Workshop for continuous GPS monitoring of tectonic, atmospheric, hydrologic, and volcanic processes in Mexico

June 12, 2009

By UNAVCO, Inc.
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Project Summary

We request funding to convene a workshop for US, Mexican, and international participants to initiate the planning phase for a 70-100 station continuous GPS network suitable for studying tectonic, atmospheric, hydrologic, and volcanic processes and hazards in Mexico. More than 50 existing continuous GPS stations in Mexico already constitute a backbone of the proposed new network. A key objective of the workshop is to assemble the individuals and institutions currently operating these sites to discuss the rationale and strategy for combining the existing GPS instruments with new GPS and ground-based metrology instrumentation and borehole strain meters to create a powerful tool for basic research, hazards monitoring, and applied work in Mexico. Funds are being requested from CONACyT to pay the workshop expenses for most invited Mexican scientists. On behalf of the conference organizers, UNAVCO seeks support for 18U.S. scientists and students from the solid Earth, atmospheric, and hydrologic disciplines, and additional Mexican participants for the three-day workshop. The workshop will be held at a Mexican venue, most likely in Puerto Vallarta.

Intellectual Merit

Cooperative research between Mexican and US solid earth scientists has been well established over decades due to the geographic contiguity of the two countries and numerous commonalities in their geodynamic settings. In particular, seismically hazardous faults that extend for hundreds of km on either side of the border in southern California and the Baja California peninsula have inspired cooperative research, as have the many similarities between the subduction zones of Cascadia and western Mexico, and between the US and Mexican Basin-and-Range provinces. Similar cross-border linkages for atmospheric and hydrologic processes are stimulating cooperative work between Mexican and US scientists. For example, the North American Monsoon (NAM) delivers half or more of the annual precipitation to the southwestern US and northwestern Mexico, but is poorly understood due to a lack of suitable meteorological observations within Mexico. Hydrologic forecasts for this dry region depend critically on how atmospheric warming will affect NAM. In all three domains (atmospheric, hydrologic, solid earth), critical observations are available in the US from a variety of sources, including the EarthScope Plate Boundary Observatory (PBO) continuous GPS array. The proposed workshop will plan for establishing a continuous GPS network in Mexico where observations will significantly benefit Mexican and other researchers in all three disciplines, while having significant practical benefits for Mexico.

Broader Impact

The international scope of the workshop and its multidisciplinary scientific objectives give the workshop unusually broad implications, ranging from seismic hazards for large areas of southern Mexico, including Mexico City, to atmospheric, surface, and ground water budgets in dry areas of northern Mexico and the southwest U.S. The workshop will provide a much needed forum for the individuals and institutions that operate continuous GPS stations in Mexico to address the scientific, practical, and societal benefits of merging their operations into a unified GPS network with open data sharing and standardized equipment and communications and to address the needs of agencies engaged in hazards monitoring and response. The workshop will thus take the first, critical step toward leveraging the roughly one million US dollars that have already been invested in CGPS in Mexico to construct a unified and sustainable solid Earth and atmospheric imaging tool. We also expect the workshop to foster new collaborations between Mexican, US, and other scientists who attend. At least two graduate students and an early career scientist, possibly including protégés of the UNAVCO RESESS or UCAR SOARS internship programs or groups underrepresented in STEM fields, will be also be selected to participate.

Workshop for continuous GPS monitoring of tectonic, atmospheric, hydrologic, and volcanic processes in Mexico

Puerto Vallarta, Mexico, April 2010

Organizing Committee
Charles DeMets, University of Wisconsin
Enrique Cabral & Vladimir Kostoglodov, Universidad Nacional Autonoma de Mexico
UNAVCO PI: M. Meghan Miller

Summary of Request: We seek $49,915 to convene a workshop for US, Mexican, and selected other international participants to initiate the planning phase for a 70-100 station continuous GPS network suitable for studying tectonic, volcanic, atmospheric, and hydrologic processes and hazards in Mexico. More than 50 existing continuous GPS stations in Mexico constitute the backbone of the proposed new network – a key objective of the workshop will therefore be to establish a collaboration among the individuals and institutions who operate existing GPS sites with new GPS, ground-based metrology and borehole strain meter observations in order to define a science plan and create a powerful tool for basic research, hazards monitoring, and applied work in Mexico. Funds are being requested from CONACyT to support invited Mexican scientists. On behalf of the conference organizers, UNAVCO seeks support for 18 U.S. scientists and students from the solid Earth, atmospheric, and hydrologic disciplines, and Mexican participants for the three-day workshop. The workshop will be held at a Mexican venue, most likely in Puerto Vallarta at the facility that hosts the Mexican Geophysical Union meetings

