G41C-05 1120h

Tidal Aliasing Induced Annual and Semi-annual Artefacts in Continuous GPS Height Time Series

Nigel T Penna[1] (61-8-9266-7604; nigel.penna@curtin.edu.au)

Michael P Stewart[1] (61-8-9266-7600; stewart@vesta.curtin.edu.au)

[1] Western Australian Centre for Geodesy, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

Coordinate time series are often derived from continuous GPS data processed as discrete 24 hour solutions. With this approach, residual semi-diurnal and diurnal crustal tide signatures are under-sampled, and aliased periodic signals in the coordinate time series arise. A secondary aliasing effect, well known from satellite altimetry studies but generally ignored in GPS analysis, arises from the repeat period of the satellite orbits being longer than the Nyquist period of the semi-diurnal and diurnal tidal signatures. The theoretical periods for these two aliasing effects are derived for the principal semi-diurnal and diurnal tidal constituents and their presence demonstrated in height time series derived from both simulated and real GPS data. It is shown that the beating of the two aliased signals invariably results in spurious time series signals with semi-annual and annual periods. Hence inadequate modeling of semi-diurnal and diurnal tidal constituents of the site deformation caused by ocean tide loading and Earth tides, can result in spurious semi-annual and annual signatures in the GPS height time series.

G41C-06 1135h

Seasonal Vertical Signals in GPS geodesy: Consequences of Using a Linear Reference Frame Model

Daniel J Johnson (dj@ess.washington.edu)

University of Washington, Department of Earth and Space Sciences, Seattle, WA 98195-1310, United States

Geodetic positions derived from GPS observations are intrinsically relative. Generally, raw GPS solutions at a given epoch are adjusted to assign a meaningful reference to the final positions. The reference frame is, in practice, a subset of GPS sites contained in the solution along with a model that specifies secular motion of those sites. The simplest reference frame is one of a pair of stations that define a baseline. Position and motion at the other site, then, could be expressed relative to the base station which, in most cases, is assumed to be motionless, or "fixed". A more complex approach is to standardize a collection of sites. To first order, the rate of tectonic motion at many locations on the Earth's surface is constant. The real motion at a typical site is also likely to be gradual and progressive on a day-to-day timescale. Hence, a reasonable choice for a model that describes motion of the reference sites is a linear model. Adjustment of the raw GPS observations, then, may be realized by shifting the solution as a whole so that the subset of reference sites matches the positions predicted by the linear model. For extended and global networks, a seven-parameter (3 translations, 3 rotations, and a scale factor) transformation is generally utilized. Position timeseries derived from adjusted GPS observations have several characteristics that may be traced to the reference frame fitting procedure. First, alignment of daily geodetic solutions with a simple model of motion of the reference sites, such as a linear model, tacitly forces day-to-day positional changes at reference sites to be gradual and progressive, similar to the model that the solutions are being fit to. In most cases, this is desirable as much of the day-to-day fluctuation in apparent position of a GPS site is likely noise. Clearly, day-to-day fluctuations that correlate between all sites within a network is not real - this coherent jitter is removed through adjustment to the reference frame model, yielding a smoothed result. The second characteristic is that velocities calculated from the adjusted solutions are linked to the base motion imposed by the reference frame model. The final characteristic - which is not a benefit, but is a problem - is that alignment of GPS solutions with a linear reference frame model means that the resulting individual station timeseries will tend to be linear as well. This is because all common-mode differences between the raw solutions and the reference frame model are subtracted out. Seasonal patterns that deviate from linearity will be removed if are coherent over the entire network. Over 100 globally distributed GPS sites have been analyzed here using GIPSY/OASIS II in a fiducial-free reference frame. The origin of the raw station coordinates is inherently close to the center of mass of the Earth system, meaning that the vertical component of site positions is well determined in the raw solutions. Inspection of the raw coordinates reveals a network-wide seasonal pattern of motion aligned with the Earth's polar axis. This coherent motion is largely removed by applying reference frame constraints. Seasonal deformation cycles related to degree-one loading are poorly managed by typical linear reference frame constraints. Some degree-one vertical motion may be absorbed by the scale parameter in the transformation which, unfortunately, will then propagate the motion to other sites as noise. Due to imbalances in the distribution of GPS sites between hemispheres, this may have the effect of creating an apparent reduction in the amplitude of annual vertical motion in the northern hemisphere and enhanced amplitudes in the southern hemisphere.

