LANDSLIDES MONITORING NEAR KRANEVO BY MEANS OF INSAR

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ABSTRACT *The InSAR method provides fast and accurate means for detecting even Earth's small movements of magnitude several centimeters which is particularly suitable for landslides monitoring. The information obtained by this technique is based on interferograms resulting from phase data processing contained in two images from different dates over the same region. One advantage of this method is that it can combine data from different SAR instruments using same wavelength thus providing larger time coverage for one and the same area. Based on this time series data conclusions can be made regarding the speed of movement of the land for several time epochs. Compared to field checks and measurements the InSAR interferograms, obtained from satellite-based instruments, cover larger areas thus offering cost effective manner for monitoring this natural phenomena.*

The motivation behind this research was twofold – first to provide high quality information with regard to continuous monitoring of the site under study and second to make use of freely accessible data from Sentinel-1 SAR mission by ESA whose main data acquisition mode is the interferometric one. Other goal that was achieved throughout this study was that, as our expectations were, we could detect small horizontal movements regardless the short time period between the two images used for interferograms creation (in this case the first image was dated Nov 2015 and the second one was dated Jan2016). The results obtained provide solid grounds to make reliable forecast with regard to further progress of the landslides processes in the studied area although the data used are from relatively short time period (less than one year). For the zone investigated the detected movements are of magnitude of 1.5 to 2cm. Those data will be overlaid with a map for the susceptibility landslides map for the same region and with map of land cover/land use.

Keywords: *InSar, crustal deformation, landslides monitoring, protected natural areas*

INTRODUCTION

InSAR (Interferometric Synthetic Aperture Radar) is one of the greatest remote sensing tools for everyone interested in crustal movements. The operational principle is simple: a satellite equipped with a radar device is constantly measuring the topography of the Earth while orbiting. When it crosses the same area a second time, the two datasets can be compared and the changes in altitude can be measured. The most remarkable thing is that these changes may be as small as < 1 cm thanks to the interferometric effect. Repeated measurements allow creating time series and monitoring large areas with crustal deformation caused by earthquakes, landslides, karst, tectonic uplift/subsidence etc. The resulting data is commonly displayed using so-called fringes, rainbow-coloured rings indicating positive or negative variations of the topography. In the following discussion, we first briefly introduce the fundamentals of InSAR and then set focus on InSAR applications in landslide detection (land subsidence/lift).

Since the landslides are widespread in the North-East Bulgaria they comprise an important element of the geological hazards of the country [1], [2]. The permanent high degree of the landslide hazard for long-term periods has been sagaciously estimated from us in section two below. In the present research paper we analyze main factors introducing instability and their impact on landslide formation and triggering.

The motivation behind this study was to check the ability of the described InSAR technology (see section ***0***) for landslides observing to be used in rapid monitoring and mapping of natural protected areas of northern Black sea coast.

REGION OF STUDY

The most valuable nature areas in northern Black sea coast are designated by the Bulgarian Ministry of Environment and Waters as protected under the Protected Areas Act. In the said area Zlatni pyasatsi natural park, Baltata managed reserve and some natural landmarks and protected localities are localized as well as parts of the Natura2000 sites (see Fig. 1).

The Baltata Reserve is located in the area of the village of Kranevo, Balchik municipality and covers the lowest stream of Batova river. It was declared a reserve since 1962 with an area of 183.2 hectares and in 1999 the reserve was re-categorized to a maintained reserve with an area of 203.2 hectares. Baltata covers the northernmost parts of Europe's dense forests, where many tree species can be seen, such as White Poplar (Populus Alba), Field Maple (Acer campestre), Black Alder (Alnus glutinosa), etc. This region is home to more than 260 species of higher plants, 28 of which are protected [3].

Zlatni Pyasatsi Natural Park covers an area of 1320.7 ha. It is characterized by natural deciduous forests composed of different types of oak and hornbeam. Under protection are rare and endangered plant species such as snowdrop (Galanthus nivalis), primerose (Primula vulgaris sibthorpii), orchids, a lot of bird species (woodpeckers, tits, owls) and mammals – roe deer (Capreolus capreoulus), wild boar (Sus scrofa), badger (Meles meles) [3]. In the same area situated is the rock monastery Aladzha Monastery, which is one of the few cave monasteries in Bulgaria, is considered as one of the cultural heritage sites of the country. At this site archaeological finds such as pottery, coins, graffiti, etc. dated to early-Christian Age were discovered.

