Satellite Remote Sensing Data for an Alpine Related Disaster Management GIS

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ABSTRACT

Natural disasters are an age-old problem that occur regularly in alpine regions, posing a major threat to the safety of settlements and transport routes. Within the project "Safety of Alpine Routes – Application of Earth Observation Combined with GIS (Hannibal)", financed by the Ministry of Transport and Innovation, information relevant for disaster management has been extracted from satellite remote sensing and integrated into a newly developed GIS based Decision Support System (DSS). Some of the required map information were inferred from ERS- or from SPOT5- and QUICKBIRD satellites, others were taken from conventional data sources such as maps or Digital Terrain Models.

Keywords

Satellite, DSS, Earth Observation, Interferometry, Change Detection.

INTRODUCTION

Natural disasters are an age-old problem that occur regularly in alpine regions, posing a major threat to the safety of settlements and transport routes as it is impossible to predict exactly when and where a disaster will occur. Not all natural disasters are triggered by local events. Many are caused by developments in regions that are remote from the site of the catastrophe. Frequently they are the result of human activities that have a negative impact on the environment, such as the felling of protection forests, the construction of new roads and tracks, changes in the density of stocking, the rerouting of rivers and streams, and pollution originating in industrial areas which adversely affects alpine vegetation. They can have a significant impact on the population and lead to consequential economical losses, if e.g. transport routes are disrupted or tourist resorts are disconnected from outside.

Within the project "Safety of Alpine Routes – Application of Earth Observation Combined with GIS (Hannibal)" relevant parameters have been retrieved from satellite remote sensing data and integrated into a newly developed GIS based decision support system (DSS) methodology. Some of the most important geomorphologic processes have been selected and their relevant indicators were identified, and quantitatively ascertained (range of values, thresholds, assessment methods). Complex analysis algorithms have been applied to extract the required information from remote sensing data. Forest parameters (e.g. age class distribution, tree species distribution, crown closure) and land cover parameters relevant for the assessment of potential threats have been derived by classification of satellite data. Change detection techniques have been applied to monitor sensitive zones, i.e. windfall and clear-cut areas, which often are places for triggering disasters. SPOT data have shown to be effective information sources for this kind of reconnaissance. Methods for interferometric processing of radar data have been optimised and used to derive digital elevation models (DEM) to detect landslides and to generate maps of motion fields along the slope surfaces.

TEST AREA

The test site is located in the “Hohe Tauern” mountains (Austria) and along the vital transition route over the mountains connecting Salzburg in the north with Carinthia in the south. Some touristic centers dominate the income of the region. The area lies in the crystalline Central Alps and high relief energy, i.e. extreme differences in elevation, characterizes this region. It includes three ecosystem regions from the high sub-alpine to the montane zone, within the sub-continental inner-alpine zone. In the high mountains forests mainly spruce, larch, mountain pine, and dwarf mountain pine are to be found. The alpine range above the timberline is characterised by a belt of dwarf-shrubs and higher areas are covered by more or less closed alpine grassy heathlands on detritus soils.

USER REQUIREMENTS

The integration of the end users (Austrian Railway Company, the Torrent and Avalanche Control Services and Forestry Boards) was an important factor in the development of the DSS as they showed responsibility for the identification of requirements as well as for the evaluation of the results. An important requirement was that the system should give full control to the operator, with respect both to the visualisation of the information and to the set-up of the rules used to extract and to combine the indicators. Thus, the system is a tool for experts rather than for the wider public, helping experts to get a large area overview on one hand and on the other hand to focus their attention to areas with an enhanced risk for the disastrous processes.

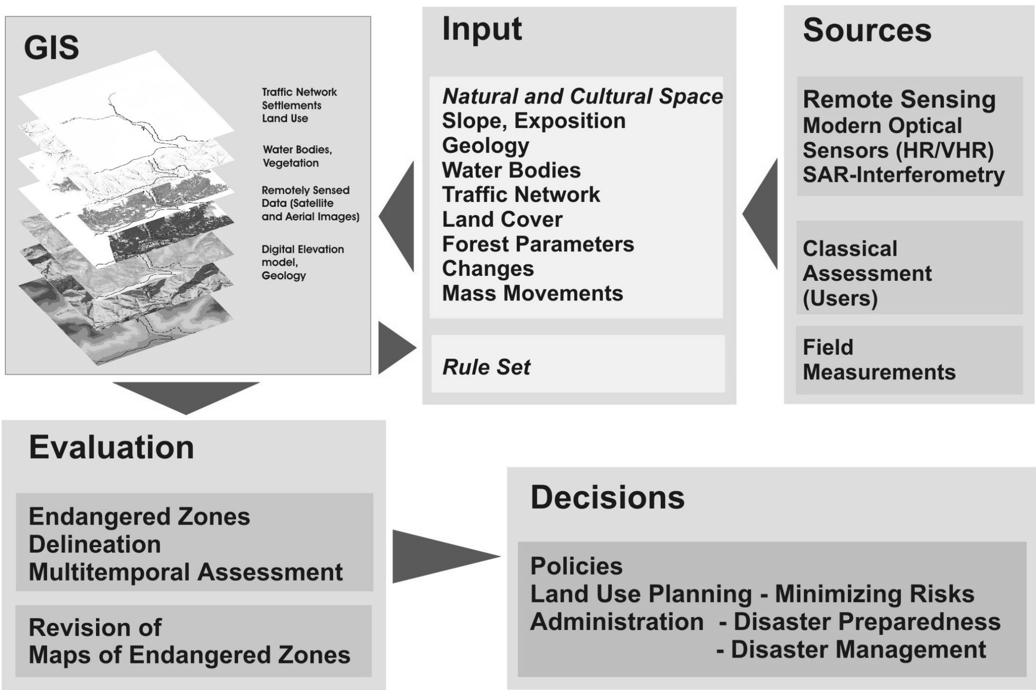


Figure 1: Concept of the DSS.

