# Challenges in predicting landslides with space borne SAR technology

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**Abstract**

Landslides are one of the major causes of natural destruction worldwide. Several techniques are adapted throughout the world for landslides studies. Among all, Space borne SAR interferometry is one of the promising technique for identifying mapping and monitoring landslides. Even though there are several advantages there are also few challenges experienced. Addressing the short comings are very important, in order to have a proper knowledge about SAR interferometry and making use of this excellent technique in the right way. In this paper we outline about SAR interferometry technique and also make clear for what kind of applications SAR interferometry is suitable and not suitable. Limitations of SAR interferometry are addressed through examples. We also discuss about few historical landslide events, challenges faced in monitoring, experiences learnt, and methods adapted to overcome, etc.

*Key words:* Landslides, Synthetic Aperture Radar (SAR), Interferometric SAR (InSAR), Permanent Scatterers InSAR

## 1. Introduction:

SAR - Synthetic Aperture Radar is a Radar based technology which requires large size antennas for operation. These large size antennas are not achievable from ground based platforms. SAR systems use airborne or spaceborne platforms wherein the flight path is made use as an alternate for large antenna. This technique gives SAR images the highest accuracy ever than other satellite images. Synthetic Aperture Radar (SAR) forms a single radar image by combining return radar echoes from several radar pulses of the same target. SAR systems are usually mounted on airborne or space borne platforms. Radar waves are very less influenced and attenuated by atmospheric conditions than other electromagnetic waves. The attenuation of radar waves is less than 0.1 decibel per kilometer and is capable of imaging in heavy rainfall and fog conditions.The usual way of predicting landslides from SAR images are generating interferograms from two or more SAR images. Interferogram is basically an image of 'phase difference' between the two SAR images. From the phase difference more information about an object can be obtained than contained in a single SAR image. Technologies available with SAR interferometry are 1) SAR interferometry (InSAR), InSAR technique is the simplest way of generating interferograms from two SAR images.2) Differential SAR interferometry (D-InSAR), SAR images of the same area acquired at different time periods (days to years) can be used to exploit the difference in earths topography. Differential SAR Interferometry is the generation of interferograms from SAR images of the same area acquired at different time periods. From the interferogram, the phase difference between the two images/ two different time periods can be known. The phase difference of the same area at different time periods is due to the surface deformation happened during that time span and hence it is possible to quantify the amount of surface deformation as well.

3) Advanced Differential SAR interferometry (A-DInSAR) A-DInSAR overcomes most of the limitations of D-InSAR and also allows increasing the deformation measurement accuracy from centimeter level to millimeter level. These techniques makes use of a large number of multi temporal stacks of SAR images of the same area, in order to identify stable radar targets on which it is possible to detect ground displacements along the Line Of Sight (LOS) of the satellite path over time. So many algorithms of A-DInSAR technique has been developed by different authors, they are given below:

- Permanent Scatters InSAR (PS-InSAR
- SqueeSAR
- Interferometric Point Target Analysis (IPTA)
- Persistent Sctterers Paris – Differential SAR Interferometry (PSP-DIFSAR)
- Stable Point Network (SPN)
- Stanford Method for Persistent Scatterers (StaMPS)
- Small BAseline Subset (SBAS)
- Coherent Pixel Technique (CPT)

According to Wasowski et al 2007 , all the above A-DInSAR algorithms can be broadly classified into two groups, they are Permanent Scatterers based A-DInSAR technique (PSI technique) and Interferogram stacking technique. Small BAseline Subset algorithm and Coherent Pixel Technique algorithm fall in the latter category, where as other algorithms belong to PSI based A-DInSAR method. In this section we discuss about PS-InSAR algorithm and SqueeSAR algorithm. Among all these method, most advanced is the latest SqueeSAR algorithm developed in 2010.

Apart from landslides triggered due to earthquakes, rainfall, floods and volcanic activity, landslides are also caused due to instability of the slope itself. Several techniques are existing for landslide detection, mapping and monitoring they are Geophysical methods (seismic methods, electromagnetic methods, ground penetrating radar), Geotechnical methods (Extensometers, Piezometers, Inclinometers and Contact earth pressure cells), GPS based methods, Satellite images based methods (aerial images, PAN images, Space borne SAR interferometry ) Ground based SAR interferometry, etc. All the above mentioned techniques have their own advantages and limitations. A combination of two or more of these techniques is in practice usually. Even though Space borne SAR interferometry is a promising technology for predicting landslides, there are few limitations. These limitations are very clear from few failure case studies where space borne SAR technology is adapted for monitoring landslides. These failure case studies give us very valuable information for other researchers adapting this technology. Rest of the paper is organized as follows, firstly we review the advanced technology practiced in the recent years for landslide detection with SAR images, secondly we discuss about how SAR interferometry can be successfully used for landslide case studies. Thirdly we discuss about few critical cases wherein the limitations of SAR interferometry are clearly visible. Finally we present the discussion and conclusions.

