Remote Sensing Methods for Detecting, Monitoring and Evaluating Geologic Hazards

Southwest Research Institute®
San Antonio, Texas

Southwest Research Institute®

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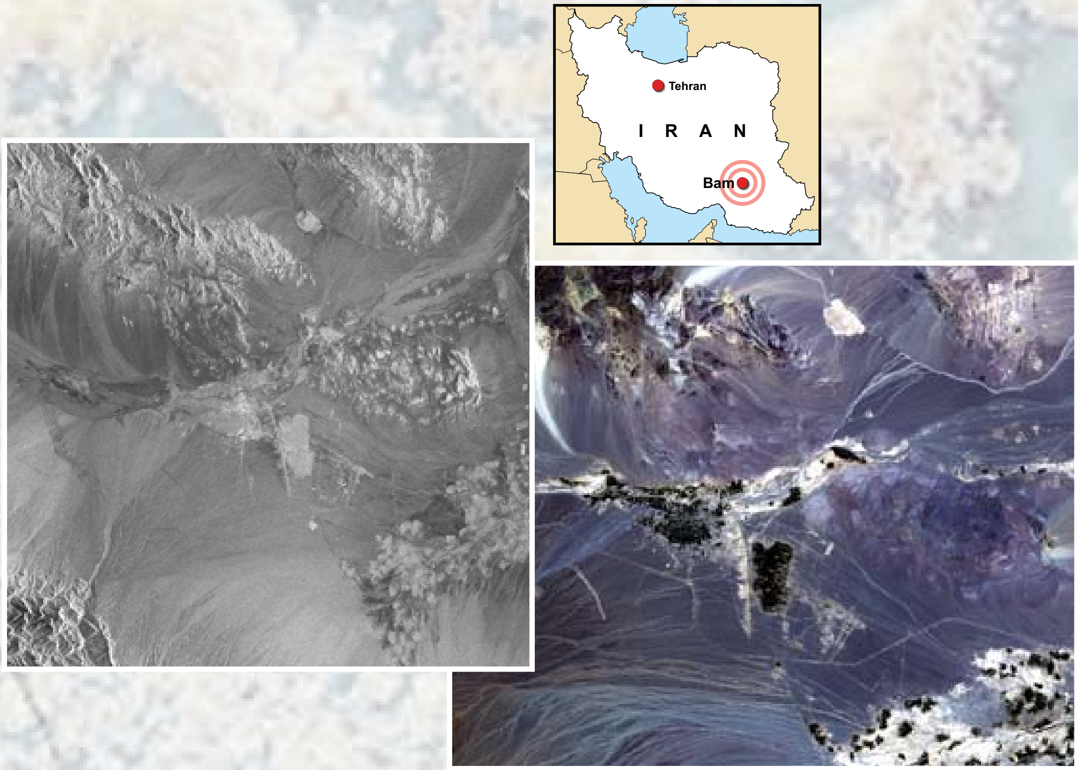
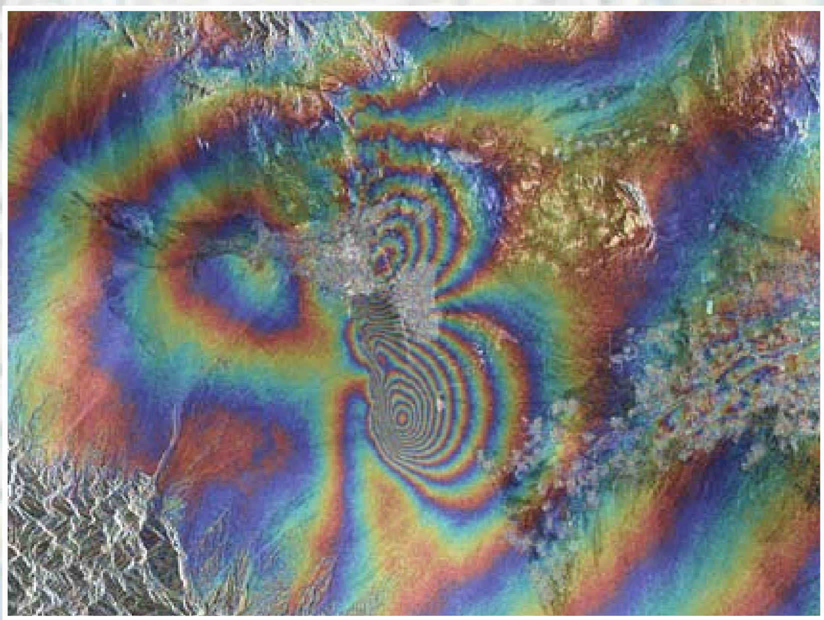
SAR SLC datasets used to generate radar interferograms were produced by the European Space Agency (ESA) and distributed by Eurimage. Optical datasets used to generate background images were acquired from Landsat 7 ETM+, courtesy of Global Land Cover Facility, University of Maryland; and ASTER, courtesy of NASA LP-DAAC, the U.S. Geological Survey and METI (Japan).





