LANDSLIDE PHENOMENA IN SEVAN NATIONAL PARK - ARMENIA

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ABSTRACT

Based on data from master and slave complex images obtained on 30 August 2008 and 4 October 2008 by satellite ENVISAT with ASAR sensor,all processing chain is performed to evaluate landslides phenomena in Sevan National park – Republic of Armenia. For this purpose Identification Deformation Inspection and Observation Tool developed by Berlin University of Technology is applied. This software package uses a freely available DEM of the Shuttle Radar Topography Mission (SRTM) and performs a fully automatic generation of differential SAR interferograms from ENVISAT single look complex SAR data. All interferometric processing steps are implemented with maximum quality and precision. The results illustrate almost calm Earth surface in the area of Sevan Lake.

1. INTRODUCTON

Synthetic Aperture Radar (SAR) is a microwave imaging system, recording backscattered signals from a target as a 2-D complex data from which SAR complex valued image with amplitude and phase is extracted. Interferometric SAR (In-SAR) technique makes use of phase difference information extracted from two complex valued SAR images acquired from different orbit positions. This information is useful in measuring several geophysical quantities such as topography, crust deformation caused by volcanoes, earthquakes, and landslides activity, glacier studies, vegetation growth etc. With increase in number of SAR sensors in orbit, In-SAR technique is rapidly gaining importance in remote sensing of planet Earth. Also, SAR system is able to provide data in almost all weather conditions as well as during day and night. On this way the global coverage of the Earth is guaranteed.

The observation of the Earth by SAR interferometry was suggested for the first time by Graham [11] in 1974 and was applied in 1986 by Zebker and Goldstein [12]. The technique was developed farther on by Li and Goldstein [13,14]. Nowadays SAR data from several space borne sensors (e.g. ERS-1, ERS-2; JERS-1, Radasat, ENVISAT) are available and large number of research groups are working on InSAR applications.

The main goal of this study is to perform all image processing chain in order to evaluate landslides phenomena in Sevan National park – Armenia. For this purpose master and slave ENVISAT/ASAR complex images acquired on 30 August 2008 and 4 October 2008, respectively, are used and Identification Deformation Inspection and Observation Tool is applied [15]. Freely available DEM of the Shuttle Radar Topography Mission (SRTM) is built in the software. The process of differential SAR interferograms generation from ENVISAT single look complex SAR data is fully automatic. All interferometric processing steps are implemented with maximum quality and precision.

2. STUDY AREA AND USED DATA

The study area is the Caucus region around Sevan Lake in Armenia. This region is characterized by very complex relief and topography and could be clearly divided in two parts: mountain area and Sevan Lake. As it can be seen from the map in Fig. 1, this area is very seismically active and has a big landslide potential. Therefore, seismic and landslide assessments and prediction maps would play a quite important role to provide the helpful information in preventing and reducing losses caused by these phenomena.

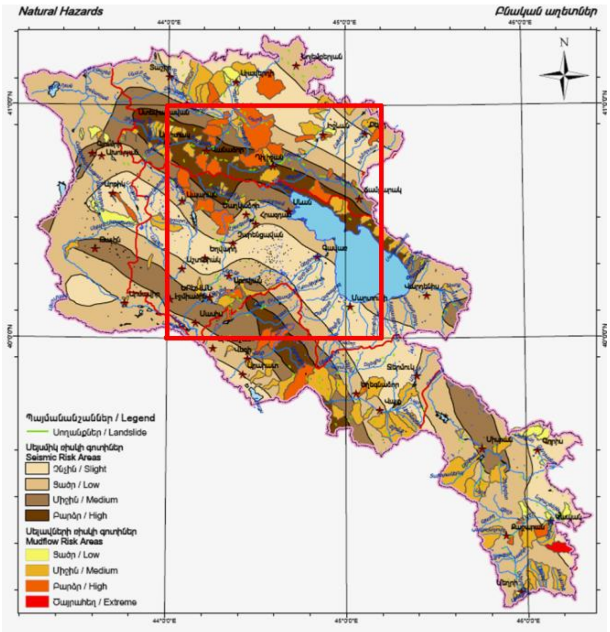


Fig.1 .Map of national hazards of Armenia, Caucus and study aria shown by red rectangle