Introduction

Over the past decade, two phenomena more than any others have raised the consciousness of scientists and the public about the importance of international cooperation in studying natural processes that span political boundaries. The death of nearly 300,000 people in the Indian Ocean basin due to the Dec. 26, 2004 M=9.2 Sumatra earthquake triggered an international response that included new efforts to build cooperative research and monitoring programs in the Indian Ocean and other ocean basins. The second phenomenon, global warming, will likely unfold over many decades, due to feedback mechanisms that link climate, oceans, and the biosphere. This area poses an unprecedented practical, political, and scientific challenges to humanity and a call to engage in cooperative international research and action. Both underscore the need to reach beyond political borders when studying natural phenomena.

Within this general context, Mexico and the United States share a 2000-mile-long border (Figure 1) that is invisible to atmospheric circulation, water vapor, natural surface and ground water flow, and active or recently active tectonic faults in Baja and Alta California and the U.S. and Mexican Basin-and-Range provinces. Since the early 1990s, NSF and numerous other federal, state, and private institutions in the United States have funded the construction of a national-scale continuous GPS network, now consisting of more than 2000 stations, to monitor atmospheric water vapor and crustal deformation. These data, which are typically

archived and available to scientists within 24 hours of being collected, are setting the stage for a period of rapid advances in our knowledge and understanding of tectonic and climatic processes in much of North America.