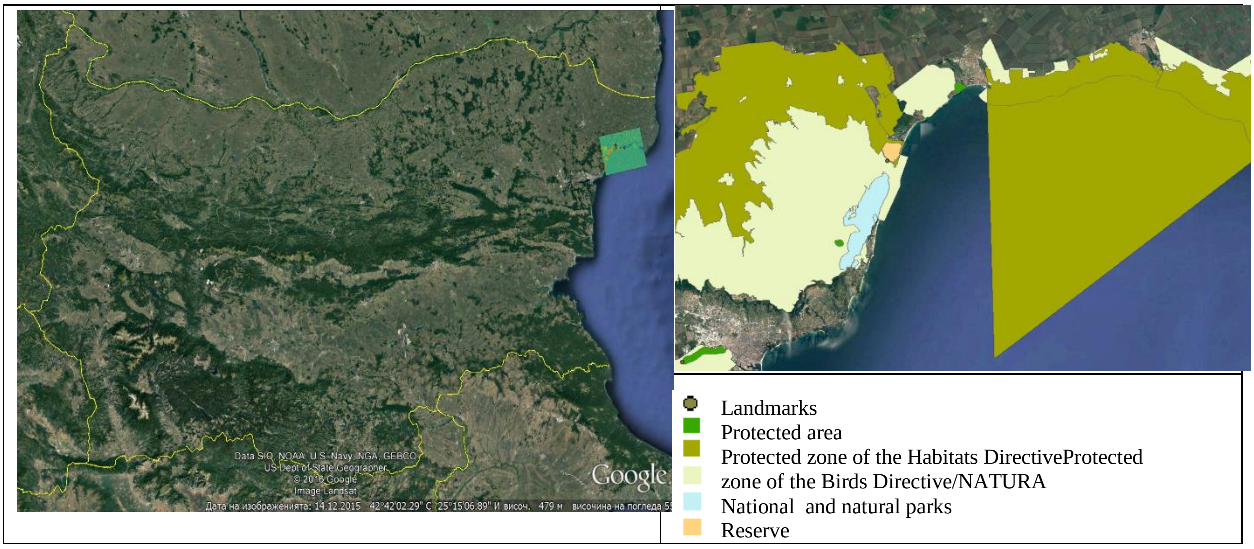


Fig. 1. Location of the studied region [4]

GEOLOGICAL SETTING

There are many factors exerting impact on the process of landslide origin and activation — endogenous and exogenous ones. The influence of earthquakes, erosion, sea erosion, surface and ground water level fluctuations and technogenic activity is strongly expressed (see Figure 2) [1].

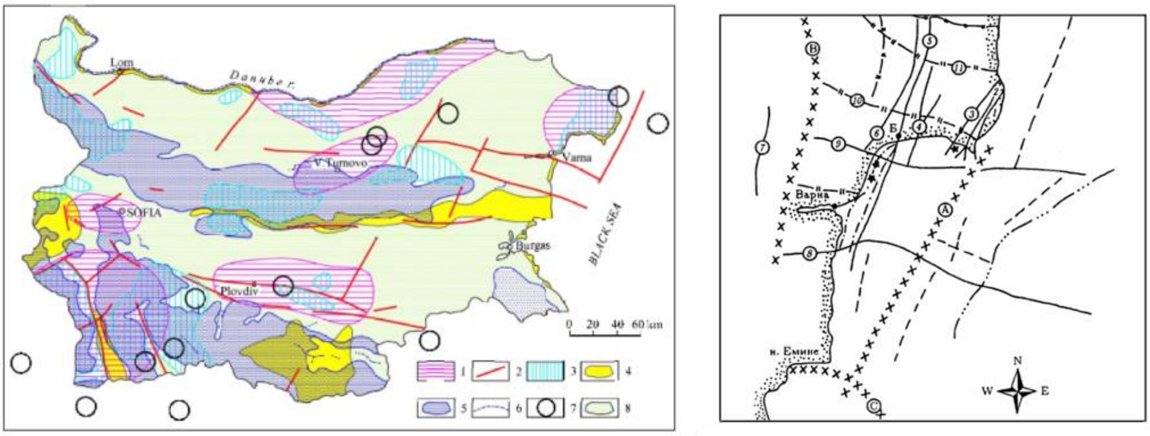
The impact of **seismic** forces on the landslide slopes is complicated and is still insufficiently studied — it depends to a significant extent on its intrinsic intensity, amplitude and duration, as well as on the geological structure of the slopes and their stability reserve [1].

This part of northern Black Sea coast, namely the region close to Kranevo village, used in our research falls within the eastern part of Moesian platform is seismically active region. The tectonic structure of the Black Sea basin is a complex zone of collision between the African and Eurasian plates and a movement around the various microplates has created an area that has the potential for occurrence of earthquakes. The region is located in an earthquake zone with an expected level of intensity VII [5]. Earthquakes in this region are mainly related to north-south **fault zone.** On Figure 2 faults are presented following the research done by I. Genov [5]. However, the majority of tectonic activity in the area of study dates from before Quaternary [5]. It is believed that the majority of the faults present in the region of study are not highly active.

To the north of the said region Bezvodishko-Selchenski fault is located and at its south is crossed by fault Batovsky. It divides the continental terrace Moesian plate of northern and southern parts. To the west the area of the study is limited by Venelin-Tolbukhin fault and east of Kaliakra fault. Multiple faults oriented north-south are mapped in the area – Trigorski, Balchishki, etc. In this area there are several faults associated with gravity-landslide processes.