Figure 2. ASAR SLC image: 30 August 2008

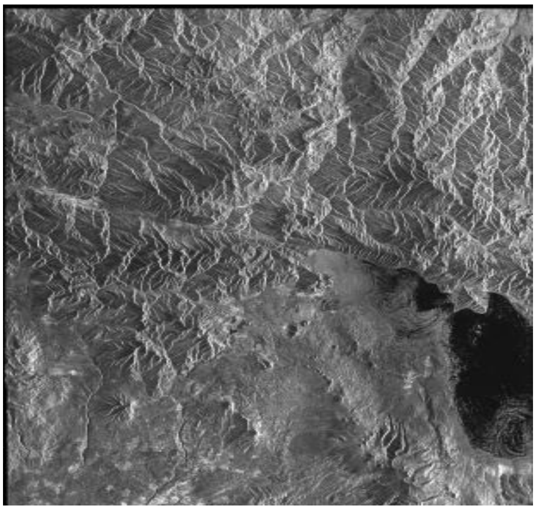


Figure 3. ASAR SLC image: 4 October 2008

The SAR images used for this research are provided by European Space Agency. A full ASAR scene covers an area of 100km x 100km.

3. INSAR GEOMETRY AND BASIC EQUATION DESCRIPTION

If the two positions of the satellite ENVISAT with ASAR mounted on it are considered as S_1 and S_2 [1], then in position S_1 the following geometrical relations would hold: $S_1P_0 = R_0$ - the reference line of sight, R_0 - the distance from the satellite S_1 to the reference point P_0, lying on the zero level, $S_1P_1 = \sqrt{(R_0 + R_p)^2 + N_p^2}$ - the distance to the point of interest, $R_p = P_0P$ - the displacement of the wave flat phase front along the line of sight from the reference point P_0 to the point P_1, lying in nearest resolution cell at height $q = P_1P_2$ from the zero level. In position $S_2 : S_2P_1 = \sqrt{(R_0 + R_p - B_r)^2 + (N_p - B_n)^2}$.

After simple mathematical manipulations the distance variation $\Delta R = (S_2P_1 - S_1P_1)$ can be expressed by

$$\Delta R = \frac{B_n N_p}{R_0} = \frac{B_n}{R_0}\left(\frac{R_p}{\tan\theta} + \frac{q}{\sin\theta}\right). \qquad (1)$$

The phase difference Φ corresponding to the distance variation ΔR is proportional to the travel path difference $2\Delta R$ (the factor 2 accounts for the two ways travel path from S_1 and S_2 to P_1), i.e.

$$\Phi = k(2\Delta R), \qquad (2)$$

where $k = \frac{2\pi}{\lambda}$ is the wave number; λ is the wavelength.

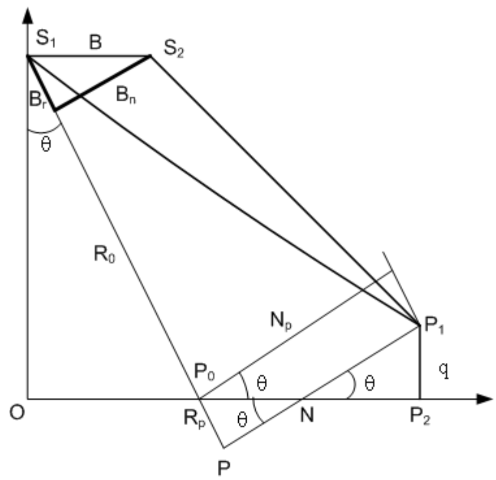


Fig. 4. InSAR geometry.

Thus, based on (1) the phase difference called an interferomegtric phase can be expressed as

$$\Phi = \frac{4\pi}{\lambda}.\frac{B_n}{R_0}\left(\frac{R_p}{\tan\theta} + \frac{q}{\sin\theta}\right) \qquad (3)$$

The phase difference is divided into to two components

$\Phi_1 = \frac{4\pi}{\lambda}.\frac{B_n}{R_0}\left(\frac{R_p}{\tan\theta}\right)$ - phase variation proportional to the slant range displacement R_p of point targets P_1 and P_0.

