TIGIR WORKSHOP

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Proposal Submitted

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to

NSF EAR–Geophysics: "Troposphere, Ionosphere, GPS, and Interferometric Radar (TIGIR) Workshop Proposal"

We propose to convene a workshop to bring together experts and stake-holders in synthetic aperture radar and GNSS systems, the data processing and the products they generate. The workshop will examine the wide range of different approaches that have been developed to understand and mitigate the atmospheric "noise" in SAR signals, and establish the current best-practices in atmospheric imaging and mitigation techniques, generate priorities for further investigations, and recommendations for upcoming missions for how best to maximize the utility of the data products they will produce.

Ionospheric and tropospheric imaging using SAR and GNSS and stochastic and deterministic modeling have great potential for correcting media effects on space geodetic systems, however, although many of these approaches have shown promise in particular circumstances, effectiveness and general applicability are yet to be demonstrated. Small amplitude, non-linear and non-periodic ground motion signals abound in geodesy from a wide range of sources, and InSAR holds great promise for giving us new insights into these types of physical phenomena. For a wide spectrum of the signals we might hope to explore, however, the delays induced in the SAR signals by the ionosphere and the troposphere overprint and confuse the interpretation of interferograms.

Intellectual Merit The impact of the troposphere and ionosphere on InSAR signals has emerged as the single largest factor limiting the ability of these observation systems to reach their full potential for ground motion studies. As many major new earth science initiatives, like Earthscope, have InSAR as a key components, and a new generation of instruments will soon be deployed, it is increasingly important to estimate and reduce the impact of atmospheric noise in order to increase the effectiveness of InSAR as an operational monitoring tool, extend the possibilities for investigations using it, and improve the resolution of the technique and the data products it generates.

Broader Impacts This workshop is multi-disciplinary bringing together atmospheric and solid earth researchers, operational centers and technologists to find ways to understand and mitigate the effects of the atmosphere on new satellite SAR systems. Coupled with the compelling hazards research applications of SAR and GPS, this workshop provides an excellent venue to engage students. Two students and one career researcher will be recruited from a pool of protégés from UNAVCO and UCAR's RESESS and SOARS summer internship program. These two programs have operated in partnership for many years providing research opportunities for students from underrepresented groups. In addition, a workshop report of the results and outcomes of the workshop and statement of recommendations for upcoming SAR missions will be generated after the meeting and disseminated via the UNAVCO website.

Project Description

1. Introduction

Space-based radio interferometric techniques such as synthetic aperture radar (InSAR) and Global Navigation Satellite System (GNSS) networks are increasingly forming the core infrastructure for monitoring and exploring a wide range of geophysical signals that impact our understanding of earth processes and natural hazards. As the instrumentation and processing techniques mature, the capability of these systems is being constantly extended to enhance science returns, particularly in the imaging of the solid Earth. The impact of the troposphere and ionosphere on the InSAR signals has emerged as the single largest factor limiting the ability of these observation systems to reach their full potential. Small amplitude, non-linear and non-periodic ground motion signals abound in geodesy from a wide range of sources, e.g. magma transport, fault slip transients, hydrological loading, aquifer state changes, soil moisture, and slope creep. InSAR holds great promise for giving us new insights into these types of physical phenomena, and initiatives like the NSF-funded WInSAR community promote the use and development of InSAR technology and provide value-added InSAR products. For a wide spectrum of the ground motion signals WInSAR members and other researchers might hope to explore, however, the delays induced in the SAR signals by the ionosphere and the troposphere overprint and confuse the interpretation of interferograms.

