Geodesy [G]

G21B MS:Exh Hall B Tuesday

Developing a Stable North America Reference Frame Posters

Presiding: G Blewitt, Nevada Bureau of Mines and Geology, University of Nevada, Reno; M Craymer, Geodetic Survey Division, Natural Resources Canada

G21B-0490

Investigation of site-dependent GPS errors and monument stability using a short-baseline network of braced monuments

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A short-baseline network that we have established at Yucca Mountain, southern Nevada, is enabling us to put new constraints on the level at which individual site motion can be detected by continuous GPS stations. We use this network to investigate and quantify aspects of the GPS error budget at a level of precision that would have been hard to imagine only a few years ago. The network consists of three GPS stations (established in 2006) with baseline lengths of ~10, 100, and 1000 meters with respect to site REPO (established in 1999). The four sites together lie along a N-S line, and have nearly identical instrumentation and setup configuration. The site with the shortest baseline to REPO (REP2) has a shallow-braced (to ~1 m depth) monument, while the remaining two sites (REP3 and REP4) and REPO are deep-braced monuments fixed into bedrock to a depth of ~10 m. This setup enables us to investigate processes affecting monument stability in a relatively controlled environment. In addition to the very short baselines, the desert environment of the area further reduces the influence of systematic errors in the results. Furthermore, the network was designed so that baselines to additional BARGEN sites at distances of ~10, 100, and 1000 km allow us to assess baseline-dependent errors over a full five orders of magnitude. Analysis of the data for the short-baseline network, using the GAMIT software, produces baseline time series with a very low level of noise (from tens to hundreds of microns). However, seasonal signals with amplitudes of ~0.1--0.5 mm are clearly discernible in some of the baseline time series, even for the shortest baselines. Surprisingly, these signals are primarily in the horizontal time series and are less evident in the vertical. Values for the RMS scatter of the daily baseline time series about simple models for the seasonal cycle are 0.04--0.16 mm for the east component, 0.06--0.18 mm for the north, and 0.10--0.48 mm for the vertical, with the higher values for the longer baselines. These numbers indicate the high precision of these measurements, but also leave us with the intriguing question regarding the cause of the seasonal signals. We will introduce the experiment, present these results, and discuss various hypotheses for the possible cause of these seasonal signals, including multipath and thermal effects.

G21B-0491 INVITED

The Translation and Rotation With Which to Define the North American plate

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Estimates of site velocity in International Terrestrial Reference Frame 2005 [Altamimi et al. 2007] may, we propose, be transformed into a reference frame in which the North America plate is fixed using: Translation 1.9 millimeters per year toward 82.6S 121.8E Rotation 0.205 degrees per million years CCW about 0.3N 96.6E Resulting estimates of vertical rate of site motion are relative to (CE) the mass center of just solid Earth. Using four space techniques we simultaneously estimate the velocity of CE and the angular velocity of the plates assuming that places on plates not beneath or along the margins of the former ice sheets are moving horizontally negliglibly realtive to CE. Our estimate velocity of CE is likely nearer the true velocity of (CM) the mass center of Earth, oceans, and atmosphere than the velocity of CM in ITRF2005. The velocity of CM differs between ITRF2000 and ITRF2005 by nearly 2 millimeters per year, suggesting that the velocity of CM estimated using SLR observation of LAGEOS is poorly constrained. No phenomena is believed to sustain a velocity between CM and CE for many years, and the velocity of CE is constrained tightly by the 4 space techniques.

G21B-0492

HTDP: A tool to partially correct survey data for tectonic motion

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Deformation in the western United States, due to tectonic forces associated with the Pacific-North American plate boundary, causes ongoing changes of the positions of points on the Earth's surface relative to a prescribed reference frame. As a result, accurate surveying in the western US requires an equally accurate description of this deformation to allow survey measurements conducted at different epochs to be corrected for such movement. NOAA's National Geodetic Survey (NGS) has developed the HTDP (horizontal time dependent positioning) software that enables its user to make these corrections to horizontal (latitude/longitude) coordinates. HTDP contains a model of the secular velocity field and separate models for the displacements associated with 28 earthquakes (1 from Alaska, 27 in California). This software will be updated periodically to address the displacements associated with each new earthquake. This paper describes a major update to the HTDP that is currently being developed. The new version includes an updated secular velocity field and new models for several recent earthquakes with M>6. Our model of the secular field is based on a block model of the western contiguous U.S., from the Rocky Mountains to the Pacific coast. It involves inverting several thousand horizontal velocity vectors, derived from repeated geodetic observations, hundreds of fault slip rates and fault slip azimuths. We have also updated models for the co-seismic and post- seismic displacements associated with the 2002 Denali, 2003 San Simeon, and 2004 Parkfield earthquakes. HTDP filled a critical role in facilitating the success of the recent NSRS2007 readjustment to estimate NAD 83 coordinates for nearly 70,000 U.S. control points. In particular, HTDP was used to update GPS data observed over the past 15 years to corresponding values as if these data were all observed on the same date. To demonstrate the effect that proper earthquake models can have on the adjustment of survey data, we adjusted GPS surveys performed in California, which span the hypo-central region of the Parkfield and San Simeon earthquakes, in each

