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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

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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

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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)

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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

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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.

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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

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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).

G42B-03 1410h INVITED

Accuracy Requirements for Moisture Observations Using Space Geodetic Techniques

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Most of our information about the structure and variability of moisture in the atmosphere comes from three operational sources: radiosondes, surface measurements of dew point temperature (convertible to relative humidity), and satellite measurements of brightness temperature in the infrared and microwave portions of the electromagnetic spectrum. These observing systems function synergistically, since no one system provides all of the information required for weather forecasting, climate monitoring, and scientific research. Notwithstanding the strengths of the operational composite moisture observing system, its shortcomings preclude significant advances in weather prediction, our understanding of atmospheric processes, and climate monitoring and prediction. In recent years, the use of space geodetic techniques for atmospheric remote sensing has been proposed, demonstrated and verified. Space geodetic techniques, especially techniques using the Global Positioning System, have certain attributes that strongly complement both operational (or soon to be operational) and research observing systems. NOAA's Forecast Systems Laboratory in Boulder, Colorado, has been evaluating techniques to retrieve integrated (total atmospheric column) precipitable water vapor (IPW) from zenith tropospheric signal delays since 1994, and use IPW in operational weather forecasting since 1997. As a result of these evaluations, the use of ground-based GPS-Met is expected to become operational within the National Weather Service over the next few years. However, space geodetic techniques will neither replace conventional observing systems, nor will they completely mitigate their deficiencies. In this talk, I will review the requirements for water vapor measurement accuracy, and show that this is application dependent. I will then discuss the strengths and weaknesses of the more common operational moisture sensing systems, and examine the attributes of some space geodetic techniques in this context.

URL: http://gpsmet.noaa.gov

G42B-04 1425h

Statistical distributions for water vapor parameters

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In assessing the accuracy of atmospheric information obtained from GPS observations, it is customarily (and conveniently) assumed that water vapor parameter estimates follow a Gaussian distribution. This assumption is clearly inappropriate for atmospheric information of interest such as wet zenith delays and wet delay gradients. Wet zenith delay estimates, for example, can present very asymmetric (skewed) distributions, and wet delay gradients are known to be nearly zero for most of the time accompanied by instances of relatively large values. A Gaussian distribution is a poor descriptor of such parameters. It is thus critical to determine the statistical basis of these atmospheric parameters for assessing the accuracy of GPS-based meteorological and climatological inferences and predictions. Comparisons of root-mean-square and other statistics that are based on a Gaussian assumption will lead to erroneous conclusions regarding the significance of these statistics. In this presentation, we will describe our theoretical approach and experimental studies to determine the statistics of water vapor parameters.

G42B-05 1440h

An error analysis of ground-based GPS slant-path residuals in a simulation study

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The accuracy of a method for obtaining slant-path delays from GPS double difference residuals is assessed in a severe squall line case. To retrieve the absolute value of phase delay along each ray path from GPS double differences, Alber et al. (2000) introduced "zero mean difference assumption" as an additional independent constraint. In this study, we perform an error analysis of the zero mean difference assumption by simulating "true" slant-paths defined by GPS receiver sites and satellite orbits in a high-resolution numerical weather prediction model. Using these slant delays we examine the validity of the so-called "zero mean assumptions". Despite the existence of a strong systematic bias associated with the surface cold front and severe convection, deviation from the zero mean difference assumption is on the order of a few mm in the unit of phase delay. This implies that slant-path residuals contain useful information on the spatial variability even when the zero-mean assumption is violated due to atmospheric conditions. The representative error is also investigated by comparing the vertically integrated zenith hydrostatic delay with the one averaged over all available zenith-mapped slant hydrostatic delays for a certain period of time. In spite of strong horizontal pressure gradient over the entire observation network, the representative error of zenith hydrostatic delay is about 0.1%.