Researchers around the globe have explored a range of different approaches to understand and mitigate the atmospheric “noise” in the signals. Ionospheric and tropospheric imaging using SAR and GNSS and stochastic and deterministic modeling have great potential for correcting media effects on space geodetic systems, however, although many of these approaches have shown promise in particular circumstances, effectiveness and general applicability are yet to be demonstrated. As a new generation of instruments will soon be deployed, such as the L-band InSAR to be carried by the DESDynI satellite and the completion of the GLONASS and the launch of the GALILEO GNSS constellations, it is a timely moment to bring together experts and stake-holders in these systems, the data processing and the products they generate. The workshop will explore the new developments and establish the current best-practices in atmospheric imaging and mitigation techniques, and generate recommendations for the WInSAR community and for upcoming missions for how best to maximize the utility of the data products they produce by, for example, the acquisition of ancillary data streams or by additional data processing.

1.1 Atmospheric Mitigation Motivation

Figure 1 illustrates the promise and pitfalls of using SAR Interferometry (InSAR) as a basis for inferring geophysical processes. Although the fringes imaged in Figure 1a suggest that the volcano Mount St. Helens inflated between the two acquisition times, a stack of 9 scenes, covering the same period (Figure 1b), and other independent geodetic measurements show that it actually deflated during this period. Evaluating the hazard presented by the volcano depends critically on recognizing whether it is inflating or deflating. In this case the fringes in Figure 1a are artifacts created by changes in the refractive properties of the troposphere between the two radar images used to form the

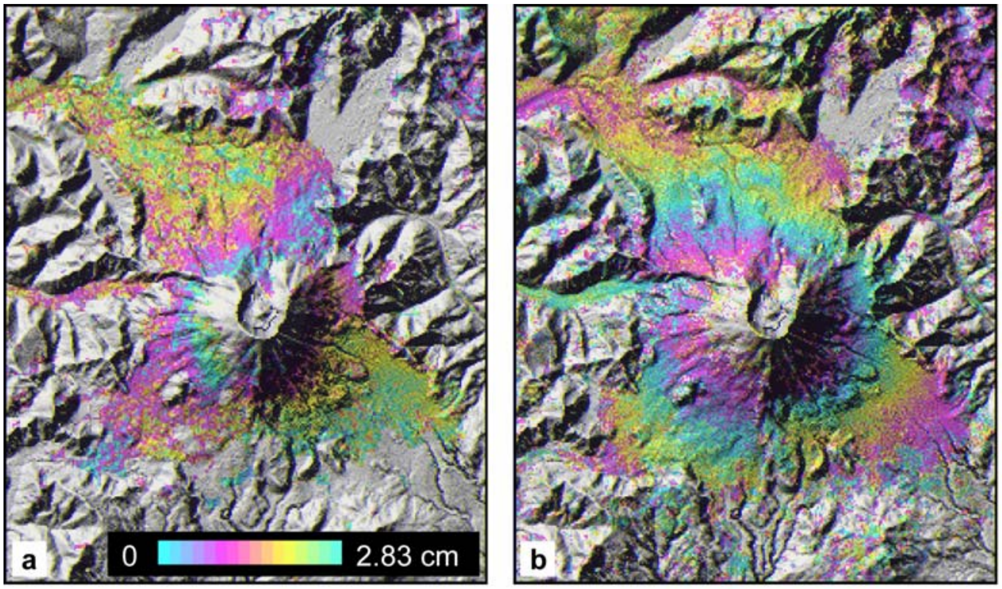

Figure 1. RADARSAT-1 images of Mount St Helens from the co-eruptive 2004–2005 time period. a) Interferogram for 23 July 2004 and 31 May 2005 (standard mode 5) showing line-of sight reduction centered on the volcano which could be interpreted as inflation. b) Interferometric stack of 9 (standard mode 2) interferograms spanning 2004 - 2005 showing line-of-sight increase, suggesting subsidence of about 3-cm [*Poland and Lu*, in press].

