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# InSAR Observations Revealed Surface Subsidence Over Permafrost in Northern Alaska

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The Arctic climate has experienced more rapid warming than anywhere else on Earth over the past hundred years and this trend is expected to continue over the next century [Intergovernmental Panel on Climate Change (IPCC), 2007]. About 80% of Alaska is underlain by permafrost, which is soil at or below 0°C for at least two consecutive years. The active layer is the surface layer of soil that thaws in the summer and freezes in the winter. Observations indicate the active layer and permafrost are already responding to the Arctic warming. For instance, the Beaufort Coastal Plain on the North Slope of Alaska is underlain by ice-rich permafrost that contains ground ice up to 70% by volume (Figure 1). In this region, permafrost temperatures have increased by 2° to 3°C since the mid 1980s in response to the rapid warming of the Arctic (Osterkamp, 2007). It is generally hypothesized that climate warming causes permafrost degradation, i.e., thickening of the active layer, warming, and thawing of permafrost. However, ground-based measurements show no significant trend in the active layer thickness (ALT) in northern Alaska (Brown, et al., 2000).

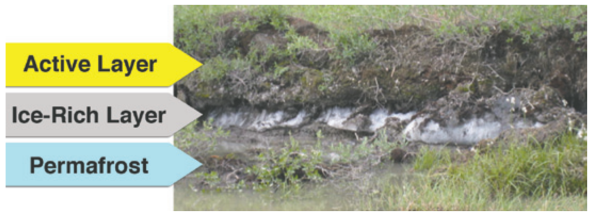


**Figure 1**: A 40-cm thick layer of ice lies right beneath the active layer on the North Slope of Alaska.

Permafrost degradation has profound effects on mechanical stability of ground, on biological, biogeochemical, hydrologic, and landscape processes, on the flux of greenhouse gases, and on human infrastructure. It is critical to conduct comprehensive measurements to monitor changes in permafrost and the active layer at regional scales. The International Permafrost Association's Circumpolar Active Layer Monitoring (CALM) program has conducted site-specific and grid (one km by one km) measurements of active layer thickness over the past two decades and has produced valuable data and information (Brown, et al., 2000). However, the existing CALM network is still underpopulated and does not represent the full range of climatic and physiographic variability.

Satellite remote sensing using the Interferometric Synthetic Aperture Radar (InSAR) technique has the potential of providing regional-scale monitoring of the active layer and near-surface permafrost dynamics across a broad climatic and physiographic spectrum. The InSAR technique was applied to the European Remote Sensing Satellite-1 (ERS-1) and ERS-2 SAR images taken during summer seasons between 1992 and 2000 to measure surface deformation over the permafrost area on the North Slope of Alaska. The SAR data was archived at the Alaska Satellite Facility (ASF). Surface subsidence of 2 to 4 cm was found in each thaw season between June and September (Figure 2a). In addition, a relatively small, but significant long-term trend in surface subsidence at rates of one to 4 cm per decade was found (Figure 2b). The physical mechanism of surface deformation is linked to soil water phase change within the active layer and near-surface permafrost. The active layer on the North Slope of Alaska is generally saturated with water content greater than 40% by volume. When pore ice melts in the active layer in summer, its volume reduces by about 9%, resulting in surface subsidence. Therefore, the seasonal subsidence is directly related to the volume of melted water in the active layer. A retrieval algorithm was developed that estimates ALT and its change from the InSAR-measured seasonal subsidence using the vertical distribution of water and ice within the soil. As an alternative method, remote sensing of ALT, using InSAR, could be particularly useful for filling the spatial gaps between ground-based measurements in remote permafrost areas.

