ASSESSMENT OF MASS MOVEMENTS DRIVEN BY EXCEPTIONAL METEOROLOGICAL EVENTS THROUGHOUT THE USE OF DINSAR IN AUSTRIA

Filippo Vecchiotti [1], Kociu Arben [1], Nils Tilch [1]

[1] *Austrian Geological Survey, Neulinggasse 23, 1030, Vienna (Austria), Email:filippo.vecchiotti@geologie.ac.at*

ABSTRACT

The main focus of this paper it´s to elaborate a cost effective strategy for SAR images processing in the aim of assess the Austrian mass movement cadastre through the use of open source software. A new method, aimed at verify the best compromise between statistical probability to detect movements on the ground, temporal and geometric decorrelation, attenuation of the electromagnetic wave by the atmosphere for DINSAR products, is proposed. A comparison of DINSAR displacement maps with GEORIOS (georisken Österreich) cadastre, geological, geomorphological and geotechnical available data were carried out.
The ability to detect very slow deformation phenomena was positively assessed. However the possibility to associate precursory vertical displacements to on-going slope degradation processes requires a more detailed advanced DINSAR investigation.

1 INTRODUCTION

The use of SAR radar interferometry has becomed more and more diffuse in the field of geomorphology and engineering geology. Nowadays the number of opportunity for governmental organisations to processing SAR images in house is largely augmented due to the existence of open source software which enables a competent user to visualise process and analyse available ESA ERS and ENVISAT data. Since few years the ESA in cooperation with the ARRAY have developed NEST a new open source software which allows earth scientists to perform complete differential interferograms for SLC (single look complex) pairs. The aim of the project called “Austrian landslide catalogue assessment through the use of radar interferometry application” approved by ESA and carried out by the GBA engineering geology department is mainly to compare and integrate the DINSAR results with the GEORIOS cadastre data. The redaction of this cadastre started in 2000 and it consists, on one hand, on a complex, data management system GIS based used to localize and display all the relevant information. The other part of the data management system is a relational database for the digital management of thousands of documents, photographs and publications [1].

2 AIMS AND OBJECTIVES

The objective of this project is, beside the integration of the information concerning landslide in Austria present in GEORIOS cadastre with the new insight from the DINSAR application technique, to use extreme meteorological events occurred recently as major triggering factor for inducing activation or reactivation of mass movements in Austria. In fact the application of an analogue of the pre-seismic and post-seismic approach, the so-called “pre-triggering” and “post triggering” approach for SAR interferometry in three study areas will be introduced and analysed.

3 DATA AND METHODS

The methods adopted for the realisation of the project were the following:

- creation of the PSI predictability model for Austria;
- estimation of detectable GEORIOS mass movements with the DINSAR method;
- search for areas recently (1992-2010) interested by meteorological driven catastrophes in Austria;
- selection of the SAR images to be processed;
- SAR processing with the NEST software.

3.1 Creation of the PSI predictability model for Austria

We adapted a model [2] addressed to forecast the PS density discarding those areas which are affected by layovering and shadowing and which locally present suitable land use cover types to a traditional DINSAR technique. The main idea it's to process Aster DEM tiles for the whole Austria together with CORINE 2000 land use cover data in order to better choose the right orbit geometry for SAR. In order to determine the most suitable areas where to apply the DINSAR as a tool for well mapped landslides in Austria the PSI predictability model (fig.1) and a selection of slow mass movement’s extracted from the GEORIOS cadastre were joined in a GIS project.