The **river erosion** (deep and lateral) also plays a role for the activation and development of landslide processes. This type of erosion is caused both directly by water and by the carried in the stream rock materials, applying their action on the bottom and around the riverbed. (Fig.2). The influence of this type of erosion on the landslide phenomena activation is expressed in carrying away the material from the lower retaining parts of the slopes and disturbing the force equilibrium.

The basic influence of **sea erosion** provoking sliding is the washing away and transporting of materials from the retaining part of the landslide, which is the reason for reduction of the retaining force magnitude. Sea erosion is displayed approx. on 70% of the length of the Bulgarian Black Sea coastline (Fig. **2**) [1]. The highest values for sea erosion are observed in the coastal sections near Kranevo, Balchik and Kavarna.



Endogenic and exogenic landslide factors of the country 1. Seismicity above VIII degree by MSK-64; 2. Active faults3. Regions with recent vertical movements > +2 mm/a; 4. Regions with river and sea erosion slope destruction; 5. Regions with precipitation > 700 mm/a; 6. Levels fluctuation of rivers and reservoir more than 5 m; 7. Earthquake epicenters with magnitude M >5 (for period 1940—2000); 8.Regions with low degree of endogenic and exogenic landslide factors	A – Kaliakra; B - Venelin-Tolbukhin; C – Zadbalkanski; 1 – Tyulenovski; 2 – Balgarevski; 3 – Gorunski; 4 – Iztochnobalchishki; 5 – Balchik; 6 – Trigorski; 7 – Sindelski; 8 – Bliznashki; 9 – Batovsky; 10 - Bezvodishko-Selchenski; 11 - Silistra-Belgunski

Fig. 2. Endogenic and exogenic landslide factors of the country (left picture) as in [1] and main faults of the North-East Black Sea cost (right picture) as in [5].

It should be mention that strong relation between precipitation and shallow and medium-to-deep landslide activation has been established. Kranevo village situated in the climatic region of the

Northern Black Sea coast has highest monthly precipitation in November, with a secondary maximum in June-July and this is the reason strong movements could be expected in those periods.

The changes in the erosion basis due to the **vertical movements** of the Earth's crust blocks provoke processes that modify the relief of the Earth's surface — transport of materials from high to low places, alterations of the geological burden in the single crustal blocks and hence of the stresses in the rock massifs.`

Technogenic impact – the most recent, but at the same time very significant factor for the slope instability is the human activity. The undercutting of the slope related with roads and railroad construction, deep excavations for building sites and underground structures, etc., are especially dangerous from the viewpoint of landslides' stability.

The technogenic changes in underground hydrodynamics are in many cases the basic factor for the occurrence and activation of landslide processes. The groundwater regime is altered substantially as a result of dam construction and backwatering, undimensioned irrigation, concentrated leakages from pipelines and channels, household water infiltration, etc. The unfavourable effect of water is more strongly expressed for the stability of shallow landslides, but in some cases it might be considered that the technogenic changes in the natural underground hydrodynamic regime destabilize deeper landslides too [1].

Distribution of landslides

The parameters of the landslides investigated vary in a wide range. Their geometric dimensions are directly related with the geologic and tectonic structure, the geomorphological peculiarities of the slopes and the magnitude and intensity of the factors determining slope stability quoted above.