$\Phi_2 = \frac{4\pi}{\lambda}.\frac{B_n}{R_0}\left(\frac{q}{\sin\theta}\right)$ - phase variation proportional to the altitude difference q between point targets P_1 and P_0, referred to a horizontal reference plane.

Multiplication of the complex interferogram with complex conjugated phase term $\exp(-j\Phi_1)$ is called interferogram flattening. This procedure generates a phase map proportional to the relative terrain altitude. The change of the phase with elevation of the target point is given by the derivative [2]

$$\frac{d\Phi}{dq} = \frac{4\pi . B_n}{\lambda R_0 \sin\theta} \quad (4)$$

This relation describes the height sensitivity of interferometric measurements, which may also be described by the height or altitude of ambiguity.

The altitude of ambiguity H_a is defined as the altitude difference that generates an interferometric phase change of 2π after interferogram flattening. The altitude of ambiguity is proportional to the wavelength, reference slant range distance and sinus of look angle θ, and inversely proportional to the perpendicular baseline B_n:

$$H_a = \frac{\lambda R_0 \sin\theta}{2B_n} \quad (5)$$

According to this relation long baselines would be preferable to derive accurate elevation data from InSAR measurements, but there are theoretical and practical limits. Above a certain baseline (the critical baseline) the spectral shift between the two SAR images exceeds the system bandwidth, and interferograms cannot be formed.

4. TERRAIN MOTION MEASUREMENT: DIFFERENTIAL INTERFEROMETRY

Such motion could be detected in cases when backscattering points on the ground slightly change their relative position in time interval between two SAR acquisitions (in the event of subsidence, landslide, earthquake, etc.). The additive phase term independent of the baseline is proportional to the projection *d* of the displacement on the slant range direction, i.e. [2]

$$\Phi_3 = -\frac{4\pi}{\lambda} d \,. \quad (6)$$

Thus, after interferogram flattening the resulting interferometric phase contains altitude and motion contributions, i.e.

$$\hat{\Phi} = \Phi_2 + \Phi_3 = \frac{4\pi}{\lambda} . \frac{B_n}{R_0}\left(\frac{q}{\sin\theta}\right) - \frac{4\pi}{\lambda} d \,. \quad (7)$$

In order to reveal the motion contribution term a differential InSAR technique is applied. Consider the case of single interferometric pair (master and slave) acquired by non-zero baseline and available DEM. The processing steps are [2]:

- DEM must be converted from geographic to SAR coordinates and the elevation must be converted into interferometric phases (interferometric fringes). The baseline should be the same as used for the interferometric pair.
- Synthetic interferometric phases should be subtracted from those of the available interferometric pair. This operation can be conveniently done in the complex domain by multiplying the actual interferogram by the complex conjugate of the synthetic one.

Consider the case with three SAR images and no terrain motion between two of them, one image should be selected as a common master. Two interferograms are then formed: the two slave images are co-registered to the common master. The shortest temporal difference (to gain coherence and avoid terrain motion) and a medium/high baseline (to gain elevation accuracy) should be selected for the first interferometric pair. The second pair should have a larger temporal difference (it should contain the terrain motion) and a short baseline. The processing steps include:

- The first interferogram should be unwrapped and scaled by the ratio of the two baselines.
- Its phase should be wrapped again and subtracted from that of the second interferogram (generally done in the complex domain).

If the baselines of the two interferometric pairs are in an integer ratio, unwrapping can be avoided. The phases of one interferogram can be directly scaled by the integer ratio between baselines and subtracted from the phases of the other interferogram.

5. CO-REGISTERING

The co-registration is a fundamental step in interferogram generation and consists in the definition of co-registering coefficients. It ensures that each ground target point contributes to the same (range, azimuth) pixel in both the master and the slave image. Proper space alignment between the two images should be performed on a pixel by pixel basis, with accuracy of the order of one tenth of the resolution, or better.