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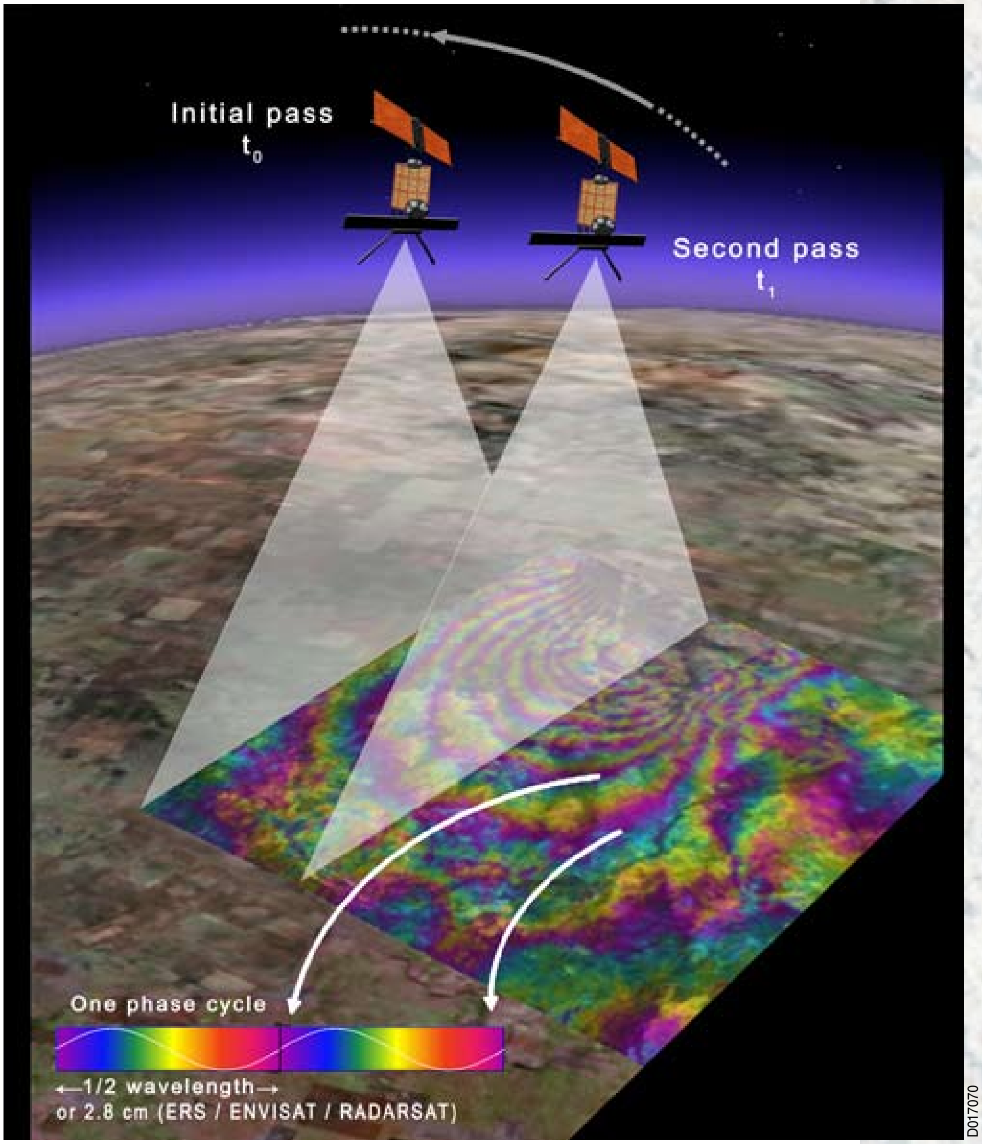
In 2003, a 6.6-M_w earthquake demolished the historic city of Bam, Iran, killing and injuring tens of thousands. The Bam earthquake area is depicted by radar and optical satellite images (top). In the bottom image, a radar interferogram created by SwRI scientists shows two strong line-of-sight displacement lobes in the east and two weaker lobes in the west — a typical pattern for a right-lateral strike-slip earthquake on a north-south oriented fault line. "Noise," the speckled areas in the image, corresponds to the cities of Bam and Baravat, where most of the surface damage took place. The fringe color pattern corresponds to 28 mm of displacement along the satellite line-of-sight.