At the starting point of the project in a series of workshops six important event processes were selected for the investigations, i.e. snow avalanches, torrent, rockfall, deep-seated landslide, shallow landslide, and hazards due to vegetation. In addition to identifying the indicators, the quantitative aspects of the indicators (range of values, thresholds) have been investigated and set up. The results of these workshops have been compiled in an extensive table listing a total of about 20 indicators for the six different processes. The indicators have been grouped into the categories topography, geology, geomorphology, hydrology and land cover.

The purpose of indicators in the context of natural hazards is to find a set of parameters which can be used to evaluate the disposition of an area to the above listed processes. Morphological parameters, i.e. slope, aspect, height and curvature, were obtained from the digital elevation model, land-cover information from optical remote sensing data, and surface motion features using interferometry.

EARTH OBSERVATION

SPOT5 and QUICKBIRD satellites, both panchromatic (PAN) and multispectral (MS) data, were ordered for the investigations encompassing a range of spatial resolutions from 0.6m over 2.5m (see Figure 2) to 10m/20m, and thus, allowing the derivation of the requested parameters on different scales.

Radar is one of the few (quasi) operational active remote sensing techniques. A persuasive reason for using radar is its high degree to penetrate clouds and, to a high degree, rain. The information content of radar is mainly sensitive to the physical and electrical properties of the surface and is, therefore, complementary to the optical sensors (Buchroithner & Granica, 1997). In this project, however, the focus was put on motion aspects for landslide analysis, consequently interferometry techniques have been applied to observe surface movements.

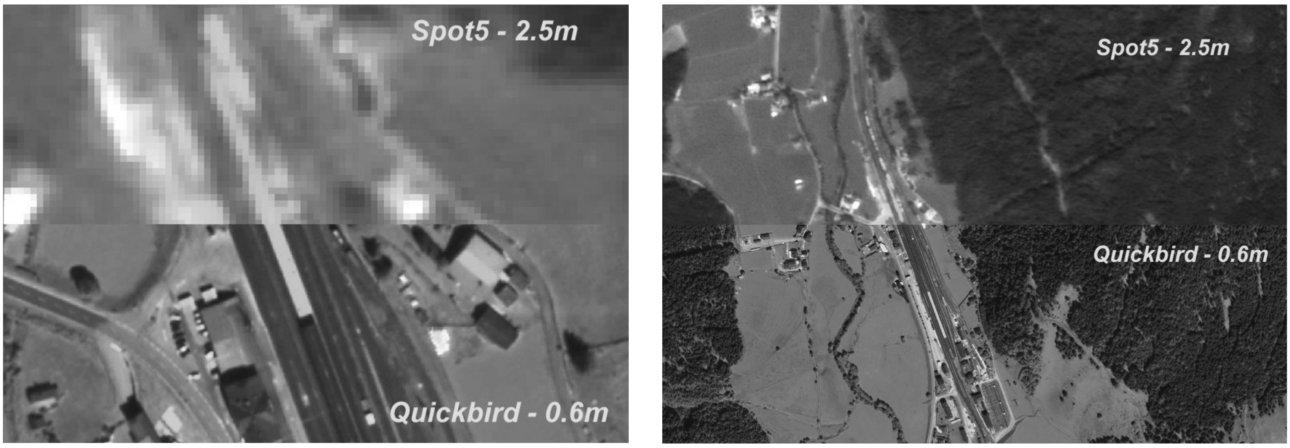


Figure 2: Comparison of Spatial Resolutions for SPOT5 and QUICKBIRD.

OPTICAL SATELLITE DATA

For the derivation of the input parameters to be integrated into the DSS System very high resolution QUICKBIRD and SPOT5 bundle scenes have been used. A land cover classification with a special focus on detailed forest categories was assigned to yield the needed landscape information. Because of the different information content of the selected satellite data and the heterogeneous land cover in the test area (natural areas above the alpine forest border line, alpine forests and agricultural used areas in the valleys) different methodologies had to be developed, i.e. visual interpretation for the large scale analyses of QUICKBIRD data, and pixel-based classification of a medium scale land cover classes and forest parameters based on SPOT5 data. The methodology for the processing steps is displayed in Figure 3.