Co-registration depends on the (local) topography. However the impact of the elevation is almost negligible in most cases. Therefore, the co-registration map can be provided as a smooth polynomial that approximates the pixel-to-pixel shift with the assumption of targets lying on the ellipsoidal Earth surface. In satellite-borne Synthetic Aperture Radars such as ERS and Envisat-ASAR, the sensor velocity and attitudes are so stable that the master-slave displacement on the frame (100 × 100 km) can be well approximated by the following polynomial [2]:

$$r^S = a\left(r^M\right)^2 + br^M + c(as)^M + d \quad (8)$$

$$(as)^S = e\left(r^M\right)^2 + fr^M + g(as)^M + h, \quad (9)$$

where r^M, $(as)^M$ are range and azimuth coordinates of the pixels on the master SAR image; r^S, $(as)^S$ are range and azimuth coordinates of the pixels on the slave SAR image. Co-registration coefficients can be computed by least mean square regression based on a regular grid of points displaced over the whole frame of the SAR image.

6. COHERENCE

A precondition for calculating an interferogram is that the phase within the borders of the pixel is preserved, that means the SAR return in the two complex images is correlated). The complex coherence quantifies the phase relation between pixels in two SAR images.

The coherence of co-registered SAR images is calculated as a modulus of the complex coefficient of coherence defined for a particular pixel of the master and slave images by expression [3]

$$\dot{\gamma} = \frac{\sum_{a\in N}\sum_{r\in K} S_{ar}^M \left(S_{ar}^S\right)^*}{\left\{\sum_{a\in N}\sum_{r\in K} S_{ar}^M \left(SM_{ar}^M\right)^* \times \sum_{a\in N}\sum_{r\in K} S_{ar}^S \left(S_{ar}^S\right)^*\right\}^{\frac{1}{2}}} \quad (10)$$

where S_{ar}^M and S_{ar}^S are complex values of *ar*-th azimuth-range resolution element from master and slave images, N is the number of azimuth resolution elements and K is the number of range resolution elements in the particular pixel of the SAR image.

The coherence magnitude $\mathrm{mod}(\dot{\gamma})$ of the estimate (also called degree of coherence) is used to describe the phase relation.

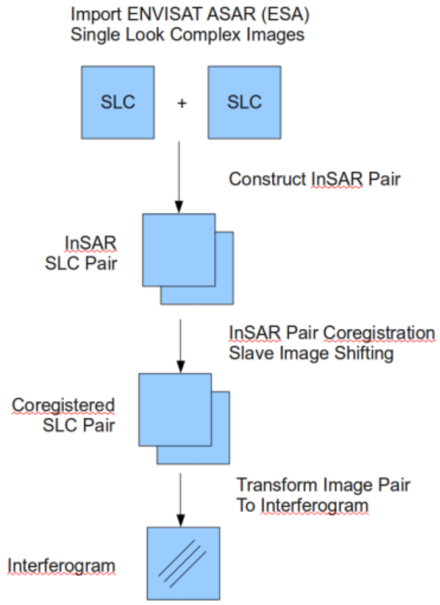
7. LANDSLIDE PHENOMENA IN SEVAN LAKE ARIA

Over last several years, it has been demonstrated that satellite SAR interferometry can detect earth surface deformations induced by earthquakes, volcanic activities or ice sheet flow [4-7, 11]. Researchers are now seeking other application fields of SAR interferometry. Landslide is one of great social concerns from disaster prevention point of view. Attention in the present study is directed to landslide detection, selecting a certain area as a study area and tried to apply SAR interferometric technique. Landslide is divided into two types, one is continuing slide, and the other is sudden slide. Our interest is placed on the former case in which the suffered area is generally smaller than areas affected by strong earthquakes or volcanic activities. We know well that the method referring external DEM is widely used and works to detect large field of displacements from InSAR technology. With this method topographic effects in a SAR interferogram are removed by using external DEM. This technique is strongly recommended by Massonnet [5]. However, we wonder this method will work to detect relatively small and ongoing landslide. Therefore we challenged to do the three-pass method. This method doesn't require external DEM. From worldwide application point of view, this method would be useful. Main points of this technique are a) baseline estimation, b) phase unwrapping and c) detection of slide area. In case of differential interferometry by the multi-pass method, good baseline estimation and phase unwrapping are necessary, since topographic contribution should be eliminated by themselves. Besides, detection of landslide from only SAR interferograms is a new challenge. In this paper, these points are mainly discussed.

