Scientific Research Centre of the
Slovenian Academy of Sciences and Arts

Log pod Mangartom Landslide, Slovenia

»Space and Major Disasters«

Final Report

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Contents

1 Introduction

Following from continuous rainy weather on November 15th, 2000, a mass of morainic material and slope gravel began to move near the Mangart stream ravine (situated under Mount Mangart ridge, near Bovec in the north-western part of Slovenia). The mass moved up to Predelica gorge and blocked the waterflow of Mangartski potok (Mangart stream) where it stopped for several hours. Part of the Mangart local road (Bovec-Predel) was also covered at this time. In the early morning of November 17th, 2000 a major landslide occurred on the slopes of Mount Mangart. The second slide most probably started because the slope was already generally instable and as a consequence of extreme rainfall. This, together with local dynamics, caused the ground material to become "liquefied".

In a few hours the slide was transformed into "debris flow" – a fast moving mixture of water, soil and other material. The landslides moved extremely quickly along the bed of the Predelnica, and through the village of Log pod Mangartom. The materials continued moving down the valley, and along the bed of the Koritnica into the Soča river, travelling for several kilometres.

According to the latest information, the area of the second failure (actually a debris flow) is estimated at around 26 hectares, and approximately 3 million cubic metres of material moved down the mountain. Experts estimated that velocity of the flow ranged from 8 to 15 m/s, and the slide time merely 5 minutes, or even less. The nature of debris flows, having immense mobility and transportation capability, caused the landslide to impact the landscape and the nearby village severely. Tragically, the landslide claimed seven lives. Two bridges, linking Log pod Mangartom and Predel (on the Slovenian-Italian border at the Predel mountain pass), and many houses were completely destroyed. The reason for both landslides was probably the recent intensive rainfall, the specific geological composition of the ground and the considerable seismological activity of the area.

The mountain ridge west of Mount Mangart is composed of Upper Triassic carbonate and clastic rocks. A block of poorly permeable carbonate-clastic succession, representing the base of the landslide, is situated between fault-bounded blocks of massive and bedded dolomite. The landslide scar in the upper part of the slope exposed a cliff in the bedrock topography, probably produced by faulting. According to the geological situation in the area, it seems that the fundamental reason for the landslide was the poorly permeable bedrock combined with the extreme weather situation.

Shortly after the disaster a professional group was established to monitor the slide and propose solutions for its stabilisation. As the area is dangerous, further slides could happen at any time, the group relied heavily on remote sensing techniques. The group also paid special attention to a range of possible causes of the slide. Events that could be related to the slide, including for example the earthquake that happened on April 12th 1998, are being investigated. As past events (without prior measurements) were to be observed, remote sensing remained one of the few available tools.

This report starts with a general introduction to the landslide and short description of the affected area. Some geological issues are presented in order to understand better the process behind the landslide. Furthermore, in section 2, the landslide's effects on the village of Log pod Mangartom and to the landscape in general are also briefly considered. In chapter 3 schedules of the work and activities undertaken as part of the project are listed. Satellite imagery used in the project and other data utilized, together with details of the image processing itself are described. In sections 4 (ERS), 5 (RADARSAT) and 6 (SPOT) the estimation and evaluation of different data sets (satellite images) with respect to their value and applicability to natural disaster research in Log pod Mangartom landslide event is presented. Section 7 incorporates GIS analysis and its interpretation. All satellite images have been integrated into a geographical database, together with digital elevation model and landuse map. Analyses including the exact location of the landslide, area of destruction, the changes in the natural environment consequent to the landslide etc., are thus described. Section 8 is devoted to the overall conclusions of the work.

2 Landslide

In the night of November 16th to 17th the village of Log pod Mangartom, located underneath the Mount Mangart range in the Posočje region (see Figure 1) was hit by a massive landslide that claimed seven lives. The damage caused by the landslide, the remnant of which is still threatening the Alpine village and valley, is yet to be fully estimated.

The pleasant village of Log pod Mangartom lies in the Soča area of the Triglav National Park, and below the Mangart mountain range. The Mangart range contains Veliki Mangart (2,679 m) the third highest mountain in Slovenia, and rises above the valley of the Koritnica stream and the Mangart Valley in the Julian Alps, close to the border between Slovenia and Italy. On the southern slope of the mountain range one finds the source of the Koritnica river, while the northern side includes the Lower and Upper Mangart Lake. The Koritnica flows into the Soča river near the village of Kal-Koritnica. Smaller glacial side valleys (Zadnjica, Vrsnik and Lepena near the Soča, and Možnica and Bavščica near the Koritnica) are characteristic of both rivers, which are known for their extraordinarily picturesque water channels. The village of Log pod Mangartom, lying on the front moraine of the former glacier, is composed of Spodnji (Lower) Log (620 m) and Gorenji (Upper) Log (650 m).

In the area of the Mangartski potok (stream), above the village of Log pod Mangartom, a landslide flowed down the slopes on November 15th at 12:45. This landslide did not threaten the village. However, the bridge over Mangartski potok, linking Bovec and Predel was destroyed. The first landslide reached the confluence of Mangartski potok and Predelica at a height of 905 m.

Figure 1: Location of the landslide within Slovenia.

Figure 2: Part of the landslide covered with snow (photo J. Mlekuž).

After one day, and during the night of November 16th to 17th another, much larger landslide (or debris flow) flowed down from Mount Mangart. The landslide spread out over a height of 1200 to 1600 m, covering almost 26 hectares. Over million cubic meters of rock and earth has been moved in the area of the origin of the landslide. The landslide rested for several hours becoming saturated from the waters of the Mangart stream supplemented by heavy rain. Following this the debris flow moved extremely quickly, travelling for several kilometres. It is estimated that about million cubic meters of materials moved downwards along the bed of the Mangart potok, poured out the valley along the bed of the Koritnica and Predelica, hitting the village of Gorenji Log (650 m), and finally flowing into the Soča river.

The surface of deposited material in the area of the Log pod Mangartom village covered approximately 50 hectares or composed 700.000 m^3. The average thickness of deposited debris was about 4,5 m. Over 150.000 m^3 of smaller material was moved towards the Soča river.

As noted in the previous section, the reason behind the flow is most probably the intense rainfall during the period, the specific geological composition of the ground and the considerable seismological activity of the area. The mountain ridge west of Mount Mangart is mainly composed of massive Upper Triassic carbonate that is in areas interrupted by clastic rocks, and some poorly permeable Carnian Calc stoneware. A block of poorly permeable carbonate-clastic succession, the base of the landslide, is situated between fault-bound blocks of massive and bedded dolomite. In the Pleistocene over stepped bedrock, poorly permeable grounding glacial sediments rich with silt were deposited over dolomite gravel.

A direct triggering mechanism for the landslide and the evelopment of a debris flow was the intense rainfall (in the first part of November 2000). The landslide scar in the upper part of the slope exposed a cliff within the bedrock, probably produced by faulting. Low permeability of

Figure 3: The village of Log pod Mangartom destroyed by a landslide (photo J. Mlekuž).

the bedrock caused the concentration of water in diamicts and thus a rapid increase in material-rich water tension. The end of this process caused rapid "liquefaction" of the first landslide material into an immense flow without almost any solidity. At the crucial moment the debris flow (incorporating the material of the first landslide) moved and resulted in the catastrophe in the village Gorenji Log pod Mangartom and surrounding landscape.

2.1 The landslide consequences

150 people lived in the village of Log pod Mangartom. The settlement is composed of Spodnji Log and Gorenji Log and contains the Predelica creek, a tributary of the Koritnica. Over the years this river has carved out a deep gorge in its lower part from the underlying dolomites. The houses in the village are line road, exploiting best the landscape which otherwise possesses little room for settlement. The houses are made according to the Alpine-Bovec tradition, and both Logs are considered the most beautiful settlement examples in Triglav National Park. As the surrounding land did not allow locals to survive from agriculture alone, prior to World War I inhabitants earned money by maintaining the Predel road and by working in the lead and zinc mines in Italy, reached by going through a tunnel under the Predel and straight into the mines.

On the night of November 16th to 17th, the village of Log pod Mangartom was buried under tonnes of mud. Several residential (50 houses) and industrial buildings were also destroyed, and there was damage to the low- and high-voltage networks, power facilities and water reservoirs. The operation to stabilise the situation at Log and provide overall sanitation is still underway and more than 100 locals evacuated from the affected area will not return before spring.

