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# New Radar Interferometric Time Series Analysis Toolbox Released

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Interferometric synthetic aperture radar (InSAR) has become an important geodetic tool for measuring deformation of Earth's surface due to various geophysical phenomena, including slip on earthquake faults, subsurface migration of magma, slow-moving landslides, movement of shallow crustal fluids (e.g., water and oil), and glacier flow. Airborne and spaceborne synthetic aperture radar (SAR) instruments transmit microwaves toward Earth's surface and detect the returning reflected waves. The phase of the returned wave depends on the distance between the satellite and the surface, but it is also altered by atmospheric and other effects. InSAR provides measurements of surface deformation by combining amplitude and phase information from two SAR images of the same location taken at different times to create an interferogram. Several existing open-source analysis tools [*Rosen et al.*, 2004; *Rosen et al.*, 2011; *Kampes et al.*, 2003; *Sandwell et al.*, 2011] enable scientists to exploit observations from radar satellites acquired at two different epochs to produce a surface displacement map.

The past decade has seen the development and verification of numerous algorithms that combine phase information from multiple radar interferograms to produce internally consistent time series of land surface deformation [e.g., *Ferretti et al.*, 2001; *Berardino et al.*, 2002; *López-Quiroz et al.*, 2009; *Hetland et al.*, 2012]. Combining multiple interferograms allows detection and quantification of both secular and transient displacements. These methods also help to mitigate the effects of change in scatterer properties and phase delay introduced by the atmosphere between SAR acquisitions, resulting in measurements of surface deformation with subcentimeter accuracy.

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A new repeat interferometry time series analysis toolbox, Generic InSAR Analysis Toolbox (GIAnT) 1.0, was released in December 2012. GIAnT 1.0 is a user-friendly, open-source, documented framework for rapid generation of time series of surface displacement using InSAR data. GIAnT 1.0 includes numerous published time series techniques, in some cases with improvements, allowing geophysicists to efficiently analyze the large and ever-increasing archive of SAR data acquired over the past 2 decades as well as allowing scientists to test the sensitivity of results to different analysis approaches.

A typical processing chain for generating InSAR time series products consists of (1) assembling a stack of phase-unwrapped interferograms; (2) optionally applying corrections, also known as atmospheric phase screens (APS), to mitigate the differential path delay effects due to the stratified atmosphere; (3) optionally estimating residual long-wavelength errors (e.g., due to imprecise orbits) empirically or through the use of other prior information such as surface displacement fields provided by dense GPS networks; and (4) estimating time series of line-of-sight displacements and residual turbulent APS using one of several time series analysis methods.

GIAnT 1.0 addresses steps 2 to 4 in the processing chain and includes implementations of various time series analysis methods for step 4, while allowing users to implement step 1 using their favorite processing tools [e.g., *Rosen et al.*, 2004; *Rosen et al.*, 2011; *Kampes et al.*, 2003; *Doin et al.*, 2011; *Sandwell et al.*, 2011].

GIAnT 1.0 enables mitigation of the effects of signal delays due to the stratified troposphere in each interferogram using either an empirical approach or estimates from global atmospheric models. Empirical estimates are based on the evaluation of the dependency of interferometric phase on topography and the stratification of the lower atmosphere [e.g., *Lin et al.*, 2010]. Alternatively, global atmospheric models provide daily estimates of atmospheric variables, including temperature, pressure, and water vapor partial pressure, which in turn can be used to derive the phase delay related to spatial and temporal variations in the refractivity index of air [e.g., *Jolivet et al.*, 2011]. GIAnT 1.0 implements atmospheric corrections as a stand-alone Python module named PyAPS (Python-based Atmospheric Phase Screen) and includes support for automatic download of meteorological data sets (European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA) Interim, North American Regional Reanalysis (NARR), and Modern-Era Retrospective Analysis for Research and Applications (MERRA)). GIAnT 1.0 can optionally correct each interferogram from residual orbit errors by removing a simple parametric function determined empirically or using GPS-derived time series of displacements or velocities. All corrections are consistently applied within a given interferometric data set and generally increase the signal-to-noise ratio of inferred time series.

GIAnT 1.0 implements four existing InSAR time series approaches, and new ones are easily added to the toolbox. These approaches are the Small Baseline Subset (SBAS) [*Berardino et al.*, 2002], the New-SBAS (NSBAS) [*López-Quiroz et al.*, 2009], a temporally parameterized inversion (TimeFun), and the Multiscale Interferometric Time-Series (MInTS) [*Hetland et al.*, 2012] algorithms. In SBAS and NSBAS algorithms the temporal evolution of the phase is derived assuming each interferogram is the linear combination of each SAR acquisition's phase value. Additionally, the NSBAS method takes advantage of a user-defined functional form of the phase evolution to overcome the issue of missing links in the interferometric network due to temporal and spatial decorrelation. The MInTS approach allows the characterization of the temporal behavior of surface deformation using a dictionary of user-defined functions, including linear trends, seasonal oscillations, steps, exponential and logarithmic decays, and various splines [*Hetland et al.*, 2012]. MInTS also transforms InSAR observations into the spatial wavelet domain and allows for distinction between different spatial scales of deformation and atmospheric noise. Within GIAnT 1.0 the temporal inversion component of MInTS has also been adapted to the conventional nonwavelet approaches (TimeFun).

Each of these methods includes a data-driven bootstrapping approach to estimate uncertainties associated with time series products. While numerous variants of published time series algorithms exist, GIAnT provides several tools in a simple and efficient framework so that users can test a variety of techniques and customize their processing chain, specific to a given data set. Users are encouraged to make their modifications or even new algorithms available for inclusion in future distributions of GIAnT. The goal is to make GIAnT an open collaborative environment for InSAR time series analysis.

GIAnT 1.0 is primarily an ensemble of Python routines but includes an interface for some optimized C and Fortran 90 routines. GIAnT 1.0 relies extensively on numerical Python libraries to develop an object-oriented, flexible, and generalized framework for InSAR time series applications. The user manual describes available scripts and functions and includes detailed instructions for installing the set of prerequisite libraries using standard repository management tools on Linux and OS X platforms. The developers are heavy users of GIAnT for their own geophysical projects, and they will attempt to fix software bugs as they arise.

GIAnT 1.0 is available from http://earthdef.caltech.edu. The Web site includes details regarding access to the version-controlled software repository and a user discussion forum and wiki. Other related packages can also be obtained from the same Web site. While not designed to match the standards of a well-maintained commercial package, GIAnT 1.0 provides a set of tools to be used by researchers who need the flexibility and access to various stages of processing in InSAR time series applications. Future versions of GIAnT will include support for working directly with wrapped interferometric data, persistent scatterer algorithms, improved constrained and regularized solvers, automatic correction of elastic ocean tidal load response, and direct download of APS maps from third-party projects. An immediate gain from using GIAnT is the ability for able and willing users to easily share large interferometric data sets in a standard format and to compare the performance of various time series approaches on any data set in a common framework. The rich suite of library functions that is distributed with GIAnT 1.0 should also facilitate faster development and prototyping of new InSAR time series processing algorithms.

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