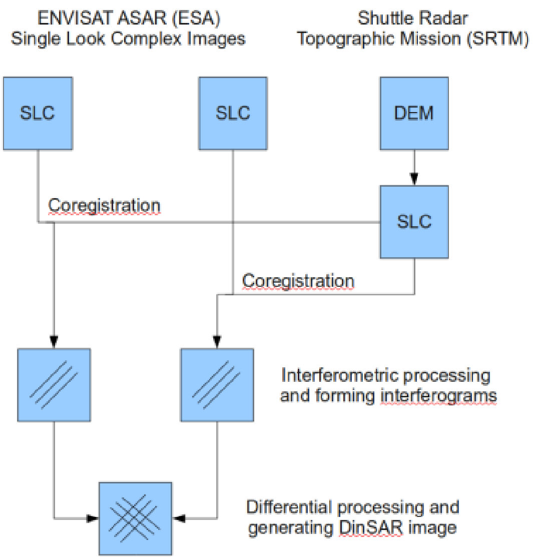
A flow chart of the main steps for differential InSAR processing of landslide motion maps in Caucasus areas is shown in Fig. 5. As input data single-look complex SAR images from the Advanced Synthetic Aperture Radar (ASAR) of ENVISAT is used.

ASAR operates at C-band and a wavelength λ = 5.66 cm and spatial resolution 9.5 m LOS · 5.5 m along track. The polarization is selectable, and electronic beam steering enables the selection among seven sub-swathes with incidence angles between 15^0 and 45^0 [8]. The swath width is 100 km. The standard orbit repeat interval of the satellite is 35 days. Master and slave complex images are obtained by satellite ENVISAT and sensor ASAR on 30 August 2008 and 4 October 2008, respectively. In order to compensate for topography and generate a differential interferogram Shuttle Radar Topography Mission (SRTM) held in February of 2000 is used.

The first component of the processing line is concerned with deriving the topographic phase and optionally producing a digital elevation model (DEM) (Fig. 5, *a*) while the second is concerned with determining the motion–related phase and producing maps of surface motion (Fig. 5, *b*). The flat earth phase is removed as a first step after interferogram generation both for the topographic and motion analysis (not shown as separate step in Fig. 5). In order to derive the iterferometric phase as a first step, coarse and fine co-registration of slave to master images is applied. Then the complex conjugate multiplication of the co-registered SAR images yields a map of the complex coherence coefficient with its module (coherence) and phase (interferogram).



a)



b)

Fig. 5. InSAR processing chart

The SAR interferogram represents two-dimensional relative image phase (wrapped phase) that is the 2π-modulus of the absolute phase (unwrapped phase). A critical step in interferometric processing is the reconstruction of the absolute phase from the modulo 2p image phase (phase unwrapping) due to its non-uniqueness [9]. In order to be able to resolve the 2π phase ambiguity it is necessary that the relative phase difference between adjacent pixels is less than $\pi/4$. This is not always fulfilled in case of fore-shortening and layover, in particular in case of long baselines, resulting in phase discontinuities. Phase noise causes smearing out interferometric fringes and phase ambiguities.

A least squares method for unwrapping is applied. It consists in iterative error correction, checking the difference between the measured (wrapped) phase and the retrieved unwrapped phase after each of iterations. [10]. At the end of the processing chart the displacement–related phase is transformed to map projection and scaled, using a DEM, either derived by InSAR or an external one, precise orbit data and, if available, geodetic ground control points.

