

## **InSAR DEM; why it is better?**

### **What is a DEM?**

Digital Elevation Model (DEM) refers to the process of demonstrating terrain elevation characteristics in 3-D space, but very often it specifically means the raster or regular grid of spot heights. DEM is the simplest form of digital representation of topography, while Digital Surface Model (DSM) describes the visible surface of the Earth.

Radar is a useful tool for land and planetary surface mapping. It is a good mean for obtaining a general idea of the geological setting of the area before proceeding for field work. Time, incidence angle, resolutions and coverage area all play important role at the outcome.

InSAR is a sophisticated processing of radar data for combining synthetic aperture radar (SAR) single look complex (SLC) images to form interferogram and utilizing its phase contribution to generate DEM, surface deformation and movement maps and target velocity. The interferogram contains phase difference of two images to which the imaging geometry, topography, surface displacement, atmospheric change and noise are the contributing factors.

Considerable applications of InSAR have been developed leaving it an established technique for high-quality DEM generation from spaceborne and airborne data and that it has advantages over other methods for the large-area DEM generation. It is capable of producing DEMs with the precision of a couple of ten meters while its movement map results have sub-centimeter precision over time spans of days to years. Terrestrial use of InSAR for DEM generation was first reported in 1974. It is used for different means particularly in geo-hazards like earthquakes, volcanoes, landslides and land subsidence.

### **Data sources and software**

Satellite-based InSAR began in the 1980s using Seasat data, although the technique's potential was expanded in the 1990s with 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 NASA STS-99 mission in February 2000 used two SAR antenna with

60-m separation to collect data for the Shuttle Radar Topography Mission (SRTM). As a successor to ERS, in 2002 ESA launched the Advanced SAR (ASAR) aboard Envisat. Majority of InSAR systems has utilized the C-band sensors, but recent missions like 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 also used commonly. IMAGINE-InSAR, EarthView-InSAR, ROI-PAC, DORIS, SAR-e2, Gamma, SARscape, Pulsar, IDIOT and DIAPASON are common for interferometry and DEM generation.

### **DEM generation steps**

The procedure for producing interferograms involves applied software and needed precision, but it usually includes some basic steps. InSAR operational steps for DEM generation from SLC-SAR data are performed in three major stages including data search, processing and product validation, while data processing stage comprises of five steps of data pre-processing, co-registration, interferogram generation, phase unwrapping, and geo-coding.

Two coherent SAR images are required to produce an interferogram. The images are first co-registered for finding the offset and difference in geometry between two amplitude images. Normally the baselines of 80-300m are suitable for DEM generation. One SAR image is then re-sampled to match the geometry of the other, meaning each pixel represents the same ground area in both images. The interferogram is generated by multiplication of the first image (master) to the complex conjugate of the second image (slave), and the interferometric phase due to the reference ellipsoid is removed; the process is referred to as flattening.

When 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, which involves interpolating over the  $0-2\pi$  phase jumps to produce a continuous deformation field. At some point, before or after unwrapping, incoherent areas of the image may be masked out. The final processing stage requires geo-coding, which involves resampling the interferogram from the acquisition geometry related to direction of satellite path into the desired geographic projection. By applying phase information in the interferogram, extraction of DEM with meter accuracy, height change information, and fine scale temporal change measurements will be possible.

## **Methods**

DEM is important for surveying and other applications in engineering. Its accuracy is paramount; for some applications high accuracy does not matter but for some others it does. Numerous DEM generation techniques with different accuracies for various means are used. DEMs can be generated through different methods which are classified in three groups that are DEM generation by (i) geodesic measurements, (ii) photogrammetry and (iii) remote sensing.

In DEM generation by geodesic measurements, the planimetric coordinates and height values of each point of the feature are summed point-by-point and using the acquired data the topographic maps are generated with contour lines. The 1:25000-scale topographic maps are common example. The method uses contour-grid transfer to turn the vector data from the maps into digital data. For DEM generation by photogrammetry, the photographs are taken from an aircraft or spacecraft and evaluated as stereo-pairs and consequently 3-D height information is obtained.