G41C-07 1150h

Development of an in situ Antenna and Multipath Calibration System for GPS Geodesy

Kwan-Dong Park[1,2] (kdpark@kao.re.kr); Pedro Elosegui[1] (pelosegui@cfa.harvard.edu); James L. Davis[1] (jdavis@cfa.harvard.edu); Brian E. Corey[3] (bec@haystack.mit.edu); Arhur E. Niell[3] (aen@haystack.mit.edu); Per O. J. Jarlemark[4] (per.jarlemark@sp.se); James E. Normandeau[1] (jnormandeau@cfa.harvard.edu); Chuck E. Meertens[5] (chuckm@ucar.edu); Victoria A. Andreatta[5] (victoria@ucar.edu)

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, United States

[2] Korea Astronomy Observatory, 61-1 Hwaam-dong Yuseong-gu, Daejeon 305-348, Korea, Republic of

[3] MIT Haystack Observatory, Off Route 40, Westford, MA 01886, United States

[4] SP Swedish National Testing and Research Institute, Box 857 SE-501 15, Boras 00000-0000, Sweden

[5] UNAVCO Facility, P.O. Box 3000, Boulder, CO 80307, United States

Geophysical applications of the Global Positioning System (GPS) for studies such as global sea level change and glacial isostatic adjustment require very high accuracy (∼1 mm/year) determinations of site velocity, especially of its vertical component. However, site-dependent errors such as antenna phase-center variations, multipath, and scattering can have a significant effect on high-precision GPS applications. Despite the many efforts devoted by investigators to the calibration of those site-dependent errors, determination of these errors has proven to be elusive, since no method has been developed to measure these effects accurately in situ. We have designed and constructed a prototype antenna and multipath calibration system (AMCS) to obtain such in situ corrections. The AMCS consists of a parabolic antenna that is relatively free from these site-dependent errors. We obtain phase corrections for these errors by forming the difference between the carrier-beat phase from the GPS antenna to be calibrated and the AMCS antenna. Preliminary "sky maps" of the antenna phase and multipath contributions show root-mean-square (RMS) phase variations that are a factor of ten or more greater than the AMCS noise system we expected. To explore the source of this noise, we acquired observations over small (few degrees) patches of the sky. From the analysis of these experiments, we conclude that the source of the phase variations is antenna and multipath errors that vary ∼5 mm over small changes in satellite direction. Thus, for example, differences of 1° in elevation angle can result in several mm variations in phase. Similarly, small variations in azimuth angle can also result in significant phase variations. We have also observed day-to-day mm-level changes in the calibration. We hypothesize that these phase variations are due to changes in multipath caused by changes in the local electromagnetic environment associated with, e.g., weather.

G41C-08 1205h

Recovering Height and Geodetic Scale with GPS

Thomas Yunck[1] (818-354-3369; tpy@jpl.nasa.gov); Michael Heflin[1] (818-354-2823; michael.b.heflin@jpl.nasa.gov); Frank Webb[1] (818-354-4670; frank.h.webb@jpl.nasa.gov); Danan Dong[1] (818-393-1827; danan.dong@jpl.nasa.gov); Sharon Kedar[1] (818-393-6808; sharon.kedar@jpl.nasa.gov); Pascal Willis[1] (818-393-4748; pascal.r.willis@jpl.nasa.gov)

[1] Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

As the techniques of space geodesy - satellite laser ranging (SLR), very-long-baseline interferometry (VLBI), and the Global Positioning System (GPS) - continue to improve, much effort is being focused on applying them to refine the global reference frame in support of geophysical research. One of the more challenging quantities to pin down is the frame's "absolute scale," which is directly related to the heights of the observing sites. While the absolute scale is itself of little interest, its long-term stability is critical. Spurious variations in the scale over time would manifest as apparent variations in the size of the earth, compromising studies of sea level change, post-glacial rebound, and the like. It is generally agreed that of the three operational space geodetic techniques, VLBI is pre-eminent in both the accuracy and stability of scale determination, followed closely by SLR. The performance of GPS in determining scale is not as well understood and is the subject of considerable debate. With its broad-beam transmitting and receiving antennas GPS is subject to multipath and direction-dependent phase variations, raising doubts concerning the quality of its height and scale solutions. Opinions range from "scale with GPS is undefined" to "GPS scale accuracy approaches that of VLBI and SLR." In this presentation we step through the arguments and evidence concerning GPS scale determination and present precise new results that may help to settle the question.