However, whilst the risk of new landslides in Log pod Mangartom is diminished, it has still not passed. After a thorough examination of the affected region, experts forming the study group warned that the danger is not yet over. Approximately 300,000 – 1,500,000 m^3 of material is still poised, precariously, over the village. Some also claim that a potential landslide could attain a volume of up to 3,000,000 m^3. Such a slide could burst the banks of the nearby Soča river, resulting in extensive flooding. The area is however continuously monitored.

The villages in this area were reachable only by air for a few weeks, as the road and several houses were swept away by the landslide. The Koritnica river has dropped its level slightly, but the water may take a new course, perhaps underground. As several houses were swept away by the landslide in Log pod Mangartom, around 500 people have been evacuated, while around 100 villagers of Čezsoča, Log Čezsoški and other nearby villages were prepared to evacuate their homes at any time. Today, some of the local people are back in their homes, although 100 others remain displaced.

3 Remote sensing and image processing

Actions to obtain and process satellite imagery started immediately after the group of experts was established. A few days after the landslide the ESA (Mr. Jerome Béquignon) was contacted, and afterwards a request was made to the Charter »Space and Major Disasters«. Following information provided, a plan of action was proposed and submitted to the various agencies for tasking satellites.

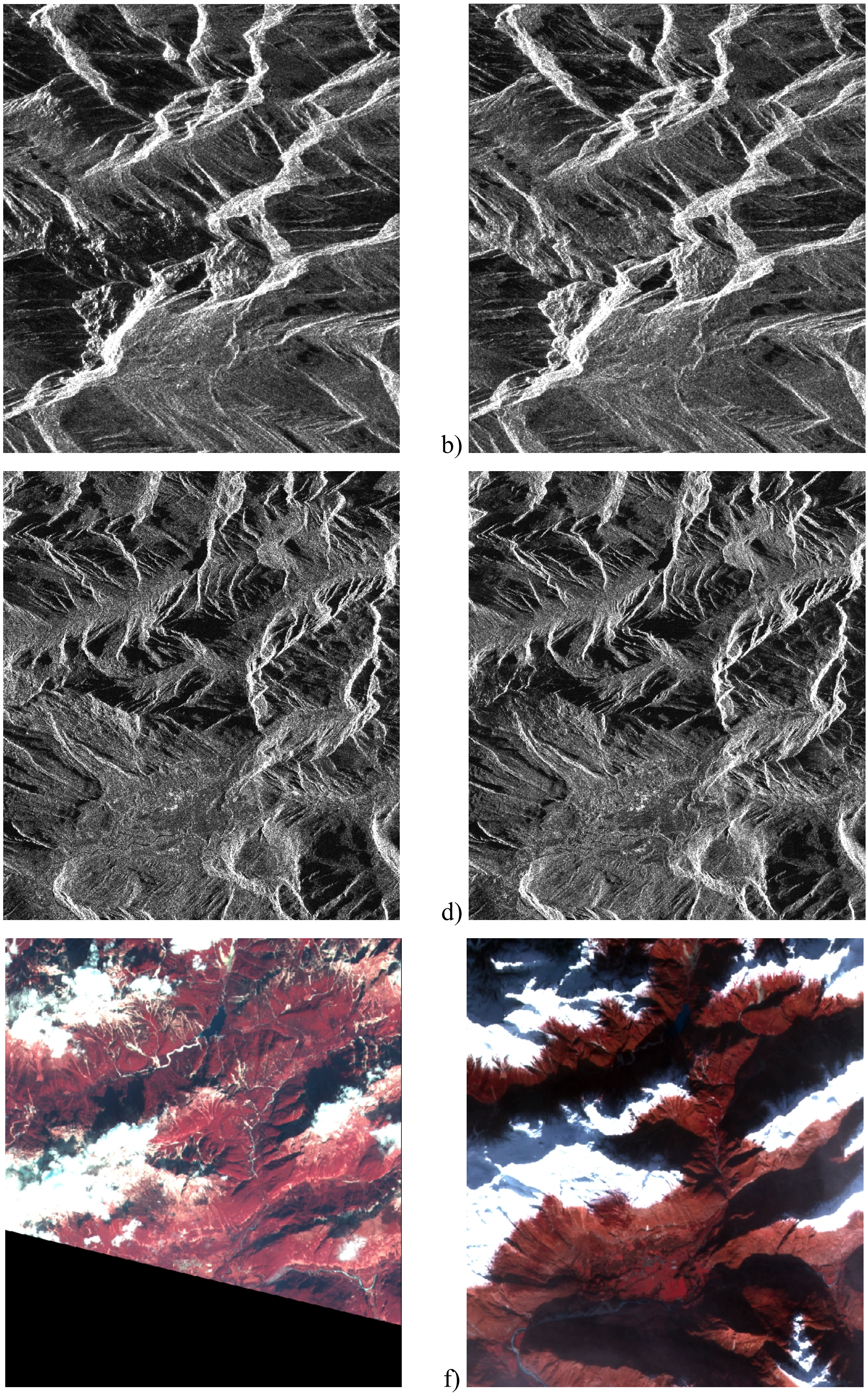
Agency	Satellite	Type	Acq. date	Acq. time	Received
ESA	ERS	radar	1999-11-05	9:56	2000.11.30
ESA	ERS	radar	2000-11-24	9:56	2000.11.30
CSA	RADARSAT	radar	1998-10-25	17:02	2000.12.13
CSA	RADARSAT	radar	2000-12-01	17:02	2000.12.13
CNES	SPOT	optical	2000-08-19	10:08	2000.12.14
CNES	SPOT	optical	2000-08-21	10:08	2000.12.14
CNES	SPOT	optical	2000-11-29	9:58	2000.12.14
CNES	SPOT	optical	2000-11-29	10:11	2000.12.14
ESA	ERS	radar	1998-03-20	9:56	before
ESA	ERS	radar	1998-04-24	9:56	before
ESA	ERS	radar	1998-05-29	9:56	before
ESA	Landsat	optical	1992-08-18	9:14	before
ESA	Landsat	optical	1999-09-15	9:14	before

Table 1: Satellite images used in the project. The first eight images were obtained in the frame of Charter »Space and Major Disasters«.

The images used in the project are listed in Table 1. In total 13 satellite images from 1992 to 2000 are being utilized:

- 5 ERS (1 and 2)
- 2 RADARSAT
- 4 SPOT (2 pan and 2 multispectral) and
- 2 Landsat.

An additional layer, a digital elevation model of Slovenia, produced using radar interferometry from ERS images, was also used. Satellite images obtained within the Charter are shown in Figure 4 on page 11.



a) b) c) d) e) f)

Figure 4: Several satellite images were obtained within the Charter: a) ERS-2 (1999-11-05), b) ERS-2 (2000-11-24), c) RADARSAT (1998-10-25), d) RADARSAT (2000-12-01), e) SPOT (2000-08-19) and f) SPOT (2000-11-29).

After the images were received a visual inspection was made. The landslide was detected directly or indirectly in the images made after the event: on ERS-2 (2000-11-24), RADARSAT (2000-12-01) and SPOT (2000-11-29). The results were forwarded to members of the expert group and were used in rescue operation and for potential danger estimation.

Geocoding and preliminarily processing followed visual inspection. All scenes were georeferenced to the national system that is the Gauss-Krueger projection on the Bessel ellipsoid. This is a very critical step for further processing and has to be carried out with special care. Although all images contain some georeferencing information it is, in our experience, not accurate enough for further processing. While there were no problems with the geocoding of SPOT imagery some difficulties were encountered with radar imagery. That was expected but annoying and therefore some automated geocoding techniques were used. To minimise misregistration, images from same satellites, both ERS and RADARSAT were coregistered on to the other at the beginning and only afterwards was the composite referenced to map.