of two ways; once using HTDP v2.8 which lacks models of the Parkfield and San Simeon earthquakes, and once using HTDP v2.9 which includes models for these earthquakes. Including the earthquake models reduced many of the larger residuals by a factor of 3.

G21B-0493 INVITED

Empirically-Derived Estimates of Glacial Isostatic Adjustment

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Generating numerical predictions of glacial isostatic adjustment (GIA) in North America is complicated by difficulties associated with constraining the full history of the ice sheet, as well as the 3D variations of mantle viscosity and lithospheric structure, with limited sets of observations. Moreover, many GIA predictions are calculated with spherically-symmetric Earth models, which may fail to capture the full range of possible crustal motions. However, most geodetic applications only require accurate estimates of the present-day variations in crustal displacement and gravity associated with GIA. Thus, Davis et al., 2006, developed a data assimilation technique to obtain a present-day estimate of GIA. The technique combines GPS and GRACE observations with the covariance of these signals derived from a set of forward model predictions. This approach has the advantage of allowing the data to improve the GIA estimate without having to associate these results with changes in input ice-sheet history and viscosity structure, which may be inadequate due to model limitations to describe the actual motions. To examine the robustness of the solutions resulting from this technique, we investigate the impact of the starting model used in the determination of the model covariances. In addition, we explore sampling issues and the ability to recover motions caused by lateral Earth structure by using input from a 3D numerical Earth model prediction sampled in the same manner as the GPS and GRACE inputs.

G21B-0494

A Velocity Field for the North American Plate Interior

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The determination of accurate continent-scale geodetic velocity fields in plate interiors is essential for investigating the processes that drive the deformation of continents and control the associated seismicity. Accurate continental-scale velocity fields are also important as reference frames for mapping crustal motions at plate boundaries. As the precision and accuracy of space geodetic techniques improves, coherent deformation patterns are now emerging from the analysis of continent-wide GPS data sets in plate interiors. In North America, studies have shown that the primary horizontal strain signal in the plate interior is consistent with that expected from Glacial Isostatic Adjustment (Calais et al., 2006; Sella et al., 2007). Current results indicate ~NS shortening at a rate on the order of 10^{-9}/yr in southern Quebec, the northeastern U.S., and just south and west of the Great Lakes, consistent with GIA, seismic moment release, and earthquake focal mechanisms in these areas. In contrast, no detectable surface strain is found south of about 38N, at the 0.7~mm/yr precision level (95% confidence). Sub-millimeter per year accuracy reamains however a challenge at the scale of an entire continent. We present an updated velocity field for North America that results from the combination of two independent solutions and includes about 800 sites. We discuss the implications of these results for earthquake hazard, glacial isostatic adjustment models, and for defining a Stable North America reference frame for geodetic studies in western North America.
http://web.ics.purdue.edu/~ecalais/projects/noam/

G21B-0495

Construction and Application of the Stable North America Reference Frame.

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In this talk, we discuss the construction of a stable North American reference frame from the combination of analyses of continuous and campaign GPS measurements at locations in North America. The stable reference frame is established by the alignment of the motions from this combined analysis with an expected glacial isostatic adjustment (GIA) set of motions at stable North American sites whose contemporary motion is believed to be due to only GIA. The root-mean-square (RMS) differences between the aligned velocities and the GIA model are 0.4 mm/yr horizontally and 1.5 mm/yr vertically. The aligned GPS analysis then allows the motions of sites in tectonically active regions to be determined in stable reference frame. The Plate Boundary Observatory (PBO) reference frame is then determined by aligning it to SNARF using sites in both GIA-only areas and in actively deforming regions for those sites that show linear motion. The RMS fit of the PBO reference to SNARF is 0.8 mm/yr and 2.5 mm/yr horizontally and vertically where the velocities in the PBO reference frame are determined form data collected since the start of PBO in 2004. The PBO realization of the SNARF reference frame is then used for daily determinations of positions in the PBO network. Comparison of velocities and time-series of daily realizations of the SNARF and PBO reference frames will be shown and discussed.