G42A MCC: Level 1 Thursday 1330h

Progress in Imaging and Understanding the Surface Deformation Field Above Reservoirs II Posters *(joint with H)*

Presiding: **D W Vasco,** Berkeley Laboratory, University of California, Berkeley**; H J Kuempel,** Leibniz Institute for Applied Geosciences

G42A-0039 1330h POSTER

Irregularities in Pump-Induced Tilt Above Shallow Aquifers

Hans- J. Kuempel[1] (49-511-6433496; kuempel@gga-hannover.de)

Marcus Fabian[2] (fabian@geo.uni-bonn.de)

[1] Leibniz Institute for Applied Geosciences, Stilleweg 2, Hannover 30655, Germany

[2] Geological Institute, Section Applied Geophysics, Bonn University, Nussallee 8, Bonn 53115, Germany

Near surface ground tilt induced by the extraction of fluids from subsurface reservoirs has repeatedly been used to constrain reservoir parameters. In general, pump-induced tilt is found to be proportional in strength to the pore pressure gradient created by the pumping, to be a function of poroelastic rock parameters, and to depend on the geometric configuration of the tilt sensor and the productive sections of a well. Assuming radial flow, the strike of the tilt signal should point toward the productive well. However, inversion of near surface tilt can be hampered through irregularities in the pump-induced signal and suffer from insufficient knowledge of the influence of heterogeneities in the subsoil, either within or above the reservoir. We can learn more about the impact of such heterogeneities and reduce ambiguities by analyzing case studies. New observational data from 3 test sites in Germany confirm that a variety of causes can produce irregularities in pump-induced surface deformation, namely: (1) The strike of a tilt signal can considerably deviate from the direction toward the active well. A reason could be that the steepest effective pore pressure gradient builds up in another than radial direction (thereby generating anisotropic fluid flow). Accordingly, tilt hodographs for a complete pump cycle may be elliptic rather than follow a line. (2) The normal rule of how the signal strength depends on the horizontal and the vertical distance may be violated. Structural heterogeneities in the subsurface are the most likely cause for this behaviour. (3) Recovery of the induced tilt signal following the cessation of pumping can be incomplete. This could indicate a non-reversible compaction possibly due to overexploitation of a reservoir. (4) A transient sign reversal of ground tilt may occur during the build-up phase of the signal. This feature could be an analogue to the so-called Noordbergum effect occasionally seen in the response of well levels at locations aside from the pumped well. We conclude that near surface deformation in the vicinity of pumped wells bears a wealth of information that may be useful to constrain the conditions of fluid flow at depth, and that there is often a need for model calculations to fully understand the involved phenomena.

G42A-0040 1330h POSTER

InSAR Observed Surface Deformation at the Buckman Well Field, New Mexico

Davis R. Thomsen[1] (858 822-4080; dthomsen@ucsd.edu)

Yuri Fialko[1] (858 822-5028; fialko@radar.ucsd.edu)

[1] Scripps Institution of Oceanography, 9500 Gilman Dr. MC 0225, La Jolla, CA 92093-0225, United States

We report on Interferometric Synthetic Aperture Radar (InSAR) measurements of surface deformation at the Buckman well field near Los Alamos, New Mexico. Based on several interferometric pairs, each spanning a three-year time period, we observe localized ground subsidence over a $\sim$25km^2 region with a maximum line of sight displacement rate of $\sim$2cm/yr. The deformation pattern is elongated in the north-south direction with an aspect ratio of 1:3. Based on the spatial correlation of the ground subsidence anomaly and the Buckman well field, we infer that this subsidence is a result of water withdrawal from the underlying aquifer. In 2002, a half-mile fissure with nearly twenty centimeters of offset has developed parallel to the long axis of observed deformation. This fissure is coincident with the recent increase in water withdrawal from the well field. However, deformation rates inferred from satellite interferometry are relatively low over the latest observed time period before failure (1997-1999), compared to the deformation rates observed in the earlier epochs (1993-1997). We interpret these observations as indicating a non-linear response of the upper crustal rocks prior to yielding caused by the water withdrawal and concomitant ground compaction.

URL: http://topex.ucsd.edu

G42A-0041 1330h POSTER

Aquifer Deformation in the Virgin River Valley, Nevada: GPS Sensitivity to Deformation Over Various Time and Distance Scales

Geoffrey Blewitt[1] (1-775-784-6691; gblewitt@unr.edu)

Thomas J Burbey[2] (tjburbey@vt.edu)

John Bell[1] (jbell@unr.edu)

Sandra M Warner[2] (smwarner@vt.edu)

Emma M Hill[1] (emmahill@seismo.unr.edu)

[1] Nevada Bureau of Mines and Geology, and Seismological Laboratory, University of Nevada, Mail Stop 178, Reno, NV 89557, United States