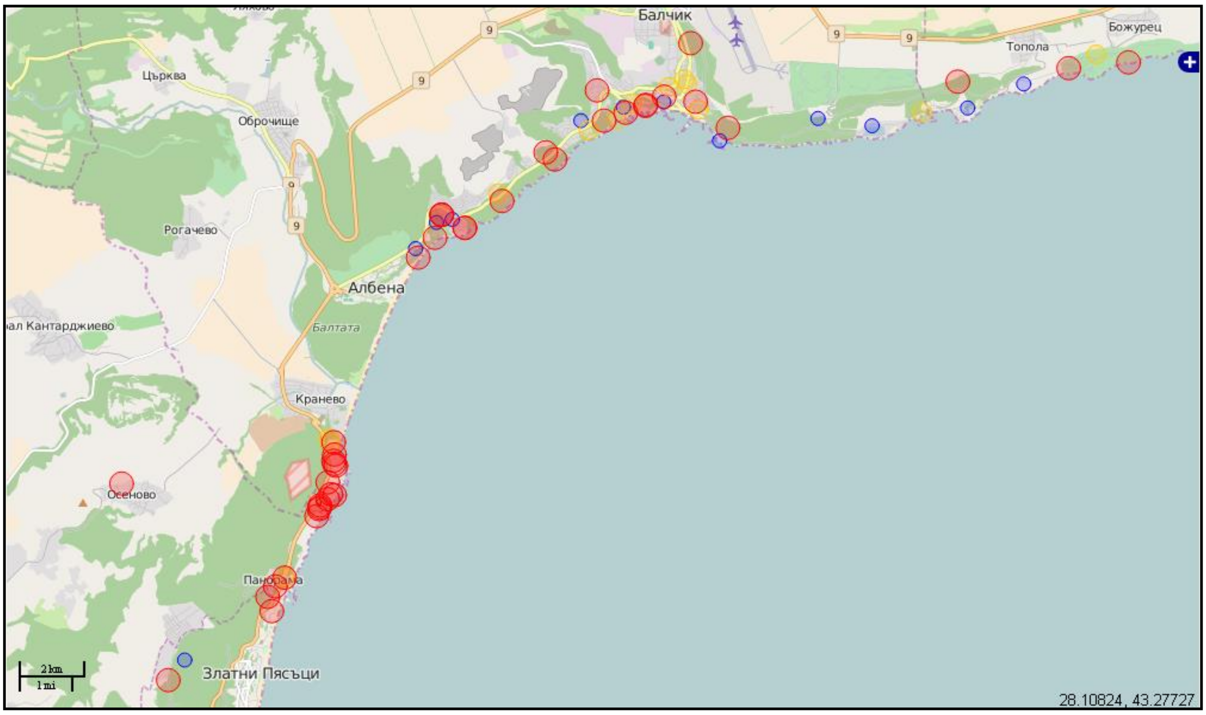


Fig. 3. Map of landslides distribution in the region around Kranevo village [1], [2]

The regional distribution of the landslides according to their volume shows that landslides with a volume up to ten million cubic meters are the prevailing type for Bulgaria. The most numerous landslides in this group — about 50% of the total number — are observed along High Danubean

Bank and Northern Black Sea coast and more specifically in the strips at Balchik–Kavarna, Zlatni Pyassatsi–Kranevo (Fig. **3**) [3]. The block landslides along the Northern Black Sea coast (Roussalka-Taukliman, Yailata and others) are characterized by a low degree of hazard, but some of those landslides could be triggered after seismic impact. Neogenic sediments of diverse lithological composition participate mainly in these landslides. The basic destabilizing factors are the sea erosion and the changes in the regime of ground water. The seismic from near and more remote centres (Shabla, Vrancea) exert also effect on the activation along the Northern Black Sea coast.

The Ministry of Regional Development and Public Works offer a quantitative assessment of landslides activity in Bulgaria by a GIS-based application for landslide hazard and risk mapping of the north Black Sea by means of susceptibility, hazard and risk maps of the region. The database of application was queried and it returned all landslides registered by the corresponding authorities. These landslides were previously identified [2] including its different features such as slope, orientation, lithological composition, areal extension, geodetic measurement, etc.

InSAR PROCESSING

InSAR (SAR Interferometry) is a technique that uses SAR (synthetic aperture radar) images to generate topographic and ground motion maps. It is based on the acquisition of two images of the same area and relating their phase information for distance measurement by comparing differences in the phase of the waves reflected by objects on Earth surface and returned to the satellite/plane. Phase information is retrieved in so called wrapped format, between $-\pi$ ad $+\pi$ radians, but it is worth to mention that phase stability is mandatory for quality measurements. This condition requires that surface features do not change between the two acquisitions. Changes in features of the surface result in a high level of noise and the retrieved signal cannot be used for interferometry due to temporal decorrelation [6].

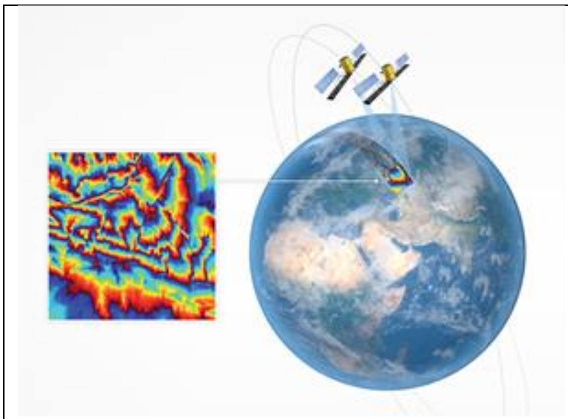
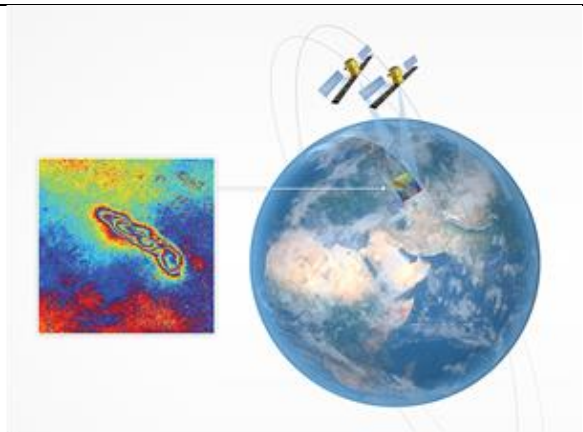
	
SAR Interferometry (InSAR). Generation of topographic maps	Generation of ground motion maps (Differential Interferometry, DInSAR)

Fig. 4. SAR Interferometry (InSAR) and Differential Interferometry, (DInSAR) [6].

