Category-1 proposal submitted to the European Space Agency

Quantifying the impact of climate change and the efficacy of climate solutions using the ERS-1/2 and Envisat SAR data archives.

Executive Summary

We request the online provision of nearly the entire ERS and Envisat SAR archives over Polar Regions via ESA's "Virtual Archive" interface for a systematic study of global warming-related changes of the arctic environment using SAR and InSAR techniques. Our approach is to use the full archive of InSAR data available for high latitudal regions in order to carry out systematic studies of climate change-related surface signals such as changes in extent and dynamics of glaciers, surface deformation due to permafrost thaw, surface uplift as a consequence of glacial isostatic adjustment (GIA). SAR images from the ERS and Envisat missions are an indispensable data source for this research due to the consistent and frequent coverage of Polar Regions and the independence from weather conditions and solar illumination. The strategic analysis of the ERS and Envisat archives will provide new insights into the response of the environment to climate change and will improve our understanding of the global carbon cycle. 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 Andrew Shepherd, a Professor of Earth Observation at the University of Leeds, U.K. The Co-PIs are Franz Meyer, a Research Assistant Professor for Radar Remote Sensing at the University of Alaska Fairbanks, USA, Noel Gourmelen, assistant professor at the University of Strasbourg, France, Falk Amelung, a professor of geophysics at the University of Miami, 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., Matt Prittchard, professor at Cornell University, Ithaca, USA, and Tim Wright, a reader in

Satellite Geodesy at the University of Leeds, UK.

Team Experience

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 three reasons. First, this project exploits for the first time the full ESA SAR data holdings in an effort to characterize climate change-related earth science signals on a wide range of spatial scales. Second, through the data processing strategies developed in this project, we will provide undisputable evidence of the ability of InSAR to detect and quantify subtle surface deformation signals of very large spatial scales. This project will therefore work towards merging InSAR with other large scale space-geodetic techniques such as spaceborne gravimetry, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and GPS, and support the development of an observation system that is capable of measuring geodynamic signals on all spatial scales. Third, 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 objectives "to better understand solid Earth processes" and "to make a significant contribution to environmental studies". The availability of the vast ERS and Envisat archives for Polar Regions will enable large scale studies of climate change-related surface deformation signals that were previously hard to access from other data sources. For instance, measurement of secular surface deformation signals in permafrost regions will improve our understanding of the susceptibility of permafrost to changes in surface temperatures. Beyond that, the access to consistent large coverage SAR and InSAR data will result in advanced InSAR processing strategies that will allow the detection of subtle, large scale surface deformation signals 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 volcanoes, earthquakes and InSAR accuracy, 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 capable of measuring centimeter-scale ground deformation from a time-series of SAR acquisitions. In recent years, the number of applications where InSAR is used to measure climate-related signals has increasing steadily. Studies of glacier flow velocities and changes in glacial mass transport have become routine. In other research, InSAR techniques were employed to determine changes in permafrost conditions (e.g., Liu et al., 2010), to analyze changes in glacier outline and topography (e.g., Atwood et al., 2009; Palmer et al., 2010), to analyze the dynamic of landfast sea ice (Meyer et al., 2011), and for monitoring ice thickness on tundra lakes (Wegmueller et al., 2010). We propose to use the global 20 year archive of ERS and Envisat data to study climate change signals on a variety of spatial scales and to develop new data processing techniques (Gourmelen et al., 2011) that will improve the accuracy of InSAR derived measurements and enhance the sensitivity of InSAR to climate-related signals.

The dedicated analysis of the available archive will inevitably lead to a wealth of new discoveries in earth science research and will improve our understanding of the susceptibility of the environment to climate changes. These new discoveries will increase the influence of SAR data in climate change research and develop new user communities that can be serviced with future ESA systems such as the Sentinel series.