[2] Department of Geological Sciences, Virginia Tech, Blacksburg, VA 24061, United States

As reported in this session [Warner et al., 2003], we have used GPS to quantify aquifer storage in the Virgin River Valley, Nevada during a three-month period of controlled pumping. Here we assess the use of GPS as a tool for aquifer deformation research, including experiment design, logistical considerations, data processing strategy, the quality of the station displacement time series, and the fitness of these time series to detect and quantify transient deformations over a variety of spatial and temporal scales. The physics of the aquifer deformation model being tested drove the network design. As time from the onset of pumping increases, the model predicts that the location of maximum surface strain propagates away from the pump head; so the surface deformation pattern scales spatially with time. In order to broaden the bandwidth of signal sensitivity with respect to time, GPS stations were situated along an approximate straight line leading away from the pump head, with an ever-increasing spacing between stations. We investigate how sensitivity to the deformation pattern depends on the characteristic distance and temporal scales that are unique to aquifer deformation problems. Distances between the GPS stations and the pump head ranged from 200 – 2,000 meters. As distance increases, one might expect the GPS relative displacement errors to increase due to decorrelation of tropospheric and ionospheric delay. In the absence of ionospheric errors, simultaneous processing L1 and L2 carrier phase data can improve relative positioning by a factor of 3 as compared to processing the standard ionosphere-free linear combination of L1 and L2, due to improved signal to noise (including multipath suppression). We assess such signal-to-noise characteristics using the observed deformation data from our aquifer deformation experiment, and draw conclusions on optimal network design and parameter estimation strategy.

G42A-0042 1330h POSTER

Permeable image using surface deformation and pore pressure through modeling tests

Kiyoshi Kishida[1] (817537535075; kishida@mbox.kudpc.kyoto-u.ac.jp)

Kenzi Karasaki[2]

Donald w Vasco[2]

Toshihisa Adachi[3]

[1] Kyoto University, Dept. of Urban Management Kyoto University Sakyo, Kyoto 6068501, Japan

[2] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, United States

[3] Geo-Research Institute, 4-3-2 Itachibori Nishi-Ku, Osaka 5500012, Japan

It is important to monitor the volume change and permeability in a subsurface when we consider the safety of the underground structure, slope stability, and the geotechnical environmental issue. In general, borehole survey has been applied to monitor of the geological condition. It has an advantage because of the directly monitoring. On the other hand, it has disadvantage for the wide range monitoring. As the high accuracy tilt meter has been developed, the inversion of surface displacement has been developed. In the research work, a coupled inversion of transient pressure and surface displacement is applied to the laboratory withdrawal modeling test. As compared inversion results with experimental results, the validity of the coupled inversion will be discussed.

G42A-0043 1330h POSTER

Monitoring anthropogenic subsidence using an absolute gravimeter in Jülich (Germany)

Michel Van Camp (3223730265; mvc@oma.be)

Royal Observatory of Belgium, Avenue Circulaire, 3, Brussels B-1180, Belgium

Since October 2000, absolute gravity (AG) measurements have been performed twice a year at the Jülich Research Centre, Germany. This station is located in an industrialised area, closed by two opencast brown coal mines located at 4 km from the Research Centre. To prevent the mines from being flooded, continuous water pumping has been carried out for 50 years, causing a subsidence of more than 1 cm/yr. This presentation shows the possibility to carry out satisfactory AG measurements in a noisy environment, able to evidence the subsidence. Today, we observe a trend of $+3.7\pm1.3$ μGal/year, which can be interpreted as a subsidence of -1.8 ± 0.7 cm/yr, comparable to the repeated levellings and GPS measurements. Assuming that the seasonal effects are the same each year, other things being equals, we should be able to confirm this gravity rate of change at the 95% confidence level at the beginning of 2004, and at the 99% level one year later. The AG Jülich observations are a long-term project and will get an insight into mass redistribution phenomena related to gradual surface subsidence.