DEM generation by remote sensing can be made in some ways, including stereo-pairs, laser scanning (LIDAR) and InSAR. There are three types of InSAR technique that is single-pass, double-pass and three-pass. In double-pass InSAR, a single SAR instrument passes over the same area two times while through the differences between these observations, height can be extracted. In three-pass interferometry (or DInSAR) the obtained interferogram of a double-pass InSAR for the commonly tandem image pairs is subtracted from the third image with wider temporal baseline respective to the two other images. In single-pass InSAR, space-craft has two SAR instrument aboard which acquire data for same area from different view angles at the same time. With single-pass, third dimension can be extracted and the phase difference between the first and second radar imaging instruments give the height value of the point of interest with some mathematical method. SRTM used the single-pass interferometry technique in C- and X-band. Earth's height model generated by InSAR-SRTM with 90-m horizontal resolution is available while the DEM with 4-to-4.5-m relative accuracy is also available for restricted areas around the world.

## **comparison**

InSAR ability to generate topographic and displacement maps in wide applications like earthquakes, mining, landslide, volcanoes has been proven. Although other facilities like GPS, total stations, laser altimeters are also used, comparison between InSAR and these tools reveals its reliability. Laser altimeters can generate high resolution DEM and low resolution displacement maps in contrary to InSAR with the spatial resolution of 25m. However, most laser altimeters record narrow swaths. Therefore, for constructing a DEM by laser altimeter, more overlapping images are required. Displacement map precision obtained by terrestrial surveying using GPS and total stations is similar or better than InSAR. GPS generally provides better estimation of horizontal displacement and with permanent benchmarks slow deformations is monitored for years without being concerned about surface de-correlation. The most important advantage of InSAR over GPS and total stations are wide continuous coverage with no need for fieldwork. Therefore, wide and continuous coverage, high precision, cost effectiveness and feasibility of recording data in all weather conditions are its main privileges. However, it is important that the InSAR displacement result is in the line-of-the-sight direction and to decompose this vector to parallel and normal components the terrestrial data or extra interferograms with different imaging geometry are required. It is shown that DEM generated by photogrammetric method is more accurate than the others. It has approximately 5.5m accuracy for open and 6.5m for forest areas. SRTM X-band DSM is 4m less accurate for open and 4.5m less accurate for forest areas.

Data availability and atmospheric effects limit using InSAR, however processing of its data is challenging. For each selected image pair, several processing steps have to be performed. One of the current challenges is to bring the techniques to a level where DEM generation can be performed on an operational basis. This is important not only for commercial exploitation of InSAR data, but also for many government and scientific applications. Multi pass interferometry is affected by the atmospheric effects. Spatial and temporal changes due to the 20% of relative humidity produce an error of 10cm in deformation. Moreover, for the image pairs with inappropriate baseline the error introduced to the topographic maps is almost 100m. In topographic mapping this error can be reduced by choosing interferometric pairs with relatively long baselines, while in the displacement case the solution is to average independent interferograms.

**Why it is better?**

Distinction between SAR imaging and the optical systems are more profound than 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 the features. The intensity of the detected light characterizes each element of the resulting image or pixel. SAR antenna illuminates its target with coherent radiation. Since the crests and troughs of the emitted electromagnetic wave follow a regular sinusoidal pattern, both the intensity and the phase of returned waves can be measured.

