MODELS TO PREDICT PERSISTENT SCATTERERS DATA DISTRIBUTION AND THEIR CAPACITY TO REGISTER MOVEMENT ALONG THE SLOPE

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ABSTRACT

Two models were developed to improve the use of persistent scatterers (PS) techniques in the landslides studies.
The first model, called "CR-Index", allows to forecast the potential PS distribution calculating the effect of topography and of the land use. The second model, called "V slope Coefficient", has the aim to calculate the percentage of the movement detected along Vlos supposing to have a slide parallel to the maximum slope line.

Key word: CR-Index, Persitent Scatterer SqueeSAR, Landslide

1. INTRODUCTION

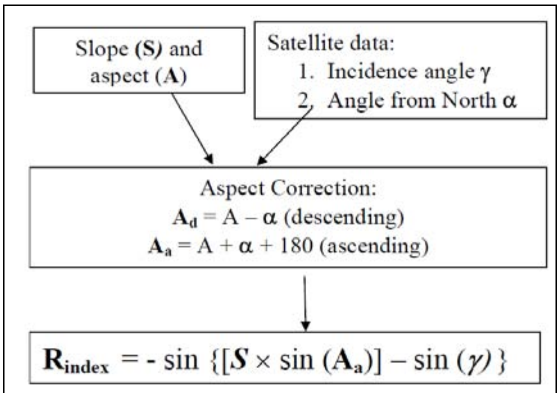
In the last years the use of persistent scatterer (PS) SAR data in the studies of some geological processes like subsidence [1], landslides [2] and tectonics [3] has shown a rapid growth.
The general PS limitations are well known in literature [4] [5]. These limitations are related to methodology of SAR image processing, to the characteristics of space born sensors (geometry of acquisitions, used wave length, revisiting time...) as well as topography and the land use.
In this work we present two models that in a simple way forecast two of those limits: the PS distribution and the percentage of movement along a slope detectable by SAR sensor.
The models were tested comparing the results with real PS distribution in different geological context.
The aim of these models is to calculate a priori map of PS distribution that may be useful to plan or not SAR survey for mapping or monitoring a process over a certain area.

2. THE CR-INDEX MODEL

The topography has strong influences on PS distribution, affecting the images with layover, foreshortening and shadowing effects. Therefore, it would be interesting to know in advance if interferometry is convenient or not and what kind of solution (geometries of acquisitions, type of processing) will be better to choose.
The "CR-index" model gives a probabilistic value to have a PS over certain area This model was created for a small sample area (30 km^2) in the Pyrenees with TerraSAR-X data [6]. In this study the CR-Index model was tested and improved in North-West Italy using C-band data Radarsat and ERS sensors.

2.1 The R-Index

The "CR-index" is composed by two components, the first is the "R-Index" that takes into account the topographic effect on SAR images [6].
The "R-Index" (Fig. 1) is a combination of slope and aspect parameters derived from DEM and LOS parameters of satellites (incidence angle and azimuth). The calculation is made with an easy map algebra operation into a GIS software.



R_{index} * 100	PS expected
<= 0	layover or shadowing effects (NO PS)
0 – 20	strong pixel compression (few PS)
20 – 30	medium – low (few PS)
30 – 50	medium slope
50- 75	good slope
> 75	Very good slope

Figure 1: "R-Index" flow chart

The "R index" is also a ratio between the size of a pixel in Ground Range and a pixel in Slant Range view.
The final result is an index that changes from negative values to 1 (or 100 if we use % stile). The negative values indicate the areas affected by layover and foreshortening effects, small values (<0.4 or 40%) indicate a strong pixel compression that limits the presence of PS. The value 1 (or 100%) indicates a slope that is parallel to the LOS. In general when the value of "R-Index" is grater than 0.4 the slope is good oriented and the main factor that influences the PS distribution is the land use.
The shadowing effects may be calculated with a shade relief model but they are very limited because they