G42B-06 1455h

Assessing the Accuracy of Slant Path Measurements Using a High Resolution Numerical Weather Model

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The ability to derive the delay induced by the neutral atmosphere along individual ray paths between a GNSS satellite and a receiving station can provide more detailed atmospheric information than zenith delay measurements. These line-of-sight integrals are often called slant path delays. Comparisons of slant water vapor measured by a pointing microwave radiometer and a collocated GPS receiver have shown better agreement than comparisons of the more commonly estimated zenith wet delay or precipitable water vapor. We have investigated the errors in slant path measurements using simulated observations from a high-resolution numerical weather model. This simulation described the passage of a squall line over a large portion of the United States Southern Great Plains region and had a high degree of both hydrostatic and wet delay variability. This simulation provided the opportunity to study the effect of realistic systematic and random errors on the slant delay sensing technique. We found that the largest errors in the estimated slant path values are systematic in nature and affect all neutral atmosphere delay estimates in the same way. This means that systematic errors introduce errors in the zenith delay estimates that are then mapped into the slant delay estimates. In contrast, the error in determining the anisotropic delay between a GNSS satellite and a receiving station is small. In summary, the retrieved slant path values can have periods where systematic errors result in significant errors of the estimated zenith delay, while the anisotropic variability of the atmosphere can still be recovered with high precision.

G42B-07 1510h INVITED

A Multi-Sensor Approach to Estimation of Line of Sight Tropospheric Delays

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We will discuss techniques for optimal integration of atmospheric measurements from collocated GPS receiver, pointed WVR, and a barometer, capitalizing on the unique strength of each sensor, and minimizing the impact of the sensor's weaknesses. The goal is to improve our ability to estimate line of sight (LOS) total atmospheric delay, which is required in support of certain high precision applications, such as radio science, and deep space navigation. The benefits from improved atmospheric sensing extend to many other applications such as geodesy and time transfer. The WVR's strength is its unparalleled accuracy in sensing the water vapor content along a given LOS, which produces the "wet" delay of a radio signal. But WVRs are incapable of measuring the contribution of the dry atmosphere to the delay, the fluctuations of which are a significant error source for certain radio science applications. GPS data is directly sensitive to the total tropospheric delay (wet plus dry). However, GPS analysis has so far failed to demonstrate comparable sensitivity to the WVR in resolving LOS delays. By using WVR to calibrate the line of sight wet delays affecting a collocated GPS receiver we will be able to tune the GPS estimation strategy to extract only the slowly varying dry delay component, improving the GPS retrieval accuracy. Barometric measurements may be used to further reduce the number of estimated parameters by modeling the zenith dry delay. The combined total delay provides the best estimate of the LOS total delay. We assess the performance of these techniques by processing experimental data from a Lamont, Oklahoma site, where all three instruments (GPS, WVR, barometer) were collocated, and describe the broad benefits of this approach.

G42B-08 1525h

Interferometry with GPS Low Earth Orbiters Occultations

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GPS signals reflected off the Earth surface can be detected by receivers aboard occulting Low Earth Orbiters (LEO). The geophysical information contained in such reflected signal, has been partially clarified for using radioholographic analysis. After calibration, occultation geometry and the troposphere have the main contributions to the relative delay between direct and reflected signal. The reflected-to-direct relative delay is a function of the location of the reflecting surface as well as the different effect of the troposphere on both ray paths. Information can be obtained from precise measurements of the interferometric delay, and by separating the geometric from the atmospheric effect. This talk presents novel results with centimetric precision in carrier-phase reflected-to-direct relative delay from GPS to LEO occultations. The separation techniques will be discussed and potential applications of the interferometric delay to Ice surface topography, super-refractivity layer determination, marine boundary layer height detection will be given. Detection of super-refractivity conditions by the interferometric signal can lead to further refinements in the retrievals of lower atmospheric refractivity profiles where biases are known to exist.

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G42C MCC: 3005 Thursday 1600h

Geodesy of Terrestrial Planets II

(joint with P)

Presiding: **D E Smith,** NASA Goddard Space Flight Center**; T Van Hoolst,** Royal Observatory of Belgium

G42C-01 1600h INVITED

Geodesy of Amalthea and the Galilean Satellites of Jupiter

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An important scientific legacy of the Galileo mission is the determination of the masses and quadrupole components of the gravitational fields of the Galilean satellites. A final report of the mission results is given including values of GM (G is the universal gravitational constant, M is satellite mass), the gravitational coefficients J_2 and C_{22}, and the correlation coefficient μ between J_2 and C_{22}. The values of J_2 and C_{22} are deduced using the *a priori* assumption $J_2 = (10/3)C_{22}$.