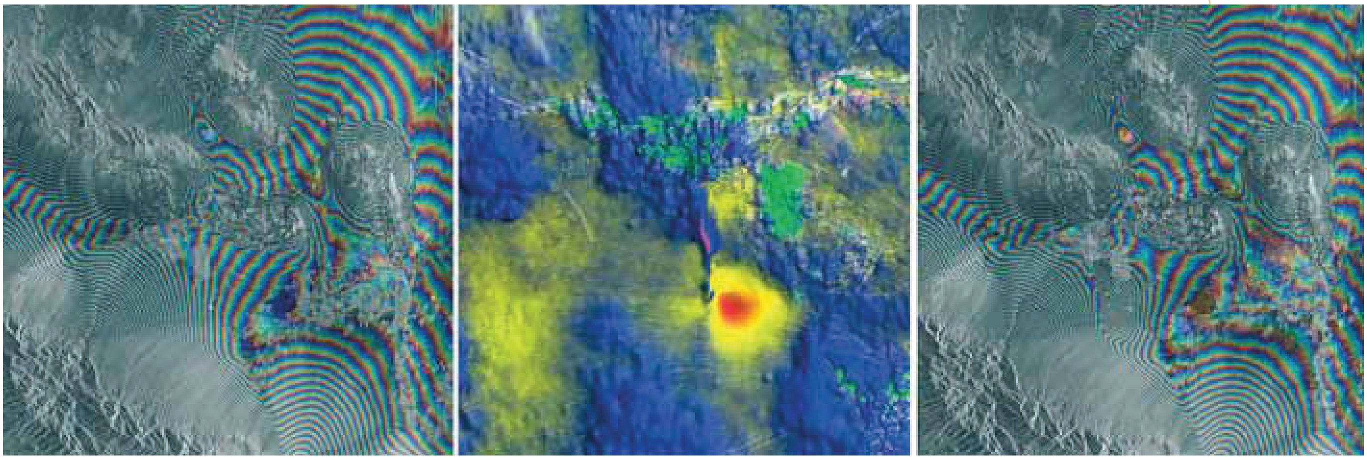


Tarikhi

DEMs from InSAR

InSAR represents the best source of digital terrain models.

PARVIZ TARIKHI

The left image is the topo-DInSAR product acquired from the Envisat-ASAR data on 11 June and 3 December 2003. On the right is a similar image from 3 December 2003 and 7 January 2004. The team led by the author used data provided by ESRIN and DORIS and IDIOT software to generate the products.

The middle radar-derived image was obtained by NASA scientists. It is the 3D perspective view of the vertical displacement of the land surface south of Bam, Iran during the 3.5 years after the 6.6 earthquake of 26 December 2003. Blue and magenta tones show where the ground surface moved downward; yellow and red tones show upward motion (particularly south of Bam). Displacements are superimposed on a false-colour Landsat Thematic Mapper image, taken on 1 October 1999.

The image on the right was obtained from ASAR pre-and post-earthquake. Notice the curl-shaped pattern to the south of Bam. It is not visible in the image on the left, which was obtained before the earthquake. For the left image, the normal baseline is 476.9 metres and parallel baseline is 141.6 metres. For the image on the right, the normal baseline is 521.9 metres and the parallel baseline is 268.3 metres. The left image demonstrates that the related interferogram includes four lobes. Since the displacement in the east is greater than in the west, the related lobes are larger. The displacements measured along the radar line-of-sight direction are 30 cm and 16 cm at the southeast and northeast lobes of the interferogram, respectively. However, the displacement related to the western part of the area is about 5 cm along the radar line-of-sight direction.

The digital elevation model is one of the most fundamental datasets in digital mapping. Using a DEM, an interesting picture of the landscape can be turned into a work-ready image that provides the basis of a GIS. It can be co-registered with other data. Meaningful measurements can be made.