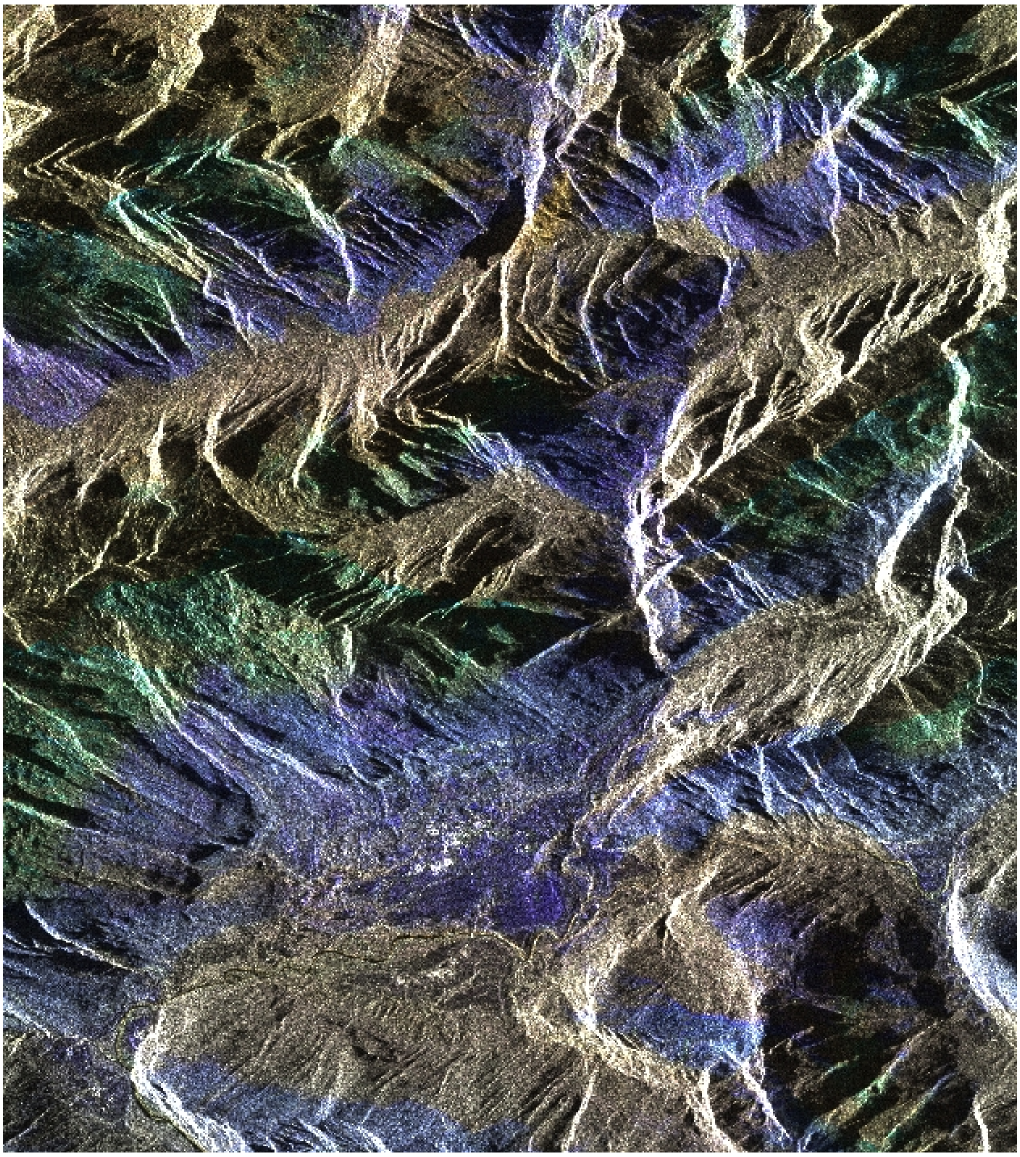


Figure 5: Data integration – SPOT and RADARSAT merge.

Georeferenced satellite images were integrated into a GIS system, together with other available data (Landsat images, landuse data, digital elevation model…). An interpretation of data is given in the following sections.

4 ERS

ERS data was used in the project in two ways – to produce a digital elevation model and to observe land properties at the time of landslide. A digital elevation model for the area of Posočje was made at the beginning of 2000, mainly to test the usability of ERS data in rough terrain and to support the observation of co-seismic activity after the April 12th 1998 earthquake. In the area mentioned 7 ERS-1 and 2 scenes were used from both ascending and descending orbit to produce partial elevation models of the area. All other available data, such as contour lines, coarse digital elevation at a resolution of 100 m, were also included in the modelling.

Interferogram combination can considerably improve the accuracy of digital elevation models and displacement maps (Oštir, 2000; Gens, 1998). Averaging of data always decreases the error, but even better results can be obtained using advanced merging techniques and with the combination of ascending and descending satellite orbits. In the project we used coherence weighted averaging and external elevation model flattening. Coherence weighted averaging of interferograms allows the production of improved elevation models and movement maps, even in cases when non-ideal data is used or when errors in the processing cannot be avoided. The method of external model flattening on the other hand can be used to eliminate gross errors in the model, while keeping the interferometric details. The digital elevation model produced with radar interferometry has an overall accuracy of approximately 8 m, less than 2 m in plains and more than 10 m in the mountains.

ERS images were also used to observe land properties, mostly humidity in the time of landslide. Two ERS-2 scenes were taken before and after the slide under, approximately, the same conditions (1999-11-05 and 2000-11-24). The images were precisely coregistered, at subpixel accuracy, one to the other and only then georeferenced. The difference between both images has been computed. Map in Figure 6 on page 15 shows the ERS-2 images of the landslide area, acquired on 2000-11-24 and 1999-11-05 as red and green respectively, while their difference is shown in blue. Increased soil humidity can be clearly seen in the area around the landslide (red vector overlay) as shades of pink. Slopes inclined towards the radar (layover areas) and larger cities (Gorica, Udine and Villach) are shown in yellow due to their high reflectance in both SAR scenes.

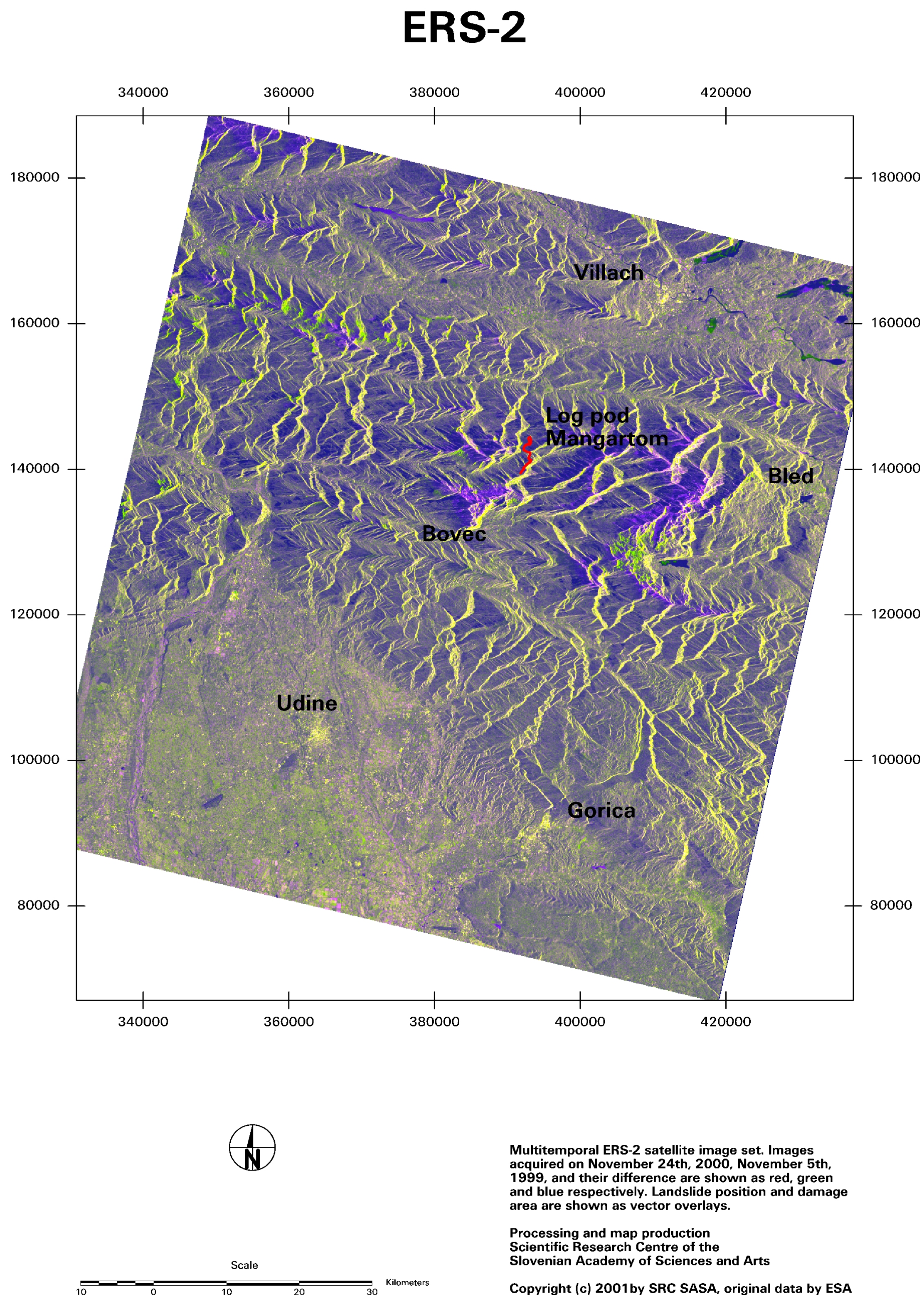


Figure 6: ERS satellite map of western Slovenia.