Access to the ERS and Envisat archive over Polar Regions will allow us to address the following research questions:

Ice Sheet Velocity and Grounding Line monitoring:
Changes in the Earth's climate impacts upon the major Ice Sheets, causing increased flow of the glaciers to the sea (Rignot et al., 2008), enhanced surface melting (Steffen et al., 2004), surface lowering (Zwally and Giovinetto, 2001, Shepherd et al. 2002, Pritchard, 2009}} and gravity anomalies related to net ice mass loss (Velicogna and Wahr, 2006). The Greenland and Antarctic Ice Sheets hold the vast majority of grounded ice on Earth and, if they were to entirely melt, would cause the sea level to rise by as much as 64 m (Bamber et al., 2001, Lythe et al., 2001). This would lead to profound economic and societal transformations. Satellite Interferometric Synthetic Aperture Radar (InSAR) is a key Earth observation technique for monitoring the state of Ice Sheets (Goldstein et al., 1993). By measuring essential climate variables such as ice sheet velocity and grounding line position, InSAR data help to infer the rate at which glaciers lose ice mass to the oceans, how this rate evolves through time, and at what rate outlet glaciers are thinning. The 20-year archive of ESA SAR data will help us understand better the link between the climate and Ice Sheets and improve projection of their future state.

Permafrost change:
Climate warming may induce an increase in active layer thickness and may result in thawing of ice-rich near-surface permafrost horizons. These processes are associated with surface subsidence signals that can be observed with InSAR techniques. Besides tracing signs of permafrost change, surface deformation observations provide interesting data for the analysis of carbon cycle dynamics. For example, surface inflation measurements are useful in understanding how fast talik and lake sediment is locked into permaforst again after the drainage of a lake basin, and how much ground ice builds up over time, paving the road for renewed thermokarst in the future ("thermokarst lake cycle"). For study areas on Alaska's North Slope and in Siberia, two types of surface deformation signals will be extracted from InSAR data and analyzed separately for their scientific meaning; i) seasonal subsidence signals that are most likely caused by thaw settlement in the active layer and whose amplitude may be used to determine thickness and ice richness of the active layer; ii) secular subsidence, which may be attributable to thawing of ice rich permafrost directly beneath the active layer.

Dynamic and Extent of Tidewater and Mountain Glaciers:

Rapidly changing tidewater and Mountain glaciers are important contributors to global sea level rise. For instance, Alaskan and Patagonian glaciers are two of the largest contributors to sea level rise outside of the large ice sheets of Greenland and Antarctica. In fact, Alaskan glaciers contribute in the same magnitude as the Greenland ice sheet in the period 2002-2008 (Wu et al. 2010). Despite their importance, detailed observations of changes in glacier extent and glacier dynamic are scares for most glaciated regions, and only a small fraction of all mountain glaciers around the globe are monitored in a systematic manner. The access to the entire ERS and Envisat archives will enable us to systematically analyze spatial extent, surface elevation changes, and ice velocities for a wide range of glaciers around the globe. Using a combination of InSAR and speckle tracking techniques we will start with an analysis of glacier changes in Alaska and Patagonia to solidify estimates for their contribution to sea level rise. In a later stage of this project, this effort will be expanded to other ice rich areas around the globe including Svalbard, the Himalaya region, the Karakoram and Hindukush mountains, Central Asia, and the Antarctic Peninsula.

Stability of Landfast ice:

Landfast sea ice is a key element of the Arctic coastal system. Its presence can mitigate the effect of winter storms on the coast and impact the degree of coastal erosion (Lantuit and Pollard, 2008). Landfast ice is also of great importance to coastal communities who use the ice for travel and to hunt. Furthermore, its presence and stability is of considerable economic importance for offshore oil and gas development in parts of the Arctic (Eicken et al., 2009). In recent years, there has been a reduced presence of landfast sea ice throughout the Arctic. Divine and Dick (2006) note a negative trend in mean landfast sea ice extent in the Kara Sea since 1953. In the Canadian Archipelago, formerly semi-permanent plugs of multiyear landfast ice have fractured or disintegrated several times since 1997. Recent studies have shown that SAR data is a convenient data source for monitoring changes in landfast ice conditions (Meyer et al, 2011). Access to 20 years of SAR data from the ERS and Envisat archives will enable us to track changes of landfast ice extent and dynamic through recent history and correlate these results to surface temperature records. Based on previous efforts, we will start analyzing data along the coasts of the Beaufort and Chukchi Sea and determine trends in landfast ice extent and stability. Observations near Barrow, Alaska will be used to cross-compare SAR derived results to measurements from other sensors that are available in this area. In later stages of the project, other test areas will be analyzed including the Antarctic Peninsula and the Russian Arctic.