Southwest Research Institute® (SwRI®) uses satellite radar and optical imagery to detect and monitor ground movements associated with geologic hazards such as earthquakes, landslides and volcanoes. These remote sensing techniques provide a fundamentally new way to study changes of the earth's surface. Techniques employed include:

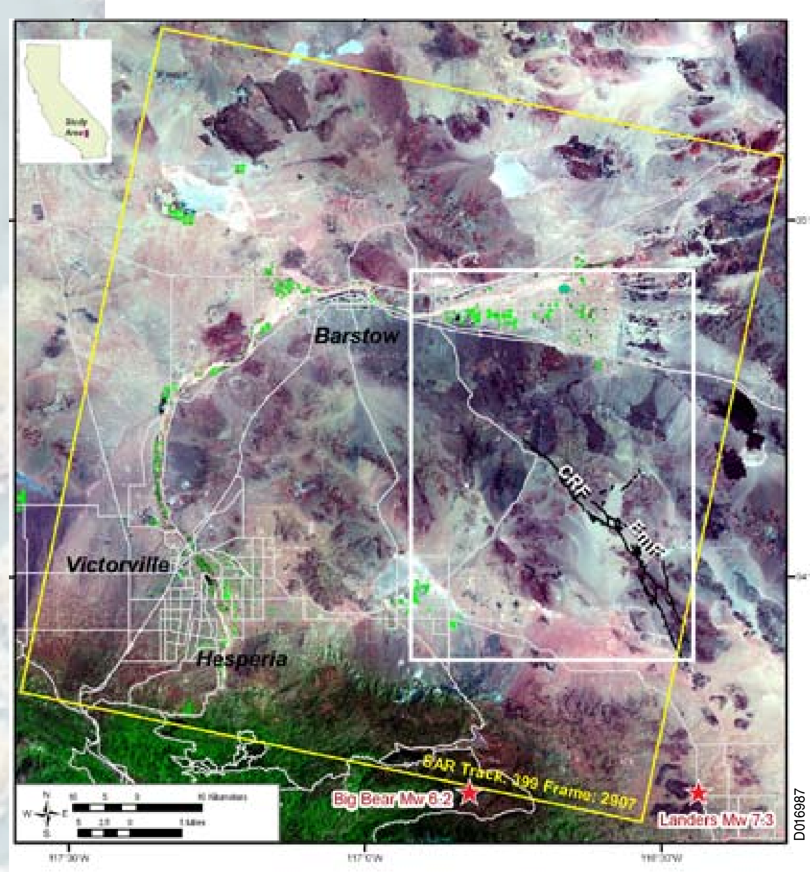
- Differential Synthetic Aperture Radar Interferometry (DInSAR)
- Persistent Scatterer Interferometry (PSI)
- Corner Reflector Interferometry (CRInSAR)
- Multispectral Data Displacement Analysis (MDDA)

DInSAR, CRInSAR, and PSI are different implementations of radar interferometry (InSAR).

Because each remote sensing technique has advantages and limitations, a multidisciplinary team of SwRI scientists and researchers tailors method selection to meet the needs of the specific application. SwRI finds solutions to client-specific challenges by using one or a combination of these techniques, depending on the type of geological event or process of concern, geographic area, technical specifications and availability of specific satellite data, topography, and atmospheric and weather conditions.



InSAR combines images of a given area to measure ground surface displacement to centimeter or millimeter accuracy. Colors represent the phase difference (displacement) at each pixel location between the times of acquisition.