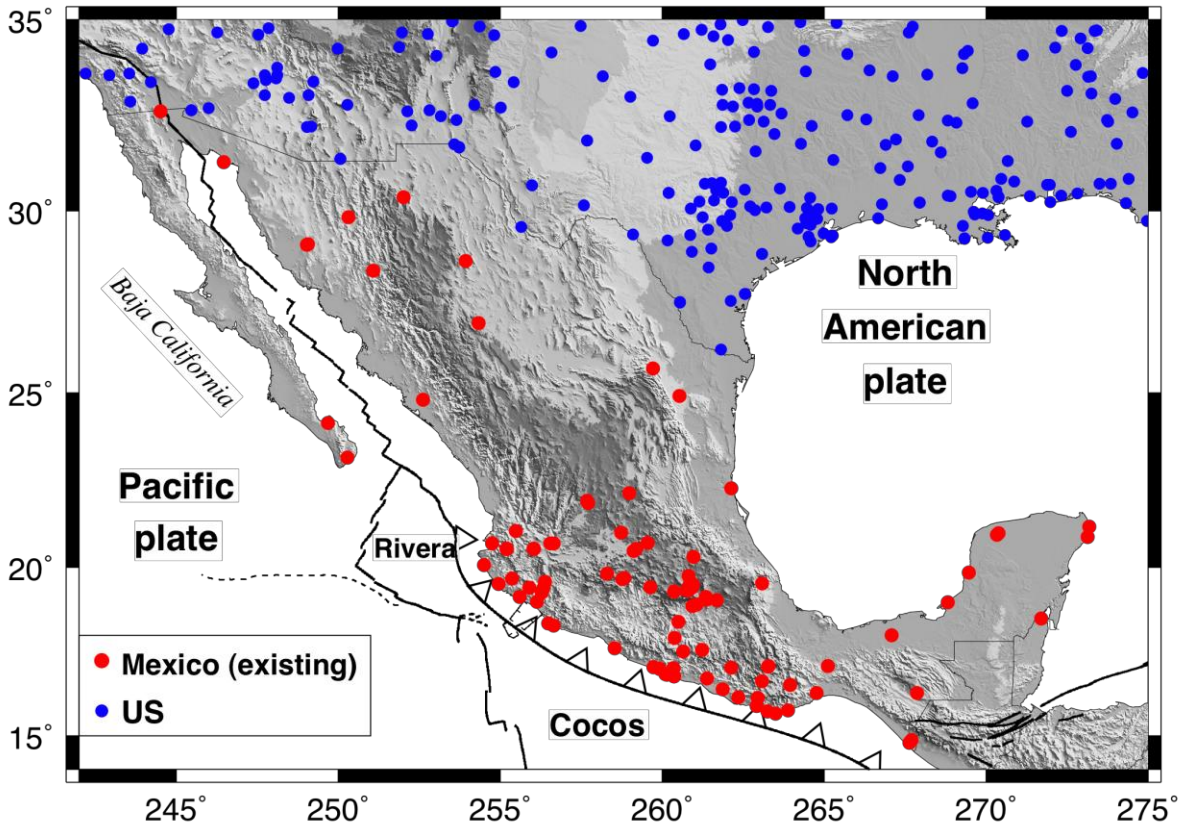

Figure 1. Map of existing continuous GPS stations in Mexico (red) and the United States. Many of the GPS stations in Mexico could be used as the backbone of an integrated measurement network if they were upgraded for real-time data transfer. Clusters of borehole strain meters will also be installed at 3-4 locations inland from the subduction zone along the Pacific coast to complement continuous GPS measurements of transient strain events similar to those being measured and studied in the U.S. Pacific northwest.

During the same period, a variety of Mexican and U.S. institutions have installed continuous GPS sites in Mexico (Figure. 1), now numbering 60-70 scattered over an area more than half the size of the United States. For a variety of historical and institutional reasons, the data from these often remote and widely spaced GPS sites are collected and archived at widely different intervals, are frequently proprietary, and share no common archive.

Despite these impediments, continuous GPS measurements at some of these stations have been central to some major advances in solid Earth studies of Mexican tectonics and will surely be a linchpin of future studies in solid Earth, atmospheric, and hydrologic studies of the North American continent. In recognition of this, the pace of new station construction has accelerated since 2005, with new stations appearing at a rate of 10-20 per year. The absence of a central data archive, open data policy, and standard protocols for daily or more frequent data retrieval, however, has limited the overall benefit of this data to the wider scientific community.

Significant and timely issues in tectonics, atmospheric science, and hydrology compel this Mexican/U.S. cooperative effort to integrate the growing Mexican GPS infrastructure into a measurement array modeled on the U.S. PBO. Many of the individuals and institutions in Mexico and the U.S. who are responsible for large parts of the still disconnected pieces of the Mexican array recognize the merits of this goal and are prepared to work toward it. The time is now ripe for a workshop to bring together this community of scientists and institutional representatives to discuss and agree on the specifics of an eventual request to NSF and CONACyT for the funds to expand the Mexican network and upgrade and integrate many existing sites to meet the research and practical needs of interested parties in both countries.

The remainder of this brief proposal outlines the multi-disciplinary scientific motivations for the proposed workshop, and gives additional information about the workshop and proposed participants.

Scientific rationale for the workshop

Tectonics: Studies of aseismic transient slip events along the Mexican subduction zone have dominated GPS-based tectonic research in Mexico over the past 5-10 years (Lowry et al., 2001; Kostoglodov et al., 2003; Brudzinski et al., 2007; Correa-Mora et al., 2008). First discovered in 2002 from GPS measurements at stations in the state of Guerrero (Kostoglodov et al., 2003), their influence on the subduction zone earthquake cycle is still poorly understood and is a critical question given that large areas of southern Mexico, including Mexico City, are vulnerable to damage from earthquakes along the Mexican subduction zone.

Figure 2 synthesizes seismic and geodetic observations relevant to the earthquake cycle for the Mexican subduction zone, emphasizing two exciting and newly discovered aspects of subduction not previously recognized (Song et al. 2009). The first is that earthquakes (rapid rupture), episodic transient slip (slow rupture), and non-volcanic tremor (slow rupture) appear to occur along progressively deeper regions of the subduction interface, perhaps with minor overlap. The second is that areas of the subduction interface that have remained devoid of transient slip during the past decade also appear to lack seismically-imaged zones of high pore fluid-pressure, possibly indicating a connection between the two phenomena. More geodetic and seismic data from southern Mexico will be critical for a fuller image of the unusual nearly flat subduction interface that lies beneath most of southern Mexico.

