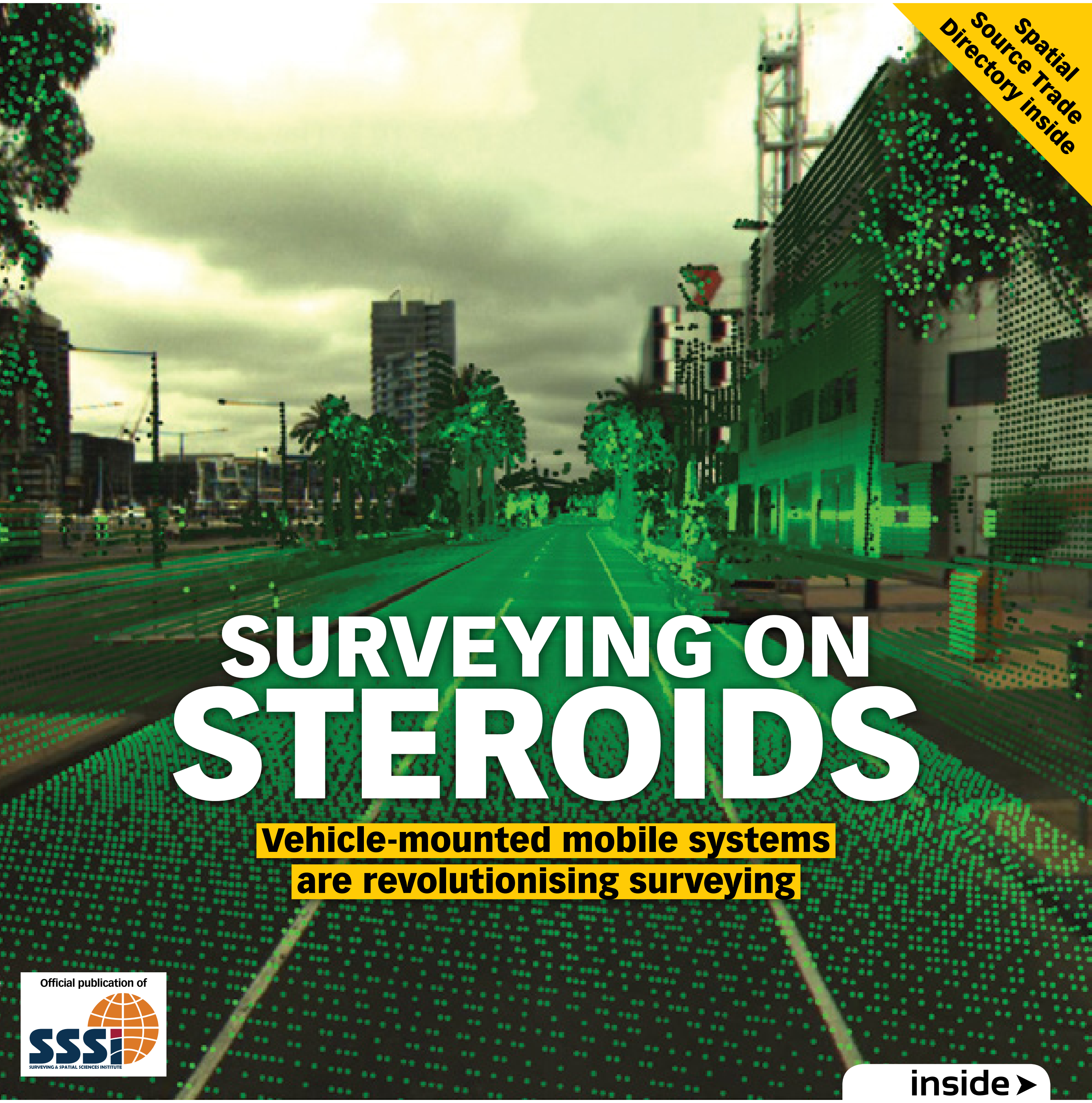
December/January 2011 – No.50

position

The Australian magazine of surveying, mapping & geo-information



Spatial Source Trade Directory inside

SURVEYING ON STEROIDS

Vehicle-mounted mobile systems are revolutionising surveying

Official publication of SSSI SURVEYING & SPATIAL SCIENCES INSTITUTE

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InSAR: a new generation

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Synthetic Aperture Radar Interferometry is an established and powerful technique for change detection. Its advantages include competitive spatial resolution, accuracy in millimetre-centimetre scale, and spatial coverage.