Coastal Change and Hydrological Mapping:

Changing climatic conditions have a pronounced impact onto coastal and near coastal environments in Arctic and Antarctic regions. For instance, coastal erosion and thermocarst activity have increased dramatically along the arctic coast of Alaska and has strongly affected its indigenous population. Spaceborne microwave remote sensing-based methodologies are well suited for efficient, large-coverage, monitoring of hydrological features like coast lines and lakes around the globe. The independence of spaceborne Synthetic Aperture Radar (SAR) data of external illumination sources emphasizes its suitability as a 24/7, all-weather mapping and monitoring data source. Using the 20 year time series of ERS and Envisat data over the Alaskan North Slope and eastern Siberia, we will analyze the rates of coastal erosion and changes in the distribution of thermocarst lakes.

Glacial Isostatic Adjustment

Some of the more indirect, and yet important, effects of changing climatic conditions on the Earth's Lithosphere are motion of the Earth's surface in response to changes in the mass of grounded snow and ice (glacial isostatic adjustment or GIA). There are two main sources for glacial isostatic adjustment. The first is the disequilibrium due to the melting of the large ice sheets 10,000 -20,000 years ago which depressed the land masses of Scandinavia and Canada by about 500 m. Since deglaciation the Earth's crust has rebounded by up to 300 m. Uplift is expected to continue until isostatic equilibrium is reached. The current maximum uplift rates are about 1 cm/yr in northern Sweden and in the Hudson Bay area of Canada. The second source for glacial isostatic adjustment is accelerated ice loss related to global warming over the last 10 years. There are indications that melting of the Vatnajokull glacier, Icelands largest glacier, is accompanied by instant elastic rebound of the ground (Pagli et al., 2007). Accelerated uplift and accelerated melting has also been suggested for parts of Greenland (Jiang et al., 2010).

We propose to use the 20 years ESA SAR archive to quantify surface elevation change due to glacial isostatic adjustment. Our focus areas are the ice-free coasts of Greenland and Antarctica, northern Norway and Iceland. We also will examine the ice sheets of Svalbard as well as the Canadian and Siberian arctic island. This part of the project is an effort to obtain independent estimates of the ice loss rates from InSAR ground displacement measurements. The convenient data provision via the Virtual Archive will facilitate the study of multiple test sites.

CO2 Sequestration

In addition to providing a capability to document changes in Earth's climate, InSAR data are able to assist in developing solutions to mitigate the effects of climate change. Carbon capture and storage (CCS) is a crucial element in the global drive to reduce emissions of CO_2 and limit its impact on climate (IEA 2008, IPCC 2005). The first experiments have been in progress for a decade now (Haszeldine, 2009), and over 100 are in the planning stage; recent studies (Vasco et al., 2008) have shown that the process is associated with deformation at the surface of the Earth allowing for monitoring strategies from spaceborn sensors.

We propose to utilize the archive of ESA InSAR data to independently monitor surface uplift in the vicinity of onshore pilot CCS sites. These data will be employed in conjunction with reservoir inverse modeling to assess the extent to which CO2 storage has been successful. The overall objective is to develop a monitoring strategy for the future operational sites that are planned as a global climate solution.

Project deliveries

1. Maps of seasonal and secular surface deformation related to permafrost change.
2. Flow velocity and extent maps for glaciers in Greenland, Antarctica, Alaska and Patagonia.

3. Landfast ice change along the Beaufort and Chukchi Sea.
4. Maps of coastal erosion rates for the Alaskan and eastern Siberian Arctic coast.
5. Measures of glacial isostatic adjustment
6. Deglaciation rates from ground uplift rates near glaciers
7. Uplift rates and stability of CCS schemes

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Schedule

August 2011. Start of project using repatriated data available in ESA's virtual archive.

January 2012. Maps of Permafrost-related surface deformation on Alaska's North Slope.

August 2012. Production of ice velocity and glacier extent maps for glaciers in Alaska and Patagonia.

January 2012. Production of landfast ice change maps for the coasts of the Chukchi and Beaufort Sea.

August 2013. Maps of coastline change rates for the Arctic coast of eastern Siberia and Alaska.

July 2014. Project completion.

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 tracks in Polar Regions, a total of ~500,000 frames. We also request software applications 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 Alaska, the Canadian Arctic Coast, all arctic islands, northern Norway, eastern Siberia, and Patagonia. In the second phase (phase B) we request data for the alpine-Himalayan belt, and the Antarctic Peninsula. In the third phase (phase C) we request the remainder (all land imagery in Polar Regions).

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