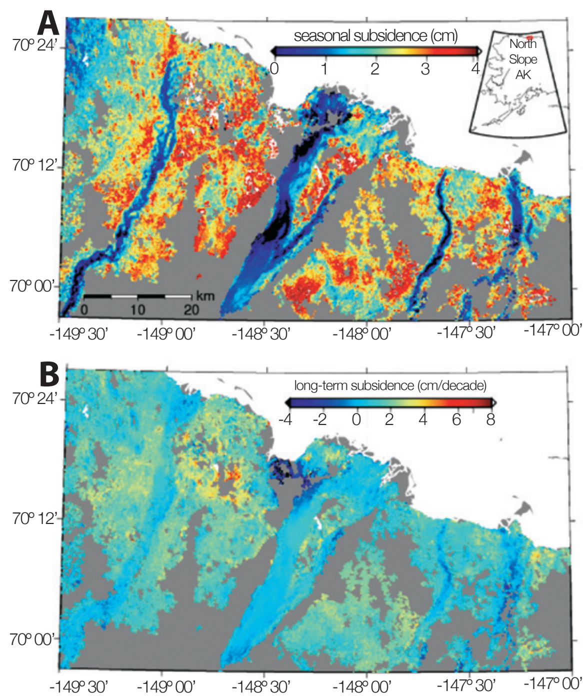


**Figure 2**: (a) Long-term average seasonal subsidence occuring between June and September based on InSAR measurements. The inset map shows the location of the study area as a red box on the North Slope of Alaska. (b) Long-term trends in surface subsidence between 1992 and 2000. The Arctic Ocean in the northeast is in white. Gray areas indicate regions where no robust InSAR measurements could be made. Figures are adapted from Liu, et al. [2010].

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# The JPL UAVSAR

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## History

The Jet Propulsion Laboratory's (JPL) Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) project began as an Instrument Incubator Program (IIP) task in 2004, funded by the National Aeronautics and Space Administration's (NASA) Earth Science Technology Office. After a year of study, JPL presented to NASA, a SAR instrument concept that would meet IIP science and instrument objectives, and could be expanded to meet future airborne radar science needs. This led to a 4-year program in that the SAR radar system was designed, fabricated, installed, and flight tested. A Gulfstream G-III aircraft at NASA Dryden was modified to support UAVSAR, including the development of a precision autopilot that would keep the aircraft within a planned 10-meter flight tube during radar acquisitions.

The primary objectives of the UAVSAR development phase were to develop a compact polarimetric L-band SAR for use on a UAV, or minimally-piloted vehicle, including an electronically-scanned antenna and the associated processing algorithms for repeat-pass differential InSAR; followed by the acquisition of measurements of geophysical interest to demonstrate the system, particularly observations of rapidly deforming surfaces such as volcanoes or earthquakes. The system was designed to support a wide range of science investigations including cryospheric studies, vegetation mapping and land-use classification, archeological research, soil-moisture mapping, geology and cold land processes.

UAVSAR became operational in 2009 and began acquiring data for a variety of science investigations. NASA Dryden operates the aircraft; JPL maintains the radar hardware, plans the missions, and processes the data. ASF is the designated Distributed Active Archive Center (DAAC) for the UAVSAR data products.

**Figure 3**: UAVSAR on the NASA Gulfstream G-III. NASA photo: Tom Tschida. ED07 0027 39.

## Instrument Characteristics

UAVSAR is an L-band SAR with a bandwidth of 80 Mhz. The antenna measures 0.5 meters in range by 1.5 meters in azimuth and is contained within a pod that hangs beneath the fuselage of the Gulfstream G-III aircraft. The antenna may be electronically steered along track; typically, it is steered to zero Doppler. The power transmitted is greater than 2 kW, and the noise equivalent for most of the swath is better than -45 dB. The single-look-complex data (SLC) have a pixel spacing of 0.6 m x 1.6 m. The Rosamond Calibration Array is used to calibrate the UAVSAR data to the required accuracy of one dB.

UAVSAR typically flies at an altitude of 41,000 feet on the NASA Gulfstream G-III, at a nominal ground speed of 430 Knots (Figure 3). The typical flight duration is 6 hours. In a typical mode of operation, full quad-polarization data are acquired. The cross-track image swath is about 20 km, and a typical flight line is 100 km in length.

## Data Acquisitions

UAVSAR first acquired data on 18 September 2007. Since 2009, over 1,800 flight lines have been acquired during more than 160 flights, acquiring over 40 terabytes (TB) of raw signal data. Data have been acquired across several NASA Earth Science and Applications disciplines, such as solid Earth science, terrestrial ecology, cryospheric science, and hydrology.