5 RADARSAT

RADARSAT images have very good spatial resolution (fine beam mode). They were also made from different incidence angles as ERS images (ERS 23°, RADARSAT 42°). RADARSAT has a more suitable directional property (ascending versus descending) for the study area. Therefore it provided clearer results than ERS, despite the fact that the relief in the area of Mount Mangart is very steep and therefore causes severe problems to the radar satellites (layover and shadows) and limits its use considerably.

Several artefacts can be seen in the RADARSAT image map (Figure 7 on page 17), where scenes acquired on 2000-12-01 and 1998-10-25 are shown in red and green respectively, while their difference is shown in blue. The map is similar to that for ERS, with yellow areas of layover and high coherence. Pink areas show high humidity, which can be detected in almost the whole area of the Alps. Nevertheless the humidity is not as high as in the case of the ERS data. The reason is that RADARSAT image was made several days after the ERS images and that there was no significant rainfall in that period. In the map one can also see areas of new snow shown as a green colour. Snow occurred a few days before the second RADARSAT image was acquired.

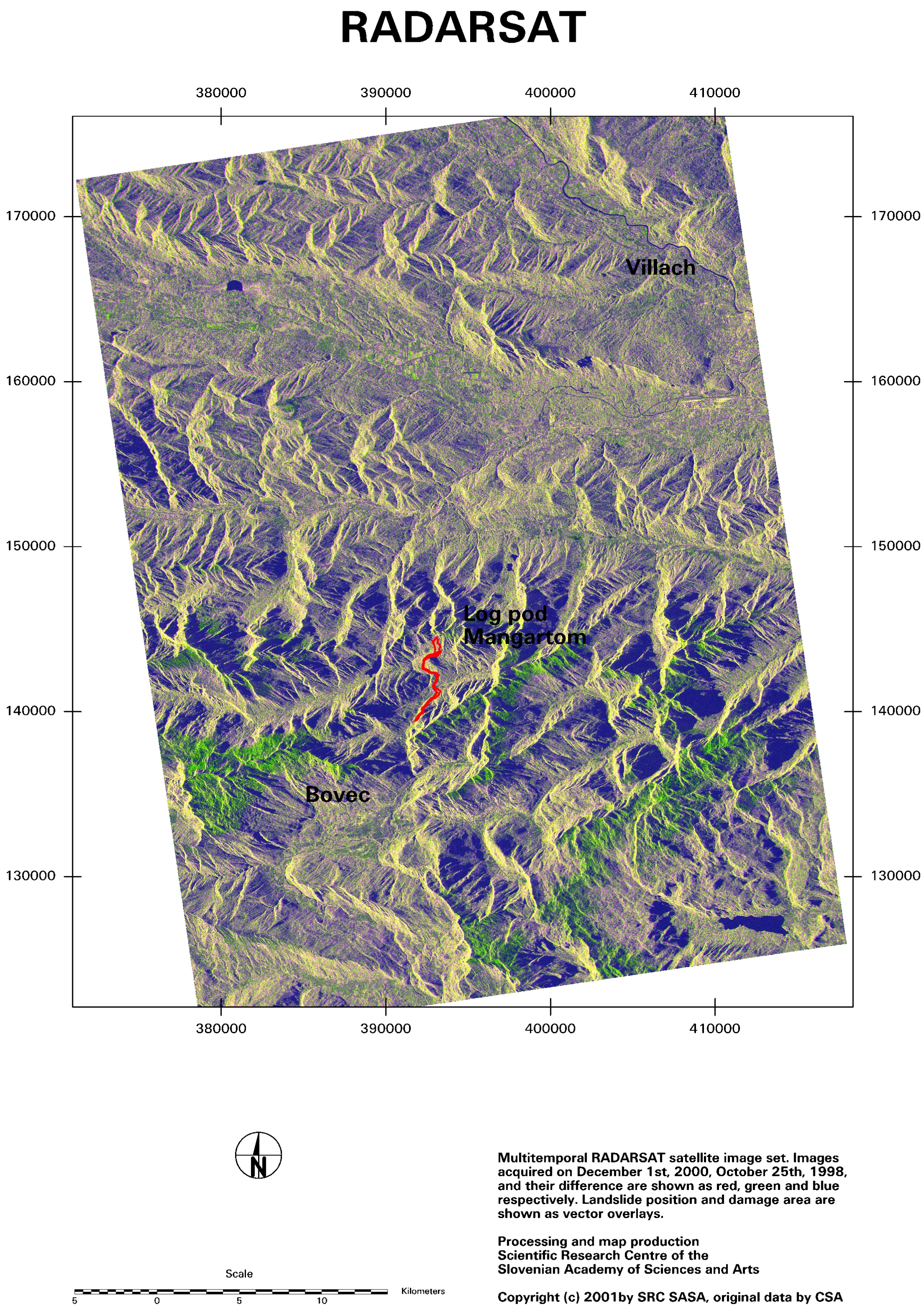


Figure 7: RADARSAT satellite map of western Slovenia.

6 SPOT

Observation of SPOT imagery, both alone and merged with ERS and RADARSAT imagery, allowed a more detailed insight into the consequences of the disaster. Two panchromatic (2000-08-21 and 2000-11-29) and two multispectral (2000-08-19 and 2000-11-29) SPOT scenes were used to detect the landslide and to evaluate its impact on the natural environment. As can be seen in Figure 10 on page 21, the landslide dramatically changed the valley of Log pod Mangartom. According to our estimates almost 76 hectares of forest, arable and urban land has been completely destroyed.

SPOT imagery interpretation allowed us to obtain the most accurate data on the slide and compare the situation before and after the event (maps in Figure 8 and Figure 9 on pages 19 and 20). The influence of the slide can be seen not only in the vicinity of Mangart and Log but further down the rivers Predelnica, Koritnica, and Soča. The landslide can be traced some 20 km downstream. The total area of the landslide is estimated to be approximately 26 hectares and the area of mud flow another 50 hectares. The interpretation of SPOT data was not straightforward, a consequence of the very low sun position in November (shadows were emphasised). In addition the November image (Figure 9) showed snow in higher areas and the August image (Figure 8) had some clouds.

A detailed analysis of landslide and damage area is presented in the following sections.

