On the generation of Digital Elevation Model By SAR (Synthetic Aperture Radar) Interferometry and SRTM data and its application in Hydrocarbon Exploration

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Summary

Generating Digital Elevation Models (DEMs) from Synthetic Aperture Radar (SAR) is one of the latest trends in Terrain Analysis today. Much of the interest in this new technology has been fuelled by the availability of inexpensive image pair from the vast archive of various satellites. DEM created with this new technology have already been successfully applied in the oil and gas industry. Its potential for the measurement of land subsidence associated with oil and gas exploitation / production has been demonstrated in many producing fields of the world.

Remote mapping of surface structures has long been done using DEMs particularly in remote or inaccessible areas. Although good surface maps are available for many previously explored regions, surface maps for remote and unexplored areas are commonly poor to non-existent.

A combination of remote sensing data, especially DEMs and fly through models and vector information can automatically be draped generated by Radar interferometry and combinations have led the prospecting companies to successful explorations. SAR interferometry for surface change detection related to hydrocarbon exploitation is being tested in Cambay basin. Terrain analysis for logistic for North West Mizoram and geoenvironmental mapping for Jharia coal field area of Jharkhand is being taken up using radar based DEMs. This will also provide spatial reference system to the GIS data sets for these areas more advanced analysis

1. Introduction

The interferometric SAR (InSAR) is a potential alternative for generation of the Digital Elevation Model (DEM) due to its high accuracy, weather independence and larger spatial coverage. Research on the SAR Interferometry has been initiated in the last decade and is going on in several renowned research groups in Europe and North America. The potential of interferometry for DEM generation is being evaluated extensively in India with different software packages and SAR data sets.

The remote sensing data whether in optical or microwave region are used to prepare a variety of thematic maps at various scales which are being regularly used in hydrocarbon exploration and exploitation. SAR, operating in microwave region, (mostly in 'C' band between wave lengths (3.75 to 7.75 cms.) and optical data complement each other in geologic applications. The active SAR imaging sensor on board a satellite/aircraft operates with a low incidence angle, which strikes the ground obliquely, illuminating the peaks, valleys, folds, lineaments and faults that optical sensor might not see. On the other hand, however, the multispectral imagery identifies the mineral content, soil condition and rock composition of the surface geology, characteristically not typically discernible in SAR data. Together, the terrain features and surface lithology provide a much better visualization of the subsurface geology to be used in oil exploration.

2. Objective

To test the applicability of DEM and SAR Interferometry for hydrocarbon exploration and exploitation in India.

3. Principle and methodology of SAR Interferometry

Imaging Radar is an active illumination system, side looking with respect to the vehicle's direction of travel. The brightness (Amplitude) of the reflected Radar echo that has been transmitted from an antenna mounted on an aircraft or spacecraft, backscatters from the surface of the earth, and receives a fraction of a second later by the same antenna, is measured and recorded to construct an image.

InSAR is a technique by which the phases of two SAR images of the same terrain are made to interfere to generate interference fringes. These two images can be taken simultaneously by an aircraft / satellite with two antennas separated by a distance known as Baseline.

Generation of accurate DEMs is the main application of InSAR. One method of raw data acquisition is through satellites ERS-I and ERS-II tandem mission on two different dates having the same target area (i.e. double pass) on the basis of baseline length and the time period between two acquisitions. The selected raw data are then processed to convert SAR signals to image products, with the prior knowledge of the precise orbit and calibration. The two images are then registered at sub-pixel level for accurate results. After registration, the complex interferograms are formed by multiplying by each complex pixel of the first image by the complex conjugate of the same pixel in the second image. The interferogram thus generated is a complex image itself. As a final step, the terrain height can be determined using several methods, which convert phases into terrain heights. These heights determined for each pixel of the SAR image form the necessary DEM in raster form.

Another method of data acquisition of a stereo pair of Radar images was by the SRTM (Shuttle Radar Topographic Mission) flown in 2002. The SRTM used a 60-meter-long mast for separation of the two antennas. The raw stereo data was acquired by a single flight. The SAR system and the primary antenna were placed in the Space Shuttle's cargo bay, and the other one fixed to the end of the extensible mask.

The following figure (Fig.1) is simplified to depict the principle of double-pass Interferometry used in case of satellites ERS-1 and ERS-2.

