NRSP-2
00-24

ASMON
Alpine monitoring for ski resorts using high-resolution remote sensing imagery

Resource Analysis
University of Amsterdam
Stand Montafon
Silvretta Nova

BCRS 00-24 MD

COMMISSIE REMOTE SENSING

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Acknowledgements

The ASMON project has been a remarkable project in terms of both team spirit and quality of the delivered products. From the beginning, it was clear that a group with a different background had a professional attitude towards the, in many cases new and challenging material. The outstanding group synergy was not only found during the official meetings, but also remained as continuity during the whole project. The communication went therefore quick and reliable.

Besides the ASMON project team, a number of persons have been involved in the project being an important factor for the success of the project. In this respect, I would like to thank Ingrid Janssen and Gerard van der Kolff for their inputs from the BCRS, Luuk Dorren and Harry Seijmonsbergen from the University of Amsterdam for their hard and enthusiastic work and of course all the end users from Stand Montafon and Silvretta Nova for their useful comments and suggestions.

Knowing the ASMON products and the pool of experts around the project, it has no doubt that there is more future potential.

Joris de Vente
(Project Manager)

Abstract

The ASMON project aims at showing how space technology can provide a cost-effective assistance in the environmental monitoring and maintenance of ski regions and to develop a monitoring and management information system (MIS) which supports the sustainable development of ski regions.

To achieve this goal the following products have been created: snow cover maps, hazard maps, land cover and land cover change maps, detailed monitoring and high quality presentations of ski areas and 3D visualisations. All these products have been integrated in a Management Information System (MIS).

A CD-rom of the ASMON project, including the Management Information System, is available on request by sending an e-mail to: Joris.de.Vente@resource.nl.

From the positive reactions from the end-users, one can say that this approach proved to be successful.

Executive Summary

Millions of tourists come to Mountainous regions every year for ski tourism. In order to deal with this seasonal flow of tourists in the region, ski area managers have to find a balance between human demands and the boundary conditions offered by the environment. This means that the ski area has to be designed for maximum efficiency. Efficiency is especially important because of the limited space and sensitive character of the ecosystem.

The ASMON project demonstrates the use of space technology as an assistance in the management of ski resorts. The use of space technology was demonstrated for information supply, impact assessments and presentations, all necessary for the management of ski resorts. Therefore, several products were developed for different specific purposes, varying from planning to monitoring and marketing. All products were integrated in the framework of a Management information System (MIS). This MIS can be used by ski area managers to design for example the most optimal location of a new ski lift using Multi Criteria Analysis.

ASMON demonstrates the use of space technology and development of a MIS for a ski area (Silvretta Nova) and a forest organisation (Stand Montafon) responsible for the forest management in the ski area in the Montafon (Austria). Below the major products are briefly introduced.

Snow Cover maps. Variation in snow cover is very important factor since it influences for example flora fauna and hazards like avalanches. Landsat MSS images were used for the classification and monitoring of snow cover development in the area. Conventionally point measurements are used for inventarisation of snow cover development. However, interpolation between these point measurements is always troublesome, and only for relatively small areas reliable information ca be obtained. The big advantage of the remote sensing based approach is that large areas can be treated at once with a consistent methodology.

Land cover classification and change detection. For detailed impact assessments it is essential to have up-to-date information on land cover and even more important the development of land cover over larger time spans. In the ASMON project a detailed and up-to-date land cover classification was made with Landsat TM images. Furthermore an inventory was made of the changes occurring in forest cover over the last 15 years. This gives important insight in the impact of ski area expansion for forest cover. the conclusion of this study was that forest cover in the Montafon actually increased over the last 15 years.

Hazard mapping. As part of the study, especially important for planning purposes, a hazard map was created by the University of Amsterdam. These maps contain a broad range of information concerning the geomorphology in the study area. The maps form an essential role in the ski area planning tool for selection of best locations for possible expansion. The creation of the maps starts with a detailed interpretation of stereographic aerial photographs, followed up by a detailed geomorphological field study.

Detailed monitoring and high quality presentations. In the last stages of the project an IKONOS image of the study area was delivered. The high resolution of these images make a very detailed monitoring of land cover changes possible. Furthermore the images are very well suited for presentation purposes. Because of the late delivery of the images in the project, they were only used for rapid land cover assessment and for presentation and promotion purposes of the ski area. Posters of the area were made by presentation of an image merge with an overview an details of lifts and pistes.

3D visualisation. Another very attractive tool for both visualisation of effects and for promotion purposes are 3D presentations. These presentations are used for both representation of the current situation and for the visual impact of user defined measures like creation of a new ski

piste. The presentations are made by overlying a DEM with a classified satellite image. Now in this image 3D objects like lifts, houses and trees are positioned. Through these images also virtual flights can be defined and in the near future even made available through the Internet.

Management Information System. Given the complexity of planning in Alpine regions, a Management Information System was developed to assist institutions in defining the most optimal solution. The MIS therefore integrates access to a GIS database with background information of the area, a management evaluation tool based on Multi Criteria Analysis and advanced 3D visualisations to show the visual impact of measures.

All separate products, including the MIS have been developed in close co-operation with the end users. The end users are very positive about the role that space technology can play in management of a ski area or forest organisation.

1 General Introduction

1.1 Introduction

Currently, about 60 million ski tourists around the world are using the facilities of the ski resorts. To cope with yearly flow of tourists concentrating in the winter period, ski resorts are planned and designed for maximum efficiency. High efficiency is needed since due to the natural topography of mountainous areas space is limited and construction of large infrastructure works as roads and urban areas is troublesome. Moreover, alpine ecosystems are among the most sensitive systems, reacting quickly to disturbances such as human influences. Altogether, the complexity of managing a ski area is large taking into consideration the economic and tourist demands as well as the highly vulnerable environment in which the exploitation of the area takes place.

One of the objectives of the ASMON project was to demonstrate how space technology can supply accurate information on the impacts and interactions of economic demands and the sustainable use of the environment. The developments within the field of remote sensing have caused a change in man's ability to monitor and understand the earth, by the use of advanced sensors, which gathered data over the last 30 years. The resulting information is used in resource exploration and development including the creation of base maps, identification of exploration prospects, planning operations, suitability mapping and delineation of environmentally sensitive areas requiring extra surveillance to monitor impact from exploration.

Space technology can be a cost effective information tool for regional and national authorities to preserve natural resources and improve socio-economic activities and ski region managers for monitoring aspects to come to a more efficient management. Within this context, the key words for bridging economic and environmental interests using remote sensing information are: Efficient Maintenance Support, Improved Monitoring capacity for resource management and environmental impacts.

1.2 Background

For detailed environmental impact assessments and monitoring studies, up-to-date and reliable information on land cover and the changes occurring in it is essential. For example, for studies regarding the health and amount of forest disappearing as a result of expansion of tourist industries detailed monitoring is needed of forest cover development over large time spans. On the other hand for promotion of ski areas it is also important to have good visualisations and to provide information on snow cover development throughout the year. This kind of information plays a crucial role in the planning of for example new pistes and hotel accommodations. Therefore, detailed monitoring of land cover features is relevant for a wide range of environmental applications dealing with subjects like environmental protection and land degradation, but also with socio-economic related subjects like urban expansion and planning of new infrastructure.

In the Montafon area, over the past centuries large changes have taken place in the tourist industry related to skiing activities. This in turn has an influence on forest cover and forest management. In general in Europe, the scale in time and space of land use changes increased dramatically during the last decades. According to the ECNC seminar on land use changes (Jongman, 1996), three processes should be distinguished clearly: intensification, marginalisation and extensification. Intensification is considered as a key activity in the development of modern society. In agriculture the use of fertilisers, machinery and fossil fuel made it possible to increase production levels. The continued increase in production per unit of land area and per unit of livestock, due to improved production circumstances, better cultivation methods and external inputs, has led to significant increases in agricultural productivity. However, land use intensification in one area might cause marginalisation in other areas. Marginalisation indicates the process of disappearing functions because of its unprofitability. It can be found in all kind of activities from industry to forestry and agriculture. Marginalisation must be distinguished from extensification because the latter indicates only changes in the way of using the land, but does not imply an socio-economic context. Both marginalisation and intensification are seen as threats to the landscapes of Europe. Related to the skiing industry there is a clear intensification of land use for tourist activities. However, on the other hand also marginalisation and extensification occurs in alpine regions. One of the reasons for this is for example the idea of sustainable tourism and minimal pressure on the environment.