interferogram. Temperature and pressure variations change the refractivity, but the biggest impact is due to changes in water vapor distributions. The difficulty with measuring or estimating these parameters with the accuracy and spatial density required to improve InSAR interferograms is one of the biggest factors limiting the potential for InSAR as an operational hazard monitoring tool. Although stacking a large number of scenes (e.g. Figure 1b) improves the signal-to-noise ratio, it requires a correspondingly long time before the signal can be identified, limiting its utility for rapid detection, analysis, and dissemination. In the case illustrated here, an atmospheric artifact masked an important volcanic signal and it took ~300 days to collect sufficient data to remove the atmospheric effects. Other important hazard monitoring targets include the small amplitude, continuous or transient signals that might be generated, for example, by slip on a blind thrust fault underlying Los Angeles (which may be a precursor to a major) and may also be obscured in InSAR images by noise generated by the atmosphere. Another target of current concern is the identification and quantification of local vertical land motions which may be superposed on global sea-level rise and increase its impact on low-lying urban areas.

The ionosphere can introduce similar artifacts into SAR data, and as it is frequency dependent, its effect is ~16x stronger on L-band SAR signals. L-band is especially promising for earth science investigations as its longer wavelength enables it to penetrate vegetation and generate coherent signals from areas earlier C-band systems were unable to image. The impact of the ionosphere, however, presents a serious challenge to the processing and interpretation of data from the ALOS Palsar instrument and the upcoming DESDynI mission, especially at low and high latitudes (Figure 2).

GPS signals suffer from the same effects as the SAR systems, and although GPS processing techniques are able to take advantage of dual-frequencies to model the ionospheric delays (Figure 2), and multiple look-angles and continuous observations to mitigate much of the tropospheric impact, the atmosphere still imposes significant restrictions on the ability of GPS to be exploited to its full potential for earth science. The ionosphere limits the utility of cheap single-frequency GPS receivers, and during space weather events can reduce the effectiveness of dual-frequency systems. The troposphere is a limiting noise source for short-time period resolution of ground motion signals, reducing the systems ability to accurately identify and quantify small transient events. Interesting synergies between InSAR and GNSS systems are possible, however, with data from one system helping to image and mitigate the impact of the atmosphere on the other.

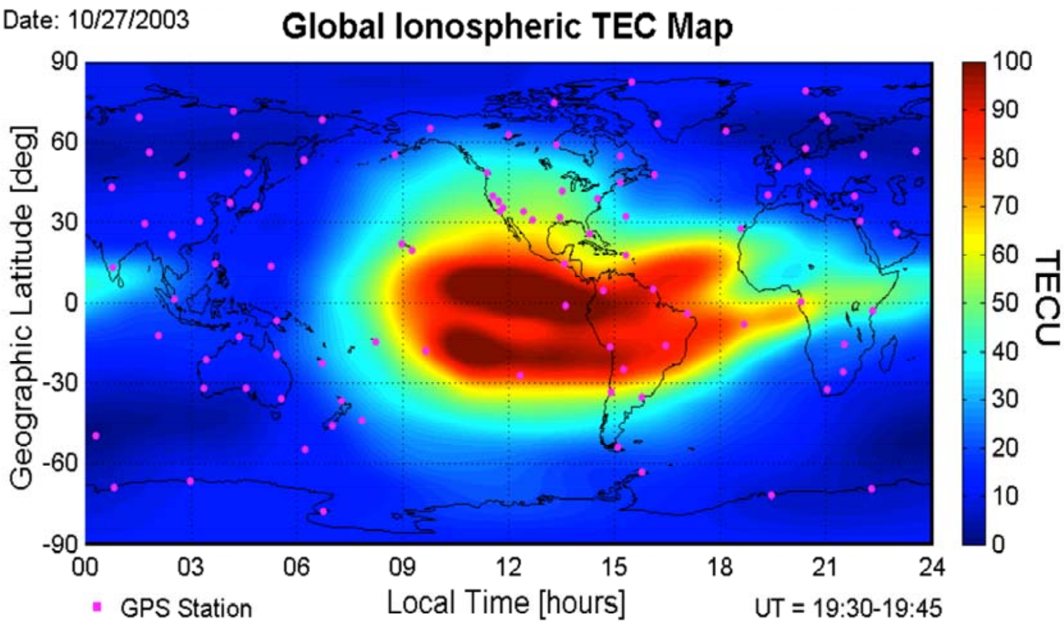

Figure 2. Map of TEC variations for UT = 19:30-19:45 10/27/2003 based on data from global GPS sites.