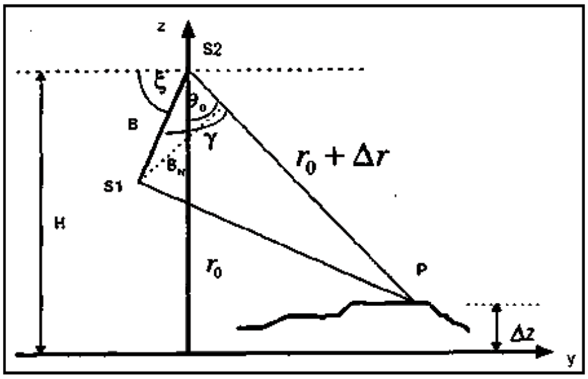

Fig.1 Observational geometry of interferometric SAR

on the ground surface as shown in the figure. The y-axis coincides with the plane containing the two satellites and the line of null Doppler of the radar cone. The baseline B, which is the small separation of the two orbits, is actually very short in relation to the height from the satellites to the ground point P. This figure is exaggerated in its baseline length for better visualization. In the case of ERS the baseline length is less than 1 km and the height H is around 800 km.

The radar signal from S1, is sent to the target point P and echoes back to the antenna of S1, and leads to a measured phase of ϕ_1. Since each individual pad of terrain has its own characteristic, this induces phase shift ϕ_{obj} in the backscattering signal. The distance from the satellite to the ground point P at an instantaneous epoch is r_0. If the signal travelling from the sensor to the ground and back to the sensor has a wavelength of λ, then:

$$\phi_1 = \left(\frac{2 - r_0}{\lambda}\right) 2\pi + \phi_{obj} \quad \text{or} \quad \phi_1 = \left(\frac{4\pi}{\lambda}\right) r_0 + \phi_{obj}$$

In a similar way the equations for satellite S2, but with a slight displacement of orbit can be written as:

$$\phi_2 = \frac{4\pi}{\lambda}(r_0 + \Delta r) + \phi_{obj}$$

The Advanced Precision Processor software used in this study splits the demodulated signal into two parts: the in-phase component and the quartered-phase component. The two channels can be regarded as components of a complex number because each is the product of a magnitude, and a sine and cosine term. If the image is solely produced from a single scene, then it is called 'Single Look Complex' or SLC image.

The images thus formed by the two satellites are called SLC (Single Look Complex) images (Fig. 2a & 2b). The magnitude component produces the intensity image (Fig. 3a &3b).

Then Δr is added due to the change in range from S2, to point P. Subtracting the last two equations the phase difference can be calculated in the form of the difference of the two slant ranges. $\phi = \phi_1 - \phi_2 = -\frac{4\pi}{\lambda}\Delta r$

The product of the two images after phase interference is the phase interferogam (Fig. 3a & 3b). This phase difference θ, which is also known as interferometric phase, is the crucial parameter to be used for deriving the height of point P. Thus, the interferometric phase can be obtained from interference. Also, the height of the point P can be determined from the expression. $\Delta Z = h - \cos(\theta_0)$

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The product of the two images after phase interference is the phase interferogram (Fig.3a & 3b). This phase difference ϕ, which is also known as interferometric phase, is the crucial parameter to be used for deriving the height of point P. Thus, the interferometric phase can be obtained from interference. Also, the height of the point P can be determined from the expression

SAR Interferometry has been applied in a few places utilizing the ERS data and SRTM data in the present study.

3.1 Case I: Generation of DEM by using ERS data

Two areas were selected for the above study namely Ahmedabad, Gujarat and Jharia coalfield, Jharkhand.

Raw data acquired through ERS-I and ERS-II tandem mission were acquired on two different dates having the same target area. The data was processed to generate SLC products. The image registration brought the coverage of the two images exactly together within a desired level of accuracy. The signal-phase shifting of the two data sets were then superimposed and mathematically interfered. The result led to an interferogram that records only the differences in phase between the two original images. These phase differences give the altitude variation of each pixel and the basic product for digital elevation models. The SLC data generated are in CEOS (Committee for Earth Observation Satellites) format. To get the impression of a SAR scene, the intensity values (magnitude), were calculated from the equation: $g = \sqrt{i^2 + j^2}$

where, 'i' is the real component and 'j' is the imaginary component for each pixel in an SLC image and 'g' is the result intensity.

The extracted SLC data was visualized by plotting the magnitude or intensity for each pixel (Fig. 3a & 3b).