It is known that if a high quality DEM from other sources is available this could be used to generate a synthetic SLC image and to transform the InSAR products into map projection (geocoding). The time interval of SAR images to be used for motion analysis depends on the velocity of terrain information. For mapping slow ground movements in Caucasus areas, with typical displacement rates of few centimeters per year, interferometric ASAR and SRTM image pairs covering time of eight years are used. After mutual co-registration of the image pairs and generation of two interferograms a differential interferogram is obtained.

For landslide investigations and hazard assessment it is recommendable to merge the InSAR motion maps with other information, e.g., topographic or geologic maps and optical images, preferably in a geographic information system.

8. EXPERIMENTAL RESULTS

Interferometric ENVISAT ASAR parameters:

- Difference in Doppler centroid: 6,3705139 Hz
- Total Baseline Length: 117,16172 m
- Off-Nadir Angle: MAS 22,620232 / SLV 22,594638

In Fig. 6 the amplitude map (*a*) and the phase map (*b*) of SLC master image are presented, while in Fig. 7 the amplitude map (*a*) and the phase map (*b*) of SLC slave image are shown. Following InSAR processing chart in Fig. 5, *a* the interferometric phase is computed. In Fig.8 the map of interferometric phase after flat-earth phase subtraction is presented. The map of interferometric phase superimposed on the mean amplitude map of the relief is displayed in Fig. 9. Interferometric fringes proportional to the height of the relief are clearly seen on the map.

The interferometric coherence magnitude also called degree of coherence is used to describe the phase relation between two co-registered complex images. In Fig. 10 the interferometric coherence map is presented.

The differential interferogram in Figs 11 and 12 with its red areas southwesterly from Sevan Lake illustrates landslides processes on the Earth surface for the period from February 2000 to October 2008.