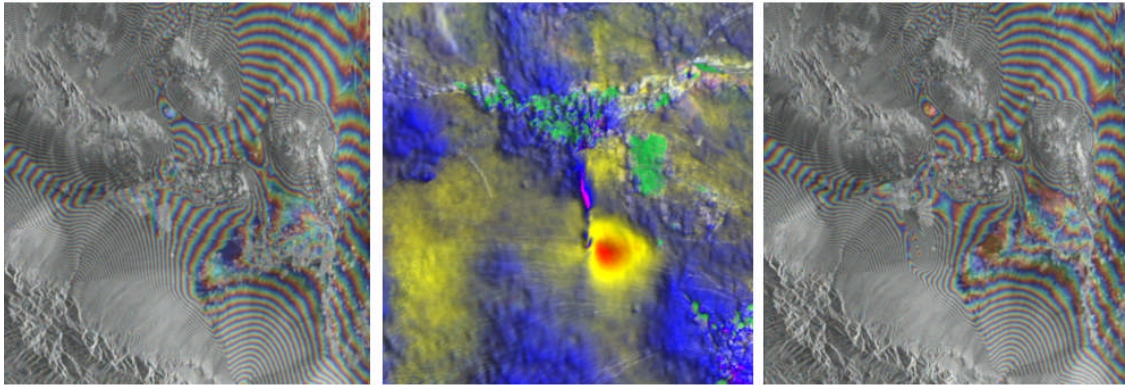
InSAR has some similarities to stereo-optical imaging in that two images of the common area, viewed from different angles, are appropriately combined to extract the topographic information. The main difference between interferometry and stereo imaging is the way to obtain topography from stereo-optical images. Distance information is inherent in SAR data that enables the automatic generation of topography through interferometry. In other words DEMs can be generated by SAR interferometry with greater automation and less errors than optical techniques. Moreover, using DInSAR surface deformations can be measured accurately.

Different DEM generation methods of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) stereoscopy, ERS tandem InSAR, and SRTM-InSAR are used. Both the ERS-InSAR and SRTM DEMs are free of weather conditions, but ASTER DEM quality may be affected by cloud coverage in some local areas. InSAR has the potential of providing DEMs with 1-10 cm accuracy, which can be improved to millimeter level by DInSAR. Its developments are rapid however it is our requirements that say which one is better for use.

**Parviz Tarikhi**

*Parviz Tarikhi specializes in radar remote sensing since 1994 and heads the Microwave Remote Sensing Research Group at the Mahdasht Satellite Receiving Station in Iran. He ran the Office for Specialized International Co-operation of the Iranian Space Agency between 2004-07. He has been involved with the UN Committee on the Peaceful Uses of Outer Space (UN-COPUOS) since 2000.*

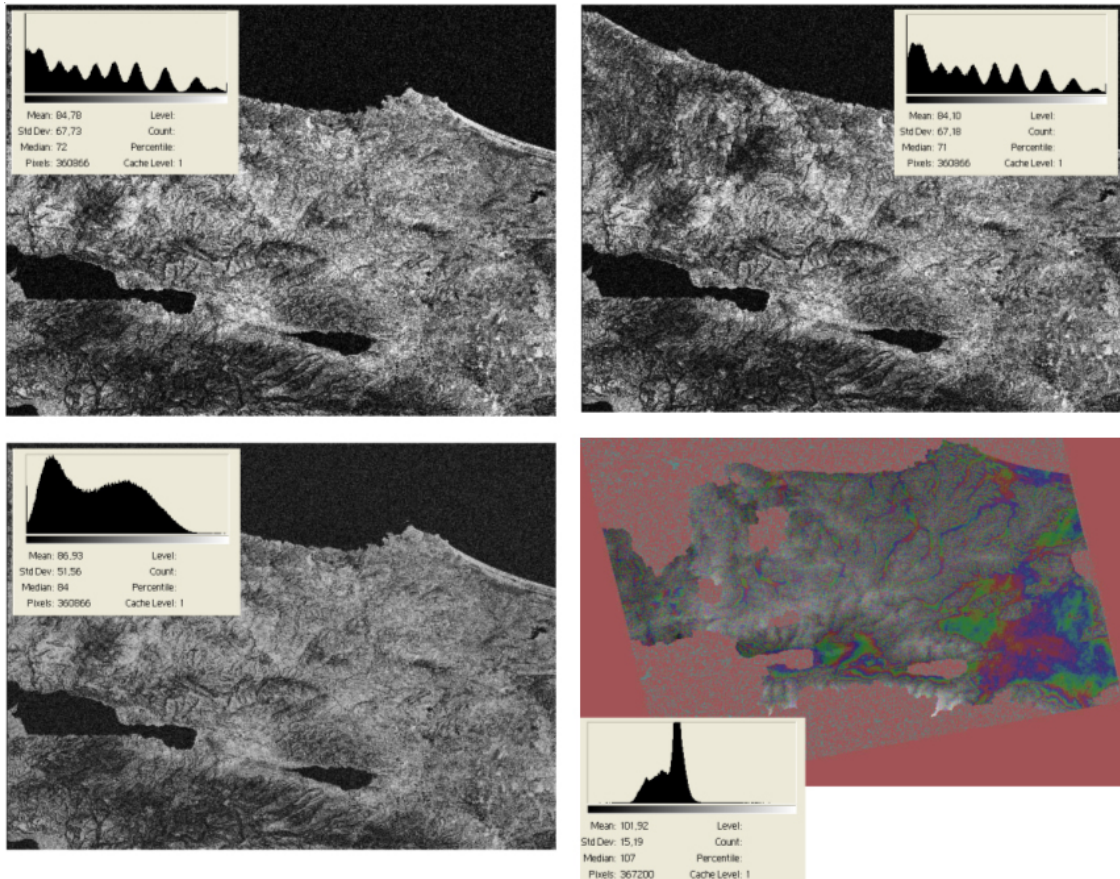
## Images:



[Bam\_topo-dem-dinsar.jpg]

**Image caption:** The left image is the topo-DInSAR product acquired from the Envisat-ASAR data of 11 June and 3 December 2003, while the image at right is the topo-DInSAR product of the 3 December 2003 and 7 January 2004. The team conducted by the author used the data provided by ESRIN, and the DORIS and IDIOT softwares to generate the products. The middle image obtained by NASA scientists is the 3-D perspective view of vertical displacement of the land surface south of Bam, Iran during the 3.5 years after the 6.6 earthquake of December 26, 2003 that is derived from analysis of radar images. Blue and magenta tones show where the ground surface moved downward; yellow and red tones show upward motion (particularly in south of Bam). Displacements are superimposed on a false-color Landsat Thematic Mapper image taken on October 1, 1999. In the right image that is obtained from the ASAR data pre and post earthquake the curl-shape pattern south of Bam is distinguishable where such the torsion is not visible in the left image that obtained from pre-earthquake data. For the left image the normal baseline is 476.9 m and parallel baseline is 141.6 m, while for image at right the normal baseline is 521.9 m and the parallel baseline is 268.3 m. The left image demonstrates that the related interferogram includes four lobes. Since the displacement in the east is greater than that 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 south-east and north-east lobes of the interferogram, respectively. However, the displacement related to the western part of the area is about 5cm along the radar line-of-sight direction.