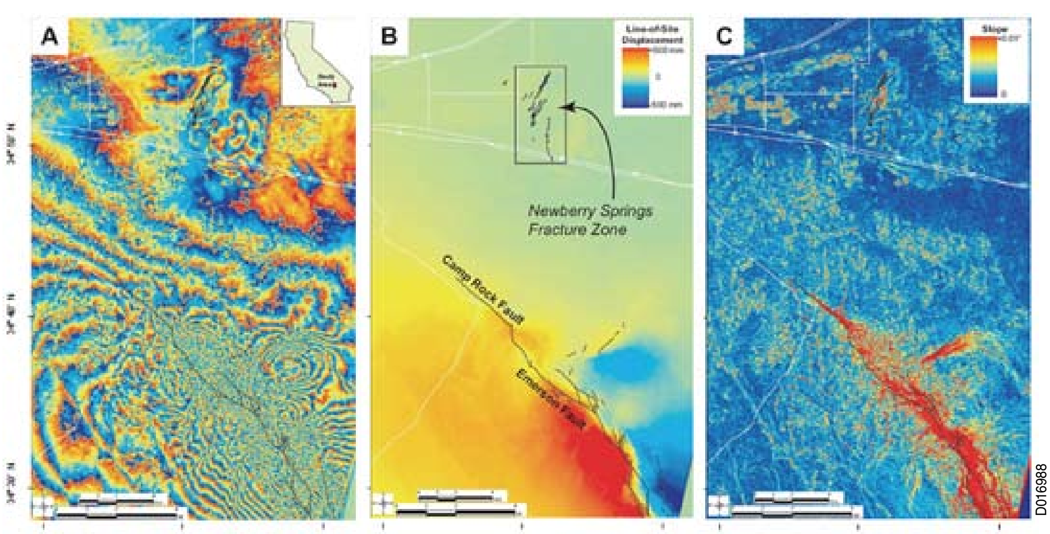
Aerial or satellite radar interferometry uses the phase shift in satellite radar signals to detect ground movement. Radar imagery alone, however, does not directly reveal ground movements. SwRI engineers and scientists use mathematical processing to produce maps of ground movement from SAR data. Multiple satellite passes over time increase sensitivity and provide a finer time resolution of surface movements and their effects. Institute staff members conduct geological interpretations to determine the likely cause of these ground movements, such as subsidence, soil creep or slumping, or deformation from subsurface gas injection, hydrocarbon extraction or hydrologic processes.

The epicenters of the Landers earthquake and its aftershock, Big Bear, are shown as red stars. The rectangles outline the boundaries of a DInSAR dataset (yellow) and the images below (white).

DInSAR

Conventional InSAR and DInSAR techniques process the phase differences between image pairs for backscattered signal data. The success of these technologies depends on the effect of spatial and temporal decorrelation of the signal and the availability of high resolution digital elevation models needed to create radar interferograms.

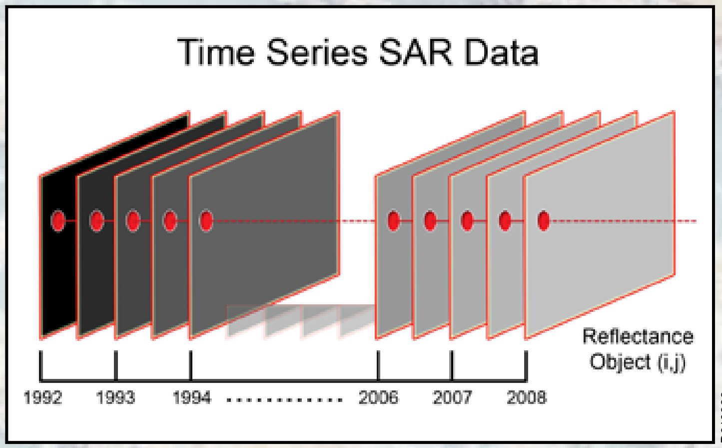
After the 1992 Landers earthquake in California, DInSAR was used to map the main coseismic ground movements with amplitudes of several centimeters to a few meters. Valuable insights were gained about fault locations and fault mechanisms. These can be used in models to forecast seismic events.



DInSAR was used to show changes in land surface elevation due to the Landers earthquake. These changes are represented by (A) a coseismic radar interferogram, (B) a displacement map and (C) a displacement gradient map to identify fault ruptures.

PSI

While conventional InSAR methods use backscattered signals from all reflecting objects, PSI uses data only from high reflectance objects of dams, pipelines, buildings, highways and exposed rocks (persistent scatterers). A large and well-distributed set of targets (on the order of a few hundred per square kilometer) can produce data to accurately model the heterogeneity of the atmosphere. This in turn creates geospatial products such as displacement maps with accuracy on the order of millimeters.