This technique allows generation of Digital Elevation Models (DEM) of the observed area. In this case the two SAR images (an interferometric pair) has to be acquired within the shortest possible period of time, in order to minimize the temporal decorrelation (surface changes that effect measurement points). After processing the phase information is transformed into height values with metric precision [6]. If some motion, such as subsidence or uplift, occurs on the ground surface between the two SAR acquisitions using the DInSAR method (Differential Interferometry, DInSAR) we are able to measure this displacement with centimetric precision. The quality of the finally generated DEMs (InSAR) and ground motion maps (DInSAR) is affected by several factors– atmospheric artefacts, topographic errors, temporal decorrelation.

Methodology

In this study we followed the widely recommended by ESA SAR processing chain [7], [8] which includes – **Precise Orbit Determination** is the retrieval of restituted orbit files and precise Orbit Ephemerides orbit files; in **Back-Geocoding** selected is the Digital Elevation Model to be used afterwards; in **Co-registering** step which is fundamental in interferogram generation, since ensures that each ground target contributes to the same (range, azimuth) pixel in both the master and the slave image; **Interferogram Formation and Coherence Estimation** coherence band shows how similar each pixel is between the slave and master images in a scale from 0 to 1; **Generation of coherence maps** or better said its absolute value (since it is a complex quantity), provides a useful measure of the interferogram quality**; TOPS Deburst and TOPS Merge** seamlessly joins all burst data into a single image; **Phase Filtering Interferometric** corrects the phase if corrupted by noise from – temporal decorrelation; geometric decorrelation; volume scattering; processing error; **Multilook** processing is used to produce a product with nominal image pixel size and less noise; **Speckle Reduction** Speckle filters can be applied to the data to reduce the amount of speckle (salt and pepper noise) at the cost of blurred features or reduced resolution; **Geocoding & mosaicking** of the interferogram are the last steps used.

Phase Unwrapping

In the produced interferogram the interferometric phase is ambiguous and only known within the range of 2π. In order to be able to relate it to the actual topographic height the phase must first be unwrapped. The altitude of ambiguity is defined as the altitude difference that generates an interferometric phase change of 2π after interferogram flattening. Phase unwrapping process solves this ambiguity by integrating phase difference between neighbouring pixels. After deleting any integer number of altitudes of ambiguity (equivalent to an integer number of 2π phase cycles), the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation.

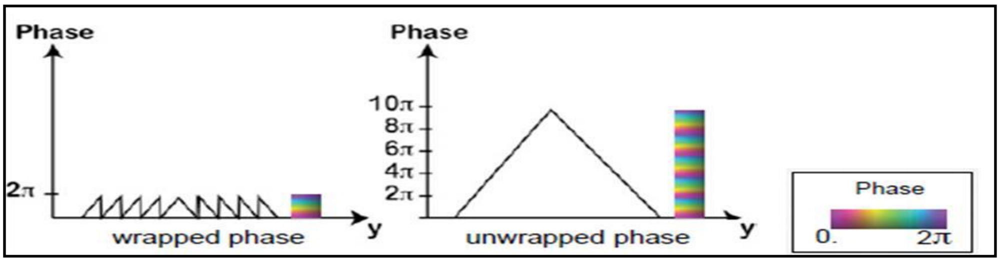


Fig. 5. Unwrapping procedure is used for establishing the correspondence between phase and height [8]

The quality and reliability of unwrapped results very much depends on the input coherence. Reliable results can only be expected in areas with high coherence. Unwrapped results should be interpreted as a relative height/displacement between two pixels. To obtain absolute estimates, a tie point can be used in the unwrapped phase to height operation.

RESULTS

Differential Interferometric SAR (DInSAR) analysis for landslides found in the area Kranevo village has been performed using two images from satellite Sentinel-1. In order to perform the interferometric processing the input products should be two or more Single Look Complex (SLC) products over the same area acquired at different times (in this case the first image was dated Nov 2015 and the second one was dated Jan2016). We employed the following methodology having with two main stages – **first** basic processing of SAR, SLC focused images to obtain interferograms with the wrapped phase using a Digital Elevation Model (DEM) of the study zone and **next** generation of the interferogram requires the pixel-to-pixel computation of the product of two co-registered, spectral-shift-filtered images. The convention assumed here ensures that the interferogram is registered in the same (azimuth, slant range) reference as the master image, and its phase is the difference between the phase of the master and that of the slave, and if necessary compensated for any further topography/flattening fringe pattern.

For the repeat-pass interferometry case, the two phase images must be properly coregistreted. The requirement for the two coregistered images to form a meaningful interferograms is stringent, which means that the two SAR phase images for the same area must be precisely aligned (as accurate as 1 pixel) so that pixels in one phase image correspond exactly to the pixels in the other in geographic location. The stability of the ground pixel, local slope of the terrain, the direction of observation, orbital configuration, frequency used for the two images, image processing procedure, topography difference observed from two slightly different points of view by the radar, all affect the formation of an interferogram.