But it has limitations in detecting Earth surface changes. The disadvantages include line-of-sight ambiguity (1-D displacement), and temporal and geometrical de-correlation (slopes, unstable ground, large deformation gradients, vegetation, etc). Another is its low sensitivity to horizontal displacement parallel to platforms' flight trajectory.

Variable tropospheric water vapour can also cause variable phase delay. This is initiated by the impact of water vapour on the speed of microwave signal propagation. The related phase changes are sometimes misinterpreted as surface change in SAR interferometry. The effects can be excessively large in tropical and sub-tropical regions. In tropical regions, over a period of several weeks, almost 10 cm of variable path delay has been observed.

InSAR exploits several characteristics of radar scattering and atmospheric de-correlation to measure surface displacement in non-optimum conditions. Atmospheric phase contributions are spatially correlated in a single SAR scene, but in time scales of days to weeks, they become uncorrelated.

Moreover, surface motion is strongly correlated in time. Land subsidence is very often steady over periods of months and years. Thus, averaging out the temporal fluctuations, the atmospheric effects can be estimated and removed by combining data from long time series of SAR imagery.

The InSAR method

Two radar images of the same area with slightly different imaging angles are needed for InSAR. Radar sensors onboard the flying platforms transmit microwave signals towards a target, and some are reflected back to the sensor. The back-scattered pulses are recorded by the microwave sensor to form radar images of the target. Using sophisticated software, pairs of images of the same scene acquired at different times are compared. This allows changes such as displacement in the land surface to be detected.

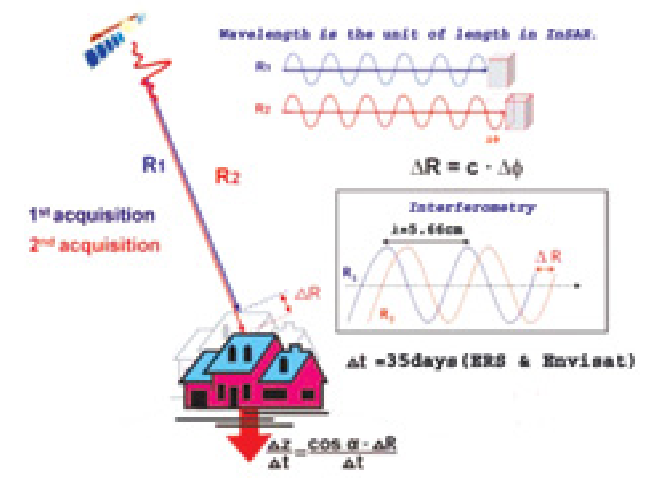
InSAR processing consists of the selection of image pairs, co-registration of images, feeding of the external digital elevation model (DEM), interferogram generation and enhancement, and phase unwrapping. DEMs and movement models are then produced, and geo-coding is the final part of the process. InSAR is a non-intrusive and non-destructive technology, measuring relative displacement over time with sub-centimetre accuracy. Its inability to remove errors introduced by atmospheric effects, orbital errors, thermal and other noises mean it is only able to measure total displacement and average displacement rates. It is also unable to distinguish between linear and non-linear movement.

PSInSAR: a developed technique

To overcome these limitations, a new technique called Persistent Scatterer InSAR (PSInSAR) has been developed. Persistent or Permanent Scatterer (PS) techniques are recent developments that rely on studying pixels that remain coherent over a sequence of interferograms. The new technique applies InSAR and Differential InSAR (DInSAR) for measuring ground displacements to a degree of accuracy and over time periods previously unachievable with conventional InSAR.