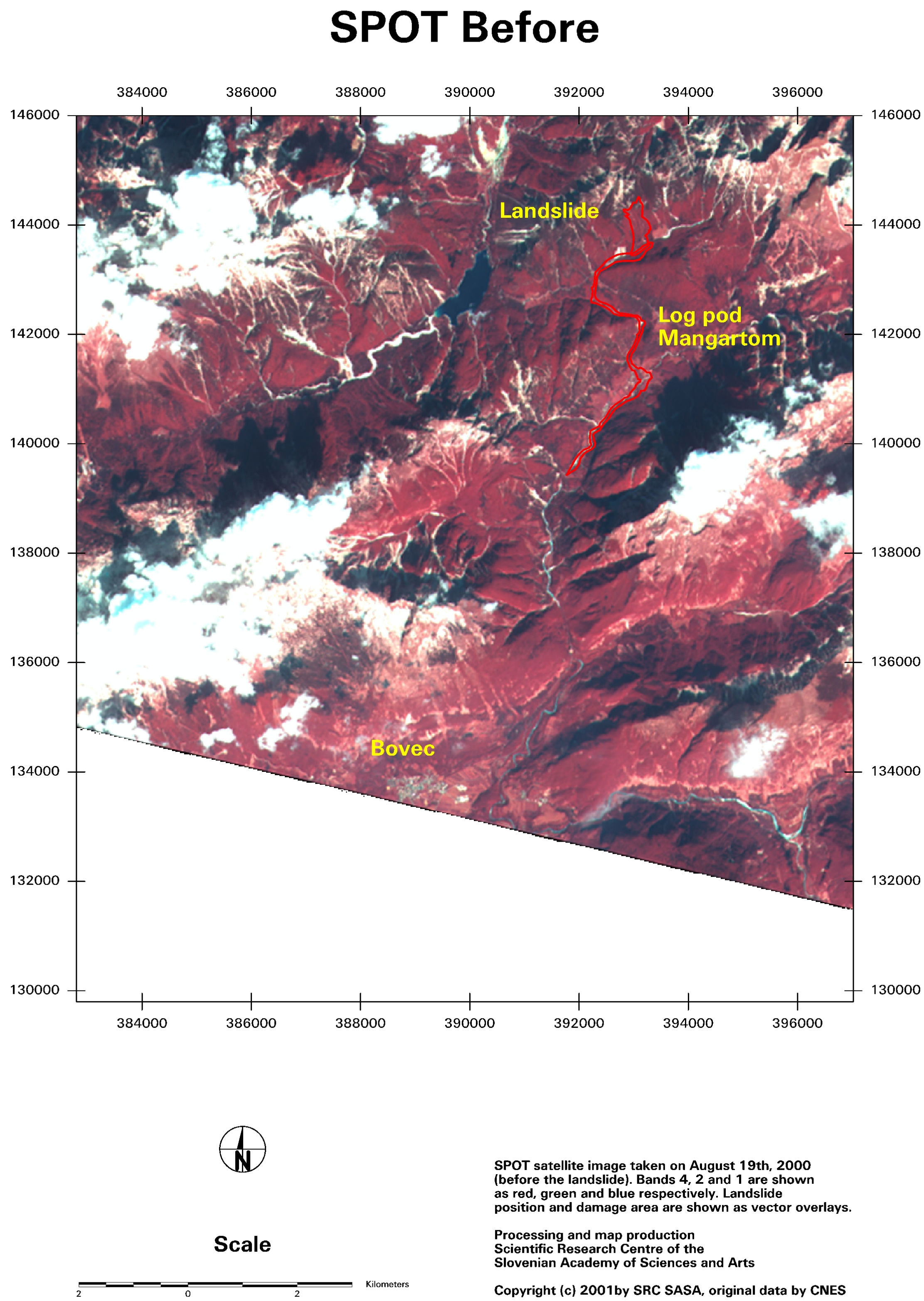


Figure 8: SPOT satellite map of landslide area (acquired on 2000-08-19).

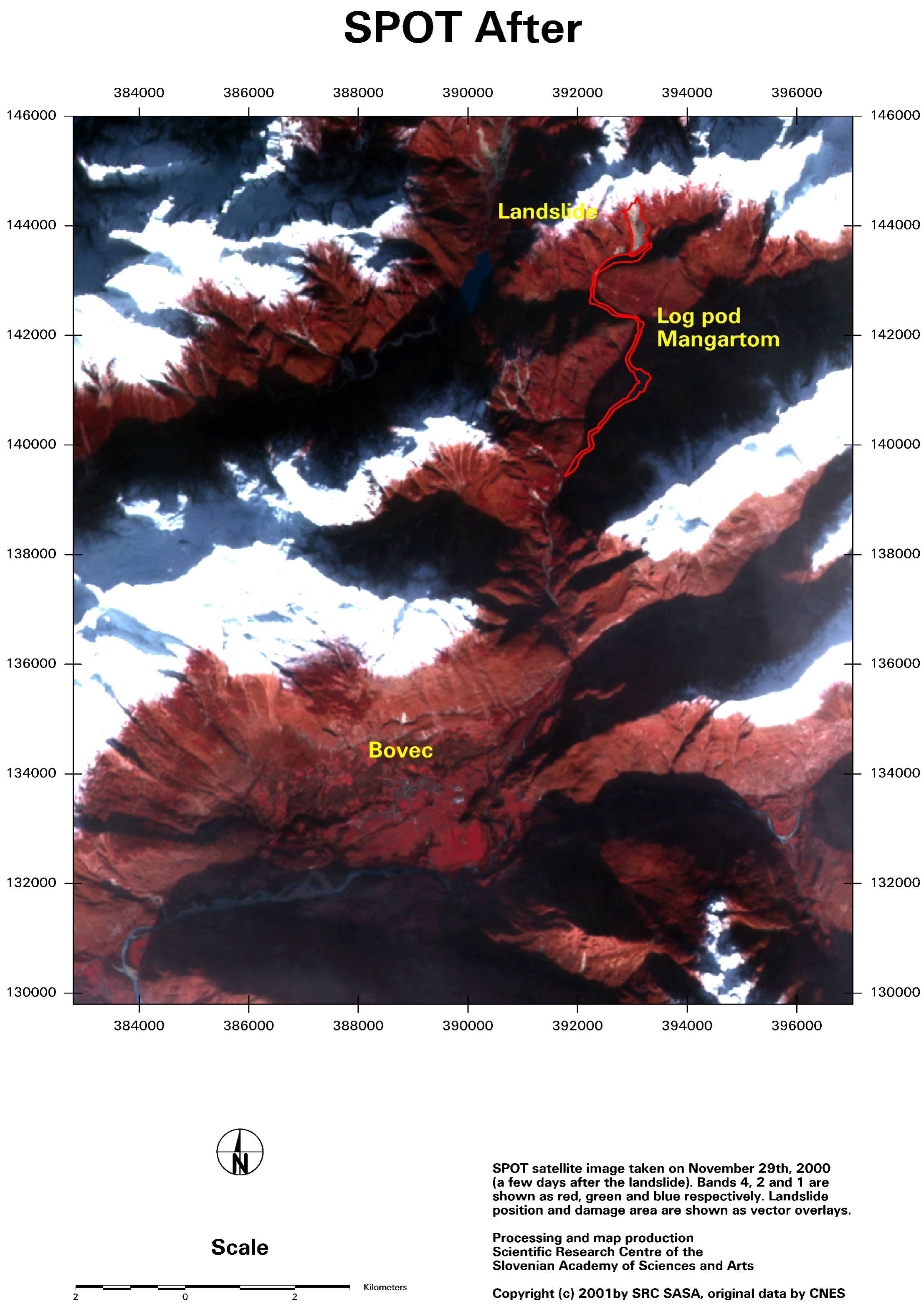


Figure 9: SPOT satellite map of landslide area (acquired on 2000-11-29).