The ASMON project aimed to demonstrate the use of especially high-resolution imagery for detailed monitoring of environmental impacts related to ski areas. This included several applications among which snow cover classification, change detection, land cover classification and high quality visualisations for 3D Internet application. Subsequently, all environmental information was integrated in a planning tool that allows a thorough analysis of effects of certain changes in infrastructure within the ski area.

1.3 Objectives

The overall objectives of the ASMON project are formulated as follows:

> *The ASMON project aims at examining how space technology can provide a cost-effective assistance in the environmental monitoring and maintenance of ski regions and to develop a monitoring and management information system (MIS) which supports the sustainable development of ski regions.*

From this main objective a number of sub-objectives can be derived:

1. What are typical management issues within ski resorts, how are they solved now and how could remote sensing information contribute in solving these problems?

2. Can we build a management information system that supports a manager in solving ski resort issues and how can we take advantage of the possibilities offered by remote sensing techniques in this?

3. Can we detect snow cover and duration with remote sensing information?

4. Can we classify land use and land use changes within ski regions and quantify these changes in usable and reliable units?

5. Is it possible to use remote sensing information to generate 3D animations, which can be used for planning, and marketing purposes?

2 User Requirements Definition

2.1 Introduction

In order to have a useful and reliable product at the end of the project, the ASMON consortium was set-up to include institutes & companies that are potential clients of the products. Therefore, the Stand Montafon and Silvretta Nova were both asked to be part of the consortium. The Stand Montafon is a forestry organisation with the task to maintain the forest and protect it against excessive impacts from amongst other things the pressure from the ski industry. On the other hand, Silvretta Nova is a skiing company in the Montafon area. Their goal is to maintain the ski region in a sustainable way and also promote their area to potential tourists.

Part of the motivation for impact assessments and environmental monitoring comes from the end users themselves, but also part comes from external legislation. There is a wide range of laws that are to be followed when maintaining or extending a ski area. The most important Austrian laws are:

- Gesetz über Naturschutz und Landschaftsentwicklung, LGBL. Nr. 22/1997 - *All ski area and ski facility extensions have to be approved by this law*
- Wasserrechtsgesetz 1959 i.d.g.F. - *Particularly artificial snow facilities have to be approved by this law*
- Eisenbahngesetz 1957 i.d.g.F. - *All ski lift facilities have to be approved by this law*
- Gewerbeordnung 1994 i.d.g.F. - *Laws concerning trade and commerce*
- Vlbg. Baugesetz 1972 i.d.g.F. - *All building applications have to be approved by this law*
- Sportgesetz LGBL.Nr. 15/1972 i.d.g.F. - *Law concerning all sport activities*
- Forstgesetz 1975. - *Extension and building of new ski runs, as far as forest ground is concerned, have to be approved by this law*

As may be evident, both mentioned end users of the ASMON products have some similar and some user specific requirements with respect to information for their management purposes. In the following paragraphs the specific user requirements for both end users are summarised. These requirements formed the starting point for the development of products in the ASMON project. In the next Chapter the required materials (both Earth Observation (EO) and non-EO) and the first pre-processing steps are described.

2.2 Requirements of the Silvretta Nova ski area

The company Silvretta Nova (SN) manages a skiing area of about 100 km^2 in the Montafon mountains (Vorarlberg, Austria) and accompanying restaurants, some hotels and other required tourist facilities. Furthermore, SN is the main employer within the valley, therefore tourism is the most important revenue for the whole valley. SN participates within ASMON to:

- retrieve snow cover data;
- retrieve land use (change) data;
- establishing a hazard monitoring system;
- develop a 3D Internet application.

2.2.1 Socio-economic impacts

The following paragraphs present an argumentation for each desired product on socio-economic grounds.

Snow cover data

Since tourism is the most important source of revenue in the Montafoner valley, the competitiveness of companies like SN has to be increased. To achieve this, these companies are forced to make ad hoc decisions more fact-based. Therefore accurate spatial information about snow cover at different times during the winter season is needed for the planning of artificial snowing installation, ski run preparation and planning of further ski area extensions.

Land use (change) data

Land use data enable a quantification of the amount of land that is used for various activities within the skiing area. This is needed for the following reasons:

- quantitative land use information (also compared with historical information) could serve as a valuable base for arguing in ski facility extension projects;
- quantitative land use information is an important base in negotiations with property owners concerning contracts to use their land for skiing purposes;
- quantitative land use information serves as a integrative data source for the evaluation of the magnitude of land use changes in connection with winter tourism and has to be seen in close contact with forest cover change;
- land use data would serve as a basis for long-term studies concerning environmental sociability of intensive winter tourism.

Hazard monitoring system

Ski areas within the Alps have to deal with natural hazards. Not only avalanches, but also landslides, slumping, and sometimes debris flows. A hazard monitoring system indicates where these hazards could occur, and how active the natural process is. Such a hazard monitoring system is based on hazard maps of the ski area and its surroundings, historical data on avalanches and mass movements, combined with remotely sensed data. To monitor hazards within the ski region, a criteria list has been constructed by the University of Amsterdam. These criteria can be used to check potential high hazard zones within the SN ski region.

3D Internet application

SN has to compete with surrounding ski areas and increase its number of tourists every year, and is therefore interested in a marketing oriented Internet site to promote the ski area. SN managers started to advertise their offers on the WWW and believe that this way of advertising will increase rapidly in importance during the coming years. An application based on high resolution remote sensing images, which enables flying through the ski area on Internet is an excellent example of ski area promotion.

2.2.2 *Environmental impacts*

SN aims at a sustainable management of the environment. An environmental analysis of the ski and surrounding area is needed as back up for their current environmental strategy. Remote sensing can provide this required data. It concerns data on snow cover, land use, and natural hazards. The current environmental strategy of Silvretta Nova includes the following aspects:

- Waste water management throughout the whole ski area, including a drainage system from the mountain restaurants to the valleys;
- Silvretta Nova invests in reforestation programs, monitoring of the vegetation cover on the alpine meadows within the ski area;
- Only water and air is used for artificial snow;
- Only 1,65 % of the total community area is used for ski runs;
- Modern technology is used in order to save energy in all restaurant facilities.

The following paragraphs present a justification for each desired product on environmental grounds.

Snow cover data

Because there is a trend of warmer winters within most alpine valleys the last years, snow security becomes the most important factor in ski area management. Current planning addresses this problem and shows a trend of the construction of new lift facilities at higher altitudes. Snow cover data can indicate the spots where artificial snow is needed in regions at lower altitudes. An efficient management of artificial snow could decrease the wasting of water and decrease the exploitation of higher located regions. It also indicates regions that should not be used at all, because of a low snow cover during the whole winter season.

Land use (change) data

Data on land use is required to determine the ratio preserved natural land and land used for ski tourism. Comparison of land use maps of different years provides information on land use changes within and around the ski area. With these data the amount of forest cover within the skiing area can be determined. The land use maps are eventually stored within a GIS database of the ski area. This GIS database contains spatial information on geomorphology, geology, average snow cover, artificial snow installations, infrastructure, ski runs, housing and other tourist facilities.

Hazard monitoring system

Ski facility extension projects respectively replacement projects need engineering geological consultant evaluation. Hazard maps could therefore serve as an additional information source for such projects, which allows to address natural hazard evaluation already during very early planning stages. This could result in more comprehensive measures like construction of artificial drainage systems on dangerous slopes (landslides).

3D Internet application

The situation up till now is lacking 3D models: conventional (painted) distorted panoramic views of the ski area (a summer and a winter picture). There is a need for a presentation that can easily be updated (new ski runs, sledging routes, winter hiking paths etc.). This ski area visualisation should include all lift facilities, restaurants, ski runs, info terminals etc.). Therefore it is important to produce GIS data layers with such information to superimpose on the surface model.

2.3 Requirements of the Stand Montafon

The Stand Montafon consists of three departments:

1. a local political department;
2. a waste water management department;
3. a forestry department.