DEMs can be generated in a number of ways. In the past, the traditional way of obtaining height information was through geodesic measurements. The planimetric co-ordinates and height values of each point of the feature were measured point-by-point. Using this data, topographic maps containing contour lines were generated. The method uses contour-grid transfer to turn the vector data from the maps into digital data.

DEMs can also be generated using photogrammetry to obtain height information. Photographs can be taken from an aircraft or spacecraft and evaluated as stereo-pairs.

Laser scanning, or lidar, can also be used. A laser beam is scanned back and forth under the aircraft, illuminating millions of discrete points on the ground. The system measures the time of flight of each pulse of laser light and hence measures the distance from the aircraft to each point.

The final technique – and the one I want to focus on in this article – is interferometric synthetic aperture radar. InSAR is a sophisticated way of processing radar data, wherein two radar images are combined to form an interferogram.

A DEM is generated using the phase difference between the two images...

An interferogram can be thought of as a map of the phase difference of the two images. The phase itself is a function of the imaging geometry, topography, surface displacement, atmospheric change and noise. Since all of these – except topography – are known or can be estimated, the topography can be calculated.

The distinction between SAR and optical systems is much more than just the ability of SAR to operate in conditions that would cause optical instruments to fail. There are basic differences in the physical principles dominating the two approaches.

Optical sensors record the intensity of radiation beamed from the sun and reflected from features of interest. The intensity of the reflected light characterises each pixel of the resulting image.

A SAR antenna illuminates its target with coherent radiation, which is then reflected back. Early radar system worked on a time-of-flight principle, just as lidar does today. Modern radar really began when processing became sophisticated enough to also measure the phase of the reflected wave.

InSAR has some similarities to stereo-optical imaging, in that two images of the common area, viewed from different angles, are appropriately combined to extract the topographic information. The main difference between the two processes is the way in which the topographical data is obtained.

In the optical case, the difference in height between two features is indicated by their horizontal displacement between the two images.

With SAR data, it is revealed by the phase difference. Distance information is thus inherent in SAR data. This makes it much easier to generate DEMs from SAR interferometry, with greater automation and fewer errors than optical techniques.

There are three types of InSAR techniques: single-, double- and triple-pass.

In single-pass, the spacecraft carries two SAR instruments that acquire data for the same area from different view angles at the same time. Using this method, the third dimension can be extracted and, using a mathematical formula, the phase difference between the first and second imaging instruments give the height value of the point of interest.

The SRTM (Shuttle Radar Topography Mission) used the single-pass interferometry technique in C and X band. An Earth height model with 90 metre horizontal resolution is available. A DEM with 4 to 4.5 metre relative accuracy is also available for restricted areas around the world.

In double-pass InSAR, a single SAR instrument passes over the same area twice. Height can be extracted by calculating the differences between these observations, on the assumption that nothing on the ground has moved. Of course, you can turn this around: in earthquake studies, parts of the Earth's surface have moved and the phase difference will be a measure of how much.

It is an established technique for generating DEMs from space and airborne data...

In the three-pass operation (DInSAR), the interferogram of a double-pass InSAR is subtracted from the third image. The temporal baseline – the difference in time between the observations – of the first two images needs to be short compared with the third image.

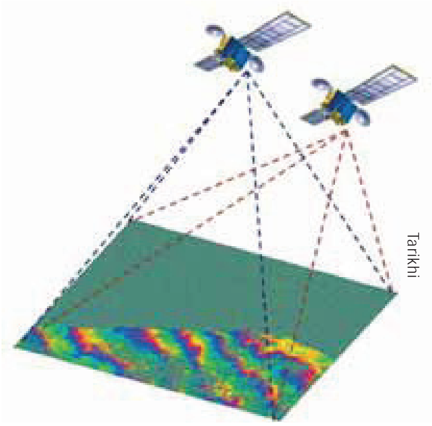
InSAR has now been developed to the point where it is an established technique for generating high-quality DEMs from space and airborne data. It has significant advantages over other methods of large-area DEM generation.