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affect very steep slopes (over 56° with Radarsat and over 67° with ERS) that are small areas also in the Alpine sectors.
The results of “R-Index” calculation over the test site area can be seen in Fig. 3
The figure 4 shows the “R-Index” calculated for two slopes with opposite orientation in the test area of Piedmont Alps. The “R-Index” was calculated using Radarsat descending LOS parameters. The slopes are in the same conditions of land use (both are covered by debris).
In the western slope the good orientation allow to obtain a high “R-Index”; a pixel (AT) in Ground Range resolution (GR) has the same size of a pixel (A’T’) in Slant Range (SR) resolution and we can find a good PS density. The eastern slope is affected by layover effect a pixel in Slant Range is very compressed and reversed. Here no PS has been detected.
If we compare the “R-Index” for different LOS inclination it is easy to observe that the topographic effects are higher using a satellite with small incidence angle (i.a). For instance the figure 2 shows the area affected by layover-foreshortening effects (R-Index < 0) near Rosone Village (Piemonte). Considering the descending geometry the RADARSAT satellite with an incident angle of 34° (left image) shows a smaller area affected by topographic effects than ERS (23° i.a.).

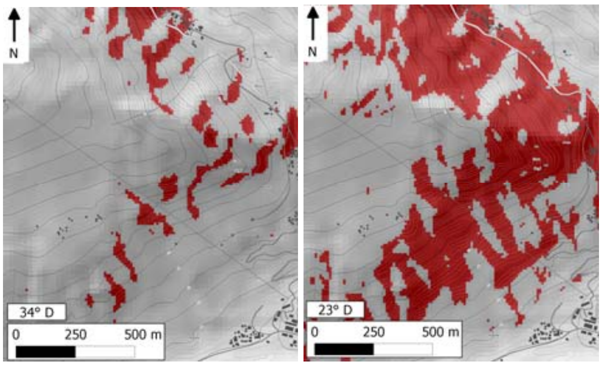

Figure 2: The comparison of area affected by layover-foreshortening effects (red) using Radarsat (34 ° i.a) and ERS (23° i.a) satellites

The use of two geometries of acquisitions (ascending and descending) allows to solve topographic effect problems and the majority of slopes are visible.
To test the efficiency of “R-Index” we compared the value of “R-Index” with the density of PS in different geomorphological sectors (NW Alps, Ligurian Alps, Apennines and Turin Hills) and with different LOS incidence angle (34° and 23°) (Fig. 5).
The distribution of PS density shows for all sectors a similar trends: very low PS density when the “R-Index” is < 0; the maximum PS density when the value of “R-Index” is between 40 and 80 and then for R-index > 80 the density decreases. This distribution confirms that over value 40 the main factor of PS distribution is landuse and the slope orientation has little influence. The flat areas or gentle slope areas, where the majority of buildings (good scatterers) have been set up, have an “R-Index” of 40 - 50. In the Alps the presence of debris on steep slope allows to have the peak of density at an higher “R-Index” value.

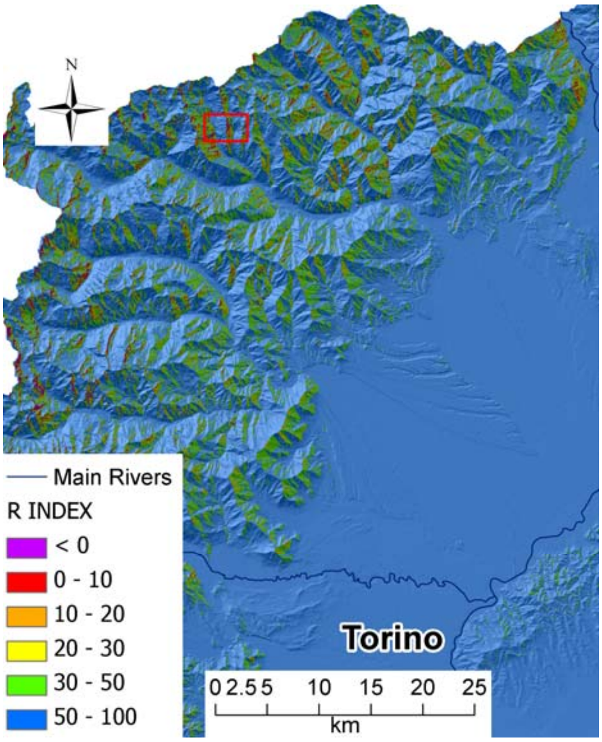

Figure 3: R Index in the NW sector of Piemonte. The red box is the area represented in the figure 4.