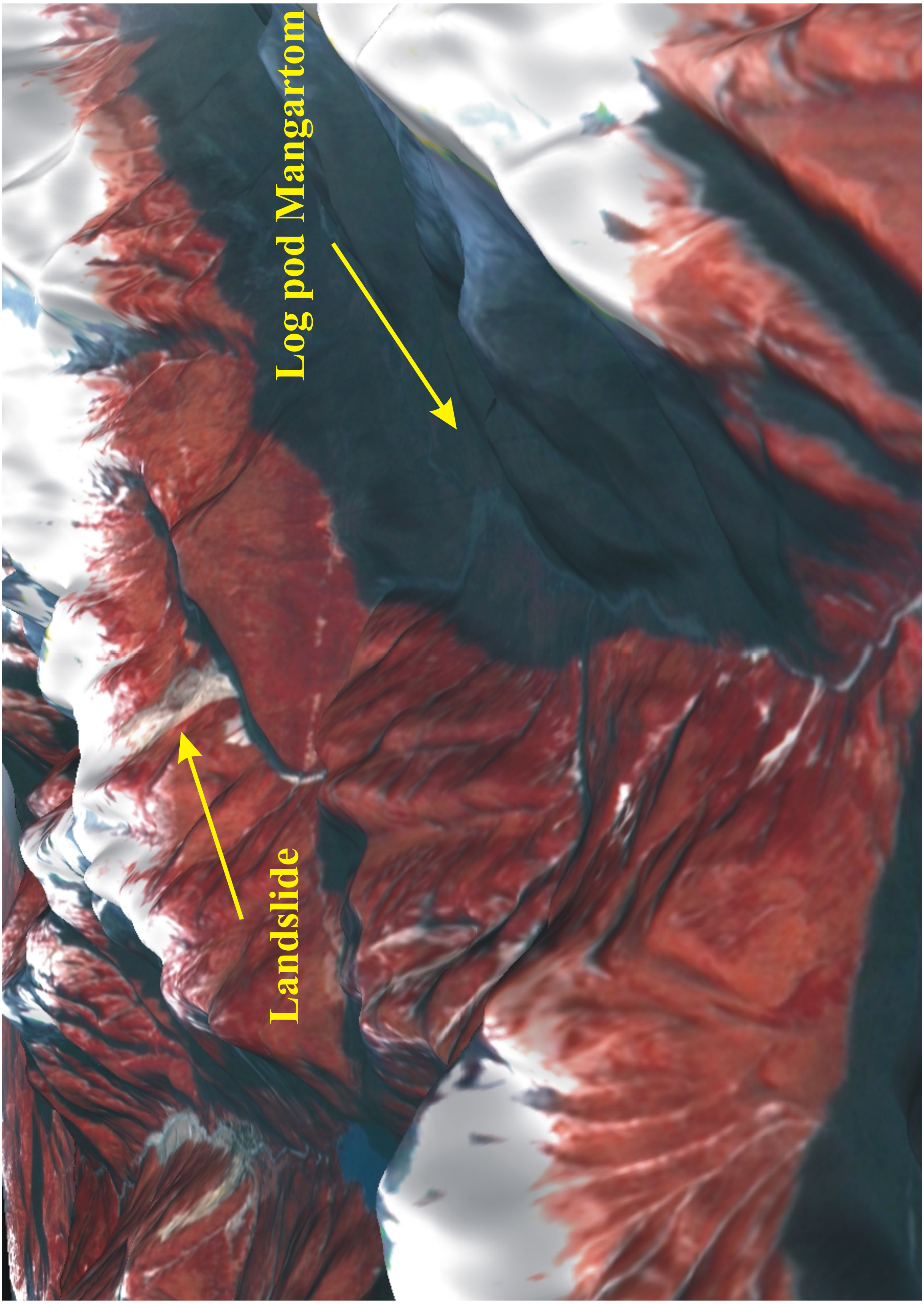


Figure 10: Perspective view of the area. A merged SPOT pan-multispectral image made on November 29th is draped over a digital elevation model.

7 GIS analysis

Image interpretation can give useful information, but it is often used only as a data source for GIS analysis. Therefore all satellite images have been integrated within a geographical database, together with the digital elevation model and landuse map.

Initially, the exact location of landslide and its direct area of influence were determined. Due to high spatial and spectral resolution SPOT satellite image, acquired on 2000-11-29, were used to isolate both areas. Afterward the areas were detailed in all remaining images, the digital elevation model and landuse maps. The estimated total area of the landslide, that is the area of the slipped land, is:

25.7 hectares.

The landslide, travelling for several kilometres, caused damage in the riverbeds of Mangartski potok, Predelnica and Koritnica. The additional area of destruction in the valley is therefore estimated to be:

50.1 hectares.

The influence of the slide could be seen more than 20 km along the riverbed of the Soča a week after the disaster. The total direct impact area on the other side is estimated to be:

75.8 hectares.

7.1 Digital elevation model

As already mentioned in Section 4, a digital elevation model was produced for the area via interferometric processing from ERS satellite images. Digital elevation model data (InSAR DEM 25) is shown in Figure 11 on page 24. Elevations in the map range from less than 500 m to more than 2500 m, the location of the slide and its impact area are shown as red vector overlays. From the elevations a slope map was produced (Figure 11 on page 25). Slope orientations are colour coded in the following way:

- North – dark blue,
- East – dark green,
- South – yellow, and
- West – brown.

Slope is shown as colour brightness, the darker the colour the flatter the area. Average elevation, slope and orientation were computed for landslide and its impact area. The results are listed in Table 2.

		Landslide	Impact area
Elevation (m)	Average	1386	824
	Std. dev.	109	243
Slope (%)	Average	24	19
	Std. dev.	6	12
Orientation (°)	Average	161	224
	Std. dev.	25	83

Table 2: Elevation, slope and orientation of the landslide and its impact area.

Table 2 shows that the landslide happened at an average elevation of almost 1400 m, at very steep slopes (24%) facing south-east (161°). Standard deviations for both slopes and orientations are small, showing that the landslide area is very homogenous. The impact area on the other hand lies much lower, approximately 800 m on average. It is also modesty inclined (19%), oriented to south-west (224°). The impact area is rather heterogeneous, with standard deviations from 2 to more than 3 times larger than that for the landslide.

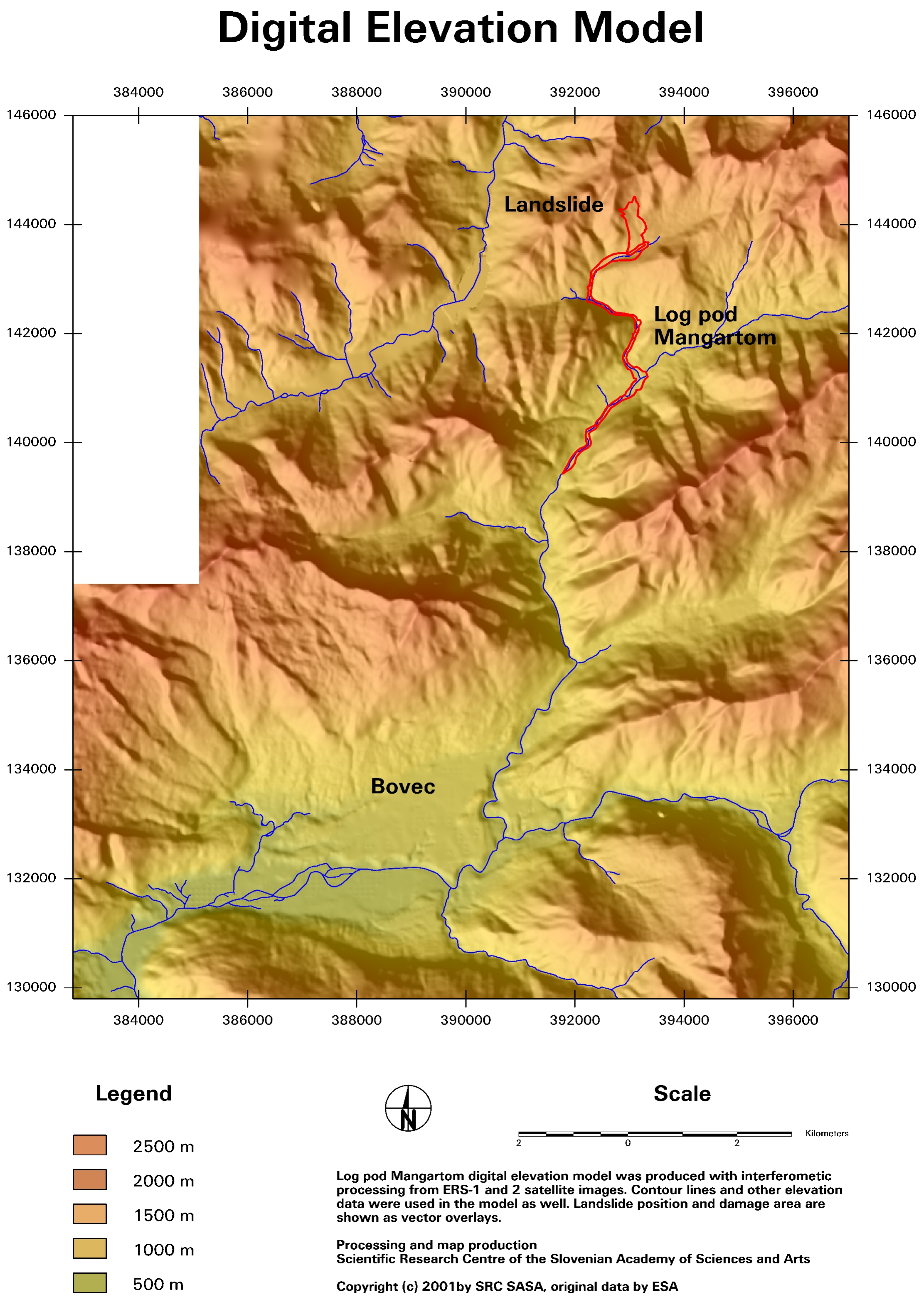


Figure 11: Digital elevation model of landslide area InSAR DEM 25 produced with radar interferometry from ERS images.