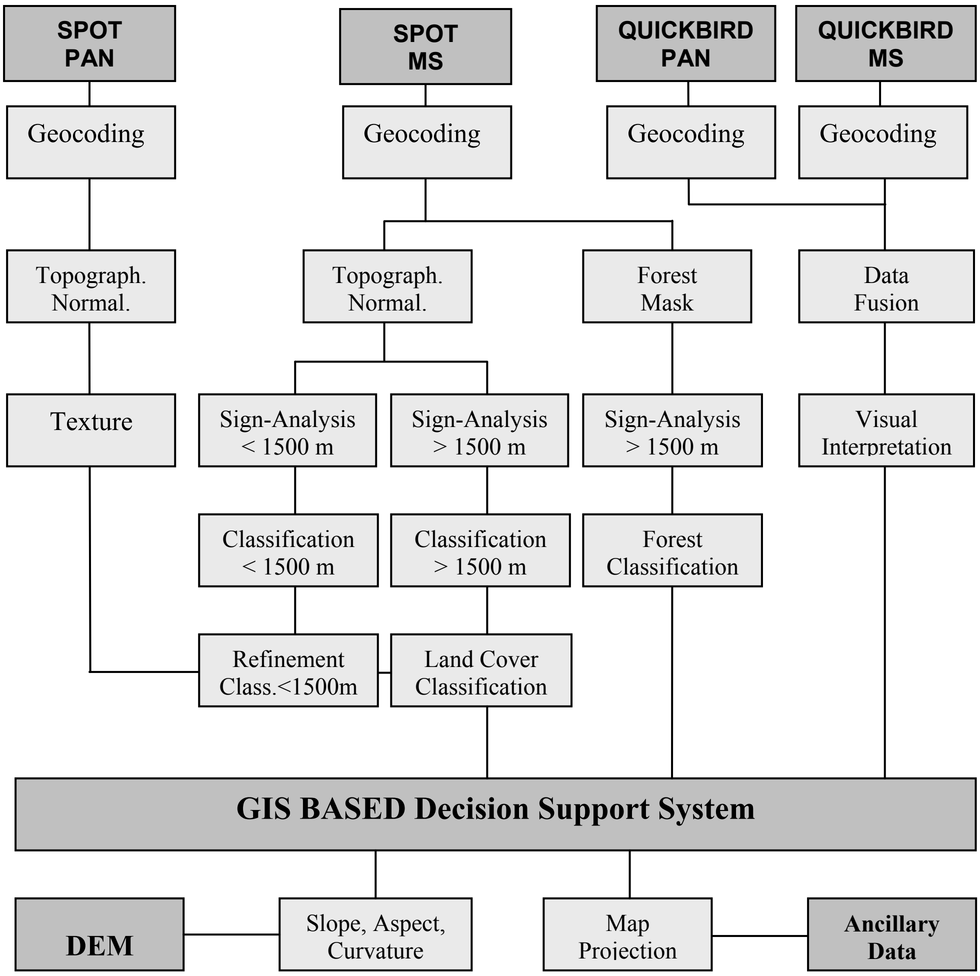


Figure 3: Flow Chart of the Applied Methodology.

Geocoding

Displacement errors caused by topographic relief must be removed to optimize the absolute geometric location accuracy of the geocoded image data (Raggam et al., 1991). In the course of geocoding, these errors were removed through the integration of a Digital Elevation Model (DEM), i.e. the consideration of terrain relief information. Geocoding was performed with the RSG software (Remote Sensing software package Graz; Raggam et al., 1991) of JOANNEUM Research.

Topographic Normalisation

An ideal slope-aspect correction removes all topographically induced illumination variations so that two objects having the same reflectance properties showing the same digital number despite their different orientation to the sun's position. As a visible consequence, the three-dimensional relief impression of a scene disappears and the image looks flat. In order to achieve this result, several radiometric correction procedures have been developed. Besides empirical approaches, such as image ratioing, which do not take into account the physical behaviour of scene elements, early correction methods were based on the Lambertian assumption, i.e. the satellite images are normalised according to the cosine of the effective illumination angle (Smith et al., 1980). However, most objects on the Earth's surface show non-Lambertian reflectance characteristics (Meyer et al., 1993). The cosine correction had thus to be extended by introducing parameters simulating the non-Lambertian behaviour of the surface (Civco, 1991; Colby, 1991). The estimation of these parameters is generally based on a linear regression between the radiometrically distorted bands and a shaded terrain model. A comparison between four correction methods, including the non-parametric cosine correction, confirms a significant improvement in classification results when applying the parametric models (Schardt et al., 2000). In this mapping project, the parametric Minnaert correction was used for topographic normalisation, as this method has been proven to achieve satisfactory results (Schardt et al., 2000; Schardt&Schmitt, 2001).

Supervised Pixel Based Classification of Forest Parameters with SPOT5 Data

The training areas required for supervised classification were selected on the basis of Color-Infrared (CIR) aerial photographs from different data sources and acquisition times or by field work. After the signature analysis, which is an important step in the supervised classification, the classification was carried out with selected signatures using the maximum likelihood method. A detailed evaluation of several classification runs based on different parameter settings and combinations of training areas resulted in the following "best practice procedure":

1. *Classification according to altitude*: the classification was carried out separately for areas above and below 1500 m, the results being subsequently combined into an overall result to account for the altitude effect.
2. *Weighted classification*: the "probability values" were reduced for uncertain training areas that were difficult to evaluate.
3. *Classification for the derivation of tree species*: the error probability increases for stands below 50% crown closure due to the strong influence of the ground vegetation. Only training areas with a crown closure of more than 50% were, therefore, selected for tree species classification.
4. Dwarf mountain pine and green alder stands were excluded for determining the *even-aged forest below 1500m altitude*.
5. For *age class determination*, ideal clusters were generated in the feature space and integrated into the training data set.

The results of the forest classification proofed that it is possible to derive forest parameters (see Figure 4) from SPOT multi-spectral data over a rather large region. With these parameters the experts have the opportunity to evaluate the actual situation in forests with respect to possible hazards. For instance, if the crown coverage is below a certain threshold the probability that snow avalanches could be triggered is increased. Consequently, the forest has to be managed properly.