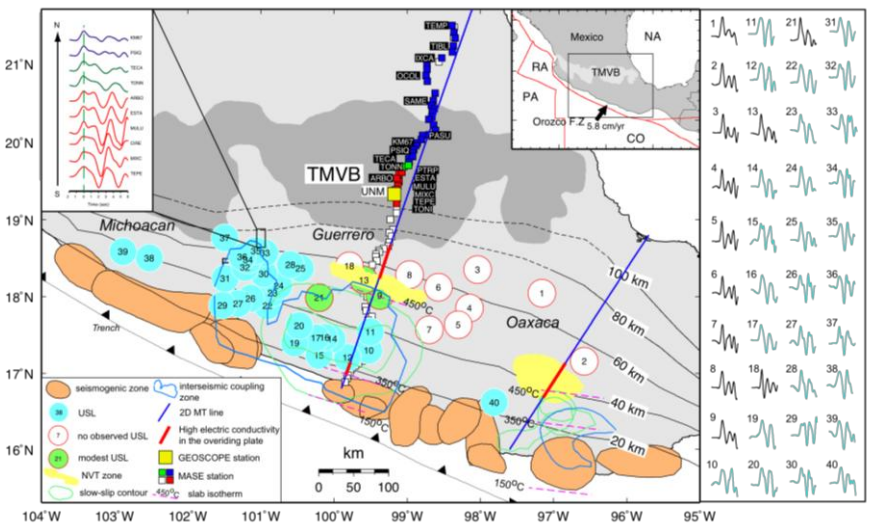

Figure. 2: Locations of earthquake rupture zones (brown), episodic transient slip zones (outlines), and ultra-slow layer locations (blue) from Song et al. (2009). Ultra-slow layers may be zones of high pore-fluid pressure and in Guerrero coincide with regions of transient slip. An absence of USL is found for areas where no transient slip has yet been reported.

Over the past 2-3 years, the level of interest and pace of research into transient slip events and more generally, the earthquake cycle of southern Mexico has accelerated. Unlike many steep subduction zones, the proximity of the trench to Mexico's Pacific coast and nearly flat slab place large areas of the subduction interface directly beneath the continent, making them superbly accessible to geophysical measurements.

A primary goal of the workshop and subsequent proposal will be to merge the existing GPS infrastructure into a single imaging array and to fill the still large gaps between the GPS stations at critical locations along and within 300 km of the Pacific coast, where transient slip is best observed. In addition, clusters of 3 borehole strain meters at either three or four locations along the Pacific coast will be constructed to improve the sensitivity by an order-of-magnitude or more to strain transients associated with subduction.

Atmosphere:

The semi-arid to arid North American Southwest has experienced, in recent decades, tremendous population growth despite limited water supplies. Water availability is highly susceptible to climate variability and change and is therefore of great concern. Climate models generally predict the region will experience warmer and drier winters in the future. During summer, incursions of moist tropical air associated with the North American Monsoon (NAM) bring critical convective precipitation particularly in northwest Mexico where most of the precipitation is already in summer.

Representing deep convective regimes in tropical regions, however, has been problematic in large-scale numerical models (e.g., general circulation models (GCM)). Without exception, the NAM is represented poorly in GCMs. As a result, the future behavior of the monsoon is uncertain but may intensify if the land-sea temperature contrast increases. The North American Monsoon Experiment (NAME) was therefore initiated to better characterize convective precipitation and its predictability during the NAM and ultimately improve its modelling. This goal is challenging given the complex interplay between moisture, diurnal heating, large and small-scale dynamics and complex terrain in convective rainfall.

GPS and related measurements made during the 2004 NAME field campaign provided significant new insights and quantified existing knowledge related to NAM moisture and precipitation and related processes (Figure 3), leading to some high-resolution model simulations of precipitation sensitivity to precipitable water vapor. The NAME field campaign lasted only a single summer, far too brief a period to fully understand the NAM and its variability, or any trends that are likely underway as part of global change.

Surface and subsurface water availability largely determine the extent and types of continental flora and fauna. Since water is delivered to continental regions via precipitation, which forms from water vapor, measurements of water vapor are ultimately critical to understanding and forecasting precipitation. In this context, our ability to measure water vapor is surprisingly and disturbingly limited. This in turn limits our precipitation forecasting skill over time scales ranging from hourly to decadal and longer. While satellite observing systems provide some information, they are limitations in fundamental ways in terms of their ability to measure water vapor. At microwave wavelengths, our ability to interpret radiances over land from orbiting microwave sounders is limited by uncertainties in surface emissivity. The ability to determining water vapor from IR sounders becomes limited as soon as clouds form which is unfortunately when weather becomes interesting. These factors generally limit the utility of satellite measurements during the North American Monsoon and continental

rainy seasons, making the upward looking GPS PWV measurements quite unique and useful, especially in combination with co-located and integrated metrological observations.