1.2 DESDynI

DESDynI will be a low-Earth orbit satellite carrying an L-band InSAR and Laser altimeter to study surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health. The NRC Decadal Survey has defined the DESDynI mission as a high priority for the Solid Earth (p. 39, Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, 2007). The DESDynI InSAR mission will have a wide-swath (350 km), enabling an 8-day repeat for InSAR observations. Such an L-band system is sensitive to both troposphere and ionosphere, which are limiting sources of noise to the systems. The planned split-spectrum data collection and POLSAR modes will provide opportunities to conduct 2D ionospheric imaging along orbital tracks. This new capability together with support from GNSS and modeling techniques will allow assessing and mitigating the influence of the tropospheric and ionospheric effects and thus enhance the mission’s capacity to achieve its science goals.

1.3 GNSS Constellations

The next few years will see a huge increase in the number of global navigation satellites and the number and resolution of the signals these systems broadcast. The U.S. GPS satellites are in the process of being upgraded to include a third frequency (L5) as well as including a publicly accessible code on the L2 carrier. In addition the Russian GLONASS constellation should shortly be completed and be fully operational, and the European GALILEO mission is expected to start launching over the next few years. The L-band GNSS signals are also sensitive to ionospheric and tropospheric variations in similar ways to the InSAR systems. Imaging and assimilative modeling of ionosphere and troposphere based on GPS data have significantly enhanced our capabilities of monitoring and studying space and tropospheric weather as well as climate. The data and techniques will be augmented as other systems of GNSS become operational, and can be used to support identifying and mitigating the media effects on the space-borne radar systems. It is now a good time to assess ways to improve these techniques and especially to explore possible synergies between the GNSS and SAR efforts in this regard.

2 Workshop Objectives

The primary objective of the workshop is to inventory and assess the effectiveness of existing methods of mitigating the impact of both ionosphere and troposphere on InSAR and GPS geodetic measurements. The workshop will develop recommendations for the instrumentation, system implementation, ancillary data collection, and data processing that should be adopted as part of the upcoming DESDynI and other future SAR missions in order to minimize the impact of the atmosphere on data products and maximize the ability of the system to achieve its science goals. These recommendations will also serve to provide a guide to the best current practices and most promises avenues for technique development for improving the ground motion signal resolution for existing SAR systems, and will be of immediate application to Earthscope science investigations.

2.1 Workshop Logistics

2.1.1 Proposed Venue

Dates: September 21-22, 2009
Location: Courtyard Marriot Hotel, Pasadena, CA
Sponsors: NASA, NSF

We propose to use The Courtyard Marriot Hotel facilities for the meeting. This is close to JPL, and as JPL employees will be the largest single group involved it is the logical venue to minimize travel costs, and it can comfortably accommodate the expected 60 attendees.

2.1.2 Proposed Agenda

The agenda for the proposed TIGIR workshop can be broken into several broad categories. We propose to open with a presentation(s) providing an introduction and general background to ionospheric and tropospheric impacts on GNSS and InSAR data and products. This will be followed by presentations describing the various methods which have been demonstrated or proposed to image and/or mitigate the ionosphere and troposphere for both GNSS and InSAR systems. Both deterministic and stochastic methods will be presented, as well as approaches using external/ancillary data sets as well as those relying only on the basic GNSS and InSAR data sets. Breakout sessions will then allow in-depth explorations of the issues specific to tropospheric and ionospheric imaging and impacts. These sessions will be tasked with identifying the most promising approaches and specific recommendations for ancillary data and processing requirements that will enable the most robust and effective characterization of the troposphere and ionosphere with particular focus on the upcoming DESDynI mission and new GNSS constellations and signals and possible synergies between them. A final wrap-up session will collate the recommendations from the breakout groups and formulate the structure and overall conclusions for the final report and recommendations.