PSInSAR makes measurements of ground movement on permanently scattering points. These scatterers are features such as metallic structures, prominent natural features and the roofs of buildings. In urban areas, as many as 600 persistent scatterers per square kilometre can be found. Uniquely, this technique provides the motion history for each individual persistent scatterer.

The technique was first introduced in 1999 by the Polytechnic University of Milan (POLIMI) in Italy, which produced and patented it as the PSInSAR algorithm. In this new multi-image approach, the stack of images is inspected for objects on the ground, providing consistent and stable radar reflections back to the satellite.



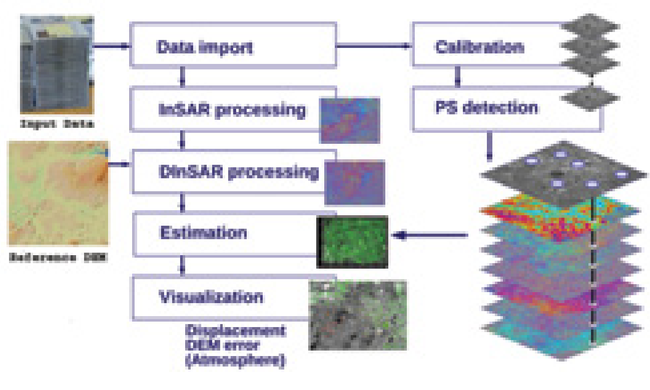


IMAGE SOURCE: PARVIZ TARIKHI

ABOVE: Persistent Scatterer SAR interferometry flowchart

LEFT: Persistent Scatterer SAR interferometry model

The objects can be the size of a pixel or sub-pixel, and are present in every image in the stack. The European Space Agency (ESA) created the collective name Persistent Scatterer SAR Interferometry to define the second generation of InSAR techniques. Tele-Rilevamento Europa (TRE) holds the exclusive licence of the PSInSAR algorithm for worldwide application.

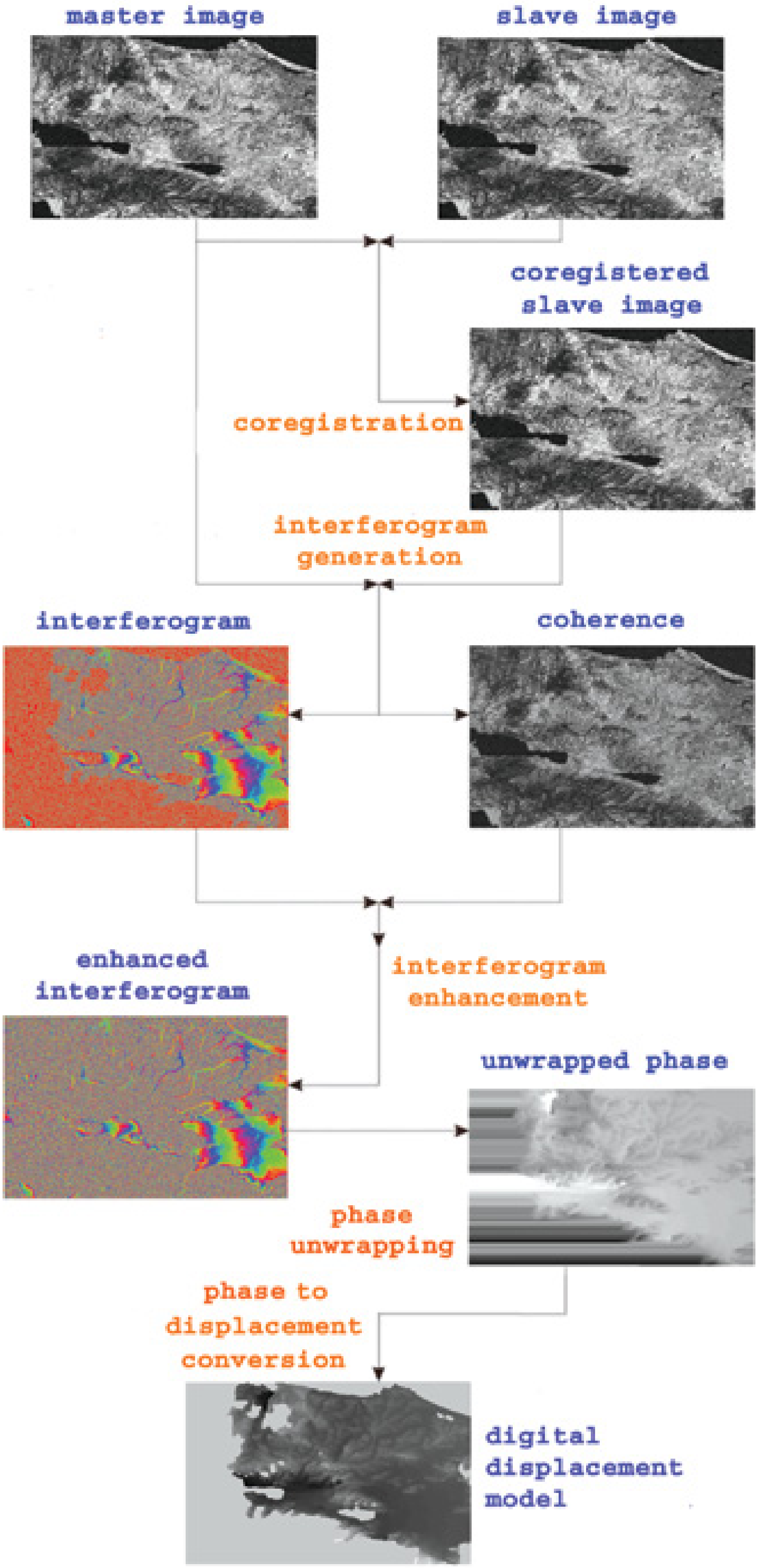
PSInSAR uses radar data acquired by satellites such as ESA's ERS and Envisat, Canadian Radarsat, Japanese JERS and newly launched satellites including the German TerraSAR-X (TSX) and Italian Cosmo-SkyMed (CSK). Most land areas throughout the world have sufficient data to allow PSInSAR processing, with new data being acquired regularly.