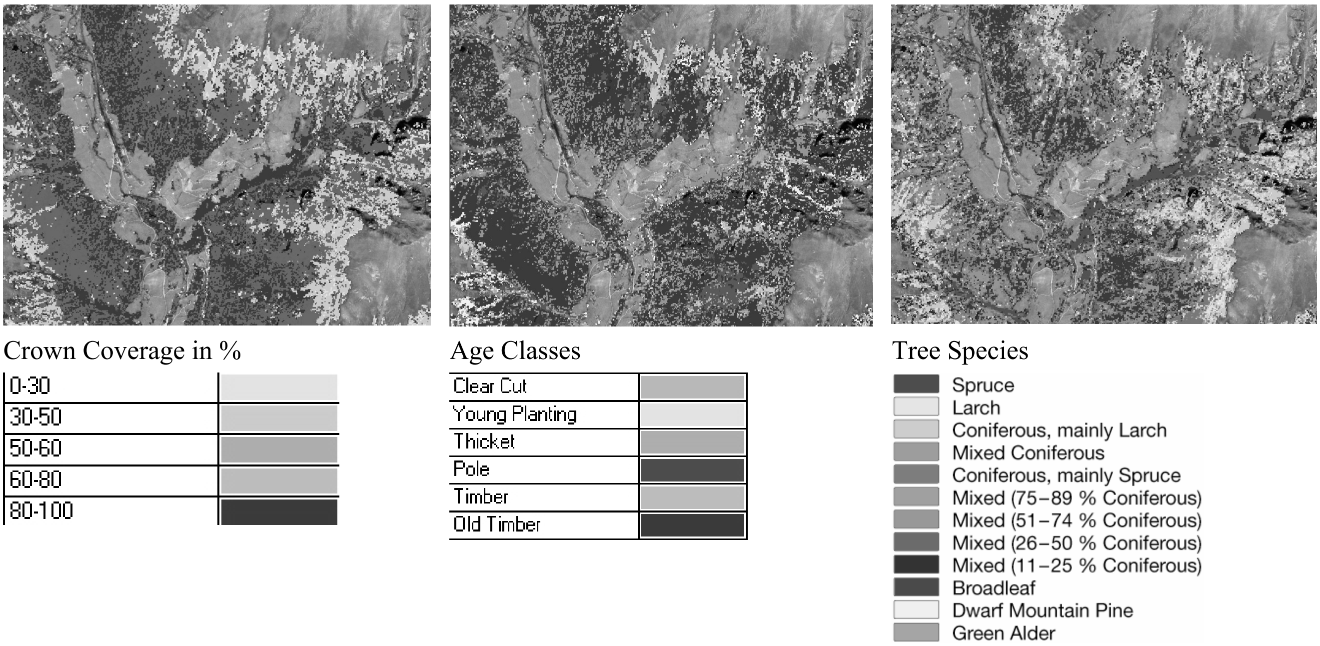


Figure 4: Results of Forest Classification Superimposed on SPOT5 Data.

Supervised Pixel Based Classification of Land Use Classes in the Valleys with SPOT5 Data

The following pixel-based land cover classification of the valley regions, i.e. excluding forest areas, was based on the spectral properties of the SPOT5 multi-spectral image. Using a hierarchical approach some main classes, i.e. water, snow/ice, debris/rock, pastures/meadows, settlements/fallow land, have been derived. However, as some of the classes could not be separated sufficiently, e.g. settlement vs. fallow land, a rule-based refinement of these classes has been performed. Additionally, a textural information from the SPOT5 panchromatic image was derived and incorporated into the classification.

The texture image was derived using an algorithm which considers statistical information within circle-sectors. The neighborhood of each single pixel is partitioned into wedges, for which the standard deviation is computed. In a next step the standard deviations within each (w)edge are compared and the minimum value is assigned to the center pixel as the final value. The textured image results in a more homogenous representation and without blurring the edges of settlement structures than with conventional filters (see Figure 5). The analyses were carried out using the image processing software IMPACT developed at the Institute of Digital Image Processing at JOANNEUM Research.

Figure 5: Left- Pan Image; Middle- Image Showing higher Texture for Houses Generated through Wedge Based Algorithm; Right: Standard Deviation Based Texture Using a 3x3 Moving Window.

Following the content of the textural image enabled the differentiation of the spectrally similar classes settlement vs. fallow land. The results of the land cover classification (see Figure 6) from SPOT data showed that the derived indicator classes are useful on a river catchment basis to enable quantitative analysis within the DSS.

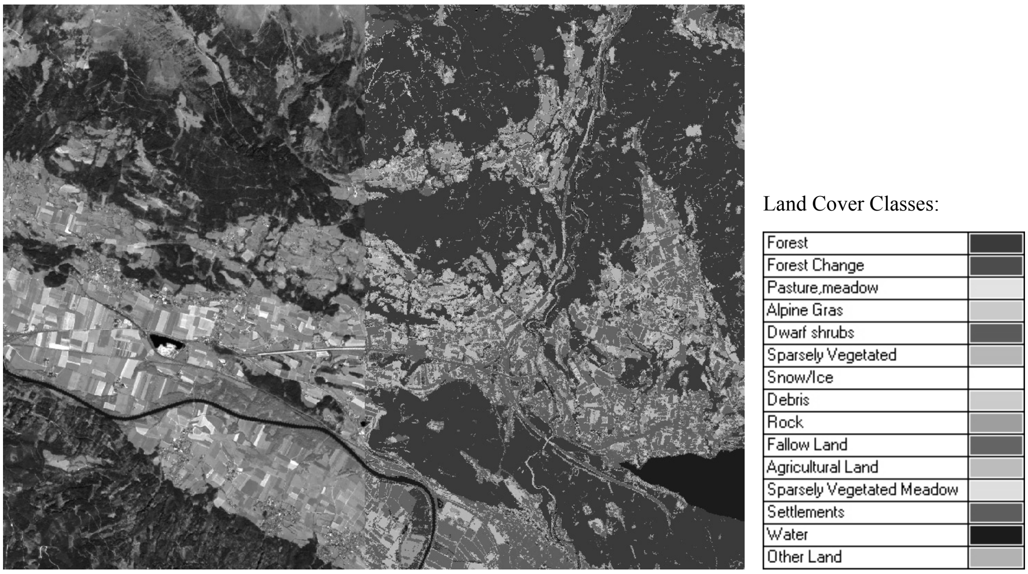


Figure 6: Left- Fusioned SPOT5 Image; Right- Classification Result.

Visual Interpretation

A visual interpretation was performed on the very high resolution QUICKBIRD data to obtain a more detailed derivation of very detailed land cover / land use classes on a larger scale. For this purpose a fused image, from the panchromatic and the multi-spectral channels, has been generated using the adaptive Brovey transform algorithm (ERDAS, 2003). The results were integrated into the DSS.

Change Detection

The developed change detection approach has been proved to be a very powerful tool, because it enables rapid mapping of changes in landscape over large areas. In the current case SPOT panchromatic scenes were used to derive changes in forest areas between 1987 and 2003. Accidentally, in November 2002 a heavy storm took place and its high damage in the forest showed a significant pattern. Based on Gallaun et al. (2001) the main processing steps, using the IMPACT software package, are described in the following:

1) Co-registration
2) Topographic Normalisation
3) Calibration of the two scenes
4) Image Differencing

Geometric Calibration

For the comparison of two scenes it is a prerequisite to transform them into a unique geometry. In the Remote Sensing Software Package Graz (Raggam et al., 1991) a DEM based geocoding was performed, because of the high-mountainous terrain. To minimize errors due to displacements, scene 1 (t1) was matched to scene 2 (t2).