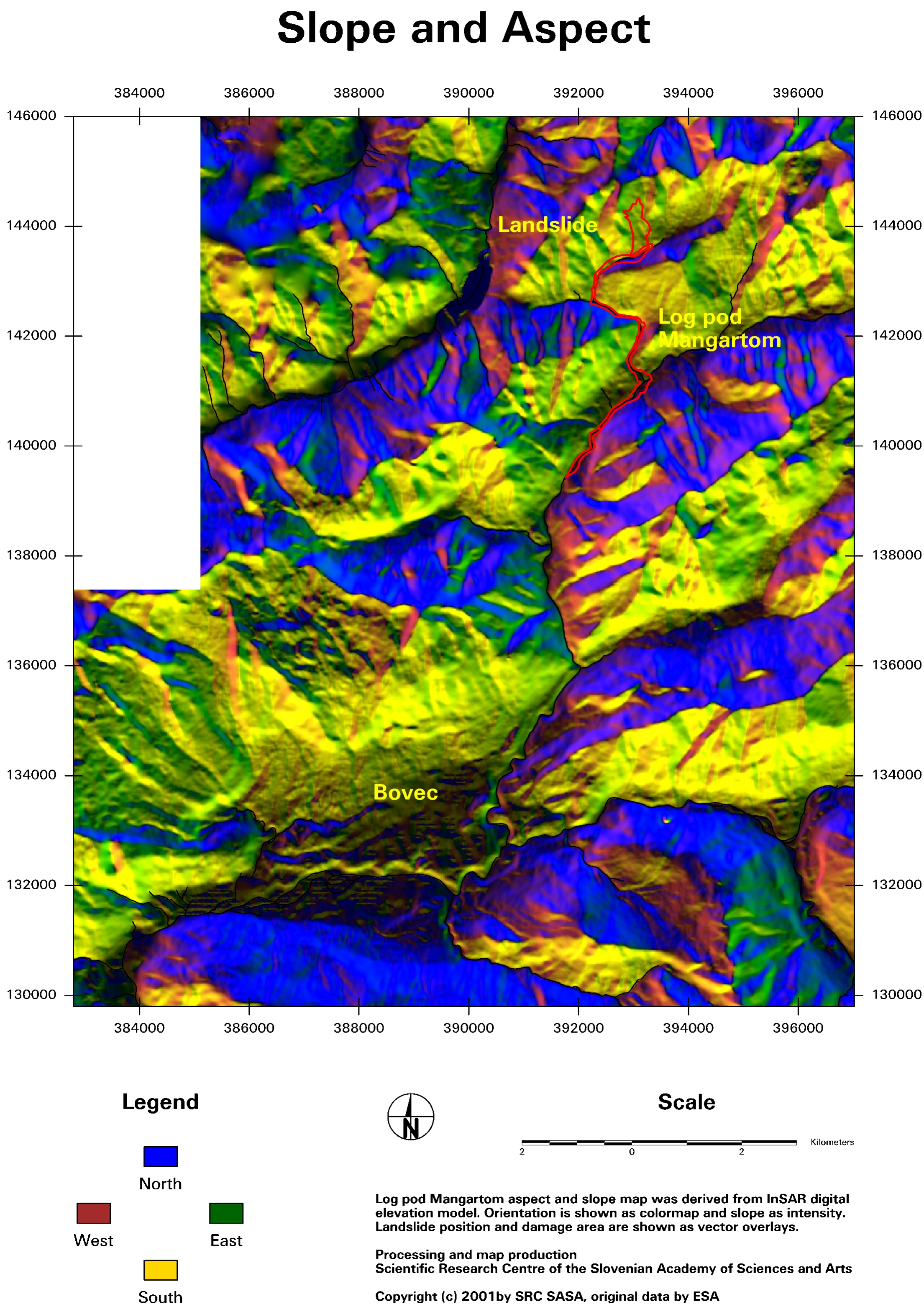


Figure 12: Aspect and slope, produced from InSAR DEM 25.

7.2 Landuse

Aside from the digital elevation model, landuse is amongst the most important of natural environment variables. Landuse map for the area of the landslide was produced from a combination of Landsat and SPOT images. SPOT could not be used as the only source of information, since the images contained clouds (2000-08-21) and snow (2000-11-29).

Classical supervised image classification has been used to obtain landuse. The land categories were divided into 10 classes:

- Urban – city centres, industrial objects.
- Built up – cities, dense villages, areas where houses mix with gardens.
- Individual houses – villages, suburbs, zones with considerable areas of "green".
- Coniferous forest – pine and fir forests.
- Deciduous forest – beech, oak, birch, maple and ash forest.
- Mixed forest – forest with equal amount of coniferous and deciduous trees.
- Bushes – low forest, bushes, forest edge.
- Water – lakes, rivers and other water surfaces.
- Agricultural – all types of agricultural areas.
- Open – bare soil, rocks, pastures.

Several test areas were used for each class. Learning samples were determined according to image interpretation, map comparison and knowledge of the area. Classification was carried out using the classical maximum likelihood supervised method. Some advanced post-classification techniques, such as elevation modelling and forest mixing were also used. The final landuse map is shown in Figure 13 on page 27. The estimated accuracy of the produced landuse map is approximately 90%.

An analysis of changes the landslide caused in the environment was carried out. Table 3 and Figure 14 (on page 28) show areas that were destroyed by the slide, in relation to landuse. The landslide, whose estimated surface is 25.7 ha, destroyed forests and almost three quarters of its area contained deciduous forests (74%), and small amounts of mixed forests (9%), coniferous forest (4%) and bush (1%). A considerable area of the landslide also covered open areas (14%), other classes were not present.

The impact area of the slide with its estimated surface of 50.1 ha was more heterogeneous, with almost exactly 50% of its area forests and bushes (coniferous 20%, deciduous 12%, mixed 11%, bushes 7%). The total percentage of forest was almost identical to that for the total area of Slovenia. There was also a notable amount of built-up land (3%) within the affected area and individual houses (4%) or 3.6 ha in total. Damage to agricultural land was also significant and estimated to 9.4 ha or 19% of the impact area. Other classes present were water (8%), including the rivers Mangartski potok, Predelnica and Koritnica, and open areas (16%).

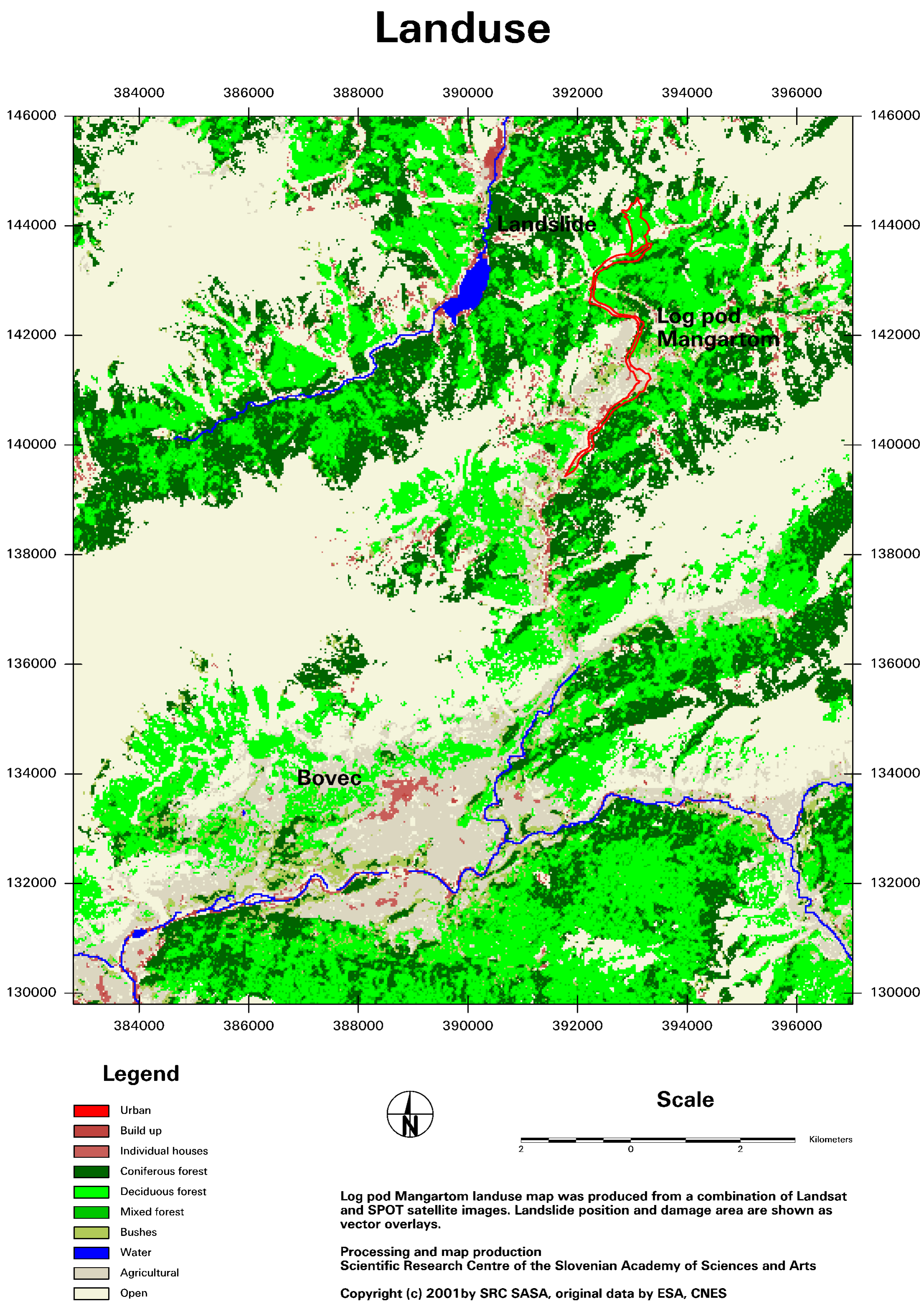


Figure 13: Landuse map produced from a combination of Landsat and SPOT images.

