Earth Observation for Landslide Assessment

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***Abstract*–This report provides a summary from the larger CEOS Landslide hazard team report, focusing on EO information requirements for landslide assessment.**

I. INTRODUCTION

This paper summarizes the current and potential uses of Earth Observation (EO) data for landslide assessment. The main objective of the CEOS (Committee for Earth Observation Satellites) Landslide Hazard Team is to assess the role of EO data by improving our understanding of the causes of ground failure and suggesting mitigation strategies. Globally, landslides cause approximately 1000 deaths a year with property damage of about US $4 billion [1]. Landslides pose serious threats to settlements, and structures that support transportation, natural resources management and tourism. They cause considerable damage to highways, railways, waterways and pipelines. They commonly occur with other major natural disasters such as earthquakes), volcanic activity, and floods caused by heavy rainfall. In many cases, expanded development and human activities, such as modified slopes and deforestation, can increase the incidence of landslide disasters.

A. EO Information Requirements for Landslide Mitigation

The main contribution of EO data is to provide the morphological, land use, and geological detail to assist in determining how the landslide failed and what caused the failure. Where failure could occur can be addressed in a more regional geographic information system (GIS) analysis as a necessary first step in risk analysis. This is because the factors contributing to slope failure at a specific site are generally complex and difficult to assess with confidence. Landslide risk studies are still not very common. This is mainly due to the fact that it is very difficult to represent landslide hazard in quantitative terms related to probability over large areas. This is because landslides do not have a clear magnitude/frequency relation, as is the case for floods or earthquakes.

Two distinct approaches can be used to determine the characteristics of different landslides from remotely sensed data. The first approach is to determine the number, distribution, type, character, and superposition relations of landslides using available remotely sensed data. The second approach complements the first one by measuring dimensions (length, width, thickness and local slope) along and across the landslides using imagery and topographic profiles (e.g. laser altimeter profiles). Where possible these dimensional data should be compared to any previous studies. With these approaches, it is possible to derive qualitative and quantitative parameters on landslides that are necessary for improved understanding of landslide processes.

Detailed scales (1:5000 or better) are required during the site investigations aimed at providing reliable information for designing engineering control works needed to prevent or repair slope failures [2]. This will be particularly the case in urban or per-urban settings where public safety is the principal issue, or where the socio-economic consequences of potential landslide damage might be severe. Therefore, the scales required during the design of slopes are often larger than 1:2000, and the most commonly used scales may vary from 1:1000 to 1:500. In some cases, even more detailed scales are utilised. This level of detail would imply a sub-meter pixel spatial resolution of remotely sensed data. Therefore, the practical or operational use of the currently available EO data in engineering geology site-specific landslide investigations is considerably limited [3]. The improved resolution of the planned future sensors (3 m or better pixel resolution), however, should provide information sufficiently detailed for assessing the feasibility of slope engineering projects and for defining some preliminary design characteristics. Various methods have been used to produce landslide inventory maps. These maps are produced from the interpretation of stereo aerial photographs, satellite images, ground surveys, and historical occurrences of landslides. The final product gives the spatial distribution of mass movements, represented either at scale or as points. When multi-temporal airborne or satellite image analysis is included the inventory maps show landslide activity.

Detailed slope information is essential for reliable landslide inventory maps. Currently, topographic maps and digital elevation data are used. Slope affects surface drainage and is an important factor in the stability of the land surface. Current research has shown that airborne and satellite InSAR techniques are being used to produce detailed slope information [4],[5],[6]. This allows a more accurate interpretation of slope morphology and regional fracture systems with topographic expressions. However, further research is needed in updating local slope information from suitable InSAR pairs using ERS1& 2 tandem, JERS-1 and RADARSAT-1. The large archive of SRTM data will assist in providing regional slope maps.

There are two aspects of EO data that are important for landslide mitigation. First of all, it has been shown that multi-temporal EO data can be used to determine the changes in landslide distribution, and as such are useful to produce landslide inventory maps. Second, EO data can be used to map factors that are related to the occurrence of landslides, such as lithology, faults, slope, vegetation and land use, and the temporal changes in these factors, which can be used within a GIS in combination with a landslide inventory map for landslide hazard assessment.

B. InSAR

Interferometric synthetic aperture radar (InSAR) can be applied for measuring displacements with very high accuracy and for topographic mapping. Both capabilities are of high relevance for landslide hazard assessment.