## 2. Review of technologies:

In this section we discuss in detail about the two advanced technologies with SAR images.

i. Permanent scatterers InSAR (PS-InSAR):

Permanent Scatterers InSAR technique is a PSI technique an advanced form of D-InSAR algorithm. PS-InSAR algorithm was developed in 1999 and patented by Politecnico di Milano (Polimi). Since then many algorithms based on the same base algorithm were developed, which are mentioned above. Objects such as buildings, fences, lampposts, transmission towers, crash barriers etc which are situated along satellites line of sight reflect back maximum radar microwaves. These objects act as Permanent scatterers (PS). Detailed explanation of PS-InSAR technique can be found in Ferretti et al., 2000a, 2001a; and Colesanti et al.,2003b. The basic concept of all PSI technique is that they develop multiple interferograms from a stack of 15 or more SAR images [9]. The more the number of SAR images available, the more accurate the results of PSI technique (includes PS-InSAR as well). Permanent scatterers show stable amplitude properties and coherent signal phase throughout all SAR images. Hence while generating interferograms permanent scatters pixels are very little affected by geometric decorrelation. Permanent scatterer's reflectivity does not vary over time; hence the temporal decorrelation is negligible for that pixel. Suppose that if N+1 SAR images are available one image is selected as master image and others as slave images and N differential interferograms are generated. Permanent scatterers are identified in these interferograms and atmospheric corrections are performed on these targets. After performing atmospheric corrections, we can detect both linear and nonlinear motion for each target.

*ii. SqueeSAR algorithm:*

Authors of [1] discuss SqueeSAR algorithm, developed in 2010, which is an advance on the PSInSAR algorithm. SqueeSAR algorithm takes into account 'spatially distributed scatters' (DS) along with 'permanent scatters' (PS) used in PSInSAR algorithm. As mentioned before Permanent scatterers (PS) are objects such as buildings, fences, lampposts, transmission towers, crash barriers etc that are excellent reflectors of radar microwaves. On the other hand, few homogeneous areas like rangelands, pastures, bare earth, scree, debris fields etc reflect back minimum radar microwaves. The reflected energy from these homogenous areas is statistically consistent. These areas are called distributed scatterers (DS) which are previously unidentified by the PSInSAR algorithm. SqueeSAR algorithm makes use of DS to process signals reflected from these areas. Since both PS and DS are taken into account SqueeSAR algorithm provides more number of ground points. Time series analysis can be done for each ground point and the standard deviation value for time series is less compared with PSInSAR algorithm. Millimeter level of accuracy can also be achieved for ground displacement values.

### 3. Benchmark achievements with SAR technology:

Many successful case studies are reported using space borne SAR, few popular success stories are Fruneau et al., 1996; Rott et al., 1999; Kimura and Yamaguchi, 2000; Nagler et al., 2002; Berardino et al., 2003; Colesanti et al., 2003a; Colesanti and Wasowski, 2004; Farinaet al., 2004; Hilley et al., 2004; Singhroy and Molch, 2004; Strozzi et al., 2005; Bovenga et al, etc. Few of the success studies with details like location, technology used, limitations etc are discussed below.

Three Georges dam in China is the world's largest dam and is been fed by the Yangtze River. Three Georges Dam and the area surrounding is one of the highest landslide prone areas in the world. Paper [10] discusses about two InSAR techniques (two pass and three pass interferometry) for monitoring landslides showing two examples in China and Greece. Baota landslide in the Three Georges area in China and Prinotopa landslide in Greece are the two study areas. In Baota landslide area nearly 4000 people live on the risk of landslide. Two pass InSAR technique was applied to Baota landslide area. Measured displacements from InSAR technique are 14mm in the middle part of the slide and 3-5mm at the foot of the slope. The authors have compared the InSAR results with the geodetical results and both are in good coincidence with each other. While concerned with Prinotopa landslide in Greece, snow melt, heavy rainfall and earthquakes are the three main triggering factors. Another danger the area encounters is the enlargement of a National Highway which is intersecting the landslide area. Both two pass and three pass InSAR technique was applied to the study area. The InSAR results show that displacement rates for the Prinotopa landslide area is about 14mm in every 3 months. InSAR results were also compared with the observations from GPS and Terrestial network. GPS and terrestrial networks provide a deformation rate of upto 30mm per year which are in good agreement with InSAR results. Authors conclude that in both the study area InSAR results and geodetic results are in good coincidence and InSAR technique is a powerful tool for monitoring earth surface processes, if the observed area fulfills specific requirements including sufficient backscattering, flat slope gradients or very slow changes of vegetation.