Topographic Normalisation

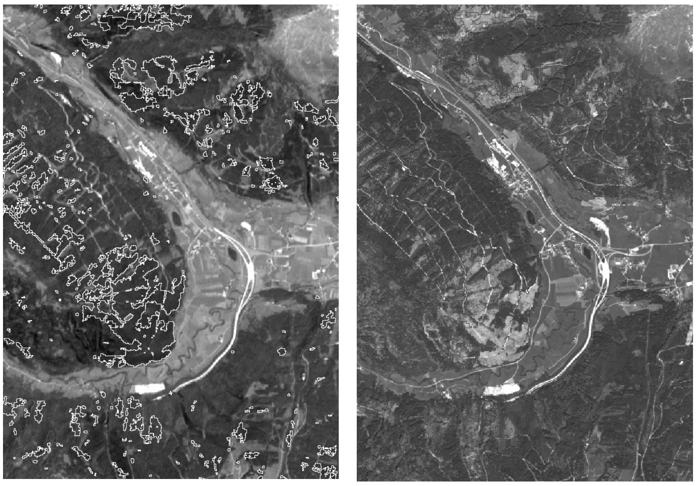
In the next phase a topographic normalisation was applied on both scenes to compensate for illumination (see description above).

Radiometric Calibration

The calibration of scenes (t1) and (t2) was achieved applying linear histogram matching. The goal of this processing step should be the exact spectral adaptation of the multi-temporal scenes. To avoid per-pixel errors based on remaining pixel distortions a “moving-window” approach has been applied. Within the “moving window” of a defined size, e.g. 5x5 pixel, the mean value has been used to compensate for local disturbances. This value had slightly to be modified in the higher parts of the mountains, i.e. the standard deviation has to be increased, because of the sparsely distributed forest pattern.

Image Differencing

Based on the above described steps image differencing was applied and as a result the forest changes occurred between 1987 and 2003 could be derived (see Figure 7). Large areas are mainly windfall areas from 2002.



a) b)

Figure 7: Example for semi-automatic Change Detection. a) SPOT1 Scene from 14.9.1987; b) SPOT5 Scene from 20.7.2003 (red lines indicate the changes).

Radar Data/ Interferometry

Unfavorable stability conditions on slopes near built-up areas and along traffic lines pose serious threads to property and life in many mountain regions. Surface movement is an important indicator for slope stability. Spaceborne synthetic aperture radar interferometry (InSAR) enables the mapping of movements at the Earth's surface with high precision over extended areas (Hanssen, 2001). The work in this project was focused on slopes with very slow movements in the order of centimetres per year, as typical for slowly moving landslides in the Alps. The basis for the analysis are SAR images spanning time intervals of months to several years.

Database

The basis for the analysis are SAR images of the European Remote Sensing satellites ERS-1, which operated from July 1991 to January 2000, and ERS-2, in orbit since April 1995, and since 2002 of the Advanced SAR (ASAR) of Envisat. ERS SAR operates at the wavelength λ= 5.66 cm (5.3 GHz), with an incidence angle θ = 23° in the centre of the 100 km-wide swath. The spatial resolution is 9.5 m across track (Line of Sight, LOS) × 5.5 m along track, the standard orbital repeat period is 35 days. In total 64 ascending and descending scenes, providing information on west- and east oriented slopes, were used.

Differential SAR Interferometry

Across-track SAR interferometry measures phase differences between two SAR images acquired from similar orbital positions (Fig. 8). The interferometric phase is a sensitive measure of the path change in slant range direction (LOS). In repeat-pass interferometry the phase difference, $\Delta\phi = \phi_2 - \phi_1$, includes the following contributions, which determine differences in the propagation path length between the two images:

$$\Delta\phi = \frac{4\pi}{\lambda}\left(R_2 - R_1\right) = \phi_{flat} + \phi_{topo} + \phi_{dis} + \phi_{atm} + \phi_{noise} \qquad (1)$$

where ϕ_{flat} and ϕ_{topo} are phase differences due to changes of the relative distance satellite-target for flat earth and topography, ϕ_{atm} is the phase difference due to changes in atmospheric propagation, ϕ_{dis} corresponds to the phase difference due to displacement of the target in slant range direction, and ϕ_{noise} is the phase noise (including thermal noise, processor noise, etc.).

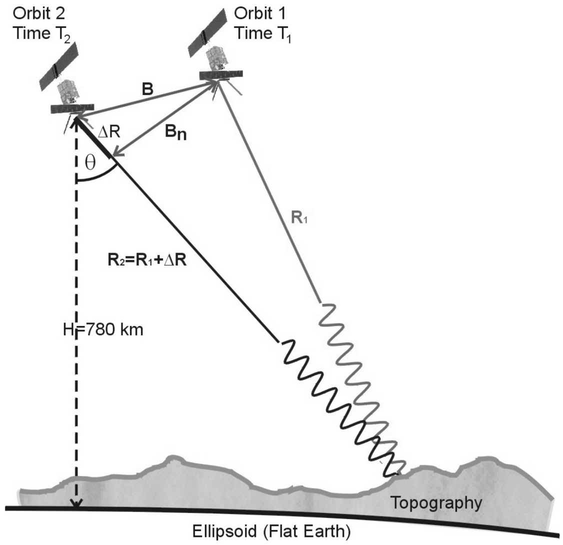


Figure 8: Imaging geometry of across track SAR interferometry. B - baseline, B_n – perpendicular baseline. θ look angle. R_1, R_2 … slant range distance sensor-target.