3.2 Estimation of detectable GEORIOS mass movements with the DINSAR method

Since the DINSAR technique is able to detect only slow

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mass movements ranging from 1 mm up to about 100 cm per year, from the GEORIOS database only 4 group of phenomena were chosen. The first group of deep seated landslides is composed by features catalogued as sagging and valley closure, whereas the second group concerns creeping mass movements. Because the goal it's to evaluate which feature cover an area of at least 10 hectares [3] and at the same time shows a probability to detect PS > of 50% among the two groups, the raster value of PSI predictability model was assigned to the centroid of the polygons. A further in-house dataset of information the "mass movement web application" [4] was used to enlarge the spectrum of possible landslide to be detected by DINSAR. Following some research on the field of interferometry [5] it's been evaluated that predictive movements connected to rock fall detachment, together with complex, rotational, translational landslides could be partially suitable for the DINSAR technique. In this case we could also be interested in investigate a third type of mass movements ranging between rock spreading, debris slides, block slide, scree, toppling, and complex landslides. All of them could be considered as probably detected by the DINSAR technique. The last group, even though connected to very fast mass movements, could be useful in case of predictive detachment rock mass movement detection. The group considered in GEORIS this time are rock falls. A geographical representation of the total amount of data related to the 4 classes of landslides (with GEORIOS features represented as polygons and GBA web application features represented as points) is shown on fig. 2.

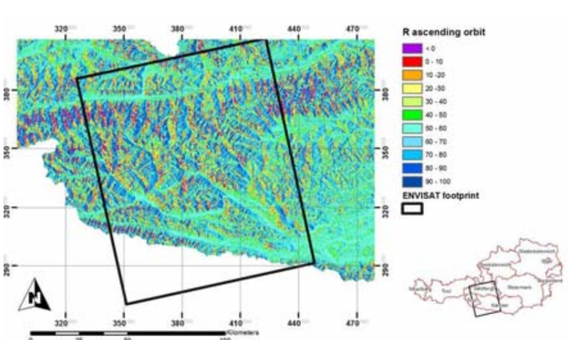

Figure 1. PSI predictability model for Austria.

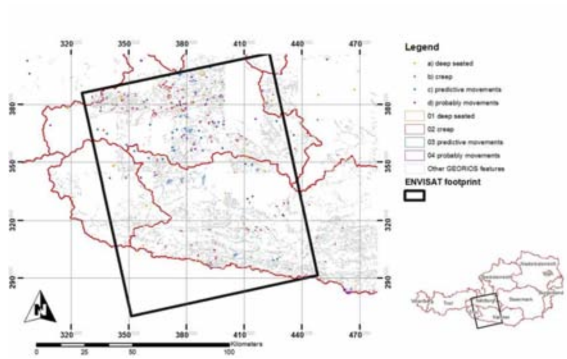

Figure 2. Representation of 4 landslide classes on the study area.

3.3 Search for areas recently (1992-2010) interested by meteorological driven catastrophes in Austria

The reviewing of major catastrophes occurred in Austria in 20 years (1992-2010) was made possible by using a published ZAMG calendar [6] and through the Zamg web site [7]. Another analysis performed was aimed at verify, on 30 year normal monthly rain precipitation calculation (1971-2000) for three weather stations located in the study areas, whose of them registered the most intense variation from the expected normal precipitation (tab. 1). By coupling information from landslide cadastre and areas interested by heavy rain, flood events or other meteorological disasters it's possible to identify the most suitable ascending SAR data to be selected from the ESA archive. At this stage it's very important to process data which correspond in time and space to a major catastrophe occurred. Concerning deep seated and creep mass movement the most representative area are the one shown on the footprint of ENVISAT in fig. 2 and correspond to the Hermagor 29-10-2004 catastrophe and to the Kötschach-Mauthen one occurred in 26.11.2002.

Particularly intense was the rain event which affected between the 29th and the 31st of October 2004 the Lesachtal, the Gail Valley, the Upper Drau Valley, the Rose Valley and the areas around the Wörthersee. Meadows, fields and basements were flooded. At the wheater station of Reisach during the last three days of October registered a total of 167 litres/m^2, this is about the average monthly rainfall [8].

Table 1. Percentage of normal precipitation value for November 2002 and October 2004 for 3 selected weather stations.