In 2009, UAVSAR participated in the International Polar Year, and in addition to acquiring L-band data in Greenland and Iceland, also supported the development of a Ka-band system tand subsequent acquisition of data in Greenland. Since 2009, UAVSAR has been monitoring deformation of the San Andreas Fault every 6 months from the Mexican border to North of San Francisco. Several terrestrial ecology missions have been conducted, from the Northeastern United States of America to Central America. Solid Earth-science campaigns have taken place from Central America to Hawai'i to the Aleutian Islands.

In 2010, UAVSAR was deployed to Haiti and to the Gulf Oil-Spill region to acquire data in support of assessing the impact of those disasters. Also in 2010, UAVSAR acquired repeat-pass InSAR results from the Baja 2010 earthquake (Figure 4). UAVSAR has been supporting several other investigations, such as regular monitoring of the Sacramento Delta, and the development of a real-time, on-board processing system.

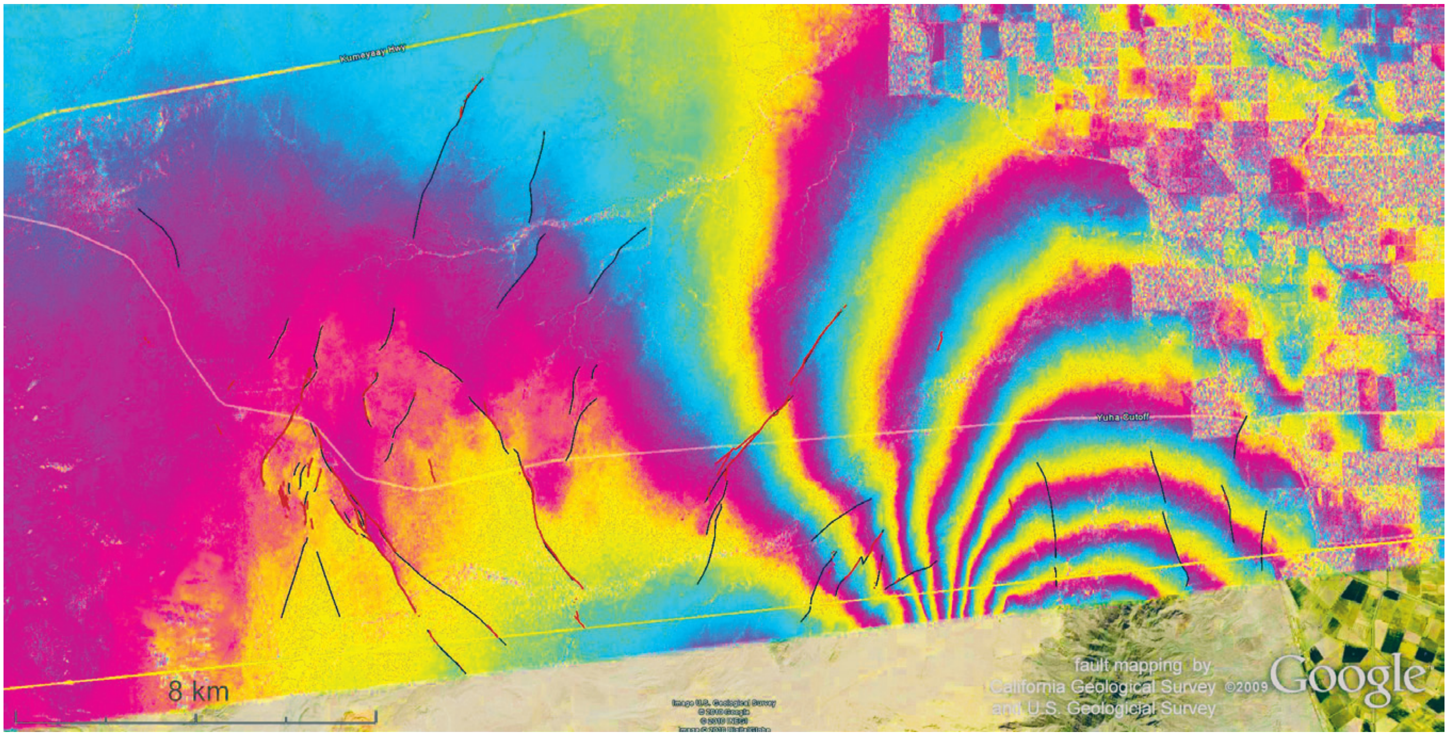


**Figure 4**: This UAVSAR image, covering the time period from 21 October 2009 to 13 April 2010, shows ground deformation that is largely a result of the 4 April 2010 earthquake in Baja, California. Black lines indicate interpreted faults and red lines show where geologists in the field confirmed surface rupture. Image credit: NASA JPL/United States Geological Survey/California Geological Survey/Google.

## Data Products

UAVSAR processes acquired data to high-resolution, fully-polarimetric data products. These products are available to anyone at no charge and may be downloaded by file transfer protocol from the data archive at ASF. Currently, over 1,400 fully-polarimetric images (almost 20 TB of data volume) are available for download, covering over 3 million-square kilometers. Included in the available products are 36-look slant-range polarimetric products at 5 m x 7.2 m pixel spacing; ground-projected polarimetric products in an equiangular geographic projection corresponding to 6 m x 6 m pixels; legacy Airborne SAR compressed stokes format data for the multilook slant-range data; and a full-resolution KMZ-formatted color composite image. SLC data products are available by request.

At the request of investigators, pairs of images are processed interferometrically to form interferograms. In addition to slant-range interferometric products, ground-projected products are also generated, as well as KMZ-formatted color overlays. These products are also available at no charge to an interested user.

