Cyberinfrastructure for enhanced access to Synthetic Aperture Radar (SAR) Data and Interferometry Analysis for Geophysical Research

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Introduction. A broad multi-disciplinary community utilizes space, airborne and terrestrial geodetic techniques to provide basic observations as well as reference frames for a wide range of scientific research and natural hazards applications. Some applications highlighted in Wdowinski, S. and S. Eriksson (**Geodesy in the 21st century**, *EOS Trans. AGU,* 90, 153-155, 2009) include plate tectonics, plate boundary deformation, geoid determination, ocean bathymetry, glacial isostatic adjustment, global/regional water budget, GPS meteorology, the earthquake deformation cycle, magma induced deformation, glacier flow, urban and infrastructure subsidence, aquifer system deformation, landslides, wetland water level changes, rivers and lakes water levels, and soil moisture and mountain snow pack.

Techniques from what might be called the "Geodesist's Toolbox" include Interferometric SAR (InSAR), Global Navigation Satellite Systems (GNSS including GPS, GLONASS, Galileo and a growing number of other international systems), Very Long Baseline Interferometry (VLBI), LiDAR, Lunar and Satellite Laser Ranging, Doppler Orbit determination and Radiopositioning Integrated on Satellite (DORIS), photogrammetry and other optical systems, strainmeters, tiltmeters, and gravity. Individually, each of these techniques requires considerable expertise to acquire, process and analyze. Collectively, they provide a broad temporal and spatial spectral range of capability to measure the shape, and change in shape over time, of the Earth's surface and gravity field. Observations span milliseconds to decades over distances of meters to continental scales. Increasingly these techniques are combined to integrate across this spectrum of signals. Results are also being integrated with other non-geodetic observations.

To use any of these geodetic techniques alone requires a significant degree of training and expertise. Workflows from data acquisition to analysis are complex, distributed, and typically employ research, not production level software. They suffer from non-standard and sometimes insufficient formats for metadata, data, and data products. Highly varied data discovery and access services present additional obstacles for users. Data volumes can be vast and require extensive computational resources for processing, analysis and modeling. In order to help overcome these barriers and enhance services, UNAVCO and its collaborators have engaged in a long-term cyberinfrastructure development effort building upon experiences with the NSF GEON project, EarthScope, and a number of NASA ROSES-funded projects. These projects, funded or proposed, involve standalone

cyberinfrastructure development for individual techniques (such as GPS or LiDAR) or broader services for integration and modeling across techniques. Here we describe a system for InSAR that is in its nascent stages but that exemplifies the type of component needed to help realize EarthCube goals.

Objectives. Enhanced data web services are needed to facilitate user query and retrieval of NASA and other international space agency airborne and satellite Synthetic Aperature Radar (SAR) data. Advanced processing services are needed to simplify the generation of new interferometric SAR (InSAR) products and provide them in a timely manner that would enable use in hazards response efforts. The generation of enhanced quality control products is desired to allow for the proper interpretation of results and integration into advanced modeling systems. The distributed archives at the Alaska Satellite Facility (ASF) and UNAVCO/WInSAR have established and mature data management, archiving, and distribution systems as well has a variety of data access and discovery web and application tools. Collaborations between these institutions, JPL, the WInSAR Consortium of institutions, and international space agencies have been established over the years as part of NSF, NASA and USGS funded projects.

An objective of possible future EarthCube-related cyberinfrastructure development may be to employ standards-compliant web services to provide uniform access to these currently independent data archives. The system architecture will be web services-based and will incorporate a modified federated repository Generic Service Layer (GSL) developed as part of an on-going UNAVCO-led NASA ROSES ACCESS project for space geodetic data (GSAC). The deployment of reusable software components and federated services will help to ensure long term sustainability and extensibility of archive web services to other applications. Part of this project will also involve the enhancement of the recently developed InSAR product generation service at ASF and archival of these products for reuse by the user community. Terrain corrections will be made using services from OpenTopography (UCSD/SDSC) that will be implemented as part of this project. We will develop and implement standard metadata and formats for the InSAR products including quality control factors. For project guidance, explicit participation in the an advisory group with representatives of the JPL teams developing the next generation InSAR processing software (ISCE), integrative deformation modeling QuakeSim, tropospheric corrections (OSCAR), and GPS and InSAR analysis for natural hazards (ARIA) will ensure that standards developed will be widely applicable and integrated into services that will either be used or provided by these new developments.