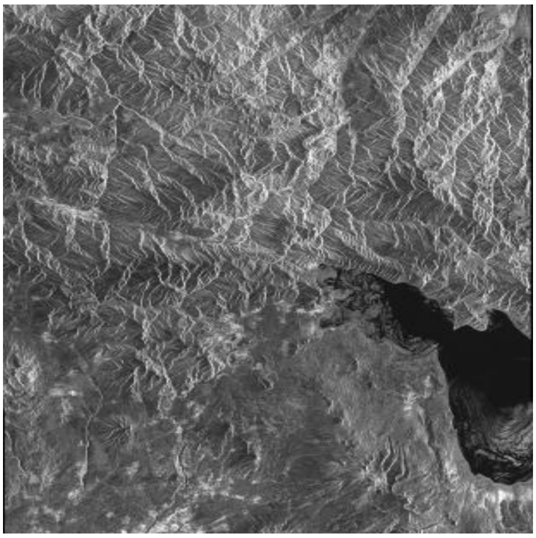


Fig. 6a. Amplitude Master SLC image

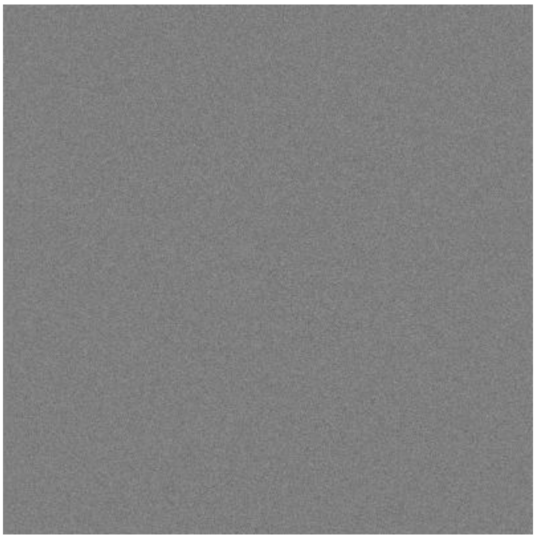


Fig. 6b. Phase Master SLC image

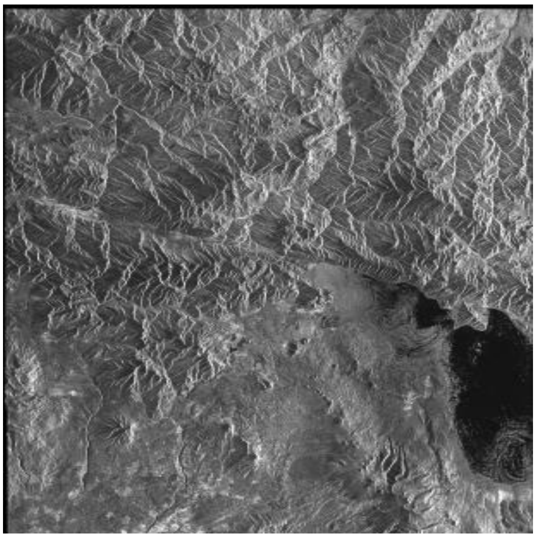


Fig. 7a. Amplitude of Slave SLC imag

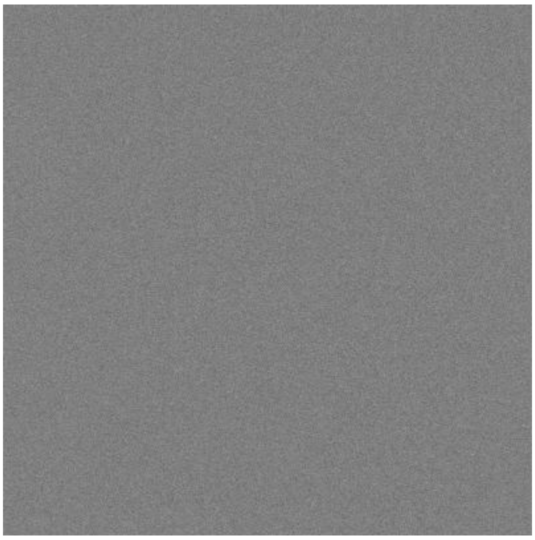


Fig. 7b. Phase of Slave SLC image

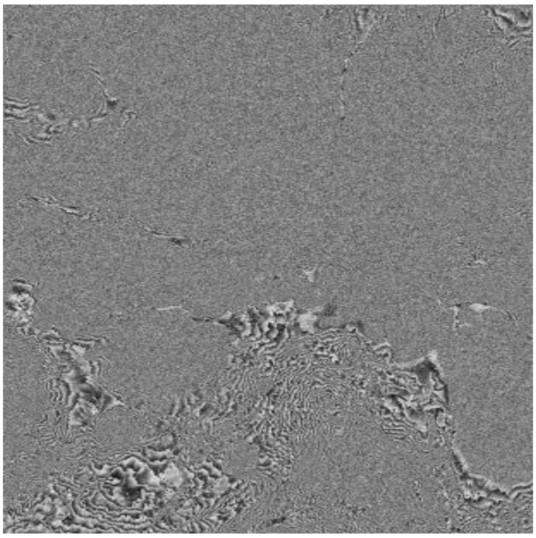


Fig. 8. Interferometric phase after flat-earth subtraction

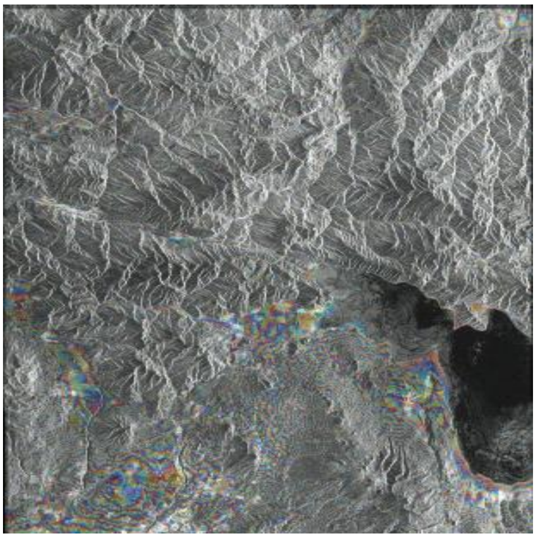


Fig. 9. Amplitude and Phase - overlay mean amplitude with interferometric phase after flat-earth subtraction