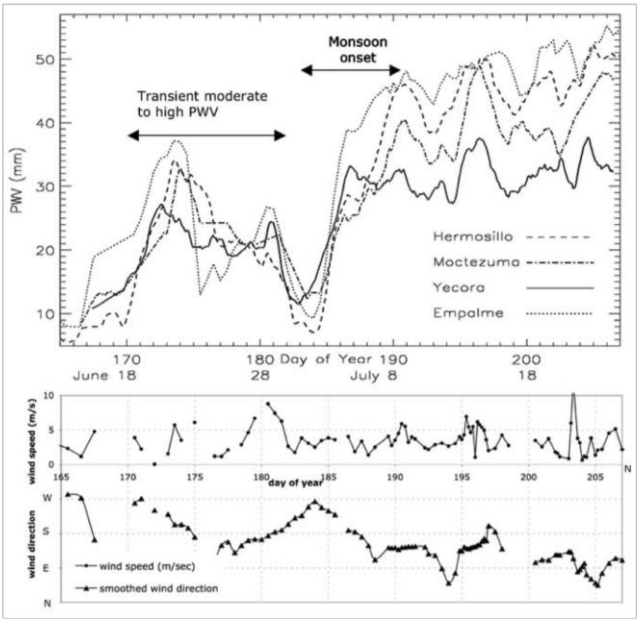

Figure 3. NAM onset as monitored from GPS PW estimates (Hermosilo, Moctezuma, Yecora) and radiosonde (Empalme). The bottom panel shows water vapor weighted wind computed from the Empalme radiosonde. Figure is from Kursinski et al. (2008).

Based on our experience in the 2004 NAME filed campaign, it is clear that a long term GPS network in Northwestern Mexico complementing the network in the Southwestern US would be an extremely useful measurement system for weather forecasting and climate.

Surface and ground water: GPS measurements are also useful for hydrologic research. One clear example is the utility of GPS for mapping vertical (and horizontal) movements associated with groundwater withdrawal and hence aquifer compaction and possible long-term degradation of subsurface water storage capacity. Measurements at continuous GPS stations in Aguas Calientes in north-central Mexico show more than 1.3 meters of subsidence since 1993 (Marquez-Azua and DeMets, 2003) and exhibit time-dependent subsidence consistent with elastic compaction of aquifer sediments due to over-pumping. GPS has also recently been shown to be useful in retrieving soil moisture parameters (Figure 4; Larson et al., 2008). This new technique uses fluctuations in ground reflected multipath signals to relate changes in the dielectric properties of soil to changes in soil moisture. In a similar fashion to the PW estimates, GPS retrieved soil moisture parameters could provide an observational improvement in surface soil for use in climate and short-term flash flooding forecasts.

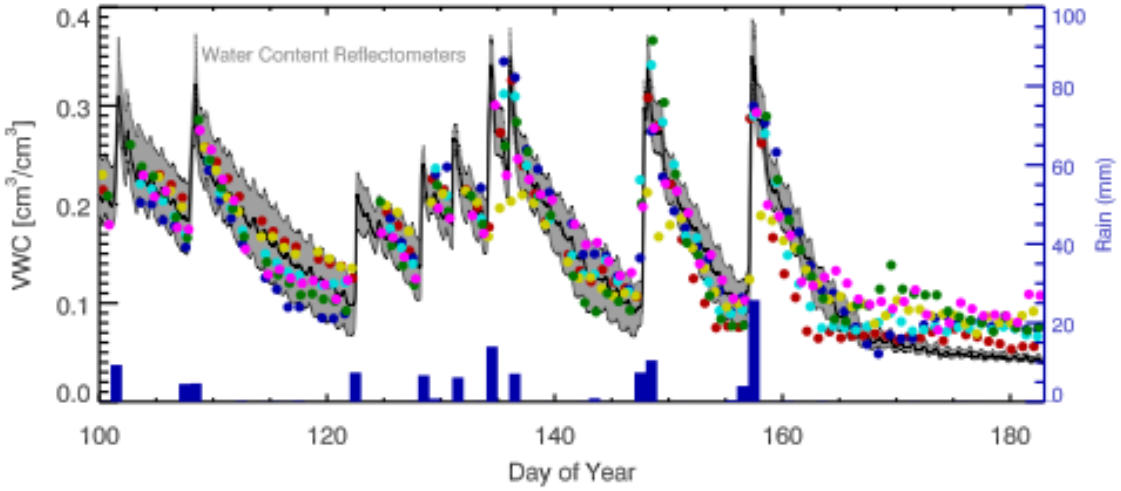

Figure 4: GPS retrieved volumetric water content (VWC), displayed as colored dots, water content reflectometer observations (gray shading represents variation among similar sensors) are shown with daily precipitation estimates. Figure is from Larson et al. (2008).