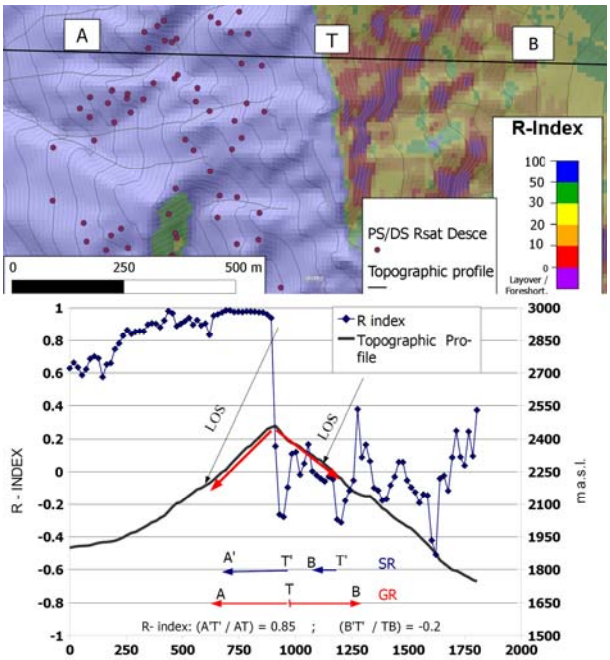

Figure 4: Cross section of R index values in a sample area in Piedmont Alps compared with RADARSAT descending datasets

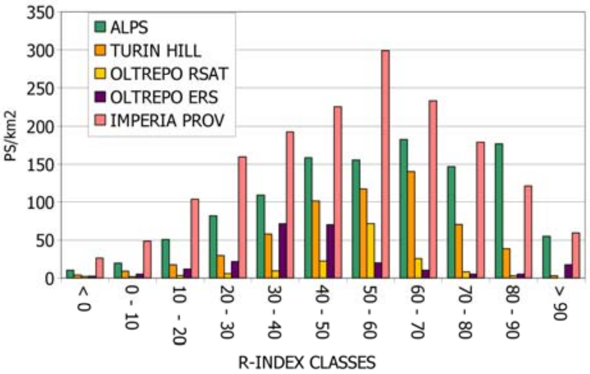

Figure 5: PS density for “R-Index” classes

2.2 LU-Index

The second parameter of the “CR-Index” model is the land use “LU-index”. By developing the model proposed by [8] to each class of land use is assigned a probabilistic value to have PS based on the experience and back analysis. For instance, buildings have a high probability to have PS (100), forest areas or lake have a probability close to 0 to contain potential scatterers. We tested also the difference in PS and DS (distributed scatterer) detection using the new SqueeSAR™ processing [9].

The quality of landuse in term of class definition and spatial resolution is very important to determine the “LU-index” reliability. It is also very important that the main source of scatterers (buildings, road and railways network, debris covered areas) are well identified on land use map.

The figure 6 shows the “LU-Index” for NW sector of Piedmont. It is possible to distinguish they high value assigned to urbanised areas (Torino city) and to the area covered by debris in the Alps.

The recent SqueeSAR™ technique allow to detect a good density of distributed scatterer also on sparse vegetated areas like alpine grassland (Tab. 1) or river bed due to the fact that, in these areas, there are a wide dispersion of single rock blocks or man-made elements such as barracks, crossroads and bridges. The value of “LU-index” is more difficult to calculate for this type of landuse because polygons that identify the classes of landuse do not take account of targets contained.

