Category-1 proposal submitted to the

European Space Agency

Orbital and atmospheric noise in InSAR data inferred from the global ERS1,2 and Envisat SAR data archives

Executive Summary

We request the online provision of nearly the entire ERS and Envisat SAR archives via ESA's "Virtual Archive" for systematic analysis of the accuracy of the InSAR technique. Our approach is to use archived data from non-deforming areas around the world for a robust assessment of the orbital and atmospheric contributions (tropospheric and ionospheric) in InSAR deformation products. One expected outcome is a precise estimate about the long-wavelength error of InSAR data and of its confidence interval. This information is critical for the interpretation of subtle InSAR deformation signals in terms of earthquake risk and volcanic hazards. Estimating orbital errors based on actual InSAR data is much more reliable than from satellite tracking data as was done previously. This project takes full advantage of the capability of ESA's new "Virtual Archive" for convenient access to large amounts of remote sensing data.

This proposal is part of a coordinated sequence of four Category-1 proposals to the European Space Agency for fully exploiting the existing ERS and Envisat SAR archives for tectonics, volcano and climate change studies through online access visa ESA's "Virtual Archive".

Team composition

The PI of the project is Falk Amelung, a professor of geophysics at the University of Miami, USA. The Co-PIs are Franz Meyer, professor of radar remote sensing at the University of Alaska in Fairbanks, USA, Eugenio Sansosti, senior scientist at IREA-CNR in Naples, Italy, Eric Fielding, senior scientist at the Jet Propulsion Laboratory in Pasadena, USA, Andrew Hooper, professor at the Delft Institute of Technology, Netherlands, Zhenhong Li, professor at the University of Glasgow, U.K., Tim Wright and Andy Shepherd, professors at the University of Leeds, U.K. and Matt Prittchard, professor at Cornell University, Ithaca, USA. Each of the team members has more than a decade of experience using InSAR to study crustal deformation and directs individual InSAR research groups. Recognizing the importance of on-line access to the ESA SAR data, the team is leading current efforts to repatriate previously produced data into ESA's virtual archive through the Geohazard Supersites initiative.

Innovation

This project is innovative for four reasons. First, this project exploits for the first time the full ESA SAR data holdings in an effort to characterize the technical limitations of the InSAR technique. Second, this project presents the first global approach to InSAR processing. Third, this project will take full advantage of emerging cloud computing technologies such as ESA's Grid Processing On Demand (GPOD) and the U.S. National Science Foundation's TerraGrid system. Fourth, the online data provision will bring ESA on par with common practice in optical remote sensing in which multi-decade imagery is conveniently available at the user's fingertips through Google Earth.

Contribution to Mission Objectives

This project contributes directly to ESA's mission objective "to better understand solid Earth processes" because the characterization of the orbital, atmospheric and ionospheric noise leads to an improved measurement accuracy of the InSAR technique and allows to detect crustal deformation processes that are currently beyond the detection threshold.

The online availability of the ERS and Envisat "Virtual Archives" will be a critical element to accomplish ESA's core mission of providing long-term, continuous Earth Observation data sets for scientific research.

This project is timely because in combination with its sister projects on tectonics, volcanoes, and climate change it will facilitate the full exploitation of the ESA SAR archives just prior to the arrival of new, unprecedented data amounts from the Sentinel-1 satellites.

Detailed Description

Over the last decade interferometric synthetic aperture radar (InSAR) has developed into a mature geodetic technique which retrieves ground deformation in satellite radar line-of-sight from a time-series of SAR acquisitions. For unchanged ground surfaces (no temporal decorrelation), the accuracy of the measurements is limited by uncertainties associated with the satellite orbits and by signal delays in the atmosphere. We propose to use 20 years of ERS and Envisat data to characterize the orbital and atmospheric noise in InSAR data products. Our approach is to analyze a large amount of SAR data in stable areas not affected by tectonic or magmatic processes in which residual signals must be due to one of the three mentioned error sources, or due to a combination thereof.