For motion mapping by means of InSAR it is necessary to separate the motion-related and the topographic phase contributions. This can be done by differential processing using two interferograms of different time periods calculated from two or three images if the motion was constant in time. If the motion is slow, the topographic phase can be taken directly from an interferogram of a short time span (e.g. the one day time span of the Tandem Phase, when ERS-1 and ERS-2 operated simultaneously).

There are two important constraints for the application of InSAR to slope motion monitoring: (1) InSAR measures only displacements in slant range, the component of the velocity vector in flight direction cannot be measured. (2) InSAR can only map the motion at characteristic temporal and spatial scales [7], related to the spatial resolution of the sensor and the repeat interval of imaging. Typical scales for ERS interferometry application to landslide movements are millimeters to centimeters per month (with 35 day repeat-pass images) down to millimeters to centimeters per year (with approximately annual time spans). Faster landslides could only be studied during special orbital repeat configurations of ERS in previous years [8], such as the Tandem Phase or the 3-day repeat cycle during the Commissioning Phase and the Ice Phase of ERS-1 during a few months of 1992, 1993 and 1994. Future SARs with higher resolution (Radarsat-2) will enable the mapping of smaller slides. With the Permanent Scatterer Technique the movement of small objects (down to about one square meter) can be monitored. A precondition for the generation of an interferogram is coherence, which means that the phase of the reflected wave at the surface remains the same in the two SAR images. The loss of coherence (decorrelation) is the main problem for interferometric analysis over long time spans, as required for mapping of very slow movements. Whereas the signal of densely vegetated areas decorrelates rapidly, the phase of the radar beam reflected from surfaces, which little or no vegetation often remain stable over years. This has been utilized for mapping very slow slope movements in high Alpine terrain [9].

Motion analysis in vegetated areas is only possible if a few stable objects (usually man-made constructions such as houses, roads etc.) are located within these areas. Using long temporal series of interferometric SAR images (typically about 30 or more repeat pass images over several years) objects with stable backscattering phase are determined by statistical analysis. Only some of the man-made objects reveal long-term phase stability. The analysis of the SAR time series with the Permanent Scatterer Technique [10], enables the detection of very small movements of individual objects (e.g. single houses). A certain number density of stable objects (at least about 5 per km2) is needed to enable accurate correction of atmospheric phase contributions. This method has been applied to map subsidence in urban und rural areas in various countries.

The future availability of spaceborne InSAR data for slope motion monitoring is not yet clear. The ERS SAR is a useful system for repeat-pass SAR interferometry because of the high stability of the sensor, good orbit maintenance and the fixed operation mode. The follow-on sensor ASAR on board the ENVISAT, as well as ALOS and RADARSAT will provide many different operation modes, and will reduce the availability of repeat pass interferometric data. On the other hand, the higher spatial resolution of some of these sensors would be of interest for mapping also small slides. The important contributions of InSAR to hazard management and to a range of other environmental monitoring tasks would justify a long-term SAR mission optimized for InSAR applications.

Due to the typical SAR repeat orbits of the order of 25 to 35 days, InSAR is mainly suitable for monitoring very slow movements of slopes and individual objects, and for mapping of subsidence. Thus it is able to fulfil specific information needs for landslide monitoring, complementary to other information sources. The main advantage over conventional techniques is the possibility of very precise displacement measurements over large areas at reasonable costs, thus being an excellent tool for reconnaissance.

II. SUMMARY

The challenge is to recognize and interpret the detailed geomorphic characteristics of large and small landslides, and determine whether or not failure is likely to occur.

- The role of EO data for landslide hazard assessment will increase as more useful techniques are developed.
- The availability of less than 3-meter resolution stereo images from planned SAR and optical systems will increase the geomorphic information on slopes, and therefore produce more reliable landslide inventory and risk maps. Recent results have shown that more use can be made from current high resolution stereo SAR and optical images to facilitate the production of more standardized landslide inventory maps which will assist hazard planning.
- Landslide prediction will remain complex and difficult even with ground techniques.
- GIS and RS techniques will remain a regional analysis tool.
- Detail slope and motion maps produced from InSAR techniques will assist in more accurate slope stabi

studies, and will compliment in-situ measurements. When the conditions are suitable, SAR interferometry is a useful tool for monitoring mass movement and thus is able to contribute to the assessment and mitigation of landslide hazards.

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