The PSInSAR process

N interferograms are formed on a common master image, using all N+1 available images (InSAR processing). Using a reference DEM, the known topographic phase is removed (DInSAR processing). A coarse grid of the best points is then identified, and DEM error and displacement is estimated (preliminary estimation). Using the preliminary estimates, the parameters on more points are estimated (final estimation).

In stake generation, all interferograms are formed in relation to the master image. The absolute calibration is then carried out, accounting for range spreading loss, antenna pattern and processor gain. In this case, the pixels with a large amplitude in most images are likely to be point scatterers; a threshold is used to identify a set of pixels for further analysis. Using multi-image datasets allows for the identification of stable reflectors, referred to as persistent scatterers. These are points on the ground that consistently return stable signals to the satellite sensor. Temporal composites of SAR images are the best way to locate the PS points. Co-registration is made by aiming correlation optimisation, and using a precise DEM. SRTM (Shuttle Radar Topography Mission) data is also used for topographic correction.

Preliminary estimation contains three steps: selection, estimation and integration. Only point-like scatterers are considered in the selection step, and the best points in each grid cell are selected. In the estima-



InSAR processing flowchart. The team led by the author used the data provided by ESRIN and the Earth-View software to generate these interferometric products. They combined the tandem ERS SAR Single Look Complex Images (SLCI) of 16 and 17 September 1999 (normal baseline: 234.44m) of the Izmit area in Turkey.
IMAGE SOURCE: PARVIZ TARIKHI