DEM generation by InSAR was first reported in 1974. Satellite-based InSAR began in the 1980s using Seasat data. The technique's potential was expanded in the 1990s with the launch of ERS-1 (1991), JERS-1 (1992), Radarsat-1 and ERS-2 (1995). They provided the stable, well-defined orbits and short baselines necessary for InSAR. The 11-day STS-99 space shuttle mission in February 2000 used two SAR antennas with 60-metre separation to collect data for the Shuttle Radar Topography Mission. ESA launched the Advanced SAR (ASAR) aboard Envisat as a successor to ERS-2, in 2002.

The majority of these systems used C band sensors, but recent missions such as ALOS PALSAR and TerraSAR-X are using L and X band. ERS and Radarsat use the frequency of 5.375GHz, for instance.

Numerous InSAR processing packages are available. Imagine-InSAR, EarthView-InSAR, ROI-PAC, Doris, SAR-e2, Gamma, SARscape, Pulsar, IDIOT and DIAPASON are commonly used for interferometry and DEM generation.

The production of interferograms involves a series of steps. Two coherent SAR images are required. The images are first co-registered by finding the offset and difference in geometry between the two. Normally, baselines of between 80 and 300 metres are suitable for DEM generation. One SAR image is then resampled to match the geometry of the other, meaning that each pixel represents the same ground area in both images.



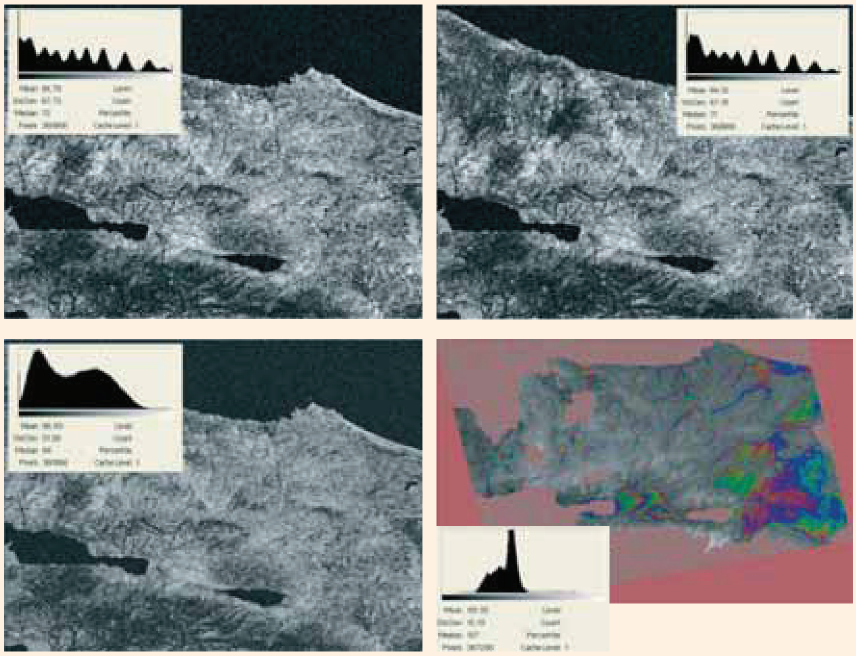
The differential interferometric SAR data collection scheme. It looks photogrammetric but distance is revealed by phase differences, not displacement.

The interferogram itself is generated by multiplication of the first image (master) by the second image (slave) and the interferometric phase due to the reference ellipsoid is removed. This process is referred to as flattening.

Once produced, the interferogram is filtered using an adaptive power-spectrum filter to amplify the phase signal. For most quantitative applications, the consecutive fringes present in the interferogram have to be unwrapped. This involves interpolating over the phase jumps, to produce a continuous deformation field. At some point, before or after unwrapping, incoherent areas of the image can be masked out.