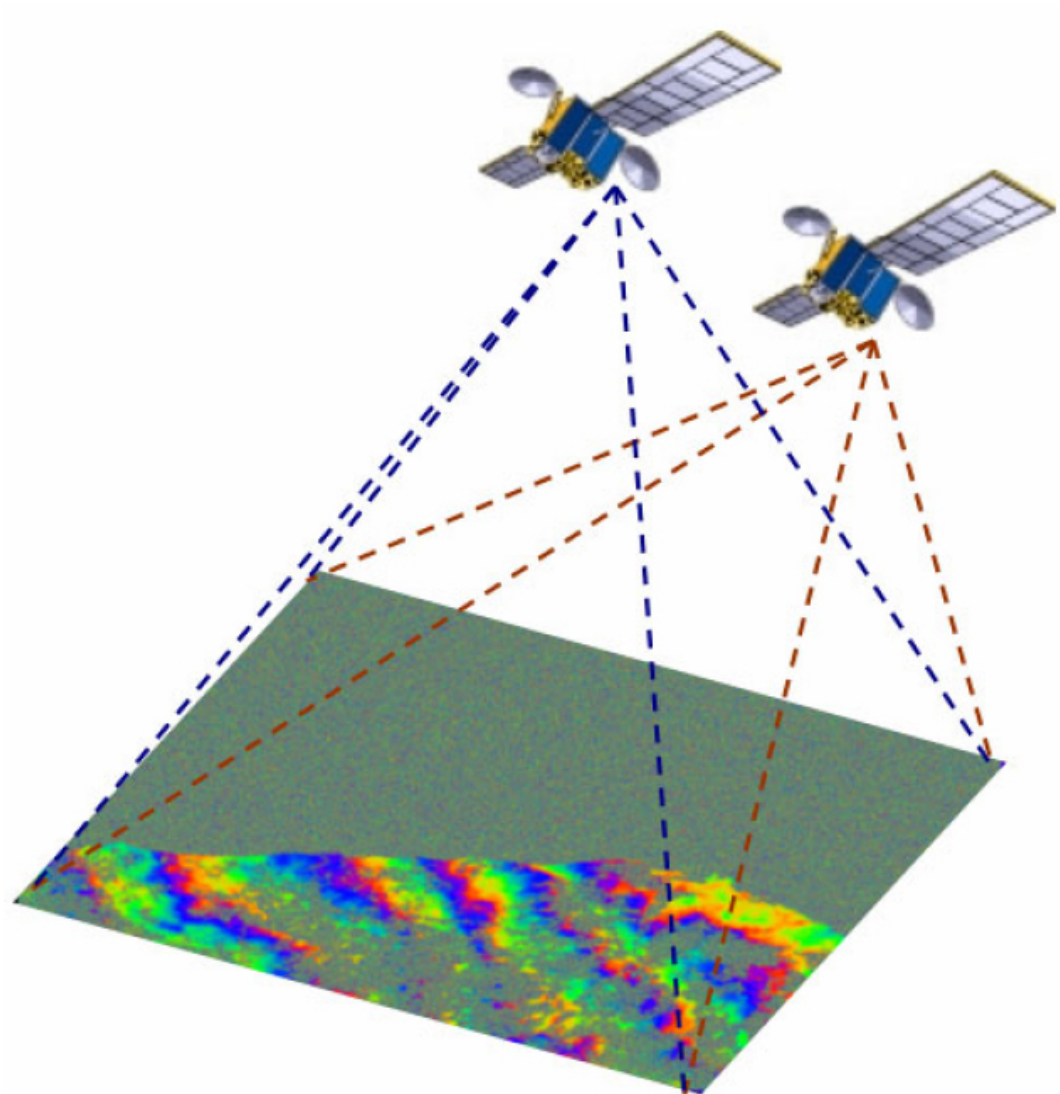
(Image source: Parviz Tarikhi)



[Izmit\_coh-dem.jpg]

**Image caption:** Top images at the left and right show the tandem amplitude data of 12 and 13 August 1999 (4 and 5 days pre-quake) of Izmit, Turkey as master and slave images respectively. The research team conducted by the author used the ERS-1&2 data provided by ESRIN, and the Earth-view and SAR Toolbox softwares to generate the variety of related products. The normal baseline for the image pair is 224.2 m and parallel baseline is 91.1 m. The image at the bottom left is the coherence image while the right image at the bottom depicts the DEM image where the interferogram is overlaid on it. For each product the relevant histogram is seen as inset. The similarity of the histograms of master and slave images is considerable due to the high correlation of the images that is clearly seen in coherence image. It is important to note that 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 center 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 August 17, 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 like the earthquake in Izmit.

(Image source: Parviz Tarikhi)



[DInSAR.jpg]

**Image caption:** Differential interferometric SAR data collection scheme  
(Image source: Parviz Tarikhi)