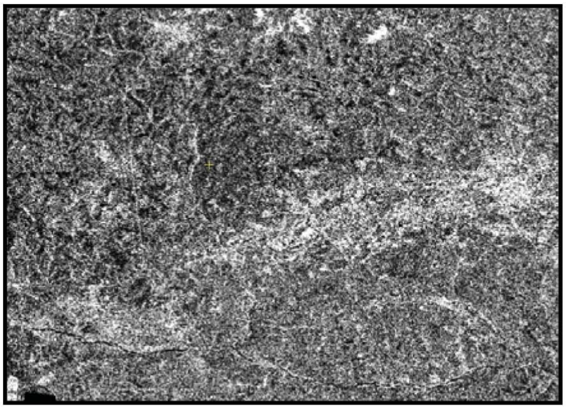

Fig. 2a ERS-SLC Image of Jharia coalfield, Jharkhand

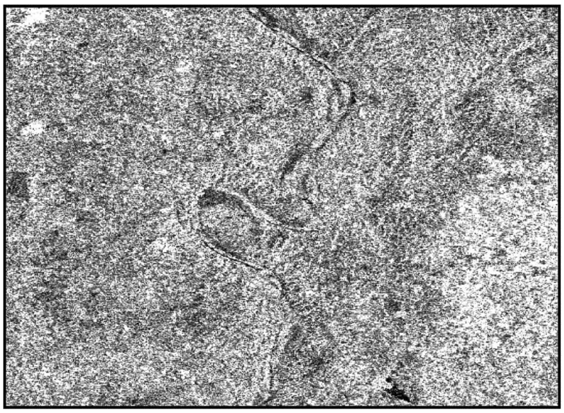

Fig. 2b ERS-SLC Image of Ahmedabad area, Gujarat

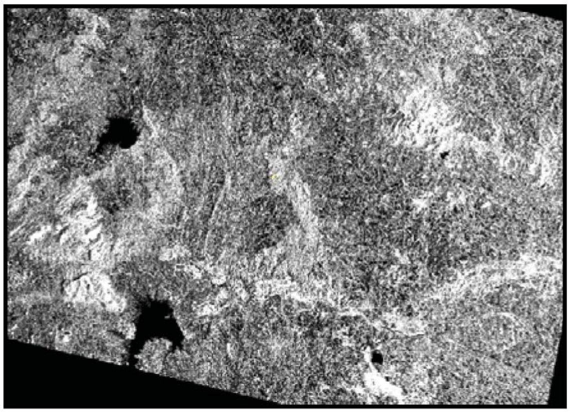

Fig. 3a Intensity image generated from ERS-1/2 SLC product near Jharia coalfield, Jharkhand

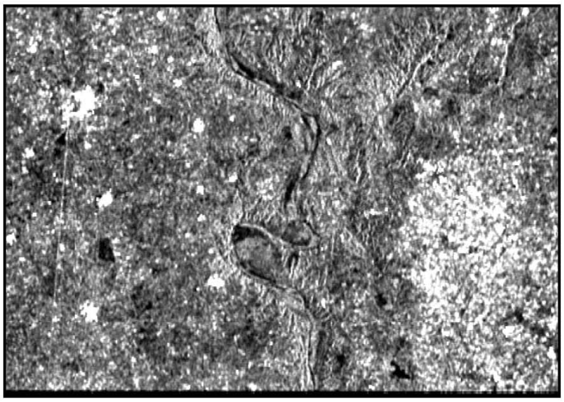

Fig. 3b Intensity image generated from ERS-1/2 SLC product of Ahmedabad area, Gujarat

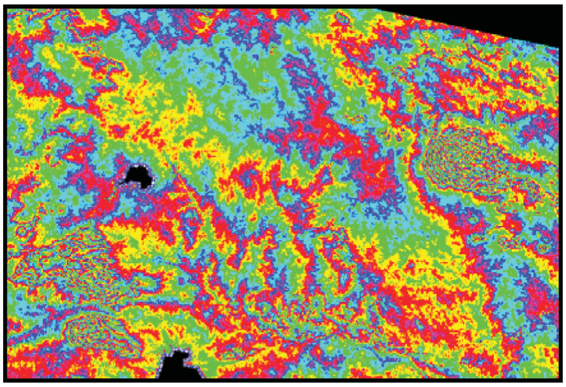

Fig. 4a Interferogram generated from ERS-1/2 SLC products near Jharia coalfield, Jharkhand

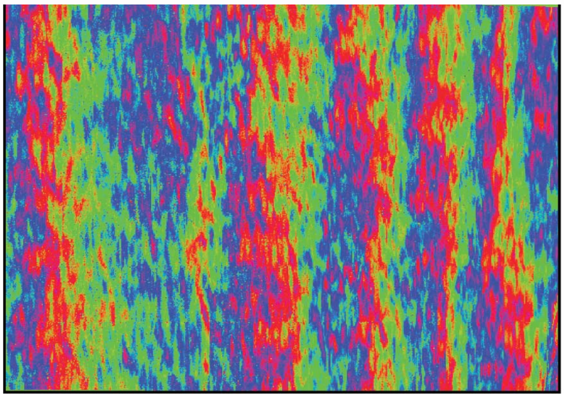

Fig. 4b Interferogram generated from ERS-1/2 SLC products of Ahmedabad area, Gujarat.