In order to determine terrain motion (corresponding to ϕ_{dis}), it is necessary to correct for the other phase terms in Equation 1. ϕ_{flat} can be calculated accurately using the precise ERS orbit data from the Orbit Data Records of the Technical University of Delft, NL. The topographic phase (ϕ_{topo}) depends on the imaging geometry and the terrain elevation according to

$$\frac{\partial\phi}{\partial z} = \frac{4\pi}{\lambda}\frac{B_n}{R\sin\theta} \qquad (2)$$

where *z* is the elevation. Eq. (2) describes the sensitivity of the interferometric phase on the terrain height. A measure for this is the height of ambiguity (H_a), which is the elevation change for a phase difference of $\phi = 2\pi$. ϕ_{topo} was estimated using ERS-1/-2 tandem pairs with 1-day time span, because the motion-related phase of the slowly sliding slopes can be neglected and the short-term coherence is usually high. By combining several tandem interferograms with different baselines the quality of the topographic phase and the derived DEM can be improved (Ferretti et al., 1999, Rott et al. 2002). The interferometric DEM or an external DEM is required for transformation of the INSAR products into a map projection (geocoding). The dominant part of the atmospheric phase variations, ϕ_{atm}, is related to water vapor (Hansen, 2001). In general, effects due to ϕ_{atm} can be neglected because the scale of landslides is much smaller than atmospheric propagation effects. These effects can be largely eliminated by selecting non-moving tie points in vicinity of the landslide (Rott et al., 2000).

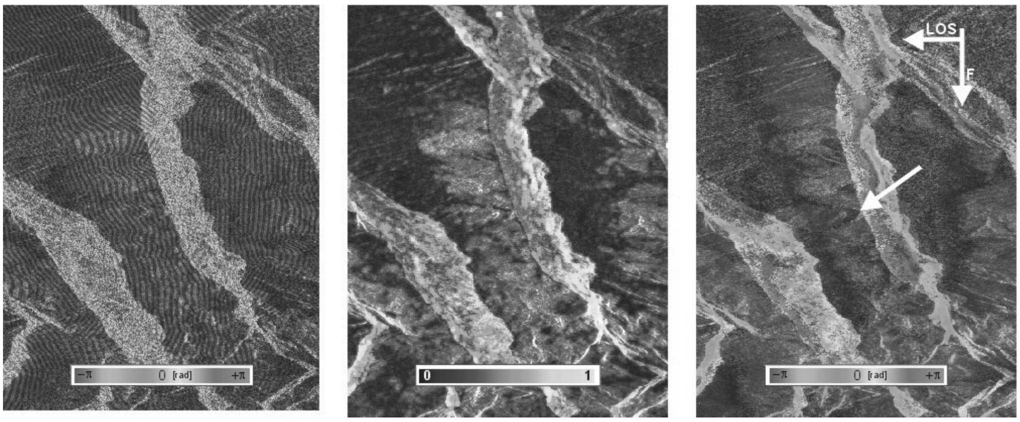
InSAR is sensitive only to the motion component in line of sight. Therefore, the look direction of the radar beam relative to the orientation of a landslide is of importance for mapping the motion field. The displacement ($\Delta R=R_2-R_1$) in LOS can be derived from ϕ_{dis} according to Equation 1. For producing maps of landslides the LOS displacements is often transformed to surface parallel motion, an assumption that is not always correct.

The limiting factor for InSAR is the phase stability at pixel scale between the repeat pass images. Factors influencing the interferometric coherence include temporal de-correlation due to changes on the Earth surface and de-correlation due to thermal noise, SAR processing and low signal to noise-ratio (Bamler and Hartl, 1998). Temporal de-correlation of the signal is the main limitation for the application of InSAR over long time periods. For dense vegetated areas (e.g. forests, agricultural fields, etc.) the signal generally de-correlates within a couple of days. For areas with low vegetation, bare soil, and rocks the coherence is usually preserved over annual or multi-annual periods as long as the surfaces are snow-free (Rott et al., 2000, Rott et al., 2003).

Case Study Felbertauern

An example for an InSAR landslide analysis is presented for the Ödtal in the “Hohe Tauern” mountain range in Salzburg, a narrow valley through which a main north-south traffic route, the Felbertauern road, runs. The slopes are very steep and the road is endangered by rockfall and landslides. The steep topography results in strong distortions in radar images (Figure 9). The analysed slope with mass movement is west-facing, and, therefore, a backslope for radar observation from descending orbit. Figure 9a. shows a section of the topographic phase image derived from ERS SAR Tandem data of 24/25 September 1995 (B_n = 275 m). A phase cycle of 2π (one fringe) in these interferograms corresponds to an altitude difference of 32m. The unstable slope extends from about 1400 to 2600m in elevation and has a mean surface inclination of about 30 degrees, with up to 35° in its lower part. The coherence image (Figure 9b) shows the average degree of coherence derived from several interferograms over annual time spans. The 2000m topographic contour line corresponds approximately to the boundary between coherent and non-coherent surfaces (assuming a threshold of 0.25 for the degree of coherence). The signal of the forested areas below de-correlates, whereas the alpine grassland and rock-covered surfaces above are coherent. Patches of low coherence at highest elevations correspond to perennual snow fields.

Figure 9c shows a 1-year interferogram with a very short baseline, B_n = 4 m, so that the motion-related phase (white arrow) is clearly evident even without subtracting the topographic phase. Fig 9a shows the motion map after subtracting the topographic phase. Figure 10b shows a transverse profile across the slide for two annual time intervals. The average velocity at this profile, assuming surface parallel motion, is 2.3 cm/a in 92/93 and 1.8 cm/a in 97/98.



(a) (b) (c)

Figure 9: (a) ERS Tandem interferogram overlaid on an amplitude image, 24/25 September 1995, baseline B_n = 275 m (H_a= 32 m), with the phase cycle colour coded in 2π intervals; (b) coherence image of annual intervals (degree of coherence); (c) interferogram 29 September 1997/10 August 1998, B_n = 4m (H_a= 2200 m). F–flight direction of the satellite.