		Nov.02	Oct.04
loc.1	Badgastein	247%	193%
loc.2	Flattach	412%	206%
loc.3	Döllach	391%	118%

3.4 Selection of the SAR images to be processed

A series of weather information from the e-HYD [9] web site and snow data from the HYSTALP [10] project allows for the discrimination of the probability to find snow free areas in specific months of the year. By combining the information on the ESRI snow Austria which represent the number of days without snow and the probability in % to have free snow in August, September and October from the elaboration of HYSTALP data we can forecast in Tyrol, Voralberg, Salzburg and Carinthia (regions with very high relief) where the radar signal could be not affected by snow at the moment of choosing the master and slave images to be processed. This step represents the snow verification stage. The following step concerns the rain verification; in fact the humidity is a factor which introduces a high atmospheric noise on the radar signal. It's important, having more than 1000 local weather rain stations, to acquire an image where, on an interval of three days (the same day, the day before and the day after), there are a very low precipitation rate (less than 6mm per day) [11]. A schema showing the methodology for the choice of the images is depicted in fig. 3.

3.5 SAR processing with the NEST software

NEST-4C is a new open source software (running in Windows and LINUX) which allows competent users to read a very wide range of SAR product (ERS, ENVI, ALOS, CosmoSkyMed and the new Sentinel-1), with a fully integrated InSAR processor for the coregistration, orbit injection, calibration, filtering, interferogram and coherence formation for RAW and 1 level SLC SAR products. NEST was essentially derived from Delft Object-oriented Radar Interferometric Software (DORIS). A very good tool implemented on NEST is the graph builder. Then with the SNAPHU software it was possible to unwrap the phase and obtain from the interferogram displacement maps.

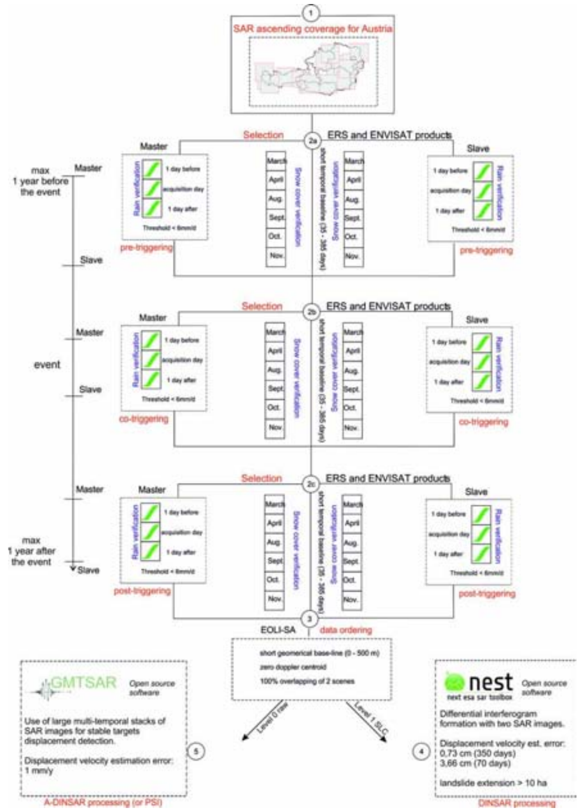

Figure 3. SAR image choice methodology.

4 GEOGRAPHICAL AND GEO-TECTONICAL SETTING

The 3 study areas are located within the eastern Tauern Window. The Tauern Window of the Eastern Alps (fig. 4) exposes Penninic and Subpenninic nappes that accreted with units of the distal european continental margin, represented by the Austroalpine nappes [12].
Penninic units comprehend European continental and Mesozoic oceanic nappes once belonging to the subducting lower plate Adria vergent. The tectonic evolution of the tauern window involves 5 deformative stages:
1) The subduction of the Piemont-Liguria Ocean and accretion of oceanic relics in front of the Austroalpine nappe stack;
2) The Subduction of the Valais Ocean and the most distal parts of the European margin;
3) Exhumation of the high-pressure units and incipient accretion of the European crust;
4) Formation of the Venediger Duplex and Tauern ''Kristallisation'';
5) Late Alpine indentation, crustal scale folding, orogen-parallel extension and lateral extrusion.
The present-day structure of the Tauern Window is characterized primarily by a crustal scale Late Alpine

duplex, the Venediger Duplex, which formed during the Oligocene. This duplex was severely overprinted by doming and lateral extrusion, most probably triggered by the indentation of the Southalpine Units east of the Giudicarie Belt [13].