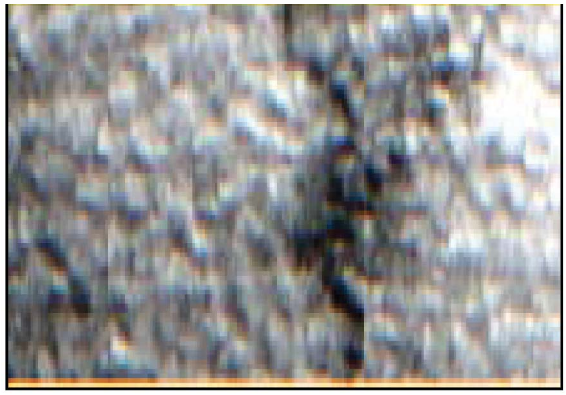

Fig.5b DEM generated by ERS-1/2 SAR Interferometry: Area near Ahmedabad, Gujarat.

3.2 Case II: Generation of DEM by using SRTM data:.

The method of preparation of DEM by SRTM is similar to that of ERS data except that the mode of acquisition is done by single pass on board an aircraft. After the final step of generation of DEM generation, FCC (False Colour Composite) image prepared by Landsat TM data was draped over the DEMs. Three areas namely North Eastern part of Mizoram, Ahmedabad area, Gujarat and Jharia basin, Jharkhand were taken for this study as shown in Figures 6a, 6b and 6c.

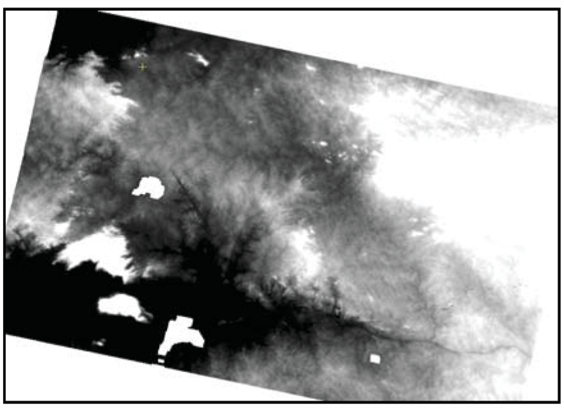

Fig.5a DEM generated by ERS-1/2 SAR Interferometry: Area near Jharia coalfield, Jharkhand.

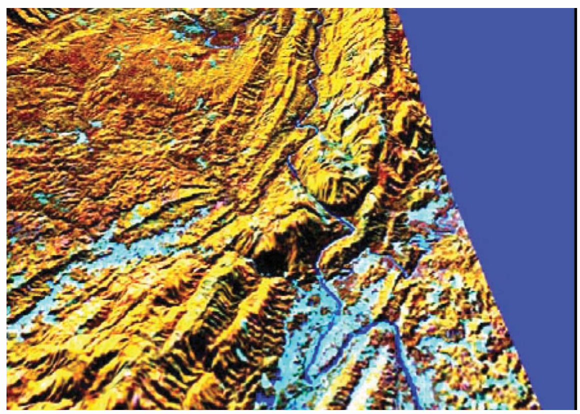

Fig.6a FCC of Landsat TM image near NW Mizoram draped over DEM generated by SRTM data.

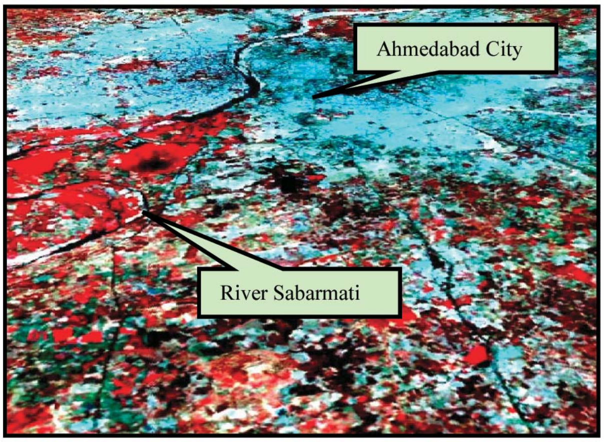

Fig. 6b FCC of Landsat TM image near Ahmedabad, draped over DEM generated by SRTM data.