Especially the forest department participates within ASMON. The forestry department is responsible for the maintenance and restoration of the forest in the Montafon area, including the forest within the Silvretta Nova ski area. The forestry department of Stand Montafon participates within ASMON to derive:

- forest cover data
- land use and land use change data
- hazard maps & risk assessment

2.3.1 *Socio-economic and environmental impacts*

Forest cover data

Many hectares of forestland were cut during the expansion of skiing facilities in the Montafon valley to build ski runs and lifts. Forest cuttings have to be compensated with replantations at other sites. Replantation is necessary because mountain forest has a huge impact on the hydrological regime and the protection against alpine hazards ('Schutzwald'). But there is no quantitative information of how much forestland was exploited for winter tourism and on the other hand how much land the forest reoccupied after decline of agricultural usage of alpine meadows. Like winter tourism there are more projects where forest is cut away. Stand Montafon needs to quantify the amounts of forest that have to be replanted, therefore up to date forest cover is a necessity.

Land use and land use change data

This is identical as described within the Silvretta Nova section.

Hazard maps & risk assessment

Stand Montafon needs hazard maps for forest management. As described earlier, Stand Montafon is responsible for replantation of forest. For the planning and execution of these activities Stand Montafon needs information on the magnitude and frequency of natural hazards in the working area. Another activity of Stand Montafon is the maintenance of 'protection forest' ('Schutzwald'). Such a protection forest functions as a safety zone along infrastructures and urban regions. Hazard maps indicate what, where and which hazards are active. Sometimes it is necessary to cut parts of a forest to decrease the risk of a natural hazard. E.g. the volume of wood that can be transported by a natural hazard within a woody flow mass, could increase the hazard. This preventive forest cutting can be planned on the basis of hazard maps. Field hazard maps for the whole Montafon area are not available. Therefore, this hazard map has to be derived from a method based on remotely sensed data, which is developed in the ski area, where detailed field data is available.

Risk assessment is a more extensive assessment compared to hazard assessment. A large number of publications in recent years have dealt with natural events and their impact on human activity. In these works themes as hazard, risk, and vulnerability have been used with different meanings by different authors. The need for clarification of meanings had been recognised: hence, within the United Nations organisations of UNDRO (Office of the United Nations Disaster Relief Co-ordinator) and UNESCO the following definitions in English have been proposed:

• natural hazard (H) means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon;

• vulnerability (V) means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss);

• specific risk (Rs) means the expected degree of loss due to a particular natural phenomenon. It may be expresses by the product of hazard times vulnerability;

• elements at risk (E) means the population, properties, economic activities, including public services, etc. at risk in a given area;

• total risk (Rt) means the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon, and is therefore the product of specific risk (Rs) and elements at risk (E). (Varnes, 1984)

Thus for a risk assessment in the Montafon a risk assessment can be conducted on the basis of hazard maps if additional information on the number of habitants, economic activities, properties, etc. are available for each hazard zone.

2.4 Current approach to the requirements

Traditionally there was no need for quantitative information on land use, environmental impact and hazards. However, at present environmental restrictions make such information necessary in arguing a case of ski area extension, artificial snow installation or replacing existing facilities. Until now planning and management of the ski area was based on long-term observations (no quantitative data). A quantitative assessment or an overview of the results of management decisions within the skiing area is not available using the current methods. To obtain an overview without remotely sensed data an overall measuring and mapping program within the skiing area would be needed. Remote sensing can provide the required information without such an extensive field-monitoring program and is therefore more cost effective.

Until now, there was no quantitative information on spatial distribution of forest cover other than old maps and aerial photos, no information on forest cover change, no information on hazards within their forest management region currently available. There is a need for these data. At present some GIS layers are produced from older maps and aerial photos. Furthermore conventional forest maps are used. But lacking is a detailed, accurate overview of the region that is managed by Stand Montafon.

Appendix A presents in more detail the results of a feasibility study applied within the ASMON project. In this study the methods applied in the ASMON project are compared to non- remote sensing based methods such as field campaigns and updating statistical information.

3 Materials and Data pre Processing

3.1 Introduction

This Chapter describes the collected data that is required to fulfil the defined end-user requirements as described in the previous Chapter. If the required parameters for the customer requirements are defined, it is necessary to define whether these parameters can be obtained from EO data or non-EO data. An important consideration for required data is to define what dates are useful to analyse or to detect changes by means of satellite images as a result of skiing activity. In addition, very important is the resolution that is chosen for the used data. Further, the (geo)reference system for referencing images and maps is also of importance. The georeference systems should be adapted to the customer requirements (local projection) instead of converting all maps to a uniform reference system.

Since there is a large amount of non-EO data, a distinction has to be made between useful and useless non-EO data. In the following paragraphs, first an overview is presented of spaceborne remote sensing systems used within the ASMON project and then different information types of non-EO data are described.

3.2 Applied EO and non EO data

Table 3.1 presents the EO data as applied within the ASMON project to come to the user requirements. The next two tables present the applied non-EO data within the project.

Table 3.1 EO data for the requirements of Stand Montafon and Silvretta Nova

Sensor type	**Resolution/ scale**	**Date**	**Format**
Landsat MSS	56m x 79m	23.07.78 04.09.80 30.08.81 03.07.85 29.03.85 24.05.85 09.06.85	PCI
Landsat TM	30m x 30m	03.07.85 30.05.90 28.05.95 28.01.98 09.09.98	PCI
IRS	5.8m x 5.8m	25.09.97	PCI
Aerial photographs of the Silvretta Nova area	1 : 18.000	1987	hardcopy
Digital Orthophotos of the Silvretta Nova area	0.5m x 0.5m	1987	TIF
Digital Orthophotos of the Montafon area	0.5m x 0.5m + 0.25m x 0.25m	various years	TIF

Table 3.2 Non-EO data applied for the requirements of Stand Montafon

Non-EO data	Resolution/scale	Date	Format
Topographical map ÖK50	1 : 50.000	1995	TIF
Contour lines 100m + 20m	Scale of base data was 1 : 10.000	1990	Vector
Forest Road map	rel. accuracy ± 5-10m	1995	Vector
Forest cover maps	rel. accuracy ± 5-10m	1990	Vector
Geological map	1 : 200.000	1999	Polygon map
Forest cover change map	30 x 30m	1998	Polygon map
Forest cover map	30 x 30m	1998	Polygon map
DEM	50 x 50m	1998	ASCII - xyz
DEM	25 x 25m	-	ASCII - xyz

Table 3.3 Non EO data applied for the requirements of Silvretta Nova

Non-EO data	Resolution/scale	Date	Format
Snow cover data, Ski tourism info, Meteorological data		Nov. + March, best year	TXT files
Snow cover map	57 x 82m	1985	Polygon map
Topographical map ÖK50	Pixel = 2.5m	1998	TIF
Geomorphologic hazard map	1 : 10.000	1999	Polygon map
Land use map	30 x 30m	1998	Polygon map
Land use change map	30 x 30m	1998	Polygon map
Contour lines 100m + 20m	scale of base data was 1 : 10.000	1990	Vector
Lift axes	± 1 - 2m	1999	Vector
Ski runs	± 2 - 5m	1999	Vector
Ski routes	± 2 - 5m	1999	Vector
Pillars	± 10cm	1999	Vector
Restaurants	± 2 - 5m	1999	Vector
Walking paths	2m		Vector
Road map	2m		Vector
Artificial snow structures, position and infrastructure (water/electricity)	2m		Vector/ Point
Buildings	2m	1999	Vector
Forest cover map	accuracy ± 5 - 10m	1990	Vector

3.3 EO data digital processing

In principal there are two types of data processing schemes:

- Digital processing
- Analogue processing

Manual/analogue interpretation and analysis dates back to the early beginnings of remote sensing for air photo interpretation. Digital processing and analysis is more recent with the advent of digital recording of remote sensing data and the development of computers. Digital processing of satellite images is unavoidable. Only in non-EO data and very little remote sensing applications it is common to use analogue methods anymore. So the main focus in this paragraph will be on digital processing of EO data.

Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer. Data delivered by the sensor provider is mostly raw data. This means a lot of processing or rather pre-processing steps must be done before one has an analysable/interpretable image. Depending on the question the EO data should answer, different steps of the processing chain must passed through. For an example of the whole processing chain see Figure 3.1. Subsequent steps are described briefly below.