The holy grail for tectonic studies is to estimate strain accumulation along locked faults. Tectonic faults undergo a cyclic behavior consisting of strain accumulation between earthquakes (inter-seismic period), the rupture of a fault during an earthquake (co-seismic period) and the relaxation of stress following an earthquake (post-seismic period). Estimating earthquake risk requires estimating the averaged slip rate from geodetic data. Inferring slip rates from InSAR is challenging because the surface displacements are small (a few millimeter/year for a slow moving fault) and distributed over a wide zone (several tens to hundreds of kilometers). The signal therefore can easily be confused with uncertainties of the satellite orbits or atmospheric contributions in the InSAR deformation products.

Several recent studies in Nevada, USA, Tibet, China and in Turkey claim to resolve subtle strain accumulation along active faults. These results have important implications for earthquake risk assessment. However, they need to be digested with caution because with the current state of the art it is not possible to unequivocally separate real deformation from apparent deformation related to uncertainties of the satellite orbits. The error distributions inferred in this project using SAR data of non-deforming areas will be very valuable for the assessment of the apparent deformation signals in these tectonically active areas and lead to more reliable seismic risk assessment.

Orbital errors. For the orbital errors we will process the data into displacement time-series using the Small Baseline (SB) approach of Beradino et al. (2002) and then estimate for each satellite orbit orbital correction terms. We will employ the approach of Gourmelen, Amelung and Lanari (2010) who parameterize orbital phase contributions in terms of correction terms to the vertical and horizontal baseline.

Atmospheric errors. The spatio-temporal variation of atmospheric phase delay signals in SAR interferograms has been identified as the other main factor limiting the sensitivity, accuracy, and temporal resolution of surface deformation measurements from InSAR. Atmospheric delay errors are caused by both the neutral (troposphere) and the charged atmosphere (ionosphere). An improved understanding of the statistical properties of atmospheric signals will improve our ability to mitigate their effects on geophysical parameters derived from SAR.

On small to intermediate scales, tropospheric phase delay signals are mostly attributed to the spatial and temporal variability of atmospheric water vapor as well as to variations in the vertical layering of the lower atmosphere (Hanssen, 2001). We will study these signals statistically through a strategic analysis of the global ERS and Envisat archives. We will investigate their correlation with weather patterns, climatic conditions, wind fields, and strong weather events and address how spatial variations of air pressure and temperature may limit the capabilities of InSAR to measure large scale inter-seismic signals.

While the physical properties of ionospheric signals in SAR and InSAR data have been studied extensively in the last few years (Freeman & Saatchi, 2004; Meyer et al., 2006), their spatial and temporal variability, and therefore their effects on InSAR observations of different wavelengths, is not well understood to date. We have conducted a first attempt to characterize the statistical properties of ionospheric signals in InSAR (Meyer & Watkins, 2011), yet a thorough statistical analysis of ionospheric signals in real SAR data is missing to date. While ionospheric signals are more pronounced in L-band, the long time span and global coverage of the ERS and Envisat C-band archives provide a unique opportunity for studying typical spatial scales and strengths of ionospheric signals together with their dependence on geographic location, time of day, and solar activity.

Our initial focus will be on North Africa, west-central North America, and Alaska's North

Slope. These areas are arid regions with good temporal coherence, good SAR coverage and little topographic relief and therefore optimally suited to analyze errors in InSAR data. Also, previous studies have shown that the likelihood of measurable ionospheric delay signals in C-band SAR data is much higher in the auroral zone and the Polar caps. Therefore, especially the mid-latitude regions can be largely seen as “ionosphere-free”, and the geographic spread of these initial test sites will be used to study all InSAR error signals separately.

Next we will focus on the global archive and aim to include all possible SAR data for which the temporal coherence is sufficient. Our objective is to produce statistical distributions of the orbital errors as a function of latitude and longitude, study atmospheric signal delay as a function of geographic location and climatic conditions, and determine the spatial structure and level of isotropy of ionospheric noise. The 20 year time span of the ERS and Envisat archives will also enable us to determine variations in the statistical properties of ionospheric noise as a function of solar cycle.

Project deliveries

1. Estimates of the probability density distributions of the orbital errors of the ERS1,2 and Envisat satellites based on the global ESA SAR archive.