Polarimetric data may be searched for and downloaded from both the ASF SAR Data Center's Web site (https://ursa.asfdaac.alaska.edu/cgi-bin/login/) and from the UAVSAR Web site (http://UAVSAR.jpl.nasa.gov). Interferometric products will be available from ASF and are currently only available for search and download from the UAVSAR Web site.

## Future

UAVSAR is continuing to conduct L-band science investigations on the NASA Gulfstream G-III aircraft for a variety of science objectives. The flexibility and modularity of UAVSAR allows for modifying the radar to operate in other frequencies and platforms. In fact, a P-band SAR capability, funded through NASA's Earth Venture program and led by the University of Michigan, is being developed to measure subcanopy and subsurface soil moisture. A Ka-band, single-pass interferometry capability, funded through the NASA Airborne Instrument Technology Transition program and led by Remote Sensing Solutions, Incorporated, is being developed to study polar ice sheets. Work is also being undertaken to add L-band, single-pass interferometry capability to UAVSAR via two wing-pod-mounted antennas on the Global Hawk UAV platform.

## For More Information

If you are interested in requesting UAVSAR data acquisitions for science investigations, please visit the UAVSAR Web site at http://uavsar.jpl.nasa.gov/reqsystem.html to plan flights, estimate the flight costs, and submit a flight request. For more information, please visit the UAVSAR Web site at http://uavsar.jpl.nasa.gov.

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At a longer time scale of a few years, melting of ground ice beneath the active layer can cause substantial thaw settlement across a broad spectrum of spatial scales and landforms. If enough heat transfers through the active layer to the underlying permafrost, ice-rich permafrost thaws and ground ice melts. Meltwater drains into lowlands, river channels, and thaw lakes, resulting in surface subsidence. Thawing of ice-rich permafrost near the permafrost table offers a possible explanation both for the InSAR-measured secular surface subsidence and for the negligible trends in ALT from ground-based measurements despite an observed increase in permafrost temperatures. This is because little soil material adds to the overlying active layer upon thawing of ice-rich permafrost.

Overall, InSAR is uniquely suited for monitoring surface deformation at high spatial resolution over large permafrost areas. Combinations of ground-based and remote-sensing measurements such as InSAR are valuable for monitoring changes in the active layer and permafrost, identifying scales of spatial variability, detecting temporal trends, and validating permafrost models.

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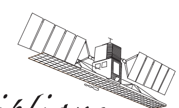

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