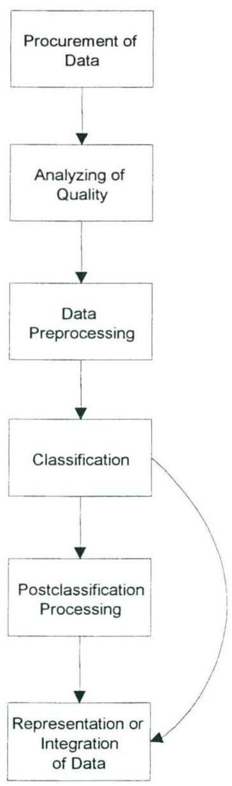


Figure 3.1 Overview of a processing chain for EO data

3.3.1 *Procurement of data*

For pre-processing and processing steps it is indispensable to have beneath the satellite data the orbital data. Thereby many parameters like sensor specific attributes (e.g. calibration of the sensors), number of scene pixels per line, number of scene lines per band and scale of inter-pixel distance are written in the image header file. This kind of information is for example relevant for execution of orthorectification.

For most modern satellites it is relatively easy to obtain the images in each desired format like projection, orthorectified, software specific formats. Also sensor characteristics can usually be obtained together with the images. Only for older satellites and sensors sometimes problems exist in the availability of sensor characteristic information. For example, for Landsat MSS images not all sensor characteristics necessary for orthorectification could be obtained.

Prices of satellite images depend mostly on the desired pre-processing and vary largely per sensor type. For example, NOAA-AVHRR images can be downloaded free of charge from the internet while Landsat TM images cost around Euro 1500 for a full scene and IKONOS images around Euro 3000 for 100km^2.

3.3.2 *Analysing of data quality*

The analysis of the data quality is done in two parts:

- *System specific elements*

These elements are formed by the influences of the recording system (sensor and platform) including the data transmission and system specific corrections. The user commonly can't control these parameters (exception: programmable sensors).

The system specific elements are divisible in three parts:

- Geometrical quality (e.g. ground speed, IFOV)
- Spectral quality (e.g. spectral response function)
- Radiometric quality (e.g. striping, banding)

- *Scene specific elements*

Scene specific elements are influenced by:

- Geometrical quality (e.g. topography, earth rotation)
- Radiometric quality (e.g. atmosphere, solar radiation)

3.3.3 *Data pre-processing*

Data pre-processing serves as optimisation for the following user application. In this step all the problems ascertained in the quality analysis stage must get corrected. A scene does not become a product until it has undergone pre-processing. Three factors loom large and it is important to take care of them:

- System specific factors

Different levels of pre-processing are available from the receiving stations.

- Scene specific factors

To have an image product the scene must get geometrically and radiometrically corrected.

- Application-oriented factors

Depending on the customers' wishes, further pre-processing steps lead to the final product.

Most pre-processing applied is described in the Chapters on snow cover classification and change detection. The general pre-processing steps are summarised below.

Both for snow cover mapping and forest cover change the images have been checked whether the region of interest is cloud free, and if the images are free of stripes. If striping was present in the image, a destripe algorithm had to be used. This destripe algorithm calculates the mean of every n-th line and normalises each line to its respective mean.

After this quality analysis, the images were geometrically corrected. About ten ground control points are selected for small areas (10 km x 10 km) and more for larger areas. On the basis of these ground control points, which are linked with a digital topographical map based on the Gauss-Krüger System, the image was geocoded. The used transformation method is an nth degree polynomial transformation. The n degree available is dependent upon the number of ground control points.

The re-sampling methods available include nearest neighbour, bilinear, and cubic convolution. For the resampling of the MSS images nearest neighbour and bilinear resampling was used. Nearest neighbour uses the nearest pixel without any interpolation to create a geo-coded image. Bilinear re-sampling does a linear interpolation using 4 pixels to resample the geo-coded image.

3.4 Ground truth data

3.4.1 Significance and problems

Ground truth is a form of reference data derived from sources others than the analysed remote sensing image. The acquisition of ground truth involves collecting measurements or observations about the objects, areas, or phenomena that are being observed remotely and are subject to analysis. The term ground truth is not meant literally since it can be collected by detailed aerial photography and can only approximate the truth of actual ground conditions. The significance of ground truth can be resumed as follows:

- Support in the analysis and interpretation of remote sensing data
- Validation of information extracted from remote sensing data

Reference can be an important source for correct analysis and processing of remote sensing data. For instance, meteorological measurements enable accurate atmospheric correction procedures and moreover, as in the case of climate-related snow cover simulations, facilitates the analysis of snow scenarios.

A second focus is directed to the validation of classification results. Only the inclusion of ground truth data in the analysis process makes that classifications relate to a certain level of confidence. Without any reference data there is no indication of accuracy of the computed classification results. Furthermore, ground truth is often used for choosing and setting training sites required in supervised procedures.

However, we should be aware of the potential problems involved in ground truth data. It can be either time-critical or time-stable, a fact that represents important implications for data analysis. Time-stable measurements are involved when the items under observation don't change appreciably with time. In geologic applications, for example, characteristics of geological ground features remain essentially stable in time frames from satellite mission to mission.

If, however, time-critical data is involved, things get more complicated. Herewith measurements of ground conditions are addressed that change rapidly with time. Using ground truth such as data of vegetation characteristics, it must be taken into account that temporal differences in the acquisition of remote sensing and ground truth data may hinder a proper classification analysis. In the case of change detection an appropriate ground reference database for every time step is often lacking. Validation can thus be restricted in terms of time and space. Mainly for cost reasons ground truth acquisition in the field is mostly limited and was hardly carried out within ASMON.

3.4.2 Sources of ground truth

As sources of ground truth a variety of databases is considered including mainly Non-EO data and occasionally EO data (i.e. aerial photo as reference data for satellite images). The following reference data is used as ground truth in ASMON:

- Maps (forest cover and forest road maps, topographic maps, geomorphological and vegetation maps).
- Inventories (vegetation inventories, building-related inventories, biozone inventories).
- Meteorological data (snow cover and snow depth, precipitation, temperature and visibility measurements).
- Field surveys (hazard mapping survey, vegetation cover and extent surveys, ground photograph campaign).
- Aerial photographs.

3.5 Data validation and data suitability

3.5.1 Introduction

Remote sensing is the process of imaging a selected part of the earth through more and more sophisticated technical instruments. Sensor systems become more improved, for instance with respect to spatial resolution (e.g. upcoming commercial satellites, 1 m). However, although this can considerably enhance classification results, principles and problems of imaging the earth surface won't change and should be taken into account here briefly.

Remote sensing systems measure a physical signal produced by the reflection of solar irradiance. No instrument can actually measure with infinite precision. If the signal varies in time, the instrument must average over a non-zero response time; if the signal varies in wavelength, the instrument must average over a non-zero spectral bandwidth; or if the signal varies in space, the instrument must average over a non-zero spatial response.

For making it more clearly, below in short an overview is given of the concept of resolution, which is vital for any sound understanding of the application of remote sensing data.

Resolution of remote sensing systems can be referred to in terms of spatial, spectral, temporal and radiometric resolution. Most important for the purpose of the ASMON project are spatial and temporal resolution. While spectral resolution determines in how many bands (channels) a system is able to differentiate the incoming radiance, the radiometric resolution specifies the system's capability to resolve a given band into numerical values (i.e. in most remote sensing sensors considered here 8 bit or 6 bit).

The ground resolution (pixel dimension on the surface) is basically determined by the flight height and the instantaneous field of view (IFOV). However, the relation between the geometrically derived ground resolution and the actual recognition of ground objects is more complex than it may appear at a first glance. It is well known, for instance, that objects considerably smaller than the sensor's ground resolution can be detected if their contrast to the surrounding background is sufficiently high. Thus, in a Landsat-TM image one frequently 'sees' roads or bridges over water that are 10 m (i.e. one third of a pixel) or less wide. Although the object is actually only a fraction of one pixel, it appears to be as large as an entire pixel size in ground resolution, or even as two pixels under corresponding reflectance conditions.

Another point, which should not be neglected, refers to mixing pixels. A single pixel in an image may often contain the spectral reflectance of more than one object. Suppose the boundary between a forest and an open ski run falls in between of one pixel. This pixel then represents a combination of the reflectance of both objects and a related classification won't perform properly.