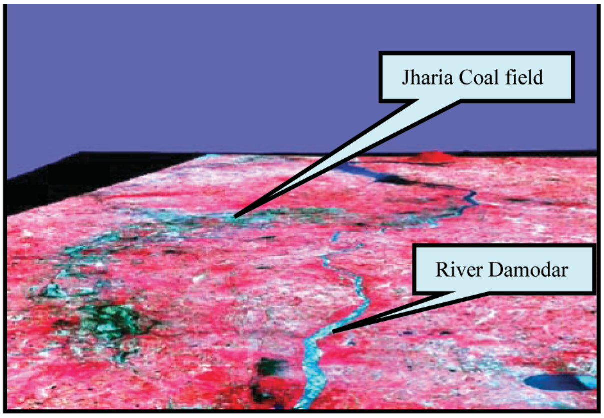

Fig. 6c FCC of Landsat TM image near Jharia coalfield, Jharkhand, draped over DEM generated by SRTM data.

4. Scope and applicability of DEMs in Petroleum Industry:

4.1 Terrain Analysis for logistic planning:

Remote mapping of surface structures is most effective using DEMs particularly in remote or inaccessible areas like Mizoram (Fig.5a). In addition to identification of geological structures, terrain analysis for logistic planning for seismic and geological field parties is very accurate and cost effective.

4.2 Neotectonism:

The differential InSAR accurately measures the change in elevation with time. When monitored accurately, it can help in picking up minor landslides and earthquake prone activities in zones like the Himalayan foothills of Uttaranchal, which are related to neotectonism.

4.3 Monitoring subsidence:

The two giant oil fields near Los Angeles, the "Belridge" and "Lost Hills" experienced substantial surface subsidence due to oil and gas withdrawal. The subsidence was monitored by SAR interferometry and could be picked up to centimeter level accuracy in a year.

It was demonstrated that the surface subsidence related to hydrocarbon withdrawal from Lost Hills Oil field near Los Angeles, USA was hydro- dynamically linked to nearby areas 'A' and 'B' (Fig.6). This led to the discovery of two subtle structures.

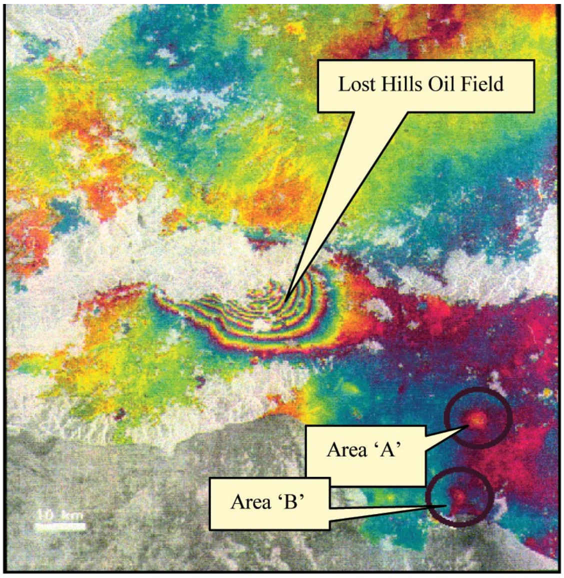

Fig.7 Two subtle subsiding areas 'A' and 'B' near the city of Los Angeles were detected having linked subsidence with the Lost Hills Oil field.

4.4 Geoenvironmental mapping:

Using SAR data, selected areas in India including Jharia Basin, Jharkhand is already under investigation (Fig.6c). The method has good capabilities to detect subtle elevation differences. Geomorphic mapping is widely being used for generation of land use, land cover maps, synthetic hill shade maps, 3D scenes and contours. The repetitive coverage helps in accessing the changes if any due to the geologic processes or human interferences.

4.5 Product enhancement:

The DEMs created using the SAR data when draped over conventional MSS or Panchromatic images enhances the interpretability of the image in terms of lineaments and other structural features. Accurate DEMs can generate Slope and Aspect maps, Synthetic Hill Shade maps, 3D scenes and contours, which also add to the product enhancement.

4.6 Creating fly through models:

Fly is a powerful terrain visualization tool, which drapes imagery and vectors over DEM data to create 3-D perspective scenes in near real-time. Proper fly through generated by DEMs with image other spatial data can be used, in geographic information systems (GIS). It produces an environment that is indistinguishable from reality in which the user can experience a place or an environment without actually travelling there.

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The opinion of the authors in this paper is not necessarily of the organization they represent.

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