2. Estimates of the probability density distributions for tropospheric delays.

3. Estimates of the probability density distributions for ionospheric delays

Computational challenges

This project will take full advantage of emerging cloud computing technologies such as ESA’s Grid Processing On Demand (GPOD) and the U.S. National Science Foundation’s TerraGrid system. One of the research priorities is to efficiently synthesize the results of global InSAR analyses, which will be an important research topic in the following years.

Related projects

This project is part of a sequence of four proposals aimed at exploiting the global ESA SAR archives. The other three proposals are: “Global earthquake cycle studies using the ERS1,2 and Envisat SAR data archives” (lead PIs Tim Wright and Zhenong Li), “Global volcano studies using ERS1,2 and Envisat SAR data archives” (lead PIs Eugenio

Sansosti and Andrew Hooper) and “Changes of the Earth’s climate from 20 years of ERS1,2 and Envisat SAR data” (lead PIs Andy Shepherd and Franz Meyer).

This sequence of proposals has been inspired by the success of the Group of Earth Observation’s (GEO) geohazard Supersites project. The data requested are of interest for the worldwide geohazard and climate change communities. We anticipate that many PIs involved in these areas of research will join these projects once they are in place.

Schedule

August 2011. Start of project using repatriated data available in ESA’s virtual archive (Tibet, Western U.S., Central Andes).

December 2011. Data analysis for North Africa, Central U.S., Northern Mexico, and the Alaskan Arctic.

April 2012. Comparison of error estimates from non-deforming areas with results of areas with known deformation.

July 2012. Global analysis over all land masses covered by 10 or more ERS or Envisat acquisitions.

July 2013. Completion of project.

Data requirements

We request the provision of the entire interferometrically usable ESA SAR archive (into ESA’s Virtual Archive in a consistent format (framed, RAW, Envisat format (including for ERS), all ERS1,2 and Envisat land tracks with more than 10 acquired orbits, a total of ~1,000,000 frames)). We also request software application to support the selection and download of large amounts of data such as an Application Programming Interface (API).

Online data provision and rapid download speeds are absolutely critical for the success of this project. At the end of the project we anticipate automated processing of several thousand SAR scenes per day.

We request data provision in three phases. In the first phase (phase A) we request imagery of arid areas with relatively low topography which are best suited for the purposes of this project. This includes the North-African countries (Marocco, Western Sahara, Mauritania, Algeria, Tunisia, Lybia, Egypt, Mali, Niger, Chad, Sudan), the west-central US east of the Rocky Mountains (Texas, New Mexico, Oklahoma, Colorado, Wyoming), Northern Mexico, the Alaskan North Slope, and Iran. In the second phase (phase B) we request framed data for the deforming areas in the Western U.S. and Tibet. In the third phase (phase C) we request the remainder (all land imagery as long as more than 10 acquisitions exist).

References

Berardino, P., G. Fornaro, R. Lanari and E. Sansosti (2002). A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. Ieee Transactions On Geoscience and Remote Sensing, 40, 2375–2383

Gourmelen, N., F. Amelung and R. Lanari (2010). InSAR -GPS Integration: Inter-seismic Strain Accumulation Across the Hunter Mountain Fault in the Eastern California Shear Zone. J. Geophys. Res., doi:10.1029/2009JB007064.

Freeman, A. and S. S. Saatchi (2004). On the detection of Faraday rotation in linearly polarized L-band SAR backscatter signatures. *IEEE Trans. Geosci. Remote Sens.*, vol. 42, no. 8, pp. 1607–1616.

Hanssen R., *Radar Interferometry: Data Interpretation and Error Analysis*, Kluwer Academic Publisher, The Netherlands, Chapter 6, pp197- 246, 2001.

Meyer, F., Bamler, R., Jakowski, N. and T. Fritz (2006). The potential of lowfrequency SAR systems for mapping ionospheric TEC distributions. *IEEE Geosci. Remote Sens. Lett.*, vol. 3, no. 4, pp. 560–564.

Meyer, F.J. and B. Watkins (2011). A Statistical Model of Ionospheric Signals in Low-Frequency SAR Data. In: Proceedings in IGARSS'11, in print.