With the inclusion of factors that come into play in real images, namely sensor noise, non-uniform targets and backgrounds, variable solar angle and topography, it becomes clear that the situation with respect to image resolution is not simple and should be reminded in the context of this project.

The above-outlined aspects have some important implications for data production and generation as performed in ASMON. Resolution and scale play a major role in determining and visualising subjects such as snow cover scenarios or landscape changes by EO data. A successful approach has to consider which scale is accurate and to take into account the sensor's capabilities. It does not make any sense, for instance, to assess the distribution of single trees with Landsat-TM satellite imagery (30 m ground resolution).

Therefore, the question should be 'what can we do?' rather than 'what do we want to do?'. Although it is a goal to test for the potential of remote sensing data in a ski area environment, the problem should be adapted to the potential of EO data.

The accuracy of the produced classification and maps depends on the exactness of the used data. As far as remote-sensing data is concerned a few points have been considered above. With respect to topographic maps as a source for deriving or validating data the level of accuracy is widely ranged. Newer and present topographic maps are generally an order of magnitude more exact than older maps. Common cartographic problems such as generalisation-induced object shift and misinterpretation have to be kept in mind when using topographic maps as ground reference and validation base.

As it becomes clear with topographic maps the question is basically one of scale. Within a cartographic context, scale is often referred to as 'metric scale', i.e. the ratio between distance on the map and distance on the ground. To other disciplines, however, scale might have another connotation, to landscape ecologists, for instance, it can mean a measure of the size of the patches in a landscape fragmented in different zones of varying ecological value.

The move to digital representations of map contents complicate the issue further, since there is no distance to measure in a database. Specification of scale values in digital databases can be a helpful hint and is applied in a few cases in the ASMON context (e.g. for hardcopy-derived digital aerial photographs), but actually is doubtful for databases that never existed as paper products.

The data available for ASMON not always fits perfectly the scales at which decisions and decision support are needed. Hence, compromises are occasionally inevitable. The subject is furthermore complicated by the fact that present geo-information systems rarely allow for full multi-scale approaches.

3.5.2 *System inherent and scene induced errors*

A variety of geometric and radiometric errors is induced by remote sensing satellite systems. Obviously the nature of such errors varies considerably with factors as image acquisition type (camera, along-track scanner, across-track scanner), platform (airborne, spaceborne) etc. We will not describe in detail the different errors but rather touch some aspects relevant to sensors used within ASMON.

A set of geometric distortions stems from the flight variations of the sensor platform according to the three degrees of freedom (yaw, pitch, roll) and variations in altitude and velocity. Another system inherent geometric distortion is known as skew distortion and results from the eastward rotation of the earth beneath the satellite during imaging. This causes each optical sweep of the scanner to cover an area slightly to the west of the previous sweep. Furthermore factors should be mentioned such as non-linearities in the sweep of the scanning process (as in the case of oscillating mirrors of Landsat).

Radiometric errors within a band can be caused by sensor deficiencies. The most significant errors are related to the detector system. For example, multispectral scanners that sweep multiple scan lines simultaneously often produce data containing systematic striping or banding. This results from variations in the response of the individual detectors used within each band and is especially prevalent in early Landsat MSS data.

Further deficiencies can come from the transfer characteristics (radiation in, signal out) of radiation detectors whose mismatches cause a non-uniform signal response.

Systematic errors are to a certain degree corrected at the satellite receiving stations (e.g. Fucino, Eurimage) based on auxiliary information received from the satellite.

Geometric errors also stem from distortions due to the cartographic projection (ellipsoid, and cartographic reference) and due to the earth (geoid, and relief). Projections are required to tie down an image to the earth's surface. The purpose of a projection is to tie down the spherical surface of the earth onto a flat surface. This transformation implies geometric distortions that are present in all projections, some are removed or compensated depending on the projection used.

Once the required projection information has been defined and the image has been corrected to overlay the projection bounds, image equirectangular pixel and line co-ordinates can be transformed to equirectangular projection easting and northing co-ordinates. Within the ASMON project the Gauss-Krueger projection is used. As map co-ordinate systems, the corresponding national co-ordinate systems are used.

Some important geometric distortions are introduced into the image by the topography. Such relief displacements are not eliminated during system corrections (i.e. at the ground receiving stations) nor during the normal geocoding with polynomial transformations that describe mathematically how the uncorrected raw image has to be warped to make it fit over the georeferenced image.

For the Landsat-TM scenes used in ASMON the displacement caused by the difference in terrain elevation can be resumed as follows: at the lateral edges of a TM frame, i.e. under a scanning angle of 7.5° an elevation difference of 230 m already implicates a systematic displacement which is equal to the size of one pixel (30 m). A difference of 1500 m, which is absolutely common in the test area chosen in ASMON, causes a displacement of more than eight pixels. It is obvious, hence, that displacements of such magnitude require a geometric correction procedure.

With opto-mechanical scanning sensors like Landsat-MSS and –TM pixel displacements due to relief changes only occur along scan lines. In vertical (nadir) viewing photographic systems however, relief displacement has a radial nature pointing away from the principal point. The size of relief displacement in photographic systems depends on the flight height and focal length and is generally more pronounced than in satellite systems. To correct for the relief displacement a Digital Elevation Model (DEM) is needed. Satellite images and aerial photographs in ASMON are orthorectified using a 50 meter x 50 meter DEM.

Radiometric, scene-related effects may influence considerably the signal measured at the sensor. Such effects include the position of the sun, the atmosphere, the reflectance properties of the objects, the influence of the topography, adjacency effects etc. The aim of the radiometric correction usually is that the same objects show uniform spectral signatures in the image and hence are made comparable.

As in ASMON several remote sensing scenes of different times are used (multitemporal approach) for change detection analysis, the fact should be considered that the incidence solar angle is varying in respective scenes. This implies that the same object in two different scenes may not show the same spectral signature, or they even differ within the same scene due to topography (e.g. shadows), atmospheric scattering, absorption etc. This may hinder the correct classification in change detection and snow mapping procedures.

4 Snow Cover Classification

4.1 Introduction

The variation of the snow cover is an important factor in Alpine regions since it has a strong influence on flora, fauna, climate, hazards and tourism (e.g. ski tourism). Snowfall is influenced by different climatic factors and in turn the snow cover affects the climate. Therefore the spatial distribution of snow is an essential factor for climate change studies (Whetton et al., 1995). Conventionally point measurements (temperature, snow depth, wind etc.) are used to explore the snow cover. However, although the number of measuring stations is steadily increasing, interpolations for larger areas, or even for the whole Alps, will always be troublesome and are of a coarse spatial resolution. In contrast, remote sensing techniques allow studying quantitatively the spatial distribution of snow for larger areas with a relatively high resolution. Limiting factors to use satellite data extensively are the temporal resolution and the often-occurring cloud cover. However, nowadays new satellite sensors are acquiring data on a regular basis with spatial resolutions between 1 and 15 m.

It was shown by Ehrler (1996) that snow cover mapping from satellite data partially obscured by clouds is possible applying an extrapolation method by means of a GIS algorithm. This research is focusing on a method of calculating daily snow coverage and snow cover duration maps (SCDM) for a snowmelt season. With the combination of SCDMs and the possibility to 'look under the clouds' remote sensing empowers the knowledge of the snow cover distribution with a fine spatial and temporal resolution.

4.2 Classification methodology and results

The methodology applied to create snow cover maps for the Montafon region and in particular the Silvretta Nova ski area is based on the methodology developed by the ETH, Switzerland (Hall & Martinec 1985; Seidel *et al.* 1989). An advantage in deriving the snow cover maps for the Montafon was the absence of clouds in all the images, which is rather exceptional. The applied classification method for deriving the snow cover maps was a maximum likelihood (supervised) classification. First, a thresholding method was tested for determining snow cover. This method combined DN values of pixels (0-255) with ground measurements of snow cover. The disadvantage of this method was that the difference between shadowed parts and non-shadowed part could not be identified. Therefore, a more sophisticated classification methodology had to be used. To improve the outcomes of this classification, the DEM of the Montafon region was added as an additional band to the Landsat MSS images of March, May and July 1985.