Table 1: PS and DS density for different land use. (Radarsat data, Piemonte region)

Landuse type	PS	DS	(PS+DS)/km^2	PS/km^2	DS/km^2
Buildings area	33%	67%	496	164	332
Grassland (Alps)	6%	94%	159	10	149
Debris areas	9%	91%	159	14	145
Bush lands	8%	92%	76	6	70
Pasture	26%	74%	65	17	48
Cultivated field	26%	74%	52	14	39
Grassland (Po Plain)	30%	70%	36	11	25
Forest areas	9%	91%	27	2	24

For instance, the figure 7 shows the density of PS/DS for each class of LU index: the unexpected presence of many DS in the river bed marked in land use as “water” (LU values = 0 - 10) is the cause of the incongruence. At the same time the areas covered by debris (LU-index = 90) present a density of data lesser than expected, this is due partly to topographic effects on steep slopes and partly to the presence of vegetation.

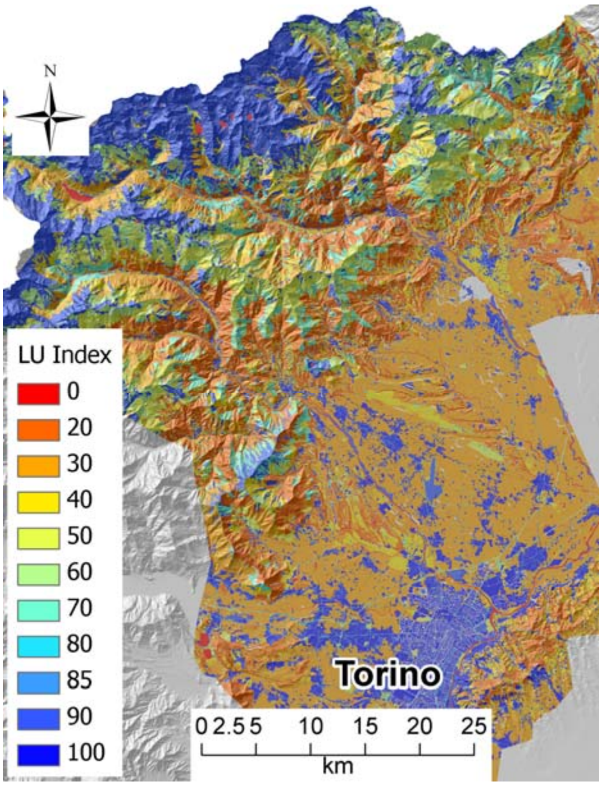

Figure 6: LU index in the NW Piemonte

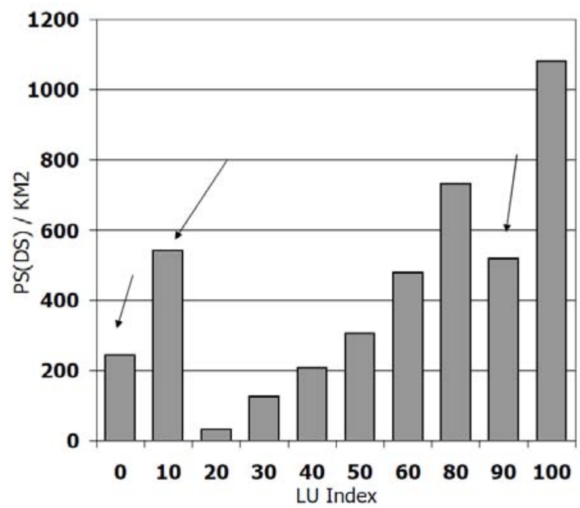

Figure 7 Landuse Index compared with PS/DS density in Imperia Province

2.3 CR-Index

A further step is the combination of LU and R indexes to obtain "CR-index". The methodology was revised from the original model. The model that we propose it is a weighted average of LU and R index based on the R index value. As seen in the previous step the influence of R index on PS density is strong for value under 0.3 (30 %) for value over 0.5 the land use is the main factor that has influence on PS distribution. Moreover, it is to consider that when the probability to have PS is 0 for one of the two parameters also the "CR-Index" is 0. The last version of the formula is reported in the expression 1.