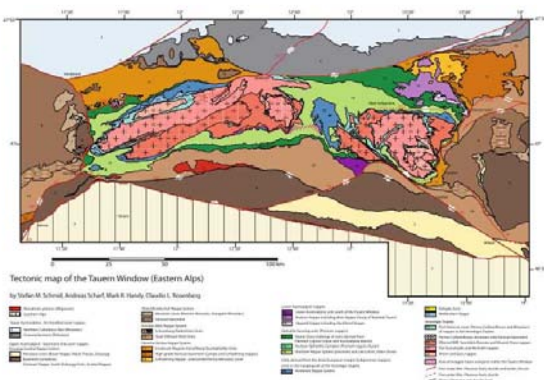

Figure 4. The geo-tectonical map of the Tauern window.

5 RESULTS

The area of investigation (100 per 100 km wide) covers part of Salzburg, most of the Carinthia region and a part of East Tyrol in Austria. The area was chosen since it's a site where it's possible to reach a good compromise between good slope aspect favourable land use and a conspicuous number of mass movements stored in GEORIOS and in the web application. Only three pairs made of 5 ascending ENVISAT image on track 358 were chosen for the interferometry processing (tab. 2).
In fact the majority of other interferograms shows large portions with signal decorrelation. Then the focus of our study was addressed to search subset areas with good coherence for the pre and post triggering time frame. The Badgestein area with medium to low relief, Maltatal with medium to high relief.and Mölltal with high mountain relief were chosen for the good overall coherence. The restrained dataset of Badgastein, Maltatal and Mölltal for the pre-triggering event 01-08-2003/16-07-2004 (masked with a coherence threshold of 0,5) are shown in fig. 5, 6 and 7.

Table 2. Summary of the processed DINSAR pairs.

subset pairs	temporal baseline	perpendicular baseline
01-08-03 / 16-07-04	350	32 m
20-08-04 / 05-08-05	350	190 m
27-05-05 / 05-08-05	70	416 m

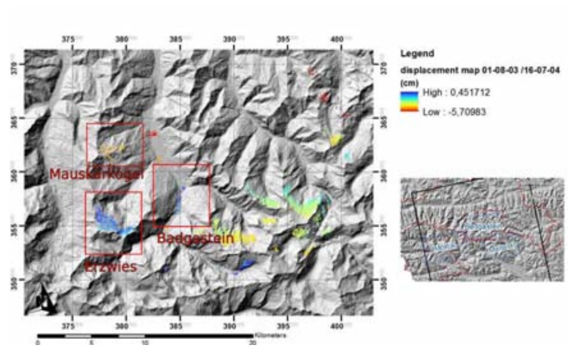

Figure 5. Displacement map for Badgastein (Aug. 2003 -July 2004) with case study extent.

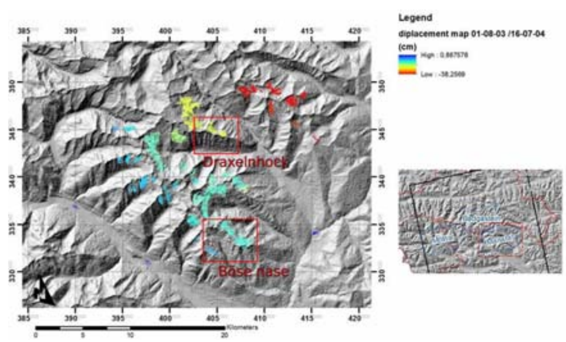

Figure 6. Displacement map for Maltatal (Aug. 2003 -July 2004) with case study extent.