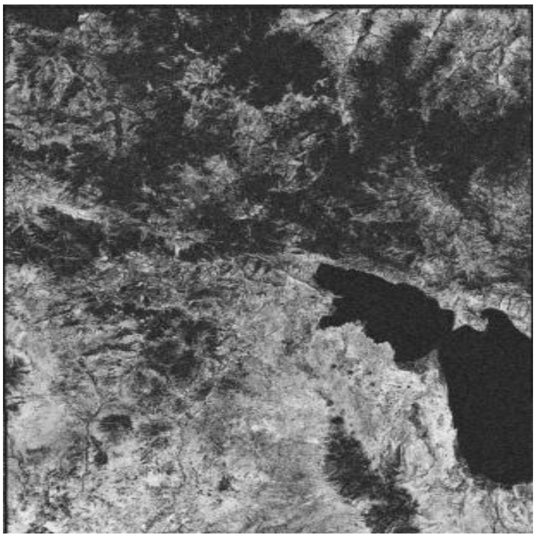


Fig. 10. Interferometric coherence

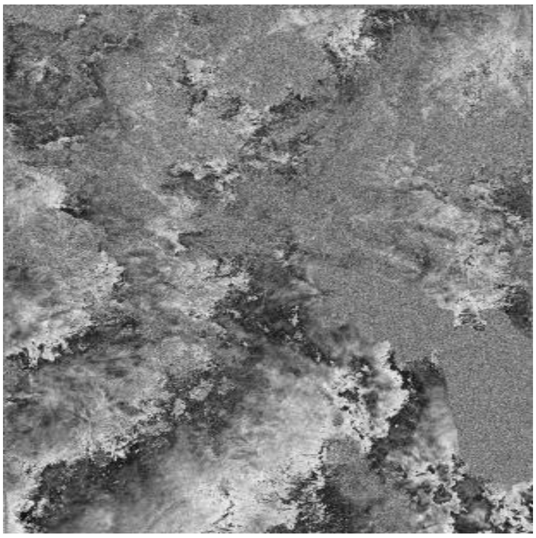


Fig. 11. Differential Phase

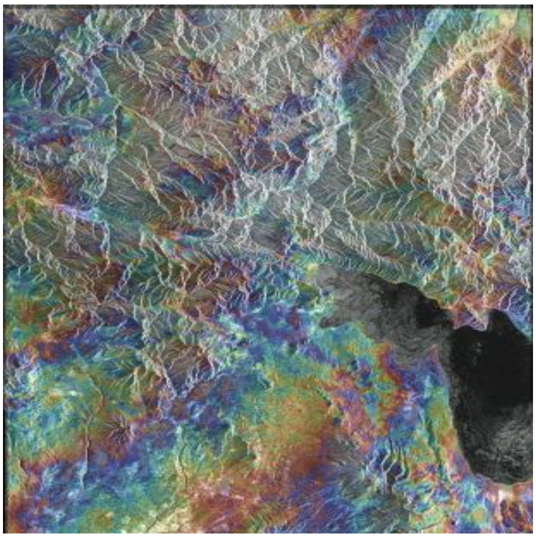


Fig.12. Overlay mean amplitude with differential phase Amplitude DInSAR

9. CONCLUSIONS

In the present work based on data of master and slave complex images, obtained by satellite ENVISAT and sensor ASAR with start and stop time: 30 August 2008 – 4 October 2008 all processing chain has been performed to evaluate landslides phenomena in Sevan National Park – Armenia. For this purpose Identification Deformation Inspection and Observation Tool created by Berlin Technical University has been applied. It is a software package using a freely available DEM of the Shuttle Radar Topography Mission (SRTM) mission February 2000 for fully automatic generation of differential SAR interferograms from ENVISAT single look complex SAR data. All interferometric processing steps have been implemented with maximum quality and precision. Two SLC images of the region Sevan National Park – Armenia have been processed to generate complex interferogram, including interferometric phase map and coherence. Differential interferogram based on the SRTM data obtained February 2000 and SLC images obtained by ASAR, ENVISAT has been produced. The results illustrate slow Earth surface displacements in the aria of Sevan Lake in the period 2000-2008.

10. ACKNOWLEDGMENT

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