When in an area both ascending and descending geometry are used, the limitations due to the topographic effects are negligible and it is possible to consider only the "CR-Index".

$$CR_i = (R_i + LU_i * \text{LU weight}) / (1 + \text{LU weight}) * (\text{"0" area}) \quad [1]$$

An example of "CR-Index" calculated in NW Piemonte is represented in the figure 8.

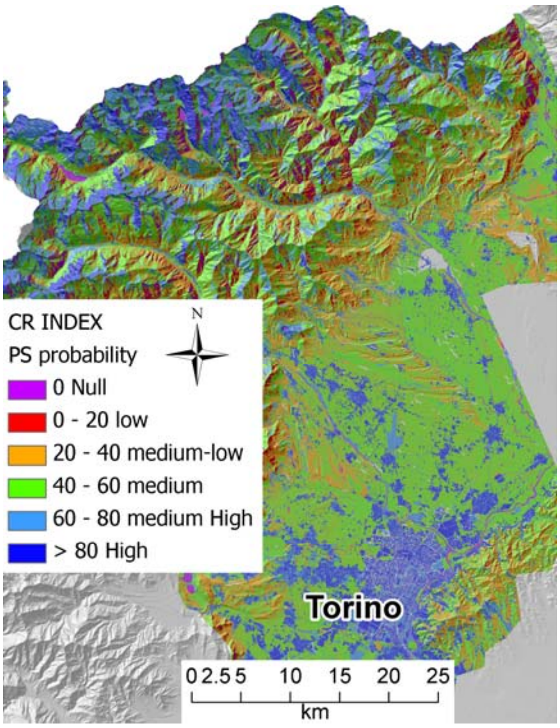

Figure 8: "CR-index" in NW Piemonte for descending datasets

"CR-index" is a probabilistic index and has the aim to help in selecting and programming a PS monitoring survey. The comparison of landslide inventories with "CR-Index" allows to know in advance how many landslides are suitable for PS study or if the use of more than one datasets improve the number of detectable landslides detectable. For instance in figure 9 the percentage of landslides with almost 1 PS is compared with maximum values of "R-Index" inside the landslides the study area of NW Piemonte. The data presents a good matching, it seems that only the landslides with a CR index greater than 60 have quite good possibility (> 40 %) to have PS data. The percentage of landslides with at least 1 PS rises to 70 % with CR > 80. In the study area the landslides with CR index greater than 80 are 25% of whole IFFI inventory.

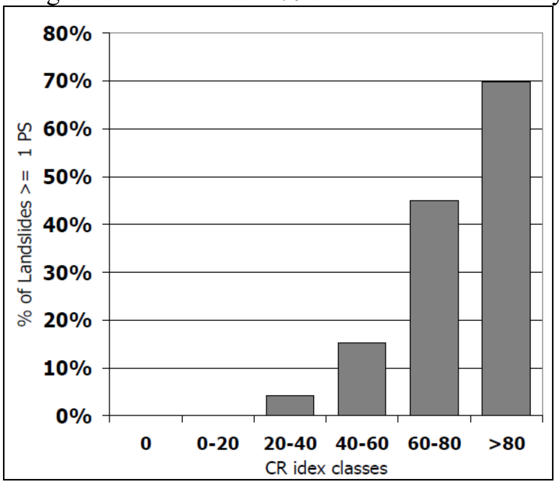

Figure 9: Percentage of landslides with at least 1 PS and the maximum CR index inside the landslide inventory.

3. A MODEL TO EVALUATE THE PERCENTAGE OF REAL DETECTABLE MOVEMENT.

The SAR sensor registers the movement along the line of sight (LOS) of satellite: a movement parallel to the LOS is fully registered. A movement orthogonal cannot be registered, a percentage a movement can be detected on the other directions.

This problem affects the correct registration of some displacement especially for the processes that have a strong horizontal component like the landslides.

For some types of landslides the problem can be partly solved by projecting the velocity assuming that the movement is along the line of maximum slope.

The velocity projected along the slope (V_{SLOPE}) is the ratio between the V_{LOS} and a coefficient (C) that represents the percentage of movement detected along the slope. The coefficient "C" can be calculated with the geometry of LOS and with a slope and aspect models derived from a DEM with the expressions reported in the box below.