The final processing stage requires geocoding. This involves resampling the interferogram from the acquisition geometry. By applying phase information in the interferogram, it is possible to extract a DEM with metre accuracy, height change information and fine-scale temporal change measurements.

As discussed, there are alternatives for DEM generation. Radar's main advantages are wide and continuous coverage, high precision, cost effectiveness and the feasibility of recording data in all weather conditions.



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The top images at the left and right show the tandem amplitude data of 12 and 13 August 1999 (four and five days pre-quake) of Izmit, Turkey – as master and slave images respectively. The research team used ERS-1&2 data provided by ESRIN and the Earth-view and SAR Toolbox software to generate the variety of related products. The normal baseline for the image pair is 224.2 metres and parallel baseline is 91.1 metres. In the bottom images, the one on the left is the coherence image while the one on the right image depicts the DEM image with the interferogram overlaid.

For each product, the relevant histogram is seen as an inset. The similarity of the histograms of master and slave images is considerable. This is due to the high correlation of the images clearly visible in the coherence image. It is important to note that the lowest coherence values (darkest values) correspond both to steep slopes or vegetated areas (especially visible in the lower part of the image) and to the lakes (image centre and left). DEMs generated from the tandem images are accurate because of the high correlation between master and slave images. Although both the master and slave images are pre-earthquake data of the 7.8 earthquake of 17 August 1999, the strain in the disaster area is visible a week before the quake. It could be a useful precursor for the advent of a disaster, such as the earthquake in Izmit.

Laser altimeters can generate high-resolution DEMs. However, most laser altimeters record narrow swaths, which means that more overlapping images are required to produce a DEM.

The precision obtained in terrestrial surveying using GPS and total stations is similar to, or better than InSAR. The important advantage of InSAR over this technology is wide continuous coverage with no need for fieldwork.

Its important advantage is wide continuous coverage with no need for fieldwork...

DEMs generated by photogrammetry are more accurate, but it is very weather-dependent and processing over very large areas is more difficult and also expensive.

Having said all this, InSAR also has some problems that need to be solved in the near-term. One of the current challenges is to bring InSAR processing to a level where DEM generation can be performed on an operational basis. This is important – not only for commercial exploitation of the data, but also for many government and scientific applications.

Multi-pass interferometry is affected by atmospheric effects. Spatial and temporal changes due to 20 per cent relative humidity can produce an error of 10 cm in deformation.

Also, image pairs with inappropriate baselines can create errors of almost 100 metres. In topographic mapping, this error can be reduced by choosing interferometric pairs with relatively long baselines.

But all these problems can be solved. The growth in the number of spacecraft carrying radar sensors and the importance of digital elevation models to the understanding of spatial data means that radar processing still has a bright future.

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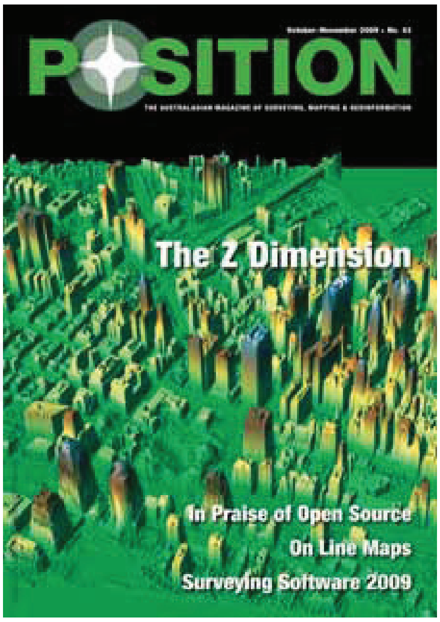

NOAA/US Army JPSD

Lidar image of lower Manhattan, New York, rendered just weeks after the World Trade Centre disaster of September 11. See page 35.