G21B-0496

SOPAC Reanalysis for SNARF and Web-based Analysis Tools

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SOPAC has been carrying out full scale GPS data reanalysis, both global and regional, as the participation of IGS reanalysis effort using most updated models and conventions. After resolving the meta data issue for CORS data set in northern America, we follow our plan to process a major subset of the data in a consistent manner and perform temporal and spatial analysis. We will report our processing/analysis strategies and preliminary result. As an effort to facilitate concerned scientists to carry out their studies, SOPAC is actively developing web-based analysis tools, such as time series analysis, spatial filtering, and strain rate estimates etc through interactive user interface and graphical presentations. We will demonstrate the implemented features

G21B-0497

Uncertainty in the Motion of the North American Plate and its Impact

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The motion of the North American plate in a geodetic reference frame is difficult to describe, because of the broad region of distributed tectonic activity in the west and the broad area of glacial-isostatic adjustment (GIA) in the north. Despite the large number of GPS sites in North America, the limited geographic extent of unambiguously stable North America increases the uncertainty in the estimate of the plate's angular velocity and makes the estimate sensitive to biases caused by even small systematic errors. Most estimates of the North American plate's angular velocity have not considered the effects of systematic biases, which is one reason why competing estimates often lie outside of the 95% confidence regions of each other. Additional uncertainty in the motion of the stable plate (in a geodetic frame such as ITRF) results from uncertainties in the realization of the frame itself, especially in the motion of the geocenter. The most recent estimates of the angular velocity come from Sella et al. (2007) and from the SNARF v.1 estimate. In the southeastern United States, these two angular velocities predict velocities that differ by only 0.1-0.3 mm/yr, so distinguishing between them using data from that region is exceptionally difficult. In the tectonically active western US, the difference between the two reaches 0.5 mm/yr, but in the far northwest, in Alaska and NE Russia, the difference can exceed 1 mm/yr. We estimate a more robust uncertainty for the motion of the plate in ITRF and test whether any sites in far northwestern North America can be considered to lie on the stable North American plate.

G21B-0498

Contributions of the North American Reference Frame Working Group to the next realization of the Stable North American Reference Frame (SNARF)

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Since the beginning of 2001, the Geodetic Survey Division of Natural Resources Canada (NRCan) has been playing a leading role in the North American Reference Frame (NAREF) Working Group of IAG Sub-commission 1.3c (Regional Reference Frames for North America). This supports the International Earth Rotation and Reference Frames Service (IERS) and the International GNSS Service (IGS) initiatives to densify the International Terrestrial Reference Frame (ITRF) in North America. The objective is to provide a globally consistent reference frame, including velocity models, procedures and transformations, tied to ITRF in which scientific and geomatics results (e.g., positions in tectonically active areas) can be produced and inter-compared. The NAREF densification network has evolved from a hundred continuously-operating GPS reference stations to nearly 1000. Following internationally accepted densification methodologies, regional North American GPS solutions, from several groups in Canada and the U.S., are combined into a single NAREF weekly solution that is aligned with the ITRF reference frame. The weekly NAREF solutions are subsequently combined into a single cumulative solution to provide estimates of both station coordinates and their velocities with respect to a consistent reference frame throughout North America. In order to provide an increased spatial sampling of crustal deformation throughout Canada, we also estimate velocities at sites of the Canadian Base Network (CBN) by combining over ten years of repeated multiple-epoch (episodic) GPS measurements. Initiated in 1994, the CBN is a network of high-stability pillar monuments with forced-centering mounts for GPS receiver antennas. To determine individual station velocities, regional CBN solutions for each measurement epoch are systematically combined into a Canada-wide cumulative solution. The resulting NAREF and CBN velocity fields display a high level of spatial- coherence and are being used to evaluate crustal deformations in various parts of the continent and to more accurately determine the motion of stable North America. More specifically these products have been used in the definition of a plate-fixed Stable North American Reference Frame (SNARF) for the Plate Boundary Observatory component of the EarthScope project. In this paper we present the NRCan-determined GPS velocity fields, and the resulting North American rotation pole derived from these efforts. We also describe recent changes in our processing and combination strategies in response to new procedures adopted by the IGS.