Relevance of GPS for applications described above

A partial summary of applications includes

- Atmospheric
  1. Constrain process studies for characterizing warm season precipitation, which is poorly represented in models,
  2. Determine climatological variability
  3. Evaluate/validate satellite derived products and GCM model performance
- Hydrology
  1. Close the water cycle
  2. Determine soil moisture
  3. Characterize aquifer behavior
- Tectonics
  1. Use GPS, borehole strainmeter, and seismic measurements to characterize interseismic strain accumulation, post-seismic afterslip and viscoelastic relaxation, and aseismic transient slip toward a more complete earthquake cycle model of the Mexican subduction zone
  2. Integrated studies of Pacific-North America tectonics in Baja and Alta California
  3. Characterize slow deformations in Mexican interior (*e.g.* Basin-and-Range, volcanic belt) and relationship, if any, to tectonics in contiguous areas of U.S.
  4. Studies of volcanic tectonics and hazards in Mexican volcanic belt (not described herein)
- Multi-disciplinary
  1. Monitor long term trends
  2. Initialize NPW forecast critical in particular for flash flood warnings in Mexico

Key features of GPS

- Column water vapor accurate to ~ 1 mm
- Works in clear and cloudy conditions
- Provides sufficient resolution in time to resolve complex diurnal cycle of behavior: 30 minute averages available operationally, higher time resolution for research
- Inexpensive instrumentation
- Autonomous operation in remote locations - well suited for much of Mexico

Workshop outline and details: The workshop will produce a science plan that evaluates the need for ongoing and expanded continuous geodetic observations in Mexico, and that will form the basis for an international collaborative effort between NSF and CONACyT to upgrade many existing GPS stations in Mexico and build a modest number of new stations in areas where they are needed. The first stage of this effort is to organize a workshop in April of 2010 in Puerto Vallarta, Mexico. The workshop will consist of five sessions: three will concern scientific themes outlined above, a fourth will cover the practical impacts (hazards) and challenges of a network upgrade and expansion, and a fifth will attempt to coordinate the consortium of institutions and individuals that have built and operate most of the existing GPS stations in Mexico for a future proposal. Each session will have a keynote presentation, to be followed by short presentations by many of the workshop participants and structured discussions.

Session 1: Tectonic applications of integrated GPS and borehole measurements

Days 1&2: This session will be co-chaired by Chuck DeMets of the University of Wisconsin and Vladimir Kostoglodov of UNAM. It will focus on the tectonic motivations and work to date using continuous GPS at existing Mexican stations, and the benefits of a network integration and expansion. Dr. Alex Song will discuss plans for installing clusters of borehole strain meters along the Pacific coast. Seismologic measurements of non-volcanic tremor will be discussed by Dr. Michael Brudzinski, a recent recipient of a NSF CAREER award, based on results from his eight-station broadband seismic network in southern Mexico. Discussion of GPS measurements in the Mexican volcanic belt and their potential application to volcano-tectonic studies will also be arranged.

Session 2: Atmospheric applications

Days 1&2: This session will be co-chaired by Rob Kursinski of the University of Arizona and a Mexican scientist to be determined. It will focus on GPS-based climatologic research relevant to Mexico and contiguous areas of the United States and the potential benefits of a GPS network integration and expansion.

Session 3: Hydrologic applications

Days 1&2: This session will be co-chaired by Eric Small of the University of Colorado and a Mexican scientist to be determined. It will focus on the potential benefits of a continuous GPS network for research into surface and ground water and related hazards in Mexico and contiguous areas of the United States.