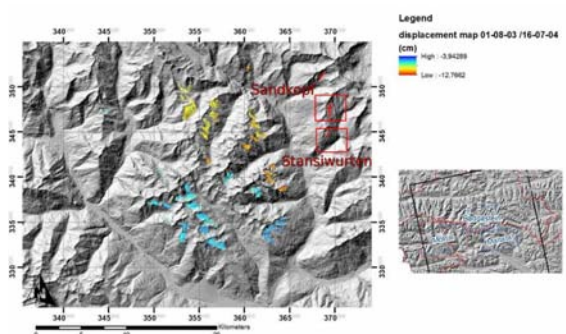

Figure 7. Displacement map for Mölltal (Aug. 2003 -July 2004) with case study extent.

The Badgastein subset has been assessed with a second co-triggering pairs (20-08-04/05-08-05), the same occurs with Maltatal (fig. 6) but with another post-triggering pairs (27-05-05/05-08-05). On the other hand for Mölltal (fig. 7) due to decorrelation and bad weather on the day of acquisition a post event showcase could not be provided.

6 CASE STUDY

The first case study is on the west slope of the village Hofgastein where a feature mapped as rock landslide was correctly identified before the rain event in october 2004 with rate up to -3.5 cm/y in Mauskarkogel and -3 cm/y in Hirchkarspitze (fig. 8) and after the rain event showing an aggravation of the vertical displacements (fig. 9). This mass movement is involving lithologies belonging to the glockner nappe series, where (see fig. 9 as a reference), clac micaschists to calc-marble (in blue) and prasinites (in green) are underlined by a layer of phillites (in pink). It has been proposed a mechanism [14] which consists on the activation of a sliding surface 125/35 oriented at the contact between phillites overlying more competent but factured rocks. The latter have 2 majors conjugate joint systems NW-SE and SE-NW. The activation was a consequence of the degradation of the valley flank started in interglacial time following the retrietment of the Gasteiner glacier which locally modelled the versant up to 1600 m. The first scarp was located at the steepest part of the slope whereas a secondary series of mass movements were generated by the dissection of the main competent layer.

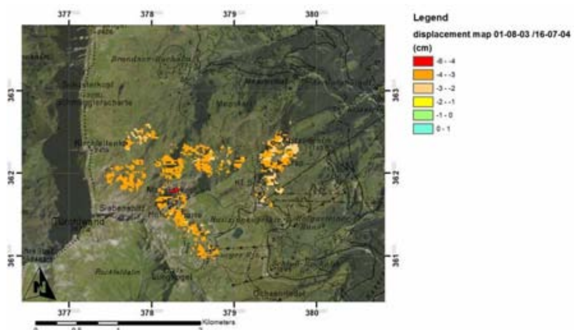

Figure 8. Mauskarkogel study case (Aug. 03 – July 04).

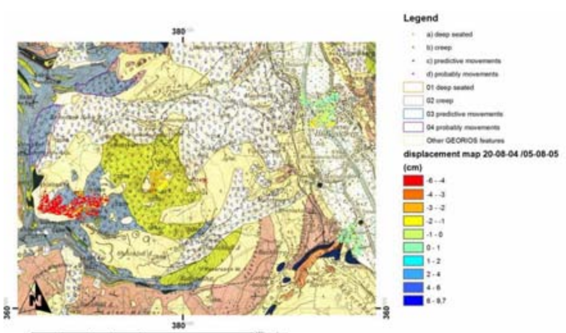

Figure 9. Mauskarkogel study case (Aug. 04 – Aug. 05).

The second case study is a well documented [15] example of subsidence in the town of Badgastein. The comparison of some geodetic measurements (taken between 1932 and 1973) and the result of the pre-triggering displacement map (fig. 10) shows a fair good agreement even though we have to admit that being the accuracy of the measurement of ±0.73 those observations must be taken with care. Furthermore the comparison with a post-triggering pairs could not be exploited since the valley floor weather station registered an amount of rain above the threshold stated as a limit for atmosphere interference.