2.1.3 Workshop Products

1. A summary report detailing the state of research and technology into mitigating atmospheric artifacts, with estimates on the magnitude of the problem, the degree to which it can reasonably be expected to be mitigated, and examples of the science that would be enabled by achieving that level of mitigation.
2. Statement of recommendations for the instrumentation, ancillary data collection, and data processing that should be adopted as part of the upcoming DESDynI and other future SAR missions in order to minimize the impact of the atmosphere (both ionosphere and troposphere) on data products and maximize the ability of the system to achieve its science goals.

2.1.4 Workshop Organizing Committee

We suggest that the following people would form a committee to develop the workshop goals, and coordinate the organization etc.

James Foster	University of Hawaii, jfoster@soest.hawaii.edu
Ben Brooks	University of Hawiaii, bbrooks@hawaii.edu
Xioaqing Pi	JPL, xiaoqing.pi@jpl.nasa.gov
Anthony Freeman	JPL, anthony.freeman@jpl.nasa.gov
Chuck Meertens	UNAVCO, meertens@unavco.org

2.1.5 Workshop Attendance

We propose that the workshop be focused. We recommended an attendance of about 60 people for this workshop, and attendance will be by invitation, with remaining places made available on the basis of applications selected by the organizing committee. In addition to the researchers involved at the forefront of the development of noise mitigation strategies for these systems, and their application to science problems, we would like to ensure the continuity of the community knowledge and experience to the next generation of scientists by making available a few supported positions for graduate students and an earlier career researcher to attend the workshop.

The following is a provisional list of researchers who would be invited to attend:

Name	**Institution**	**Discipline**	**Email**
Ainsworth, Tom	NRL, USA	Ionosphere	thomas.ainsworth@nrl.navy.mil
Amelung, Falk	RSMAS, USA	Troposphere	famelung@rsmas.miami.edu
Bevis, Mike	Ohio State, USA	Troposphere	mbevis@osu.edu
Bock, Yehuda	Scripps, USA	Troposphere	ybock@ucsd.edu
Braun, John	UCAR, USA	Troposphere	braunj@ucar.edu
Burgmann, Roland	U.C. Berkeley, USA	Troposphere	burgmann@seismo.berkeley.edu
Chapin, Elaine	JPL, USA	Ionosphere	elaine.chapin@jpl.nasa.gov
Chapman, Bruce	JPL, USA	Ionosphere	bruce.chapman@jpl,.nasa.gov
Chen, Curtis	JPL, USA	Ionosphere	curtis.chen@jpl.nasa.gov
Donnellan, Andrea	JPL, USA	InSAR	Andrea.Donnellan@jpl.nasa.gov
Dubois-Fernandez, Pascale	ONERA, France	Ionosphere	pdubois@onera.fr
Eineder, Michael	DLR, Germany	Ionosphere	michael.eineder@dlr.de
Fialko, Yuri	Scripps, USA	Troposphere	yfialko@ucsd.edu
Fielding, Eric	JPL, USA	Troposphere	eric.fielding@jpl.nasa.gov
Ferretti, Alessandro	TRE, Italy	Troposphere	alessandro.ferretti@treuropa.com
Fuller-Rowell, Tim	CIRES, USA	Ionosphere	tim.fuller-rowell@noaa.gov
Ge, Linlin	UNSW, Australia	Troposphere	l.ge@unsw.edu.au
Gutman, Seth	NOAA, USA	Troposphere	Seth.I.Gutman@noaa.gov
Hanssen, Ramon	TU Delft, Netherlands	Troposphere	R.F.Hanssen@tudelft.nl
Hooper, Andrew	University of Iceland, Iceland	Troposphere	ahooper@hi.is
Joughin, Ian	U. Wash, USA	Ionosphere	ian@apl.washington.edu
Le, Charles	JPL, USA	Ionosphere	charles.le@jpl.nasa.gov