Session 4: Challenges and impact of network upgrade and expansion

Day 3: This session will be chaired by a UNAVCO staff member such as Chuck Meertens and possibly co-chaired by a Mexican scientist. The focus of this session will be on the technical challenges that face a network expansion and upgrade, construction of a centralized data archive, build-out of communication facilities for real-time or near-real-time data transfer, and issues related to hazards applications and the possible extension of Internet connectivity in remote rural communities that host GPS sites. This session will afford an opportunity for presentations and input from individuals and agencies with important interests in hazards response and monitoring (e.g. Proteccion Civil of Mexico).

Session 5: Phase 2 planning: consortium building and proposal preparation

Day 3: This summary session will include brief presentations by representatives of the major institutions and individuals that operate GPS stations in Mexico and will focus on building consensus for a consortium that will participate in the proposal and network build-out that

will be the primary outcome of this workshop and subsequent proposals to NSF and CONACyT.

Broader implications, outreach, and workshop report

Its international scope and multidisciplinary scientific objectives give the workshop an unusually wide range of broader implications, with topics that range from seismic hazards for large areas of southern Mexico, including Mexico City, to atmospheric, surface, and ground water budgets in dry areas of northern Mexico and the southwest U.S. The workshop will bring together for the first time the community of Earth and atmospheric scientists most likely to benefit from continuous GPS measurements in Mexico and will surely foster a very valuable interchange of opinions, ideas, and information that will be essential for the preparation of NSF and CONACyT infrastructure proposals that will the workshop. Professional development will be encouraged via NSF travel funds for two or more graduate students and one or more early career scientists, including individuals from groups underrepresented in STEM fields and protégés of the UNAVCO RESESS and UCAR SOARS internship programs. Finally, the workshop will also provide an invaluable forum for discussing how the proposed GPS network can be used to benefit Mexican society at large. Ideas discussed so far amongst the group of investigators involved in the workshop proposal include piggybacking rural Internet connectivity on the communications gear that will be used to transmit GPS data, co-location of GPS equipment at schools for their educational value, and possible benefits for aquifer monitoring. Finally, a summary workshop report will be written for NSF at the conclusion of the meeting.

Workshop Organizers: Chuck DeMets; University of Wisconsin, Enrique Cabral and Vladimir Kostoglodov, UNAM; Meghan Miller, UNAVCO

Most likely date and venue: April, 2010 at the Krystal Vallarta or Camino Real in Puerto Vallarta, Mexico. Both have hosted previous Mexican Geophysical Union meetings.

Financial support requested from NSF and other sources: $47,500 from NSF and $20,000 from CONACyT. Some universities and agencies may also contribute travel funds not covered by this proposal or CONACyT.

Proposed Participants (tentative)

United States (up to 18NSF funded participants)

Atmospheric & hydrologic: R. Kurskinski (U. Arizona), J. Braun & D. Gochis (UCAR), C. Castro (U. Arizona), E. Vivoni (Arizona State), E. Small (U. Colorado), C. Minjarez (U. Arizona graduate student), A. Otarola (early career, U. Arizona).

Solid Earth: R. Arrowsmith (Arizona State), M. Brudzinski, U. Miami-Ohio (early career), R. Bennett (U. Arizona), Y. Bock (Scripps), C. DeMets (U. Wisconsin), K. Larson (U. Colorado), J. Stock (CalTech), five to be determined.

Other non-NSF participants from U.S.

K. Hudnut (USGS), S. Gutman (NOAA), G. Sella (NOAA), J. Fein, D. James, R. Kelz, & E. Zanzerkian (NSF), UNAVCO personnel to be determined

Mexico (university): (up to six funded by NSF)

Atmospheric & hydrologic: V. Magana, J. Hidalgo, & A. Contreras (UNAM), C. Watts (U. Sonora), A. Granados (U. Ciudad Juarez)

Solid Earth: E. Cabral, V. Kostoglodov, O. Sanchez, K. Singh, G. Suarez, G. Cifuentes, C. Valdes, & A. Santiago (UNAM), B. Marquez (U. Guadalajara), G. Reyes (U. Colima), P. Cornu-Nunez (UdeG- Puerto Vallarta)

Mexico: (institutional):

J. Fletcher & J. Gonzalez-Garcia (CICESE), M. Reyes & R. Moreno (INEGI), individuals to be determined from CONACyT (funding) and Proteccion Civil (hazards)

International: (none funded by NSF)

Alex Song (borehole strain meters - Japan); N. Cotte & A. Walpersdorf (U. Grenoble, France)

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