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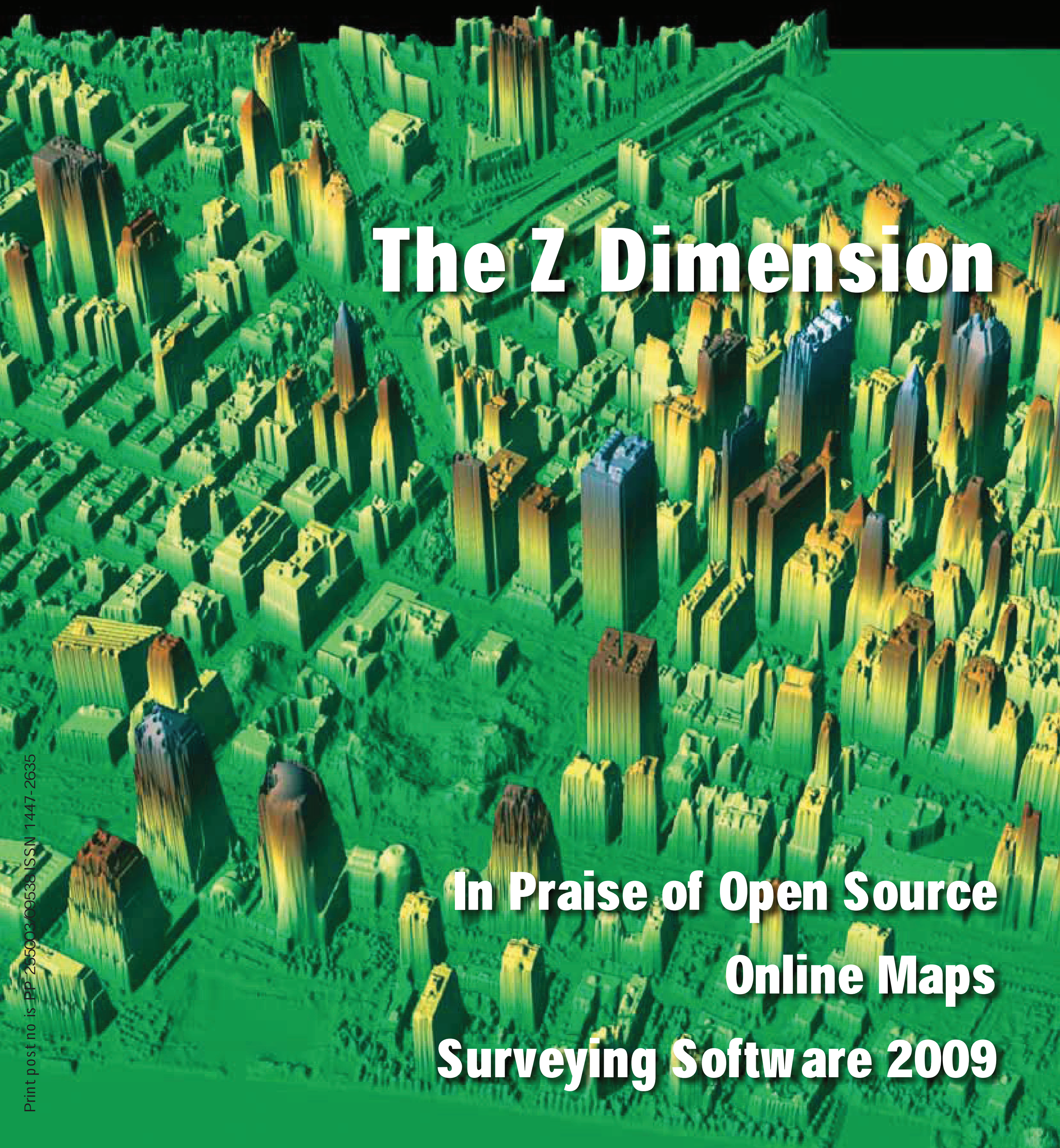

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