One of the main advantages of satellite based remote sensing technique is that, it can be used for monitoring wide and remote areas. Permanent Scatterers technique can also be used for monitoring wide area. For the first time in the year 2003 authors of [2] have applied permanent scatters technique for monitoring slow mass movements in Mountains of Valcamonica, Valtellina and most of their lateral valleys. This is the first experiment using PS technique carried out in a wide mountainous area around 4.900 $km^2$. Both ascending mode and descending mode ERS data sets were used, covering a time span from 1993 to 2000. The results from PS technique have been integrated and compared with landslide inventory map. They were able to identify some previously unknown deformations in villages Sacco and Rasura and a deep seated gravitational slope deformation (DSGSD) affecting the north facing slope of Monte Padrio - Monte Varadega in Valtellina. DSGSD has occurred in an area about 30 $km^2$ and they were able to identify 300 PS within the boundary of DSGSD. PS displacement data showed a good agreement with optical leveling data. The landslide inventory map was updated with the new deformations identified using PS technique. Authors of [2] accomplish that PS proved being a precious and operational tool for ground deformation analysis for wide and scarcely urbanized mountainous areas.

Most of the InSAR experiments are performed using ERS and RadarSAT data. After the launch of TerraSAR satellite in 2007, TerraSAR data is also used for InSAR experiments. The revisit period of TerraSAR-X satellite is 11 days at an altitude of 514 km. Paper [11] discusses about the application of PS-InSAR technology for monitoring deep seated gravitational deformation in Berkley hills. Authors have used TerraSAR descending pass data from May 2009 to August 2010 and evaluated its potentials and limitation. PS-InSAR results for the TerraSAR-X data are compared with PS-InSAR results of the same area using ERS and RadarSAT satellite data. The comparison shows that the PS-InSAR algorithm is able to extract more number of PS from TerraSAR data than from ERS and RadarSAT data. The result obtained from TerraSAR data is also consistent with the southwest motion of landslides as in ERS and RadarSAT data. Also the performance of PSInSAR algorithm increased by a factor of 5 using TerraSAR data.

3D information on displacements can be mapped by using a combination of remote sensing imageries. In Paper [7] a combination of JERS, RadarSAT, SPOT-5 and aerial images are used for observing large landslide on La Reunion Island using D-InSAR technique. The islands rough topography, wet tropical climate and specific geological context create constant slope movements and huge landslides. The Hellbourg landslide has been monitored by GPS for several years and a linear evolution of velocity of the landslide has been found. The average displacement rate of Hellbourg landslide from GPS measurements spanning from 1997 to 2000 is 0.5 m/y. The authors have applied D-InSAR technique using both JERS-1 and RADARSAT images. For D-InSAR analysis 14 RADARSAT images and 6 JERS-1 images were used. Since JERS-1 images were of more use because C-band of RADARSAT images are not suitable for vegetation cover. The D-InSAR results were also correlated with results from optical images. For the study area SPOT 5 image acquired in 2002 and aerial image acquired in 1997 are available. These optical data are used to derive 2D horizontal motions of the landslide for several years. The one dimensional vertical displacement component of the D-InSAR results are combined with 2-D horizontal motions of optical images, thereby obtaining 3D information on displacements.

## 4. Limitations:

In most of the case studies where SAR interferometry is used results from InSAR technique were in good agreement with geodetic results. Sometimes both these results do not agree with each other, but measurements from both the technique will be accurate. Such a problem is a very interesting and one such research problem is discussed in paper [6]. It is about the integration of PS-InSAR data and inclinometer data for the use of landslide monitoring at the local scale. The study area is Carbonile, a small village located in the Northern Appennines, Tuscany, where different slope instability problems are noticed since 1984. Slow moving single landslides are monitored at regional scale using PS-InSAR technique and the results are compared with ground based inclinometer measurements. ERS-1 and ERS-2 descending data is used spanning a time interval from

1992 to 2002. The inclinometer recordings are measured during the period 1992 to 1996. The inclinometer readings showed a displacement of about 3.4 mm/yr and PS-InSAR results showed displacements value of about 9.5 mm/yr. The authors state that the difference between two sets of measurements was ascribed to the different types of movement measured by two techniques. The PS-InSAR readings are only on the superficial layers whereas inclinometer readings cater to deep deformations. Moreover PSInSAR measurements are low sensitive to horizontal movements. This is one drawback of PSInSAR technique. The variation in results obtained from two different techniques and the reason for it will be a valuable piece of information for landslide study groups.