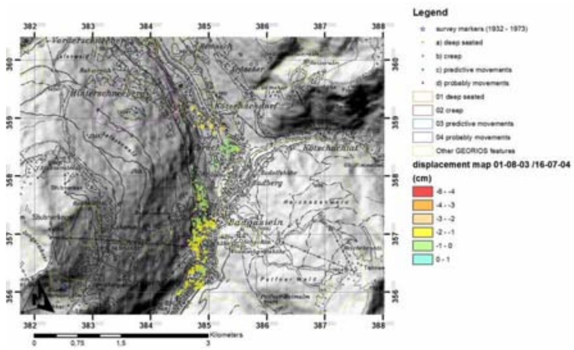

Figure 10. Badgastein study case (Aug. 03 – July 04).

The third study case is about the karsic area of Erzwies “ore meadow” on the west flank of Badgastein.

Here the predominant lithology is marble overlaid to gneiss but more interesting quarzitic schists are folded into marbles generating typical karts morpholgy. The most intense series of joints are NNE-SSW oriented and are the main “tauern gold” ore bearing. On the other hand a secondary E-W younger series of lineation interest the upper part of the slope. It's here following a recent work carried out in August 2004 [16] that 4 sink holes were mapped. By looking at the pre (fig. 11) and post triggering (fig. 12) displacement map we can clearly see that most probably on the 2004-2005 acqusition a more intensive karst activity resulted in the north-westermost part of the image (fig. 12).

The second subsetted area represents the upper Malta valley and here the 2 studied areas are: Böse nase and Draxelnock. The Böse nase is a glacial cirque at 2500 m where at least 3 classified intact rock glacier showed their activity (fig. 13) and (fig. 14). Although rockglaciers itself are not representing a tretening for people their existence and activity could be a sign of permafrost degradation (when present) which could trigger debris flows between an altitude of 2250 and 2750 m [17]. A further 2 scarps of mapped gravitative mass movement were detected in movement only in the pre-triggering pairs showing a motion of -10 cm/y.

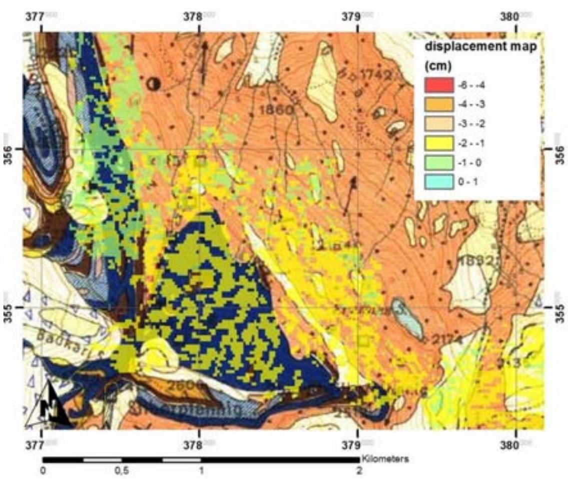

Figure 11. Erzwies case study (Aug 03 – July).

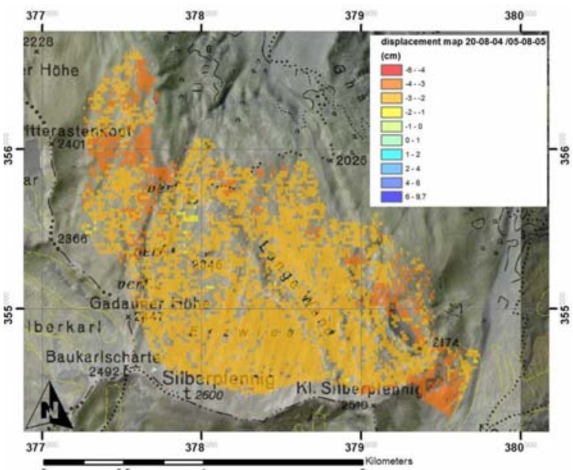

Figure 12. Erzwies case study (Aug 04 – Aug 05).