H = SEN (α)
N = COS (90 - α) * COS (n)
E = COS (90 - α) * COS (e)

C = [COS(s) * SEN(a - 90) * N] +
{ [-1 * COS(s) * COS(a - 90)] * E } + [COS (S) * H]

Where :
α = LOS Incident Angle
n = Angle of LOS with North
e = Angle of LOS with East
s = slope
a = aspect

$V_{SLOPE} = V_{LOS} / C$

The figure 10 represents the variation of "C" vs the aspect for a slope with 20°, for ERS and RADARSAT of both geometries of acquisition. The negative values represent the slopes where the direction of movement is reversed in LOS geometries. From the chart it is also possible to note that the use of a satellite with an higher incidence angle (Radarsat 34°) allows a better detection of the movement than a satellite with small angle (ERS 23°). Note that for a Southern slope only the 20 % of movement is detected for each type of geometry or sensor.

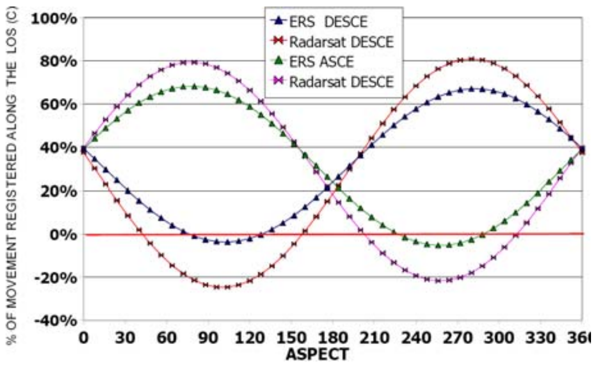

Figure 10: The percentage of detected movement (c)) vs. the aspect for a slope of 20 °

The "C coefficient" may be also represented as a raster map. The map allows to rapidly check if over a certain slope the movement registered along the LOS is near to real or not, supposing that the movement is along the maximum slope direction.

The figures 11 and 12 show a cross section over a hill near Carmine village in Oltrepo Pavese (NW Apennines). The area presents gentle slope towards East and West. The "C coefficient" for ascending and descending geometries shows two specular trends.

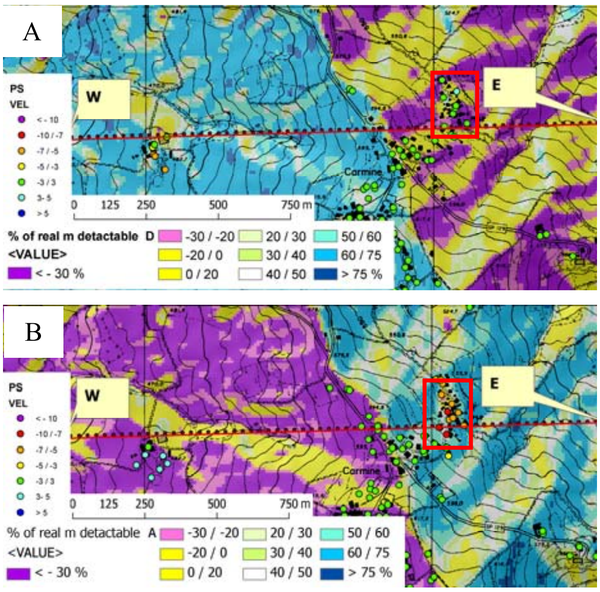

Figure 11: The percentage of detected movement, the "C " coefficient, for ascending (A) and descending (B) geometries of Radarsat sensor, over Western and Eastern slope of a Hills of NW Apennines (Oltrepò Pavese).

A landside movement on Eastern slope (the red box in fig 11) is registered for a 65 % on LOS ascending geometry, and on -20 % (reversed direction) by descending geometries.

The V_{SLOPE} values of Radarsat sensor are in agreement with the model. Using the V_{LOS} values of -6 mm/yr for ascending geometries and of + 1.6 mm/yr in descending, the projection of these values along the slope give similar results for both geometries (8 / 9 mm/yr).