G42A-0044 1330h POSTER

Application of a Model for Coupled Multiphase Fluid Flow, Heat Transport, and Mechanical Deformation to Surface Deformations Associated with Volcanic Activities

Rutqvist Jonny[1] (510-486-5432; jrutqvist@lbl.gov)

Micol Todesco[2] (todesco@geomin.unibo.it)

Chin-Fu Tsang[1] (cftsang@lbl.gov)

[1] Lawrence Berkeley National, Laboratory Earth Sciences Division, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, United States

[2] Universita di Bologna, P.zza P.ta San Donato,1, Bologna I-40126, Italy

A model for analysis of coupled multiphase fluid flow, heat transport, and mechanical deformation (TOUGH-FLAC) is applied to study the role of hydrothermal circulation in ground deformation episodes (associated with volcanic activities) at the Phlegrean Fields in Italy. We calculate the effects of an increased magmatic degassing on the deformation of a shallow elastic porous medium. Our results show that a short period of increased release of fluids from the magma chamber into the shallow hydrothermal system can represent a potential trigger for slow ground deformations, through the effects of coupled hydrologic-mechanical (effective stress) and thermal-mechanical (thermal expansion) processes. The comparison between these preliminary results and field data shows that the model captures both the temporal evolution of ground displacement and the compositional variations of fumarolic gas recently observed at the Phlegrean Fields. Such ground deformations are usually interpreted as the product of an incremental pressure increase at the magma chamber level. The results of this analysis also suggest that the movements of hot hydrothermal fluids in the shallow system play an important role in the deformation process.

G42B MCC: 3005 Thursday 1340h

Advanced Tropospheric Sensing Methods and Accuracy of Tropospheric Information Determined by Space Geodetic Techniques I *(joint with A)*

Presiding: **P Elosegui,** Harvard-Smithsonian Center for Astrophysics**; Y Bar-Sever,** Jet Propulsion Laboratory, California Institute of Technology

G42B-01 1340h INVITED

Trends in the atmospheric water vapor content derived from space geodetic and remote sensing techniques.

Rudiger Haas[1] (+46.31.772.5530; haas@oso.chalmers.se)

Gunnar Elgered[1] (kge@oso.chalmers.se)

Jan Johansson[1] (jmj@oso.chalmers.se)

Lubomir Gradinarsky[1] (lbg@oso.chalmers.se)

[1] Onsala Space Observatory, Chalmers University of Technology, Rao, Onsala SE-439 92, Sweden

The amount of water vapor in the atmosphere is an important parameter for climate related research. Space geodetic and remote sensing techniques are sensitive to this parameter and thus might provide complementary information to the traditional meteorological techniques. However, the techniques have individual advantages and disadvantages in terms of temporal and spatial resolution and instrumental stability. Therefore a combination of time series of atmospheric water vapor derived from independent and co-located space geodetic and remote sensing techniques seems to be an appropriate strategy to obtain robust and consistent results for possible trends in the atmospheric water vapor. We use the independent and co-located techniques of geodetic VLBI, GPS and microwave radiometry at the Onsala Space Observatory and additionally radiosonde observations taken at the Landvetter airport in 38 km distance to investigate possible trends. Different statistical approaches are applied and the results are compared to climate models.

G42B-02 1355h INVITED

Combination of GPS and VLBI Troposphere Parameters of the CONT'02 Campaign and Comparison With WVR

Markus Rothacher[1] (rothacher@bv.tum.de); Daniela Thaller[1] (daniela.thaller@bv.tum.de); Ralf Schmid[1] (schmid@bv.tum.de); Manuela Kruegel[2] (kruegel@dgfi.badw.de); Volker Tesmer[2] (tesmer@dgfi.badw.de); Detlef Angermann[2] (angerman@dgfi.badw.de)

[1] Forschungseinrichtung Satellitengeodaesie, TU Munich, Arcisstrasse 21, Munich D-80290, Germany

[2] Deutsches Geodaetisches Forschungsinstitut, Marstallplatz 8, Munich D-80539, Germany

In October 2002, organized by the International VLBI Service for Geodesy and Astrometry (IVS), a 15-day campaign of continuous VLBI observations, named CONT'02, took place. During this campaign also water vapor radiometers (WVRs) were co-located at several of the eight VLBI sites to measure the integrated water vapor in the atmosphere. Therefore, the CONT'02 campaign is well-suited to compare and to combine the information about the troposphere derived from VLBI, GPS, and WVRs. Using the two weeks of CONT'02 data from VLBI and the global GPS data of the same time span, daily unconstrained normal equations were generated, taking much care to use identical models (solid Earth tides, ocean loading, a priori tropospheric delays, a priori nutation model, . . .) and the same parameterization of the common parameters, i.e., site coordinates, Earth Orientation Parameters (EOPs) and tropospheric zenith delays and gradients, for both space geodetic techniques. In this contribution we focus on the combination aspects related to troposphere, namely, on the corrections necessary between the co-located VLBI, GPS, and WVR points, the assessment of (systematic) biases between the techniques, the importance of the local tie information used, and the impact of a rigorous combination of troposphere zenith delays and gradients from VLBI and GPS on other parameter types of the solution (e.g., site coordinates).