Li, Zhenhong	U. Glasgow, U.K.	Troposphere	zhenhong.li@ges.gla.ac.uk
Lundgren, Paul	JPL, USA	InSAR	paul@weed.jpl.nasa.gov
Mannucci, Anthony	JPL, USA	Ionosphere	anthony.j.mannucci@jpl.nasa.gov
Meyer, Franz	U Alaska, USA	Ionosphere	fmeyer@gi.alaska.edu
Moore, Angie	JPL, USA	Troposphere	angie.moore@jpl.nasa.gov
Nicoll, Jeremy	ASF, USA	Ionosphere	jnicoll@asf.alaska.edu
Peltzer, Gilles	UCLA, USA	Troposphere	peltzer@ess.ucla.edu
Poncos, Valentin	CCRS, Canada	Ionosphere	vponcos@nrcan.gc.ca
Quegan, Shaun	U. Sheff, U.K.	Ionosphere	s.quegan@sheffield.ac.uk
Rosen, Paul	JPL, USA	Ionosphere	paul.rosen@jpl.nasa.gov
Sandwell, David	Scripps, USA	Troposphere	dsandwell@ucsd.edu
Schmidt, David	U. Oregon, USA	Troposphere	das@uoregon.edu
Shimada, Masanobu	JAXA, Japan	Ionosphere	shimada.masanobu@jaxa.jp
Simons, Mark	Caltech, USA	Troposphere	simons@caltech.edu
Werner, Charles	Gamma, Switzerland	Troposphere	cw@gamma-rs.ch
Williams, S.	POL, UK	Troposphere	sdwil@pol.ac.uk
Wright, Patricia	BAE, U.K.	Ionosphere	patricia.wright@baesystems.com
Zebker, Howard	Stanford U., USA	Ionosphere	zebker@stanford.edu

Expected Attendees
(Besides the Steering Committee)

Institutions	# Attendees
NASA	10
Non-NASA, Domestic	18
International	13

2.1.5 Broader Impacts

This workshop is multi-disciplinary bringing together atmospheric and solid earth scientists; operational tropospheric and ionospheric weather centers as well as researchers; and experts developing new ground based GPS and space Synthetic Aperture Radar methodologies and observing systems. One of the drivers for this workshop is to discover synergisms between these interests and in particular find ways to understand as well as mitigate the effects of the atmosphere on new satellite SAR systems such as the new NASA DESDynI mission. Coupled with the compelling applications of SAR and GPS in measuring and understanding deformation from earthquakes and volcanoes, motions of ice sheets and variations in the ionosphere and troposphere, this workshop makes for an excellent venue to engage students and earlier career researchers in a range of scientific fields. It is an opportunity for them to learn about some of the effects that must be considered at the early phases of development of a new SAR satellite mission.

The UNAVCO community has a strong commitment to broadening participation from underrepresented groups and manages the RESESS student intern program to further this goal. RESESS joins UCAR's SOARS program every summer bringing together undergraduate and graduate students from underrepresented groups in solid earth and atmospheric sub-disciplines for an intensive summer internship program. We plan to recruit 2 students and 1 one early career researcher from the pool of RESESS and SOARS current and alumni protégé pool to participate in the workshop. These students are particularly well prepared to benefit and to contribute to the workshop as they have had broad exposure to both solid earth and atmospheric research as part of their internship (see e.g. http://resess.unavco.org/docs/EWSS_2008.pdf to learn more about their summer research projects).

As discussed earlier, a workshop report of the results and outcomes of the workshop and statement of recommendations for upcoming SAR missions will be generated after the meeting and disseminated via the UNAVCO website.