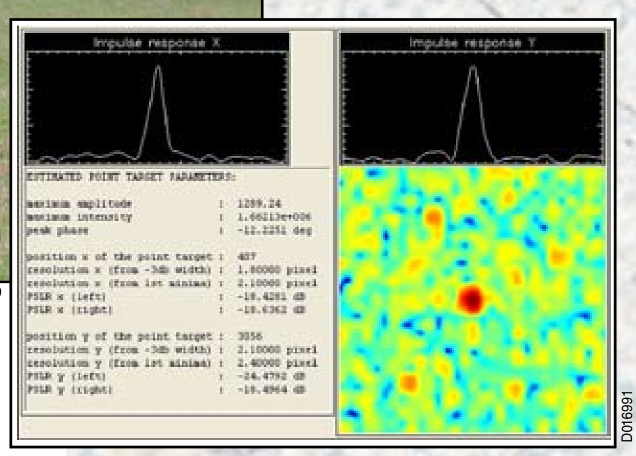


The phase history of each scatterer can provide interpolated maps of average annual ground motions or the motion history over time.

CRInSAR

CRInSAR complements PSI when neither coherent natural targets nor persistent scatterers are available. CRInSAR uses corner reflectors that are coherent radar targets and are unaffected by radar acquisition geometry and temporal decorrelation. These artificial structures provide SwRI staff members with reliable phase information that can be distinguished clearly in all images and have unvarying electromagnetic properties. Phase differences are processed at discrete target locations.

Corner reflectors, such as this one developed at SwRI, can be installed in areas that do not contain sufficient natural radar measurement points (for example, in highly vegetated, snow-covered and low infrastructure areas). These trihedral or dihedral structures have panel sizes of approximately 1 x 1 m (for C-band satellite data).



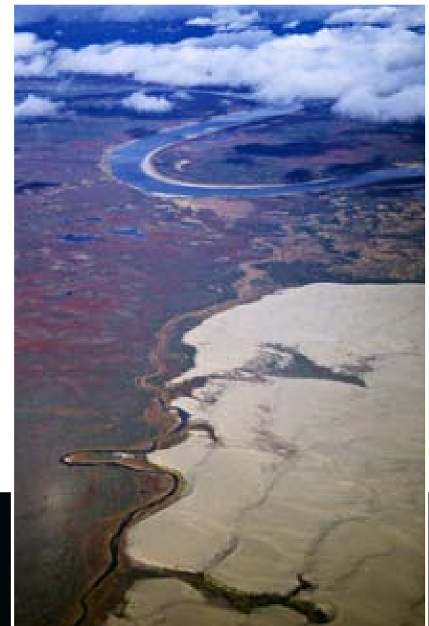
MDDA

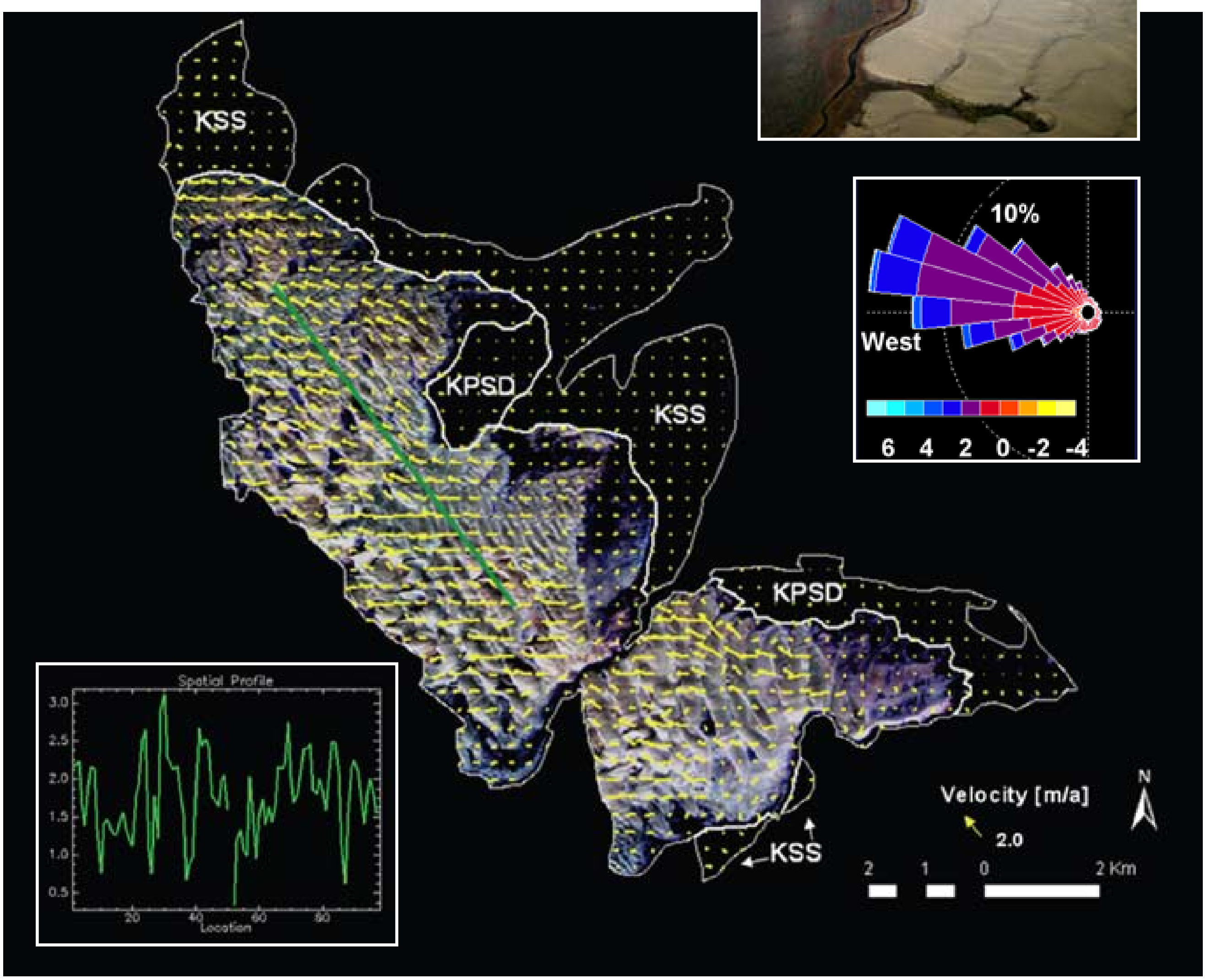
Using precise orthorectification and correlation of optical aerial and satellite imagery, SwRI has developed better ways to detect lateral movements of landscape features, such as landslides, sand dunes and glaciers, as well as linear features, such as roads, railways and dikes. MDDA detects decimeter lateral displacements in features represented by persistent patterns in visible and near-infrared satellite images.