Specific Objectives include:

- Develop and implement a federated metadata query and data and data product download capability from distributed airborne (NASA UAVSAR) and spaceborne SAR archives at ASF and UNAVCO/WInSAR by enhancing existing web browser user interfaces and data access web service APIs.
- Define and make available new QC parameters and products that will enhance the usability of data and data products from these existing SAR collections. Related goal is to develop standard formats for derived image products such as interferograms, coherence images, tropospheric effects, and terrain corrections.

- Implement a web services based InSAR terrain correction service using NASA SRTM data at SDSC.
- Enhance ASF SAR interferogram processing service to access distributed InSAR data collections, utilize a terrain correction service based on DEMs from OpenTopography, and generate enhanced QC products.
- Establish processed data products archive (InSAR interferograms and related enhanced QC products) at ASF and UNAVCO with standard formats and metadata.
- Provided classroom and web-accessible training to scientists, educators, hazards responders and decision makers, and students in the use of these new systems.

Significance of InSAR-enabled Science. The InSAR technique provides an excellent remote sensing means of observing motions and deformation over broad areas. It is capable of detecting mm-level changes of the Earth's land and ice surfaces with decameter-level spatial resolution at monthly or greater intervals. InSAR has proven to be a powerful tool to characterize large-scale deformation associated with active faults. It also can resolve small-scale deformation features such as shallow creep, postseismic and interseismic deformation. It is also an ideal method for measuring land subsidence and improving digital terrain models. InSAR complements ground-based measurements such as GPS that have higher temporal sampling (seconds to days) and absolute reference frame accuracy, but are considerably more sparsely distributed. When possible, InSAR and GPS are used in tandem such as with the NASA JPL QuakeSim and ARIA modeling and analysis systems.

The technologies and infrastructure described here will support and benefit the diverse scientific goals of the InSAR communities who utilize UNAVCO and ASF InSAR archives. The science themes being investigated span solid Earth, atmospheric and cryospheric research and include for example:

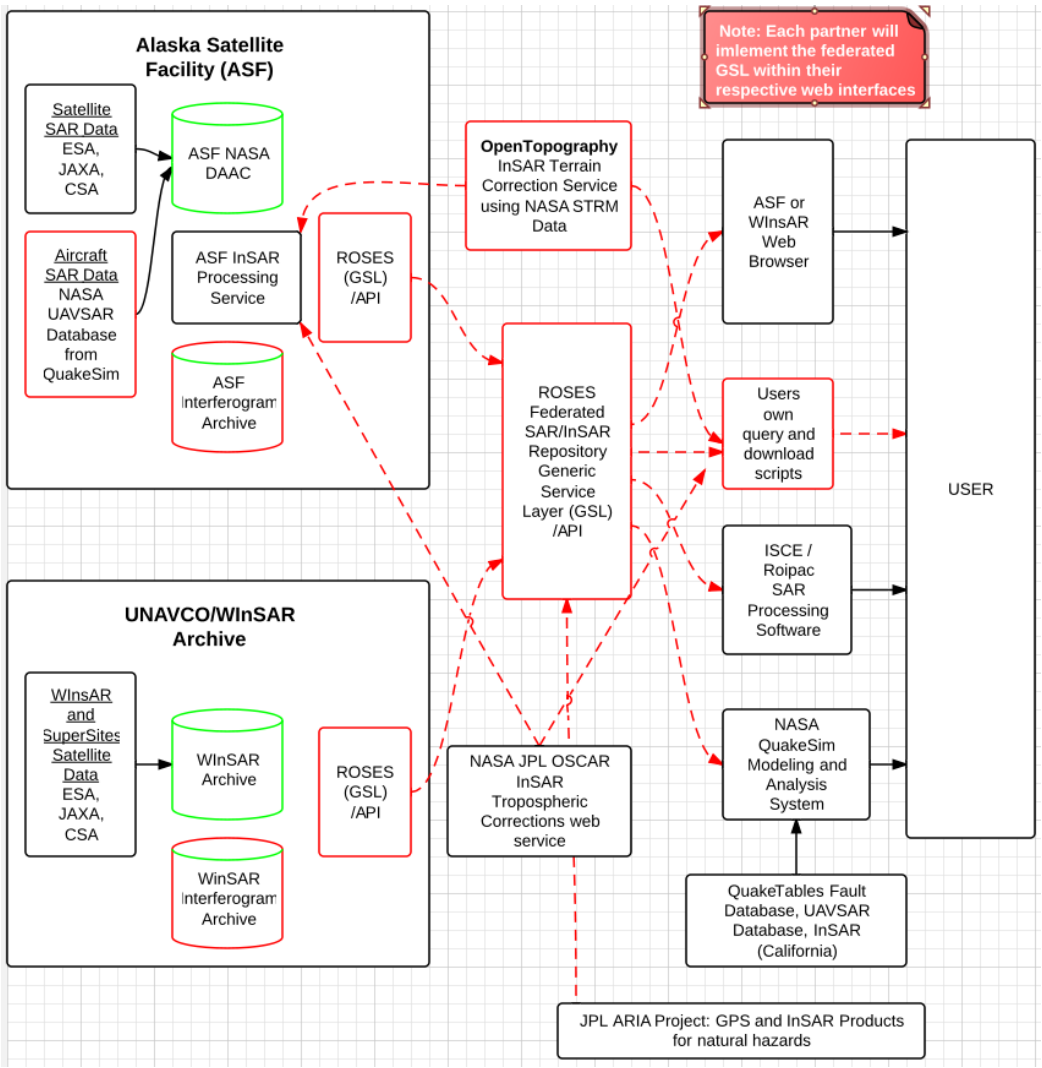
- The earthquake cycle throughout the world including the San Andreas Fault and Basin and Range
- Volcanic activity including South America, Hawaii, Aleutians and Cascade/Yellowstone
- Groundwater and coastal hazards throughout North America
- Mountain building in South America and the Himalayas
- Rifting in Iceland and East Africa
- Motions and deformation of the cryosphere related to global change
- Ionospheric and tropospheric effects
- Anthropogenic changes from oil and water extraction
- InSAR noise source mitigation and time series analysis.