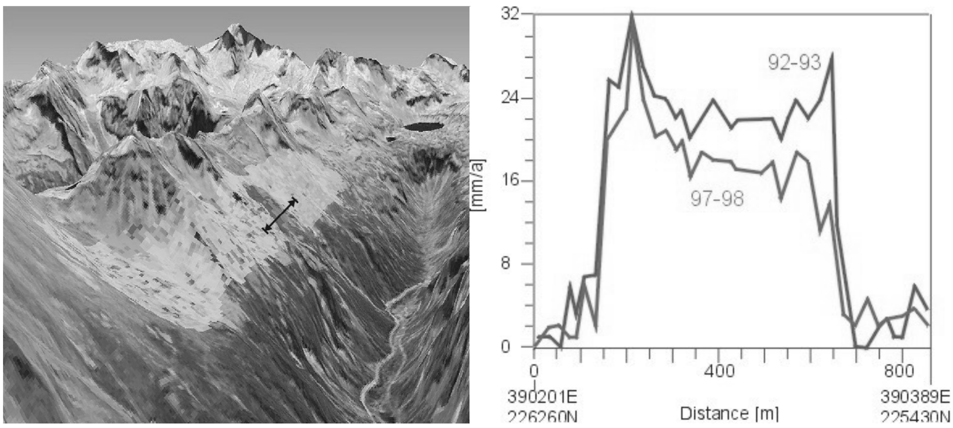


Figure 10: (a) map of surface motion from InSAR on the slope above Ödtal (colour coded) superimposed to a Landsat image. (b) Slope-parallel profile across the main landslide (corresponding to the black line in the Landsat image) showing InSAR-derived surface velocity in mm/a for two periods.

DECISION SUPPORT SYSTEM

In order be compatible with existing GIS of the end users, the DSS has been implemented as an ArcView 3.x extension in Avenue. The base data layers comprise a topographic map, infrastructure information – especially the traffic network – and the digital terrain model and layers derived from it (exposition, slope, curvatures). In a second step the information layers derived from Earth Observation data are integrated, which are described in the sections above.

Usually the analysis is started by opening the input dialogue of the Scenario Analyst. Here it is possible to identify the process of interest, to select a layer to display (e.g. slope), and to apply rules to restrict the displayed layer to an area for which this set of conditions is given. All raster data provided as GRIDs can be integrated into the set of rules. The rules applicable to the input data comprise the following operations:

- spatial operations: restriction of the operations to an area of interest or, specifically, to watershed areas,
- thematic restrictions: application of thresholds to displayed layers, e.g. to display only areas with slopes steeper than 40°,

- combinations of layers: logical combination with the information in up to six other layers (e.g. slope above 40° AND no forest).

The results of the procedure are a mask indicating all areas for which the selected conditions hold, and on the other hand a subset of the displayed layer restricted to that area. All interim results can be stored to be used later on, e.g. as input to further analyses. Note that no quantitative information on the risk is given. This is in line with the user requirement that the interpretation has to be done by the operator, not by the system.

SATELLITE SYSTEM SPECIFICATION

For the selection of an appropriate sensor system some prerequisites have to be taken into account, as there are spatial, spectral and temporal resolutions, coverage and user needs. As these needs are often conflicting with themselves a best practice solution has to be found for the topic of interest. For instance, a needed coverage of 185km x 185km (Landsat TM) would result in a number of approximately 150 QUICKBIRD scenes, which is not realistic to be achieved in any case.