Interferometric fringes represent a full 2π cycle. Fringes appear on an interferogram as cycles of arbitrary colours, with each cycle representing half the sensor's wavelength (in this case 2.8cm). Relative ground movement between two points can be calculated by counting the fringes and multiplying by half of the wavelength. Any deviation from a parallel fringe pattern can be interpreted as topographic variation.

The toolbox used in this study for SAR processing is the freely distributed by ESA (European Space Agency) the SNAP software.

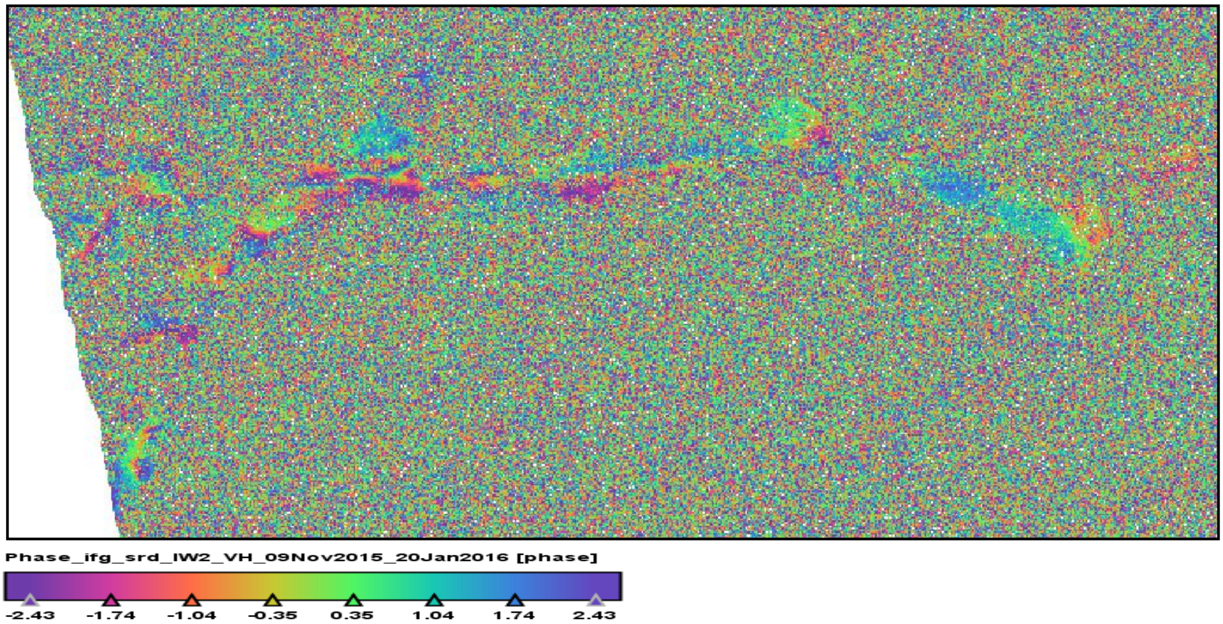


Fig. 6. Resulting interferogram from DInSAR processing for the area of Kranevo village

The image on fig. 6 shows the inferogram for area of Kranevo village and on the fig. 7 it is imposed onto a Google Earth application. On the last figure presented is the combination of an interferogram from SAR images and location of active landslides derived from landslide maps with (depicted by yellow marks) showing good correspondence between registered landslide sites and movements detected.