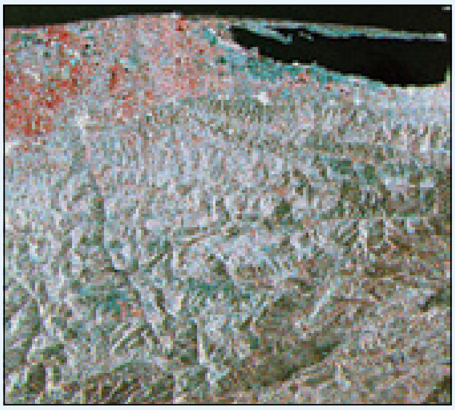


IMAGE SOURCE: PARVIZ TARIKHI

The temporal composite produced by the study team using multi-image dataset of Radarsat SAR Standard Beam 4 images of 5 May (green), 22 June (red), and 2 September (blue), 1998, of the south-eastern area of the Caspian Sea in north of Iran. SAR temporal composites are suitable for locating the persistent and distributed scatterers in the area of interest for PSInSAR and SqueeSAR.

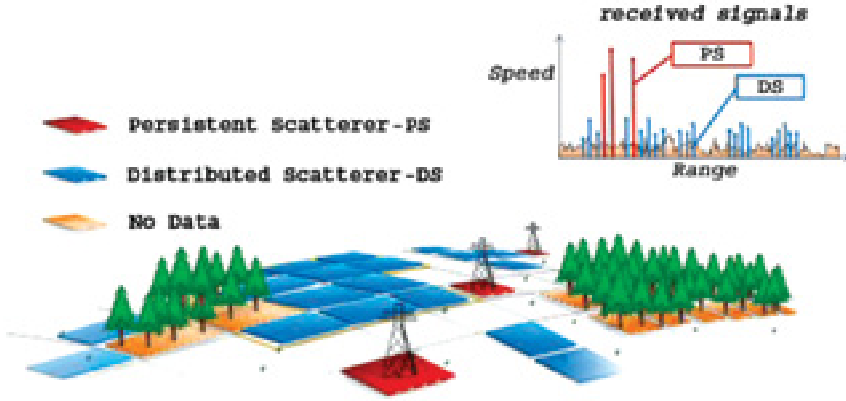


IMAGE SOURCE: PARVIZ TARIKHI

PS and DS areas used for SqueeSAR. The inset graph at the top right shows the distribution of the PSs and DSs with their relevant velocity of movement.

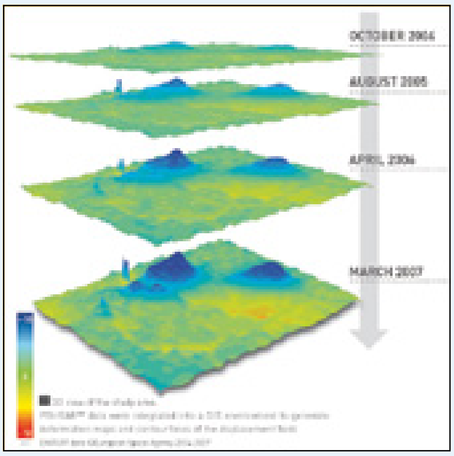


IMAGE SOURCE: TRE-TELE-RILEVAMENTO EUROPA

3D view of the study area at the Krechba field (Algerian central Sahara), where integration of 3D seismic techniques with satellite InSAR data has proved to be a powerful tool in tracking the subsurface sequestration of CO^2 for reducing greenhouse gas (GHG) emissions. PSInSAR data from ESA Envisat for 2004-2007 were integrated into a GIS environment to generate deformation maps and contour lines of the displacement field.

> *'They rely on studying pixels that remain coherent over a sequence of interferograms.'*

tion step, a network is constructed to estimate displacement parameters and DEM error difference between nearby points, in order to reduce atmospheric signal. In integration, the parameters at the points are obtained using least-square integration in relation to a reference point. In this step, the incorrect estimates or incoherent points are identified using alternative hypothetical tests, and removed.

Removal of atmospheric and topographic influence

PSInSAR removes atmospheric, orbital and topographic induced errors, related to certain weather conditions and DEM accuracy. It creates an atmospheric correction, which is calculated from the 30-scene archive that removes atmospheric artefacts from the interferograms, using an accurate DEM for the measurement points.