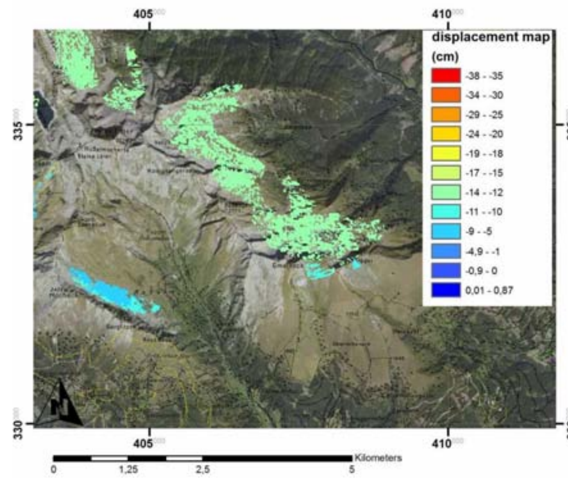

Figure 13. Böse nase case study (Aug 03- July 04).

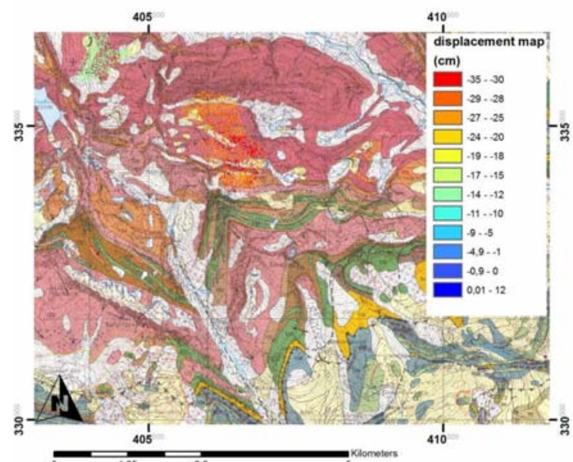

Figure 14. Böse nase case study (May 05- Aug. 05).

In the Dreaxelnock zone instead in both time frame the movement of two mass movement (fig. 15 and fig. 16) (classified as rock falls) already mapped [18] and reported in the GEORIOS could clearly be observed although the smaller ones on the geological map showed different areal extension.

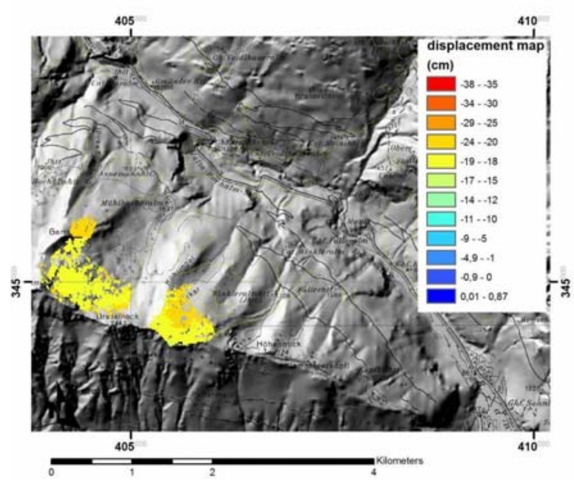

Figure 15. Draxelnock case study (Aug 03 – July 04).

