify and improve seismic hazard assessments that have typically
relied on short seismicity catalogs and limited fault slip rate data.
GPS DATA PRODUCTS FOR SOLID EARTH SCIENCE

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Over the past decade, regional and global networks of continuously operating GPS ground stations have been deployed to monitor Solid Earth deformation, and to support Earth Science Enterprise (ESE) priorities and flight projects. The focus of our project is the 250-station Southern California Integrated GPS Network (SCIGN), a multi-agency effort jointly sponsored by NASA, NSF, USGS, and the W.M. Keck Foundation, under the umbrella of the Southern California Earthquake Center (SCEC). Over the next five years, SCIGN will become an integral part of the multi-agency, multi-disciplinary Plate Boundary Observatory (PBO), an observatory of high-precision geodetic instruments spanning western North America. Our NASA funded project is designed to meet objectives of NASA’s Earth Science Enterprise and represents NASA’s participation in PBO.

Currently, SCIGN provides GPS data and metadata and low-level data products. This project will enhance delivery of these products using modern IT methodology, and produce and disseminate an entirely new set of higher-level data products to a larger community, including scientists, government agencies (Federal, State, and Local), surveyors, and GIS professionals. Building on current capabilities within SCIGN for data archiving, information systems, and data analysis, the project will disseminate the following products: geodetic position time series, crustal motion models, strain rate maps, geologic fault models, near-real-time earthquake response information, geodetic reference systems for precise GIS and surveying, and aquifer recharge monitoring. To provide these data and data products in a highly available, highly integrated system numerous improvements in archiving, end-user interfaces, delivery mechanisms and data modeling will be developed. As part of the development of these advanced information systems components, we will develop a redundant, Virtual Archive for GPS applications.
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