Class	Landslide Area (ha)	%	Impact area Area (ha)	%
Urban	0,0	0%	0,0	0%
Build up	0,0	0%	1,7	3%
Individual houses	0,0	0%	1,9	4%
Coniferous forest	1,0	4%	10,1	20%
Deciduous forest	18,6	72%	5,8	12%
Mixed forest	2,2	9%	5,4	11%
Bushes	0,3	1%	3,6	7%
Water	0,0	0%	4,0	8%
Agricultural	0,0	0%	9,4	19%
Open	3,6	14%	8,2	16%
Total	25,7	100%	50,1	100%

Table 3: Landuse categories in relation to the landslide and its impact area.

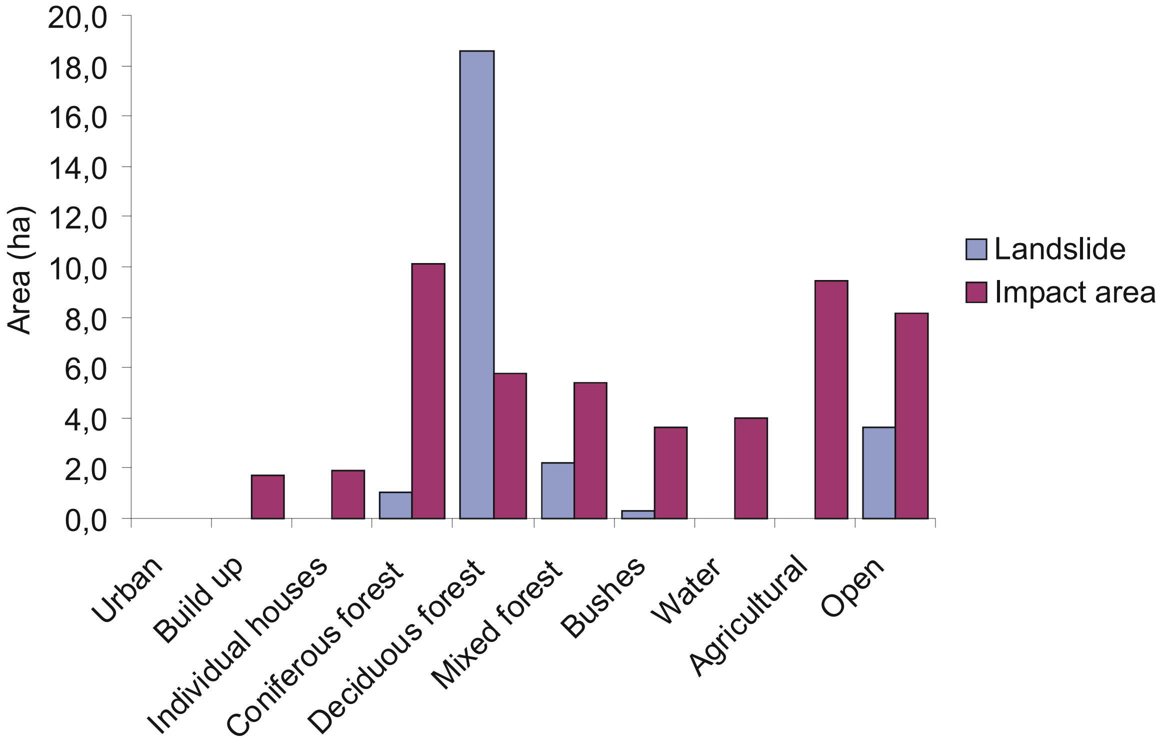


Figure 14: Landuse in relation to the landslide and its impact area.

8 Conclusions

The disaster below Mount Mangart is a classic case of the value of satellite remote sensing and an even better example for merging optical and radar data. The event happened in late November after several weeks of heavy rainfall. The extent of the slide is such that it can be detected via available satellite sensors. Unfortunately, due to heavy clouds and thunderstorms, the first SPOT image could only be made 12 days after the event. Nevertheless, optical images illustrate the situation very well and can be compared with archived data to evaluate damage.

Spectrally rich optical data could be supplemented with radar images, made on four dates before and after the event. The first radar image used here (ERS-2) was made seven days after the main slide occurred, and the second (RADARSAT) seven days later. As a consequence of the rough terrain, it is hard to detect the landslide and its consequences directly, but enhanced moisture can be seen even after several days. More information will hopefully be obtained via interferometric processing and intensive analysis of merged radar and optical data.

As a consequence of the stated goals of the report, a detailed analysis of satellite images was made before and after the landslide. The landslide has been identified on several scenes, most notably on the SPOT scene, acquired on 2000-11-29, which was used to outline both landslide and impact area. The total damage area was estimated to be almost 76 hectares – 26 ha representing the surface of the landslide itself and 50 ha its impact area. A digital elevation model, made from ERS images through radar interferometry, was used to analyse the relationship of the disaster to topographic elevation. The landslide occurred on steep south-east facing slopes, at an average elevation of approximately 1500 m. The area destroyed in the valley was more heterogeneous with respect to slope, elevation and orientation. To estimate damage in the natural environment a landuse map was produced from Landsat and SPOT images. Evaluation of landuse demonstrated that the landslide happened mostly in areas covered by deciduous forest (almost three quarters of its surface). The landslide impact zone is again more heterogeneous, half of it being covered with forests. There were also significant areas of damage to agricultural land (9.4 ha) and built up areas (3.6 ha).

The Log pod Mangartom landslide study has proven the value of remote sensing technology for monitoring natural disasters and the usefulness of the »Space and Major Disasters« Charter in particular. It has shown that remote sensing can be used in rescue operation, when real time observation is needed and in the estimation of damage, when processing speed is less important than the quality of the results.

9 References

Blonda, P., G. Satalino, A. Baraldi, J. Wasowski, M. Parise, A. Refice, and M. Pappalepore, Soft computing techniques for integration of SAR intensity and coherence images: an application to the study of a landslide-prone area, in Proceedings of the 'Fringe 99' Workshop on ERS SAR Interferometry, European Space Agency, Liege, 1999.

Fruneau, B., C. Delacourt and J. Achache, Observation and modelling of the Saint-Etienne-de-Tinée landslide using SAR interferometry, in T.D. Guyennne and D. Danesy (eds.), Proceedings of the 'Fringe 96' workshop on ERS SAR interferometry, European Space Agency, Noordwijk, 1997.

Gens., R., Quality assessment of SAR interferometric data. International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands, 1998.

Oštir, K., Analysis of the influence of radar interferogram combination on digital elevation and movement models accuracy, University of Ljubljana, Ljubljana, 2000. (PhD thesis in Slovenian)

Lillesand, T.M and R.W. Kiefer, Remote sensing and image interpretation, John Wiley & Sons, New York, 1994.

Stančič, Z. and K. Oštir, Tectonic movements in the area of the Nuclear Power Plant Krško, ESA AO3-336 final report, Scientific Research Centre of Slovenian Academy of Sciences and Arts, Ljubljana, 2000.

Stančič, Z. and K. Oštir., Remote sensing and Log pod Mangartom landslide, presented at the meeting titled The landslide Stože and its consequences on Log pod Mangartom, organized by the Civil Protection authority of the Republic of Slovenia, Ljubljana, 2000-12-05.

Public Relation and media offices, Danger not yet over in Log pod Mangartom, Government of the Republic of Slovenia, 2000.

http://www.uvi.si/eng/new/press/data/press/2000-11-20_2000-11-20-145644.html

Richards, J.A., Remote sensing digital image analysis: an introduction, Springer, Berlin, 1986.

Sabins, F.F., Remote sensing: principles and interpretation, Freeman, New York, 1997.

Vitrum, Tragedy Below Mangart Mountain, Slovenia weekly, 2000.

http://www.vitrum.si/sw/sw2000-46/index.html

Vitrum, Natural & Cultural Trails – Log pod Mangartom Triglav National Park, Slovenia weekly, 2000.

http://www.vitrum.si/sw/sw2000-46/index.html

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