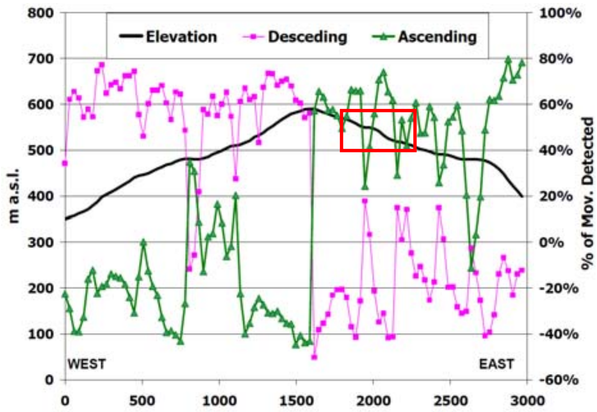

Figure 12: The percentage of movement detected for ascending and descending geometries of Radarsat sensor along a cross section of the hill shown in figure 11. In the red box the area affected by landslide

Table 2: Vlos and Vslope values for the area affected by landslides

Area	V_{LOS} mm/yr		C		V_{SLOPE} mm/yr	
	Asce	Desce	Asce	Desce	Asce	Desce
Carmine East Slope	**-6.2**	**1.6**	0.65	-0.2	**-9.54**	**-8.00**

The map of "C" coefficient has the aim to give a rapid look about a possible underestimated measures and it is also a way to evaluate how and where operate the Vlos > Vslope transformation.

The evaluation of the underestimated measures is important especially in the determination of landslides activity or in the "anomalous areas" creation [5].

The "C" coefficient also shows and explains some incongruence between PS measurements and other instruments like GPS or inclinometers that allow the measurements along direction of displacement.

The main limits of the model are the assumption that the movement is parallel to the slope, the resolotion of DEM (aspect and slope models) and errors in PS geocoding.

One of the problems of using slope and aspect derived from a DEM instead of sliding surface, can be seen in figure 11. The topographic profile shows a small variation in the slope orientation like a small scarps or counterslope. These irregularities do not change the direction of real movement but they can change the values of "C" coefficient and the value of Vslope can be wrong. If we have data from other monitoring system (like GPS) or we know the orientation and

shape of sliding surface derived from other investigation it is better to use this data to calculate the Vslope.
Another problem of "C" coefficient algorithm is the exaggeration of the multiplication of the velocity when C tends to 0 (if $C \rightarrow 0$; $Vslope \rightarrow$ infinite values) .
These problems show that also the use of Vslope can be affected by errors. This elaboration cannot be used, without other comparison, to determine fixed threshold of velocity in the state of activity classifications.
It is important to remark that the geomorphological evidences are fundamental to validate the models results.

4. CONCLUSIONS

In this work two models were developed: one to forecast PS distribution; the other to evaluate the PS capacity to detect movement along a slope. In order to facilitate the approach to these two models, the writers have also created a tool that allows to automatically calculate, through the use of GIS software, the indexes described above. This user-friendly tool has become very useful in making the PS data more understandable and usable to a wider audience.
The first model the "CR-Index" has shown good results. The comparison with real distribution of PS and the prediction match quite well.
The main problems are related with the estimation of the LU index values for certain classes of land use, to the quality and the resolution of landuse dataset used in the model. Another limit is to find a good combination (the best weighted average) between *R-index* and *LU-index.*
The algorithm used is very simple and can be used and visualized with a simple GIS software. It is also open and can be improved with the experience and adapted on the type of sensor used, type of processing and studied area.
The other model, the "C" coefficient, allows to create a map of the percentage of real movement along a slope that is registered along the line of sight (LOS) of satellite. This is also coefficient that transforms the Vlos into Vslope. The model shows quite good results. It can be also used to compare the PS measurements with other instruments, and to make consideration of the state of activity.
The main limits are represented by the assumption that movement is along the line of maximum slopes.
These two simple tools, in spite of some limitations, can be used to forecast if and how an analysis by means of Persistent Scatterer data to study a processes, especially landslides, over a certain area is useful or not.

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