G21B-0499

The CORS network and improved understanding of the motion of stable North America

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NOAA's National Geodetic Survey created in 1994 the Continuously Operating Reference Station (CORS) network in partnership with site operators of continuously operating GPS (CGPS) sites who were willing to share their data with the public. The network currently contains ~1,200 stations located mostly in the United States and is growing at ~200 stations per year. In North America most tectonic studies of deformation using GPS have concentrated on the active plate boundary of the western US and have related observed motions to the stable eastern part of the plate. Initially limited attention was paid to the robustness of the definition of the stable part of the plate as it was assumed to have little to no motion. As the resolution of GPS analysis has improved, increasing attention is now being focused on understanding the stable part of the plate. This new focus has made extensive use of CORS data as it contains most of the available CGPS data east of the Rocky Mountains. Perhaps the most dramatic conclusion of these studies has been that glacial isostatic adjustment is the largest motion affecting the stable part of the North American plate. Quantifying the extent and magnitude of this motion is critical to ensure that it does not bias geologic interpretations based on millimeter to sub-millimeter level observations. Understanding this crustal deformation assists NGS's in its mission to maintain and improve the accuracy and access to the National Spatial Reference System (NSRS). In turn NGS has been significantly improving the CORS infrastructure in collaboration with its partners as they rapidly establish new CGPS sites for real-time positioning and their desire for millimeter level accuracy. Although the legally binding reference frame for North America is the non-geocentric NAD83, the Plate Boundary Observatory's Stable North American Reference Frame (SNARF) provides a key step in its eventual replacement/update.

G21B-0500 INVITED

Finding and Defining the Edges of Stable North America: Reference Frame Effects versus Real Tectonics

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The main significance of the new Stable North American Reference Frame (SNARF) is to provide a unique reference frame in which to analyze and interpret GPS velocities in the Pacific-North American plate boundary zone. SNARF is determined while taking into account the effect of glacial isostatic rebound, but is not implicitly constrained to yield crustal velocities across the western margin of the stable continent that are

consistent with other geophysical and tectonic indicators. For instance, one would expect SNARF-fixed velocities east of the Rocky Mountains and Rio Grande Rift to be insignificant from zero, but the question is still open whether they are. At the same time, the location of the edge of the stable continent in the northern Rockies and in Alaska is still unknown and SNARF-fixed velocities may be instrumental in defining this edge. However, our ability to find and define the edge of the stable continent relies generally on the adequateness of SNARF and may depend particularly on the way we realize the SNARF-fixed velocity field. To address these issues we derive and use a GPS velocity field from a ~600 station network across the North American continent. Data come from a variety of continuous GPS networks, including PBO and CORS, but also include data from semi-continuously observed sites observed by us in the Great Basin. The daily positions are determined with the GIPSY-OASIS II software, have fixed ambiguities, and are adjusted for regional common- mode effects. We show crustal velocity fields in a variety of reference frames, including various realizations of SNARF, and discuss them with respect to the regional tectonics. These exercises are important both to assess the validity and applicability of SNARF, and also to address, for example, whether the Rio Grande Rift is still active, or if any part of Alaska can be considered part of stable North America. http://geodesy.unr.edu

G21B-0501

Mega-Network GPS Solutions: Producing a Consistent, Global-Scale, and High-Resolution View of Plate Tectonic Stability, Rotation, and Deformation.

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We present a single self-consistent GPS solution for over 2000 stations with ambiguity resolution applied for the period 1994--2007. Here we demonstrate that such `mega-network' GPS solutions provide a consistent, global- scale, and high-resolution view of plate tectonics in action. Specifically our solution is used to investigate the stability of the North American plate, its rotation, intra-plate deformation, and deformation in the Pacific-North America Plate boundary zone. A significant improvement in precision and accuracy attributable to ambiguity resolution is quantified by (1) the reduction of variance of station position time series (`repeatability'), (2) the reduction of variance in motions between stations within stable plate interiors, and (3) the relative smoothness of the velocity field in the Great Basin of western North America. The software developed to produce this solution, AMBIZAP Version 2.0 (ftp://gneiss.nbmg.unr.edu/ambizap) was made publicly available in August 2007. The method builds seamlessly on the precise point positioning (PPP) method invented by Zumberge et al. in 1997, additionally providing improved accuracy at a fraction of the original computational cost. Like PPP, the computation time of AMBIZAP (including network adjustment) is linear with number of stations N, unlike previous algorithms that exhibit power-law behavior, which presents a barrier to processing N >> 100. The longer-term significance of this development is the ease with which the software could be applied to N ~ 10000 GPS networks worldwide within the foreseeable future, including the N > 1000 Plate Boundary Observatory, which is already nearing completion.

Author(s) (2007), Title, Eos Trans. AGU, 88(52), Fall Meet. Suppl., Abstract #####-##.