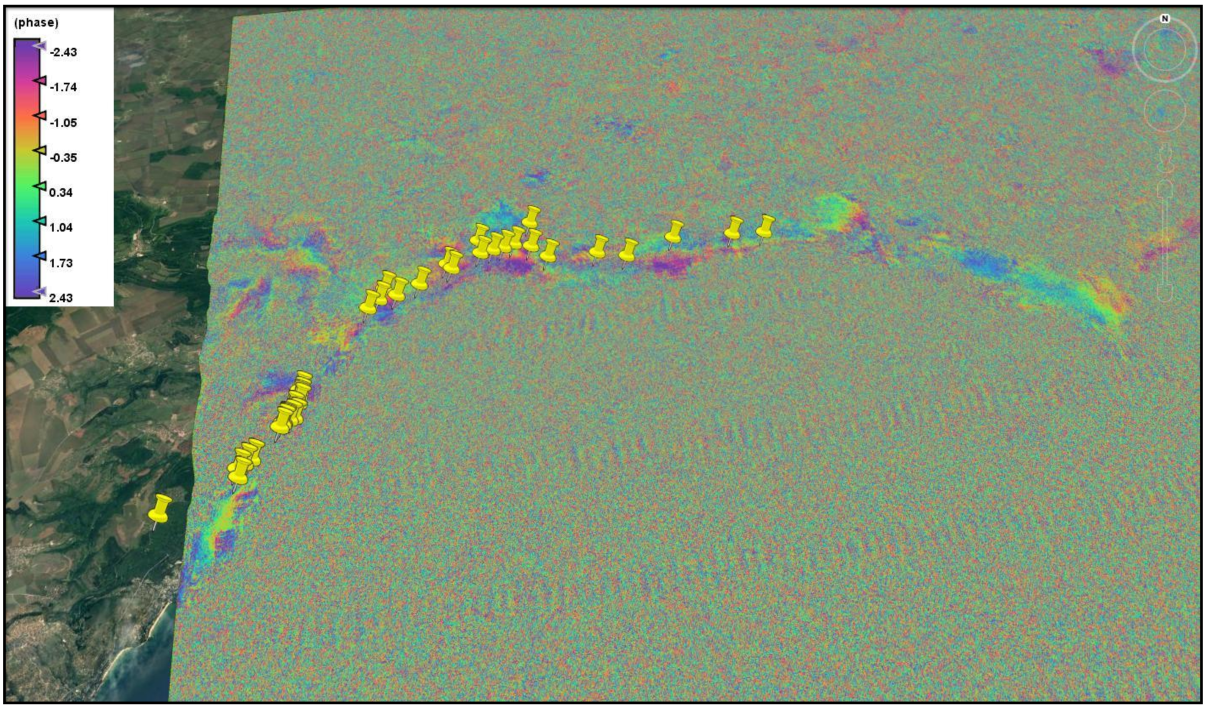


Fig. 7. Integration into a Google Earth application of an interferogram and location of active landslides [2].

The **second** step includes creation of interferograms by means of DInSAR technique in order to assess the average surface displacements in the landslide areas and to interpret of the results obtained. These results are evidence of ongoing activity in the landslides areas which potentially are affecting area between villages Kranevo and Balchik and could be included in the risk map for landslides effect. It is clear that the difficulties related to the estimation of surface deformation from a single SAR interferogram are essentially due to the presence of decorrelation effects (described above) and needs more detailed study.

For correct interpretation of the deformation map it is essential to point out that the measurements are relative with respect to a reference point, are relative in time with respect to the first acquisition and are performed in the viewing direction of the satellite. The absolute location (X,Y,Z) of the measurement points is less accurate than the deformation measurements. Relative in time means that the satellite images set can be seen as a stack on basis of acquisition date where first image is chosen as reference. This implies that the measured deformations are with respect to the date the first image acquired. While radar interferometry can measure deformations in the order of millimeters, the determined location of the measurement points (absolute location X,Y,Z of the points) has a precision in the order of meters. This location precision applies to both the location on the surface and the height. Therefore, when interpreting the measurement points on the deformation map, one should take this location uncertainty in account [9].

The landslide activity assessment resulting from this research shows (Figure 8) that a vertical displacement are of 5 mm for Kranevo landslide, -7mm for the Balchik landslide and up to 5 mm, for the Albena landslide. Particularly vulnerable areas are shown in red, less vulnerable in yellow, flat areas in light green and sinking ones are colored in white. The image on fig. 9 for Kranevo area shows the horisontal movement in the landslides. The colour of the pixel represents the surface movement measured in millimetres for period investigated ranging from -7 mm in black, green being around zero and red corresponding to +9 mm.