In this technique, sub-pixel radar reflections are analysed, linear and non-linear deformation patterns are identified, and time histories of movement are generated for every radar target. With multi-image datasets, identifying reflectors – called persistent scatterers – consistently return stable signals to the orbiting microwave sensor. They allow ground displacement velocities to be measured with millimetre accuracy. PS typically correspond to objects on structures such as buildings, bridges, dams, water-pipelines, antennae, and stable natural reflectors such as exposed rocks.

PSInSAR applications

Common examples include surface deformation measurements, slope instability, landslide inventory, flood protection, oil field monitoring, Co^2 sequestration, seismic faults and surface deformation measurement.

PSInSAR has applications in urban areas, which have many permanent structures. One example is the study of European cities undertaken in the Terrafirma project. It provides a ground-motion hazard information service, distributed throughout Europe via national geological surveys and institutions. The technology provides the data to help save lives, improve safety, and reduce economic loss. Repetitive – very similar said just above.

On subsidence or uplift, whether caused by natural or man-made activities, the PSInSAR provides monthly updates on displacement patterns. It is particularly useful in monitoring urban subsidence where conventional methods cannot match the information density at a similar cost.

Regular data updates are also vital when monitoring seismic faults and volcanic areas. They improve early warning systems by providing urgently-needed data in emergency situations.

In land use management, the technology facilitates planning – or updating – of major infrastructure such as pipelines, transmission lines, highways and railways by identifying stable corridors.

In insurance claims, a historical archive of radar data can help verify a connection between, for instance, the construction of a new tunnel and damage to facilities in the local neighbourhood. PSInSAR data has already been used as evidence in lawsuits, and insurance firms are showing interest in using it as a risk-allocation tool.

Although the data cannot substitute for site surveys to check the stability of buildings, it is still very useful in large urban areas, where regular checks of buildings are not feasible. It can also be used in the design of mitigative measures to reduce the effects of potential geo-hazards.

For landslides and instability phenomena with slower movement,

PSInSAR identifies the extent of land instability and the corresponding movement rate. Its integration with a GIS and the capability for regular updates has significantly increased the potential of radar remote sensing in these applications.

Advantages and disadvantages

Advantages of PSInSAR include the potential for regular and financially acceptable measurements of larger areas, fast data processing with little need for inclusion of the end user, high accuracy and simple export into GIS. In this case, detection of slow deformation of less than 10 cm per year in the line-of-sight direction is possible.

One limitation is that it cannot be used in vegetated areas and on continuous surfaces. Temporal measurements are also limited by the satellites' orbiting intervals.

But recent developments have delivered higher accuracies by focusing on distributed scatterers (DS) in addition to the persistent scatterers. A new technique – called SqueeSAR – squeezes the effects of both persistent and distributed scatterers.

SqueeSAR: a new solution

In 2009, ten years after PSInSAR, TRE developed this new algorithm. It represents a further advancement for satellite data analysis, and a leap in Earth observation capabilities. DS can also be used for monitoring ground displacement. They consist of a wide area where the backscattered energy can be less strong, but is statistically homogeneous within the area.

SqueeSAR enables detection of movement in areas dominated by DS, with the same accuracy as PS. The displacement time series are less noisy, and typically correspond to debris areas, non-cultivated lands and desert areas. It is also important to highlight that the PSInSAR processing chain is maintained and used within the SqueeSAR algorithm. As a result, the information output capacity (PS + DS) is enhanced, delivering better insight into ground deformation and associated surface movements.

In summary, the SqueeSAR algorithm includes: identifying ground points, PS and DS; identifying a high density of ground measurement points in urban areas (PS); identifying a high density of ground measurement points in non-urban areas (PS and DS); providing a time series for each ground point (PS and DS); access to millimetre-accuracy on ground displacement values; reducing time series standard deviation (coherence increases and noise decreases); and an increase of confidence on ground behaviour. The extensive coverage of points is particularly significant for landslides, outcrops and, in general, areas with low reflectivity.

Fast analysis of large areas of land, high density of measurement points, precision of measurements – and the ability to access an historic database make SqueeSAR a powerful tool and no doubt new processes are on the way to fulfil the enthusiasm, interest and needs of the remote sensing community. ■

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