Cyberinfrastructure developments described here will have significant impact. For example, UNAVCO manages InSAR support (data tasking, ordering, distribution and access) for the WInSAR consortium. The WInSAR consortium currently has 72 US universities and research institutions as full members and 24 non-US (adjunct) institutional members; the consortium goals include acquisition and distribution of SAR

data to scientists doing various aspects of solid Earth, hydrological, cryospheric and human impacts research. Through the WInSAR Consortium UNAVCO has assembled references to published InSAR science through the past several years. The rate of InSAR based science being produced is dramatic, with 40 publications produced in one year (this is a lower bound), indicative of a highly productive research community utilizing the data in the UNAVCO, ASF, and other SAR Archives.
http://www.unavco.org/pubs_reports/reports/annual/winsar/2010-2011-AnnualReport_WInSAR.pdf

Technical Approach. This project will employ standards-compliant web services to provide uniform access to existing data archives at ASF, UNAVCO/WInSAR, and the GEO Supersites. The system architecture will be web services-based and will incorporate a modified federated repository Generic Service Layer (GSL) developed as part of the companion GSAC project. The GSL will also access interferogram product archives that will be established at both archives, the ASF archive for products generated with the ASF InSAR processing service, and UNAVCO/WInSAR archives for contributed PI solutions. As part of this a standard product format will be created that will allow for consistent archiving and post-processing of higher-level InSAR products and related QC/QA products that will also be specified and implemented into the ASF InSAR service and the new JPL ISCE processing software. The new product format, tentatively using HDF5, will also be adapted to an InSAR terrain correction service and existing NASA JPL OSCAR tropospheric correction service.

The proposed workflow is shown in the figure below. Existing services are indicated in black and services that will be created, modified or enhanced are drawn in red. The SAR user, the large block on the right, will have several ways to access data and products from distributed archives at ASF and UNAVCO and also to learn of data that can be ordered from the agencies that might not already be in either archive (e.g. ESA). The heart of workflow will be the federated SAR/InSAR repository middleware that will implement the Generic Service Layer. For data and product access, the user will be able to use the ASF or UNAVCO/WInSAR browser tools or alternatively their own or pre-packaged query scripts using a new API to make a federated query of the available archived SAR and processed interferograms from both archives. The user will then select data or products and download what they are authorized to access. The API can be used as a data acquisition step prior to the user processing on their own using JPL "ISCE" or "Roi_Pac". Alternatively, the user can access high level processing resources including the ASF InSAR processing service. Finally, a user might go to the QuakeSim system to perform advanced modeling of a deformation event such as an earthquake using InSAR products already archived and/or GPS data from the GPS Seamless Archives Centers system. The QuakeSim "QuakeTables" prototype system (described in another EarthCube white paper) currently holds only a limited set of interferograms. The new developments described in this white paper will facilitate QuakeSim access to other interferograms archived at UNAVCO or ASF or even generate them using the ASF processing system. New enhances QC/QA products will allow for improved visibility into the quality of the original SAR data, the resulting interferogram and assessment and optional correction of the effects of terrain and troposphere.



The proposed SAR workflow. Existing services are shown in black. Proposed components and connections needed are shown in red.