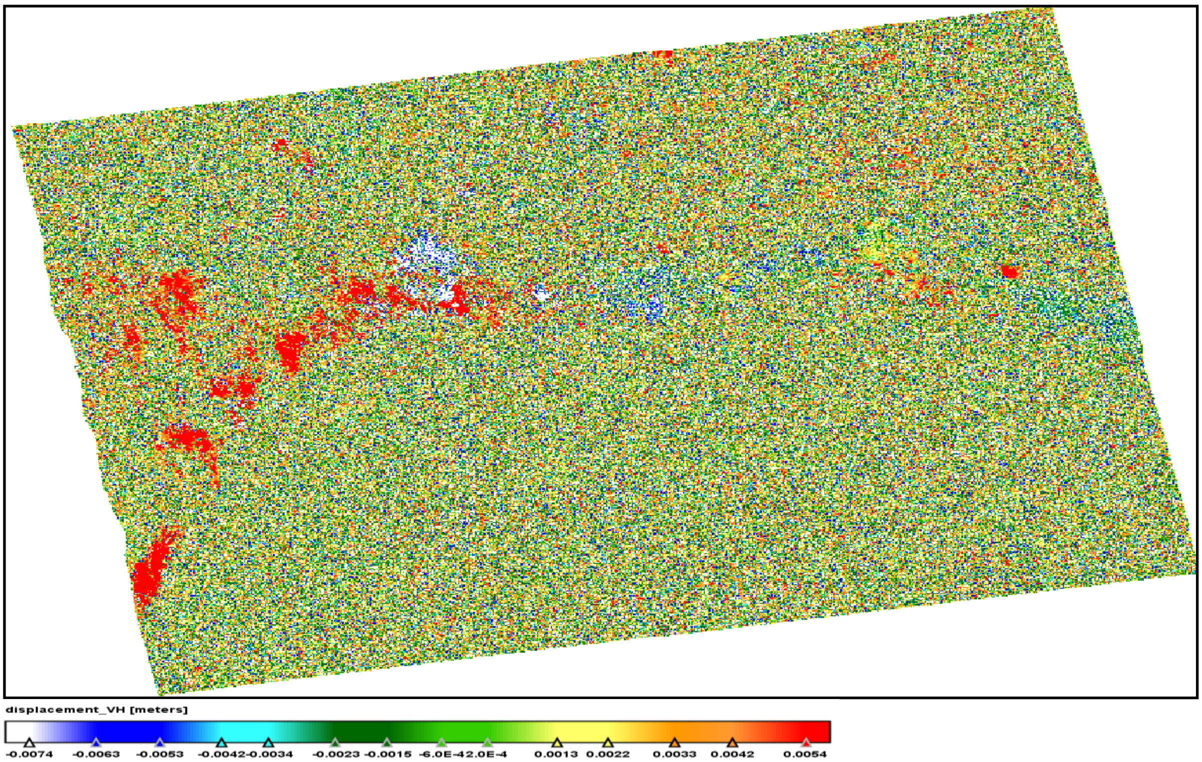


Fig. 9. Maps of vertical movement derived from SAR images corresponding of landslides

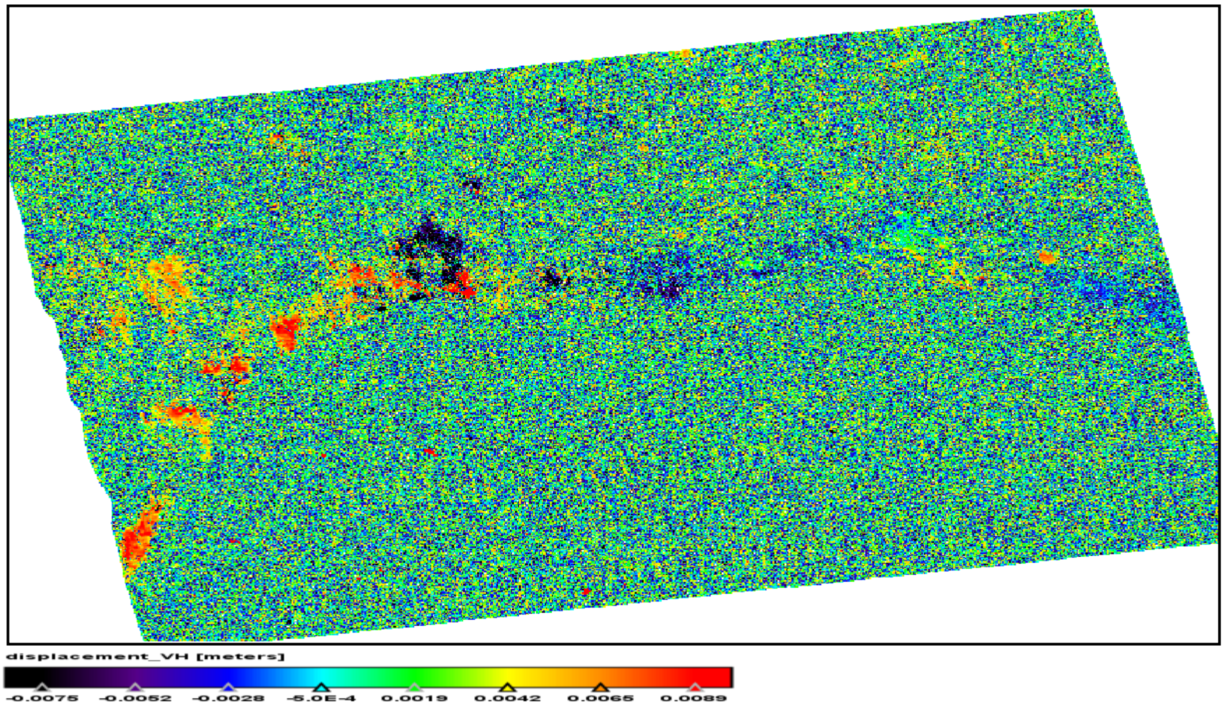


Fig. 10. Maps of horizontal movement derived from SAR images corresponding of landslides

CONCLUSION

Every year, landslides present a major threat to human life, property, infrastructure and the natural environment, in north-east sea regions. The impact natural environment from landslides is generally underestimated.

Gradual ground shifts are known to precede major landslides. Often these are on a scale of millimetres and too slight to be noticed even by local observers, but enough to be detected via satellites using a DInSAR technique. This technique is based on elaboration of multiple SAR images in such a way that even very small terrain displacements are detected.

Ground-based surveys are time-consuming and very expensive if, for example, whole Protected area or National and natural parks are to be monitored. Satellite-derived information capable of resolutions of a few centimeters or better offers detailed monitoring of changes in the surface of the ground. Therefore satellites can assist in minimising and mitigating damage caused by landslides creating risk and disaster management maps in support of the decision-making processes for civil protection activities. It can be concluded that landslide monitoring can be successfully implemented by a combination of geodetic measurements, spaceborne radar interferometry, spaceborne high-resolution optical data, geological information and GIS analysis.

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