Again another valuable information can be gained from complex 'little smoky' landslide site. Paper [3] is about characterizing complex deep seated retrogressive earth slides in the little Smoky River of Northwestern Alberta using corner reflectors and InSAR technique. Adjacent to study area is Highway 49, which experiences costly maintenance due to slope instability. D-InSAR measurements were done in 2002, and 30 zones of movement were detected on the northeast and southwest valleys. The study area is heavily vegetated and corner reflectors are installed in eighteen areas. Most of the valley walls in the study area are moving to some extent, so the authors accomplish that there was a complication in selecting stable corner reflector. For the northeast side a corner reflector number 13 and for the south east side a bridge was chosen as reference points. Seventeen deformation profiles were generated using these reference points from November 2006 to November 2007. The results obtained through D-InSAR method is compared with slope inclinometer readings in locations of corner reflectors CR7 and CR20. Reflector CR7 is located on the southeast side valley, where rotational retrogressive slide is noticed and deformations have been monitored since 2001. Slope inclinometer SI07-3B installed in this location shows a deformation of about 22.3 mm/year and CR7 shows a deformation rate of about 50mm/year. Authors have two opinions about this difference. First one is that CR7 is located on the lowermost rotational block and is likely moving at a fast rate than the upslope block where inclinometer is placed. Second opinion is that, the line of sight for the satellite is likely more directly in line with the actual deformation vector for the lower rotational block, as the block is moving likely in a rotational manner, the vertical component of the movement would not have been detected by the slope inclinometer. On the northeast side of the valley CR20 is chosen to illustrate deformation. Here the corner reflector CR20 and slope inclinometer SI 07-01 both are located at the head of a large rotational block in the lower portion of the slope. Slope inclinometer shows deformations up to 47mm/year and there is negligible deformation in CR20 readings. Authors say that, the reason for the difference in these readings is likely opposite to that observed in southeast valley. It is expected that the large block on which CR20 is located is moving in a rotational manner, it would be expected that there is a downward vertical component to the movement. If the downward vertical component was significant enough, CR20 would then be moving nearly perpendicular to the line of sight of the satellite and deformations would not be quantified using CR-InSAR. Authors mention that a review of these trends in relation to other reflectors is currently underway. Little smoky landslide site experiences a complex deformation, and there are so many challenges in assessing the deformation rates.

A landslide case study in NW Slovenia was able to identify higher magnitudes of uplift in Alps Mountain. Paper [5] is about characterization and analysis of surface deformations, mass movement and alpine region lifting with PSInSAR technique in NW Slovenia. ERS-1 and ERS-2 descending orbit images, 57 of them from the time period of April 1992 to December 2000 are used for analysis. The number of permanent scatters detected in the area of interest was 16,304 out of which only best 1646 permanent scatters was used for time series displacement estimation. PSInSAR result shows a constant uplift of Alps, and the uplift is of higher magnitude than considered before. The relative uplift of Alps from the reference point town Tolmin is 3.35 mm per year. Four landslide areas Jablenca, Koritnica, Modrej, Ilovica were characterized in this study. Displacement results of all the landslide areas were compared with rainfall and seismic data to assess the cause of displacement. It was found that Jablenca landslide is governed by seismic activity. Koritinca landslide is triggered by rainfall and Ilovica landslide is also caused by rainfall but one or two months after rainfall. The authors say that, the delay may most probably due to the geological setting of the surface, shale with limestone and sandstone. In case of Modrej, landslide may be due to a combination of several factors and not due to seismic activity or rainfall. The authors state that the reasons for the uplift of Alps mountain range are more or less clear. It is due to the consequence of active tectonics and those extreme ones are probably the result of locally limited condition. The subsidence activity of the mountain is due to a combination of tectonic activity and gravitation.

## 5. Conclusion:

In this paper different landslide case studies all over the world have been discussed. Each case study area differs in geography, terrain model, morphology, tectonic activity, etc., Different methods and algorithms existing with space borne SAR technology are also discussed. Space borne SAR technology can be used for monitoring wide mountainous areas and for the first time an area of about 4.900 km2 is monitored for landslides successfully [2]. One common fact noticed is that Space borne SAR technology is primarily used for monitoring slow moving landslides, creeping landslides etc. They are not used for monitoring sudden mass movements. JERS Satellite operating in low frequency L band capable of monitoring vegetation cover also. The launch of new satellites like TERRASAR-X and CosmoSKYMED operating in high frequency X band, are capable of producing high resolution SAR images, which promises the growth of space borne SAR techniques in landslide studies. Low sensitivity to horizontal movements is a limitation of PS-InSAR technique, and this limitation became a challenge for monitoring displacement in Northern Appennines, Tuscany[6]. Other limitations with SAR technology are Low spatial resolution in areas of steep slopes, Low temporal resolution, not suitable for fast movements, Landslide displacements are measured parallel to satellites line of sight. Researchers who are planning to adapt SAR technology should take into account these limitations in order to benefit maximum from this technology. Critical case studies give us valuable information which is an experience of their work. These experiences give us the limitation of SAR technology, methods to overcome, result interpretation from different measuring devices, tolerating factors, etc.

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