The goal of these classifications was to determine whether pixels were snow free, snow covered or part of a transition zone (between full cover and snow free) at the moment of image recording. To classify the Landsat images on snow cover, several 'shadow based' training classes were defined. These are required for an accurate supervised classification of images of mountainous areas with lots of shadow effects in it. Classification took place into the following snow cover classes:

1. Totally snow covered in the sun
2. Totally snow covered in the shadow
3. Snow in forest in the shadow
4. Snow in forest in the sun
5. Snow free in the sun
6. Snow free in the shadow
7. Transition zone

Training sites were selected by visual interpretation of the images. A good method for defining these training classes is on screen digitising while band 3 (NIR channel), band 2 (green channel) and band 1 (blue channel) are displayed. This combination shows distinct differences between snow, water, clouds, bare rock, forest and grasslands. The classification resulted in snow cover maps, which are presented in Figure 4.1.

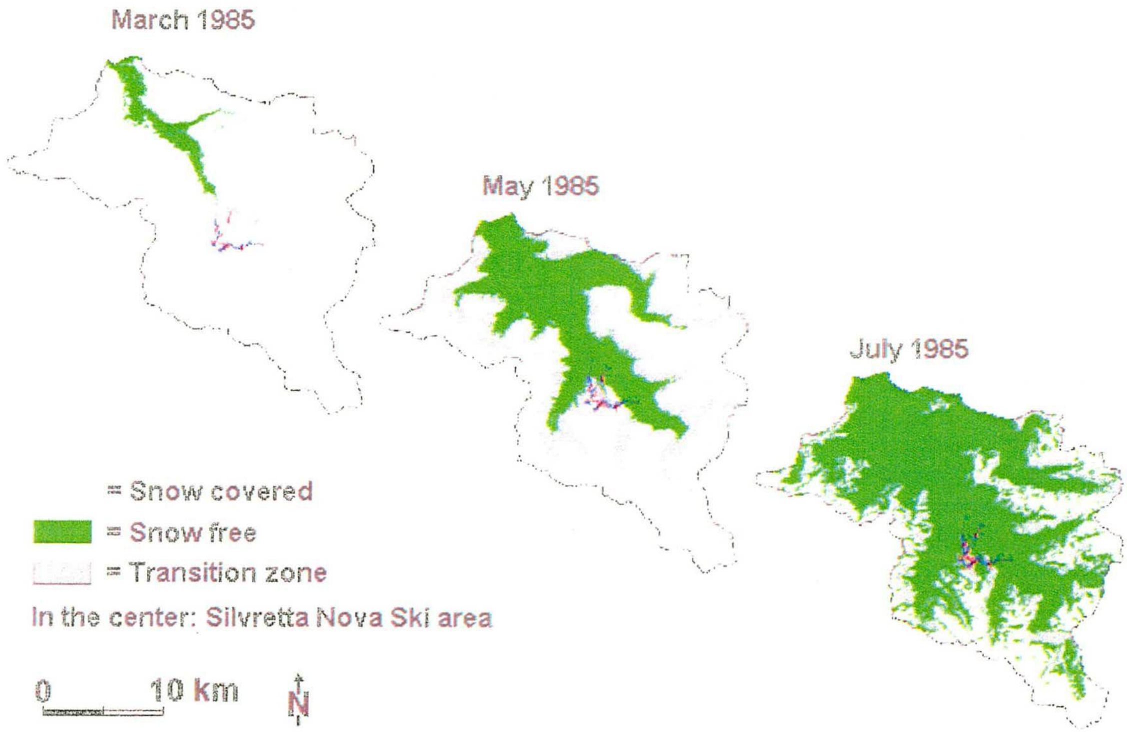


Figure 4.1 Snow cover maps derived from classifications of Landsat MSS images, showing snow covered snow free and transition zone areas for the whole Montafon region for March, May, and July 1985. In the centre skilifts and pistes of the Silvretta Nova ski area. are indicated

5 Land Cover Classification & Change Detection

5.1 Introduction

For detailed environmental impact assessments and monitoring studies, it is essential to have up-to-date and reliable information on land cover and the changes occurring in it. For example, for studies regarding the health and amount of forest disappearing as a result of expansion of tourist industries, detailed monitoring is needed of forest cover development over large time spans. On the other hand, for promotion of ski areas also demonstration of snow cover development throughout the year is of high relevance. This kind of information plays a crucial role in the planning of for example new ski pistes and hotel accommodations. Therefore, detailed monitoring of land cover features is relevant for a wide range of environmental applications dealing with subjects like environmental protection and land degradation, but also with socio-economic related subjects like urban expansion and planning of new infrastructure.

There exist several remote sensing based techniques suitable for detailed environmental monitoring. In general, these monitoring techniques are summarised under the term 'change detection'. Change detection with remote sensing actually consists of two steps. First, the detection of areas where changes in land cover took place and second, identification of the actual type of change. This last step implies that a land cover classification should be part of the change detection process.

Change detection can be applied both in a qualitative and a quantitative way. For example, changes in relatively small areas can easily be detected by simple comparison of normal photographs taken at different dates. More, detailed analyses can be carried out for larger areas by numerical comparisons of satellite images or aerial photographs. The basic postulate when using remote sensing data for change detection is that changes in land cover must result in changes in radiance values that are large compared to those caused by other factors (Ingram et al. 1981; Singh 1989). The change of interest, (e.g. land cover change) and the disturbing other factors can also be defined as the different components of changes which are contained by multi-temporal images. These components are global, background and non-background changes (Shettigara 1997).

Global changes are caused by changes in atmospheric transmission, sun angle and sensor characteristics. Some of these effects can be avoided by selecting data belonging to the same time of the year. This reduces the problem of a different sun angle and differences in vegetation phenology.

Background changes or systematic changes are not as general as the global changes, but are fairly widespread in the image. These changes are due to terrain changes or vegetation changes, mainly caused by seasonal variations. The changes are normally predictable.

Non-background changes are mostly the changes of concern in change detection studies. These changes are often due to man made activities or due to natural events. For detecting these changes using multi-temporal satellite images, a wide range of change detection methods can be used. Some of the most common techniques are listed in Table 5.1. The most direct change detection technique is visual analysis of unclassified images. Visual comparison of two satellite images is a simple but less efficient method to detect changes than most other techniques. Furthermore, it is a non-automated method (Martin & Howarth 1989).

Digital change detection techniques are based on numerical comparison of original or transformed (typically classified) image data acquired on two or more different dates. There are two basic approaches to change detection using digital image data (Singh 1989):

1. Comparative analysis of independently produced classifications for each of the image dates (often known as 'post-classification change detection')

2. Simultaneous analysis of multi-temporal data.

In terms of change detection analysis, post-classification techniques are perhaps the easiest to implement because two independently produced information layers are compared on pixel-by-pixel basis at a thematic level. Change maps can be derived quickly, as can 'confusion' (or 'contingency') matrices showing a summary of all changes. However, since such a change map is the product of two single date classifications, its accuracy is directly dependent on the accuracy of each of the single-date classifications. A classification error on either of the two dates will give a false indication of change.

Table 5.1 Examples of different change detection techniques.

Change Detection Techniques
- Visual analysis - Post-classification change detection - Spectral/Temporal change classification - Image differencing - Spectral mixture analysis - Image rationing - Image regression - Principal component analysis - Change vector analysis - Fuzzy logic

The alternative to post-classification change detection is to use the original image data. Changes are detected by comparing either multi-date bands or transformed image data. The simplest method is image differencing, where the image of time t1 is subtracted pixel by pixel from the image taken at time t2. The resulting 'difference' image is assumed to show high absolute pixel values in areas of change, whereas pixels representing unchanged areas should have values around zero. This method is easy to apply but has a number of drawbacks. First, the resulting differences might not only be due to land-cover/land-use change, but also to external influences caused by differences in atmospheric conditions, differences in sun angle or differences in soil moisture (Jenson 1983). Second, the nature of change is difficult to detect, as the method provides only differences of the radiance in different wavelengths. Third, the decision regarding which threshold to use to separate 'change' from 'no change' is highly subjective and scene-dependent. Application of similar approaches such as regression analysis of the two images, image rationing and comparison of image indices can reduce the impact of the external influences, but still lack a clear interpretability of the detected changes (Lambin & Strahler 1994; Green et al. 1994).