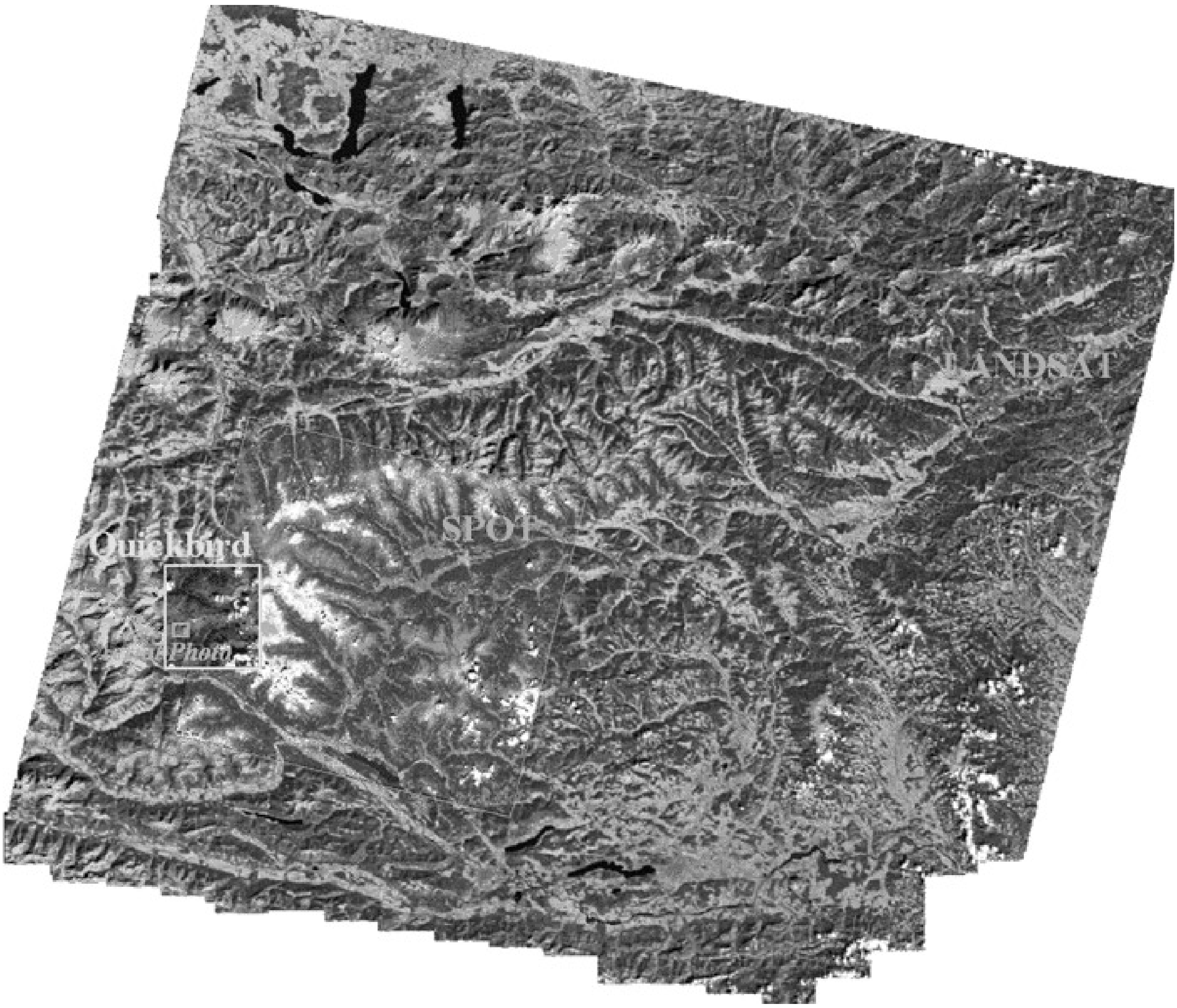


Figure 11: Coverage of Different Sensor Systems.

Optical Domain

For the optical domain the combination of different satellite systems could increase the output information and the temporal resolution. The receiving of satellite imagery is still a bottleneck, especially in the often clouded regions of the Alps not every pass is recording cloudfree data. A possibility to overcome this problem could be the increasing of overpass orbits through new systems. For instance, the new constellation of RAPIDEYE – to be launched in spring 2006 - is offering daily coverage in five channels. The spatial resolution (6m x 6m) of this system would be sufficient for the related topics and the aerial coverage is close to SPOT images. It has still to be analyzed which data type fits to which application, e.g. a quantitative assessment of huge forest areas does not need the counting of single trees. For this purpose the use of SPOT like sensors proved to be a practicable solution. For more accurate interpretation of objects/features a combination with QUICKBIRD data in selected regions could support detailed investigations. QUICKBIRD2 could offer very high spatial resolution (maybe 20cm) in four channels with 1m, but an automatic classification of that kind of data is still not available yet. A combination of different kind of satellite data faces some drawbacks in terms of sensor specifications, sun angles, atmospheric influences and phenological aspects.

The latter aspects are also valid for applying change detection. However, for this purpose the medium resolution satellite systems, i.e. from 10m to 30m, seem to be adequate instruments, because they offer a large coverage and sufficient accuracy. The exact assessment of the cause of change has to be performed anyway by ground checks. Preferably, the same sensor type will be used for change detection tasks, because different sensor systems are prone to create false signals, because of the their difficult calibration.

The combined use of different sensor systems for classification of land surface parameters is not operational yet. New algorithmic and methodological developments have to be performed in this context. On the contrary the classification of single images has been performed successfully over the past years (Schardt et al., 2000).

Radar Domain

The InSAR processing in this paper refers to the area extended InSAR method, which required a few SAR images. The method has been successfully applied in high alpine areas (above the tree line), sparse vegetated areas and built-up areas. The main limitation of SAR interferometry for landslide monitoring in alpine areas is the lack of information in densely vegetated areas due to signal de-correlation over annual and multi-annual periods. In these areas the coherence is somewhat better preserved at longer wavelengths (L-Band) (Strozzi et al., 2003). Future L-Band SAR systems, such as PALSAR on the ALOS satellite, will bring some improvements in vegetated area, but de-correlation in dense forests is still expected. If long time series of SAR images are available, the Permanent Scatterer (PS) method can be applied, by which the displacement of long-term stable targets (mainly man-made objects, but also some natural targets) is derived. As another alternative, we are presently testing the use of radar reflectors in forested zones. (Ferretti et al., 2000, 2001).

CONCLUSIONS

A GIS based DSS has been created by a group of scientists to support disaster management tasks in Alpine environments. The need of a wealth of quantitative input data for the complex disaster prevention tasks guided to the use of satellite remote sensing data. Optical as well as radar data have been selected to fulfill this purpose. Based on developed methodologies the indicators defined by the end users have been derived and incorporated into the DSS. It could be shown that SPOT5 imagery could satisfy many of the requirements in terms of quantitative assessment and spatial resolutions. The land cover mapping of the main categories has been performed successfully over a large region. The ascertainment of detailed forest parameters from the new SPOT5 imagery could be demonstrated as major input for detecting of potential hazardous zones in the highly-relief terrain.

The monitoring of changes in forested areas has been applied with change detection methodology by using SPOT data from different dates. This approach can be considered as one of the big advantages of satellite remote sensing in many phases of disaster management. The currently existing bottleneck with respect to data recording/acquisition could be accomplished by some of the planned satellite systems in the near future, especially the RAPIDEYE satellites.

The investigations on slow slope deformation confirmed that spaceborne InSAR provides very accurate data of surface displacements from the scale of single landslides upwards. Because of the large coverage of SAR scenes it is an economic tool for surveying large regions. Presently ENVISAT ASAR and Radarsat are widely used for interferometry. Launches of several radar satellites, planned for the next couple of years, will provide the data for operational detection and monitoring of mass movements worldwide. The synoptic use of SAR based displacement maps with thematic information from high resolution optical images and information from other sources (e.g. geological maps) will further support the landslide risk assessment.

During the assessment of the DSS by potential users, i.e. the Austrian Railway Company, Torrent and Avalanche Control Services and Forestry Boards, it has been considered a powerful tool for the envisaged applications.

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