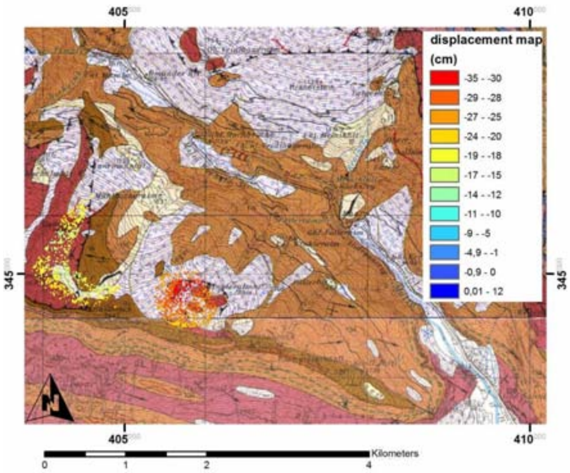

Figure 16. Draxelnock study case (May 05 – Aug.05).

The Mölltal area is characterised by post varisican cover of nappes in the venediger duplex, by the subpenninic nappe derived from the distal european margin by the penninic ophiolite nappes and by part of the lower austroalpine unit [19].

The anomaly -11.5 showed in Stansiwurten can be associated to the beside "predictive movement" (fig. 17) stored in GEORIOS as rock fall and could represent a previous stage of rock fall detachment probably connected to a deep seated rock mass movement.

In Sandkopft instead (fig.18) the movement detected could be associated to the fissured bedrock visible on the aerial laser scan DEM (1m pixel resolution).

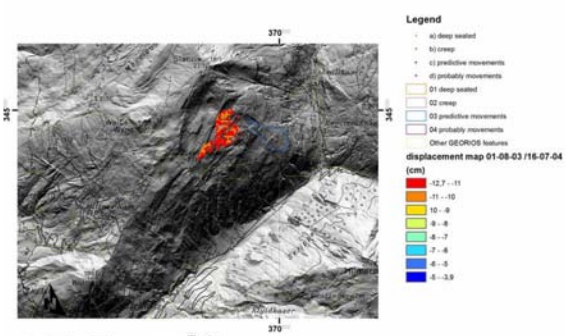

Figure 17. Stansiwurten study case (Aug 03 – July 04).

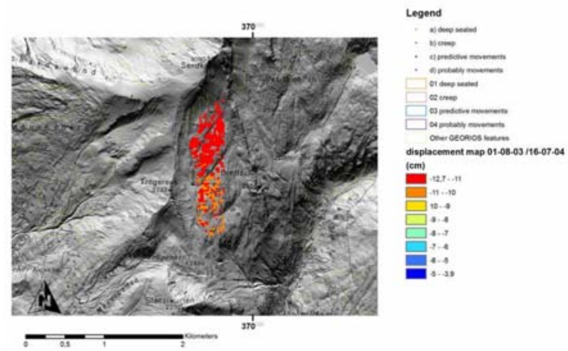

Figure 18. Sandkopf study case (Aug 03 – july 04).

7 DISCUSSIONS AND CONCLUSIONS

The pre-triggering and post triggering method for DINSAR, which performs well especially in medium to high relief topography with right land cover for SAR and with images pairs characterised by perpendicular baseline < 200 m, has been tested. Some mass movements, rock-glacier, karts and subsidence activity already known by experts or stored in GEORIOS cadastre were correctly identified and in some case a new definition of the mapped boundary, supported by a new field investigation should be required. Some new landslides, which in some cases manifested similar mechanisms of movement of surrounding previously mapped features, were identified. Considering the learning curve of software like NEST and the use of such cost effective method for landslide recognition with DINSAR some drawbacks have to be clarified. First of all a co-triggering acquisition sometimes, especially for fast mass movements, can lead to a total decorrelation of the interferogram if the two dates of acquisition are too close to the day of the event. In valley floor (e.g. villages with very good coherence) the displacement velocity estimation error is still too high (±0,73 cm) for a correct interpretation of the final unwrapped interferogram. It's highly recommended adopting a PSI or A-DINSAR approach instead. A lesson learned it's to take in consideration, every time a similar approach is attempted and once the area of interest it's found, the acquisition of images with the same orbit but different track in order to improve the probability to find better images with suitable dates.

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