5.2 Techniques used

Since the beginning of the project the user requirements of the Austrian end users shifted from an integral land cover change detection to 2 products, which are:

1. A reliable land cover map derived from a recent Landsat TM image

2. A forest cover change analysis for the last 15 years

For the first product an orthorectified Landsat TM 5 image from September 1998 was classified using the supervised classification method: maximum likelihood classification (probability threshold = 0.56). This seemed to be the best classification method for the image of the Montafon. The following classes were defined for the applied supervised classification:

1) Bare area in the sun (not vegetated)
2) Bare area in the shadow
3) Snowfield/glacier in the sun
4) Snowfield/glacier in the shadow
5) Valley meadows
6) Shrubs and alpine meadows
7) Coniferous forest in the shadow
8) Mixed Forest
9) Coniferous forest in the sun

Training sites for the classification were digitised on screen on the basis of orthophotos, expert knowledge (information from forest managers working in the area) and topographical maps. However, a problem was caused by the temporal differences between the different used data sources. Not all the used data sources were compiled at the moment of satellite images recording, but some were compiled several years ago, which could lead to errors. In contrast, by digitising the training sites on screen for the classification this error is minimised, because visually it is often clear whether a pixel belongs to a certain defined class. During accuracy assessment (after the classification) the incorporated error of 'older' information is more severe.

For accuracy assessment the classification result has been compared with ground truth data. The ground truth data was derived from a forest map made in 1992, field measured lake perimeters, and newly created ground-truth polygons, again digitised on screen with backup from orthophotos and terrain photographs. The accuracy assessment gave an overall accuracy of 92.70%, which is exceptional good, and a Kappa Coefficient of 0.692, which is fairly good. Table 5.2 shows the confusion matrix of the classification result compared with the ground truth data.

During testing of the best classification method two errors arose constantly:

1) Shadow was confused with forest on north faced slopes

2) Urban regions and infrastructures were confused with bare regions

Since urban areas and infrastructures are well defined in GIS data layers of the end users (road maps, building maps, ski lift maps) the most important error was the mix-up of 'forest' with 'shadowed areas'. To solve this problem, again the DEM of the Montafon region has been added to the satellite image as an additional band. Combining the DEM with the satellite image significantly decreased the classification error while the most parts with real shadows in the images were rock cliffs high up in the mountains, above the timberline.

Since the timberline in the Montafon lies at about 1800-meter altitude, every pixel classified as forest above approximately 1800-meter altitude had to be shadow. By adding the DEM to the classified bands 1, 2, 3, 4 and 5 of the Landsat TM image the training sites could be linked to altitudes. Statistically, the training site defining forested parts had a maximum value in the DEM band of approximately 1800. The training sites defining shadowed parts could reach values a high as the highest mountain in the Montafon region (Piz Buin, 3312 m) in the added DEM band.

Table 5.2 Confusion matrix of the classification result of the Landsat TM of Sept 1998 in combination with the DEM.

	Ground Truth						
Class	glacier/ snow	lakes	bare	shrubs/alpine meadow	forest	valley meadow	total
Unclassified	0	0	0	0	0	0	0
glacier/snow	6365	553	0	0	2	0	6920
Lakes	0	6145	0	0	0	0	6145
bare	0	984	4891	0	2963	4	8842
shrubs/alpine meadow	0	71	17	1799	1260	0	3147
forest	0	38	0	95	188428	0	188561
valley meadow	0	47	1	0	10361	482	10891
total	6365	7838	4909	1894	203014	486	224506

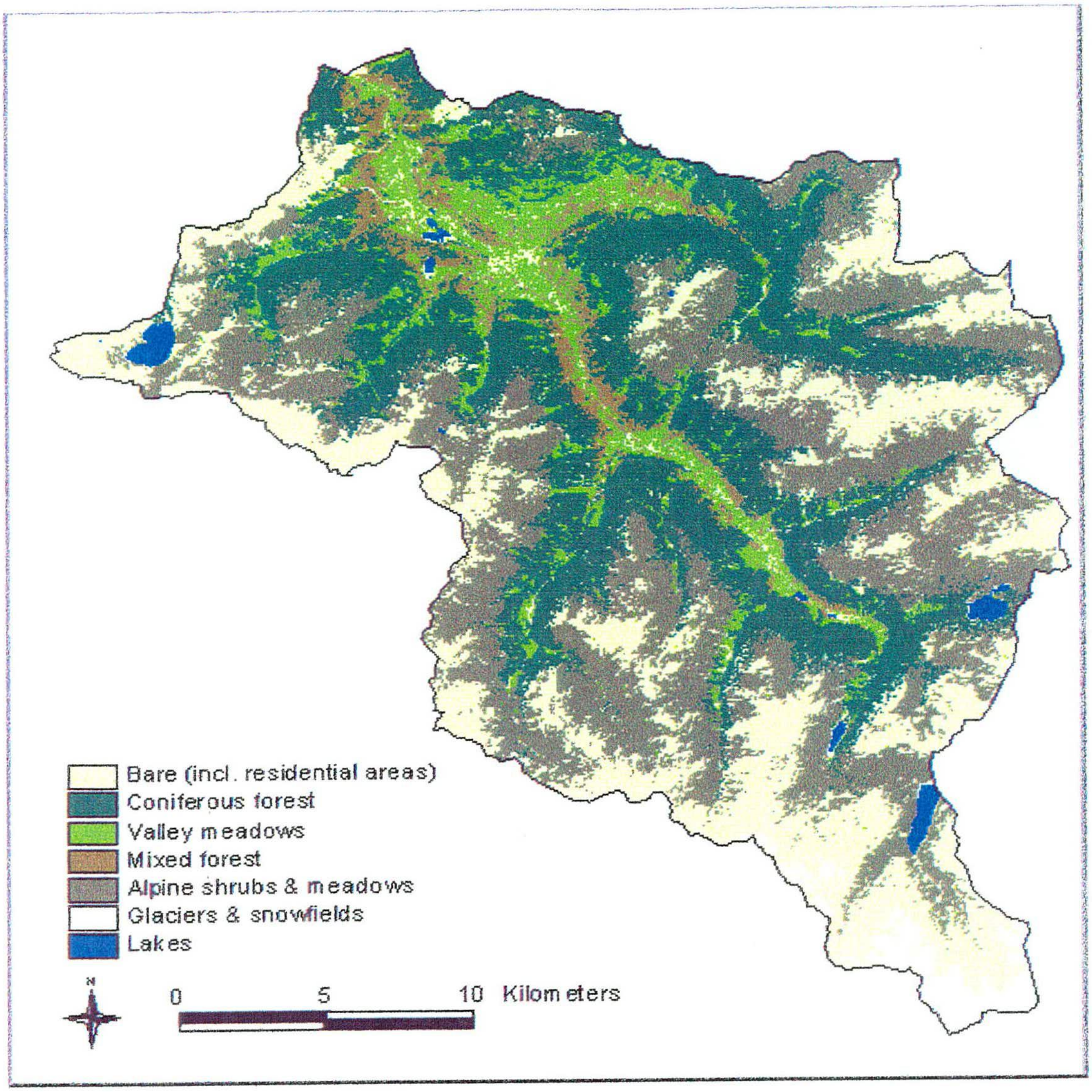


Figure 5.1 Land cover classification of the Montafon based on a supervised classification of a Landsat TM image of September 1998.

5.3 What has changed and how much?

For the forest cover change analysis for the last 15 years post-classification change detection has been carried out. This is a rather simple method. It means that change is detected by comparing different classifications within a GIS. The method is simple but the interpretation is difficult, because not every detected change in the GIS is a real change. This is further explained in the section on *Error Analysis*.

For the forest cover change detection two satellite images classifications from Landsat TM images recorded in 1985 and 1999 have been compared. To reduce the complexity of the change detection only the forest classes have been compared as is shown in Figure 5.2.

Mostly, the causes of forest cover decrease are known, because these are the effect of human impact or natural hazards. Forest cover increase is a more gradual change due to natural succession and reforestation. This is a process of which the effect can only be seen after several years. In contrast, the impact of a landslide, avalanche or forest harvesting action is more radical.