Although not as precise as InSAR, MDDA complements InSAR analysis of vertical land movements with information on lateral movement. MDDA also detects and monitors events every few days because optical satellite imagery is collected more frequently than radar data. Because MDDA reveals displacements in persistent optical patterns, it can be used to detect and monitor landscape changes – not only from ground movements, but from land use changes.

Sand dune migration rates (yellow vectors) are superimposed on a contrast enhanced color composite satellite image. Migration rates along the green transect are graphed in the lower left inset. A rose diagram of wind distribution over the entire active dune field is shown in the upper right inset.

Aerial photo © QT Luong/terragalleria.com.





REMOTE SENSING METHODS		
METHOD	**ADVANTAGES**	**LIMITATIONS**
DInSAR	Provides useful results using a small number of SAR datasets. Provides relatively quick results if the geometry of a satellite InSAR system is within appropriate limits. Provides surface displacement information throughout the boundaries of SAR images.	Has limited success in vegetated environments using SAR C-band datasets. CRInSAR and PSI can overcome this limitation. Typical ground displacement resolution is on the order of centimeters. Displacement resolution depends on the quality of digital elevation model used in the interferometric process. Analysis quality degraded by atmospheric heterogeneity and/or temporal decorrelation of the pair of radar datasets. These factors can result in phase ambiguities of a magnitude equal to the ground displacements anticipated.
PSI	Determines motion history over a decade or more depending on SAR data availability. Typical ground displacement accuracy is on the order of millimeters.	Provides only point displacement information for each location of a persistent scatterer. Data coverage depends on the number of scatterers within the area of interest. Requires a large number of SAR datasets (typically greater than 25), which can significantly increase project cost.
CRInSAR	Obtains measurements at the exact location required. Can be applied if little or no archival data are available; can generate the first measurement results with only three images. Measures displacement rates with a vertical precision of 1 mm per year.	Corner reflectors may require periodic maintenance. Installation of corner reflectors may not be practical or suitable for all geologic locations due to site accessibility, orientation, ground condition, and theft/vandalism.
MDDA	Can use ancillary aerial surveys, allowing change detection over several decades. Does not require external information such as GPS measurements or ground control points. Provides surface displacement information throughout the boundaries of optical images.	Depends on the availability of high-quality optical images; accurate digital elevation models, especially in mountainous areas; and quality of the ancillary data provided with optical images. Radiometric noise, sensor aliasing, and saturation can limit accuracy and precision. Typical accuracies are lower than with InSAR.

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