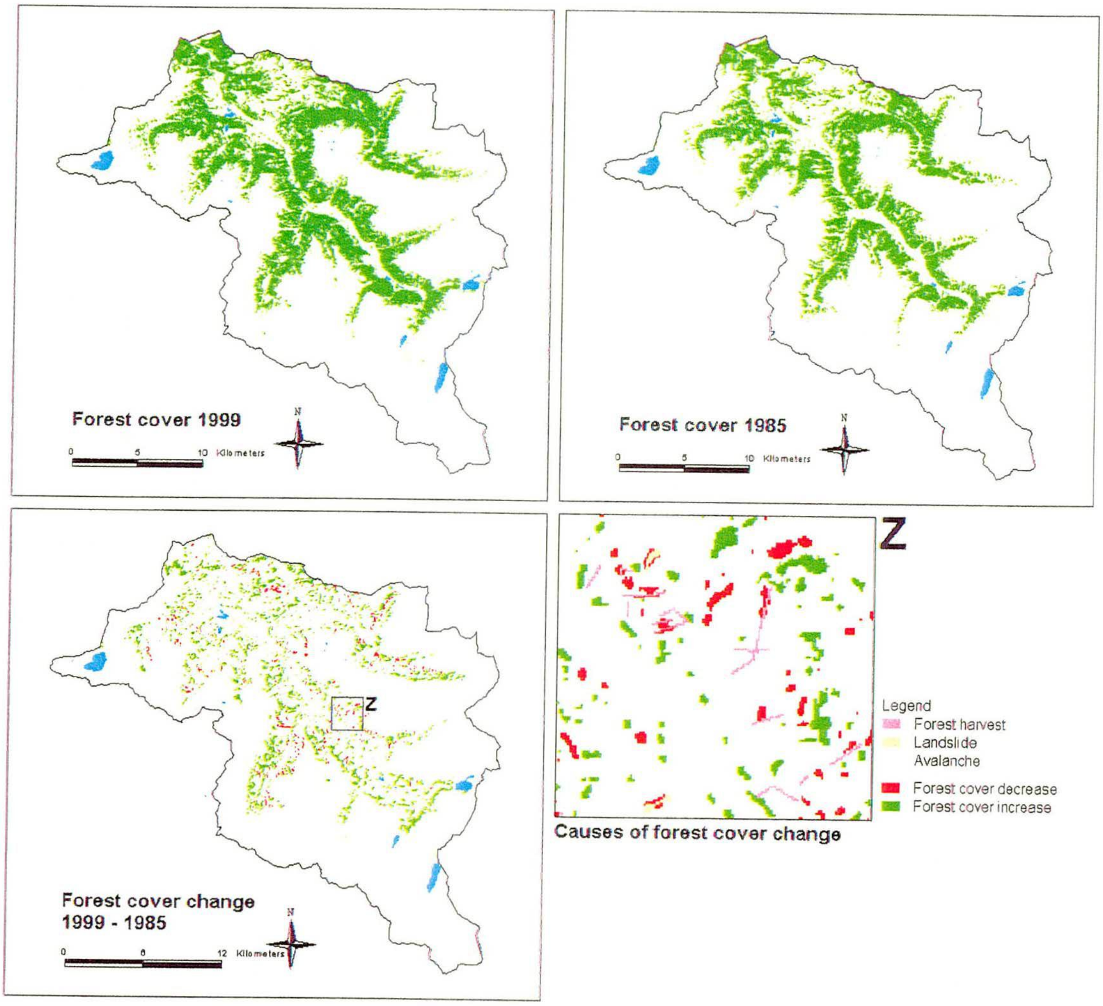


Figure 5.2 Forest cover change and causes of this change between 1985 and 1999 in the Montafon region. The blue areas are lakes, which are depicted for orientation in the map. Z is a zoomed out part of the 'forest cover change map'.

Table 5.3 Areas of land cover types for 1998 in the Montafon.

Land cover types	**Hectares**	%
Lakes & rivers	478.3	0.9
Glacier & snow fields	1114.2	2.0
Mixed forest	2152.1	3.8
Valley meadows	5072.9	9.0
Bare (incl. residential areas)	15045.4	26.8
Coniferous forest	15359.4	27.3
Alpine meadows & shrubs	16985.7	30.2
Total	56208	100

Not all calculated changes are the result of actual forest cover changes (especially the forest cover increase). Still it is possible to quantify the forest cover change. The following numbers have to be treated as an indication. The total forest cover in 1999 was 15608 hectares. This is a decrease of 9% forest cover in 1999 compared to 1985 and an increase of 29% forest cover in 1999 compared to 1985. The net change in forest cover from 1985 to 1999 has been an increase of 20%. An overview of the areas of different land covers for 1998 in the Montafon are given in Table 2.7. The Landsat image of September 1998 has been used for the land cover classification for the whole Montafon, because this image was cloudless and therefore more suitable to use for a covering map. The clouds in the Landsat image of 1999 luckily did not cover forested areas so this could be used for the forest cover classification.

5.4 Error analysis

The most distinct errors in change detection occur at forest boundaries. Due to the small differences in the ortho-rectification of both images, there is a geometrical difference in the border of forests. This small shift results in forest cover change. Another error results from the classification accuracy. Both images have been classified with an accuracy of 94%. This means 94% of the pixels have been accurately classified. The remaining 6% are confused with other land cover types. A reason for this is the large amount of mixed pixels in the image. Mixed pixels are pixels that are the result of two or more different land cover types, e.g. forest, meadow and houses. The classification error has an effect on a forest cover change analysis. Pixels, which should have been classified as forest in the image of 1985, but have been defined as meadow for example, result in a forest cover increase if this pixel has been classified as forest in the 1999 image. This mistake has to be taken for granted if an analysis is carried out using satellite images. Because of the resolution of a Landsat TM image, which is 30*30 m^2, only rather big changes in forest cover can be detected (big changes are changed areas that are at least as big as several pixels).

6 Hazard Maps

The applied methodology for hazard mapping was developed at the Alpine Geomorphology research Group (AGRG) at the University of Amsterdam (de Graaff et al. 1987, Seijmonsbergen 1992). This methodology starts with a stereographic aerial photograph interpretation and is followed up by a detailed geomorphological field study in the area of interest. This methodology enables the reconstruction of the landscape development and provides insight in the dynamics of a geomorphological system. Such a geomorphological analysis contains a description of the variety of landforms (morphometry / -graphy), but also an analysis of materials and processes, derived from the surface morphology and outcrop description.

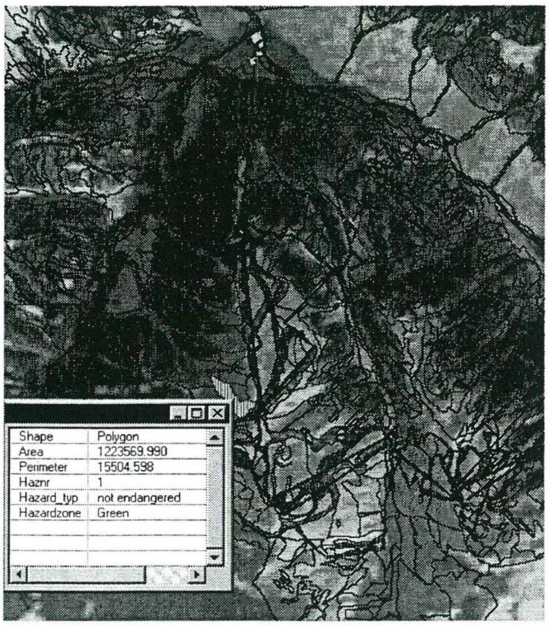


Figure 6.1 Screendump from the GIS database for the Silvretta Nova ski area. The background is a Landsat TM winter image. The coloured polygons are the ski runs. The black outlined polygons are hazard map polygons. The inset window shows that for every activated polygon information can be retrieved from the GIS database.

The geomorphological map contains a broad range of information concerning the geomorphology of the study area. It can be seen as a result of the detailed field study, map interpretations and the stereographic aerial photograph interpretation. After detailed geomorphological mapping, the obtained map is transformed in a polygon map by encircling all identical geomorphologic units. These terrain-mapping units enclose homogeneous processes, underlying materials, genesis and form. Polygon maps provide the opportunity to digitise and store them as digital maps in a Geographical Information System (GIS). A disadvantage is a loss of detail. The solution to prevent a loss of detail is to introduce multiple attributes for each polygon. That is, for each polygon in the polygon map several geomorphological variables are defined. For example, the geomorphological environment, the underlying rock and if this rock is exposed, active superimposed processes, the relative age of the unit, the stability of the unit, etc. In this way, many derived maps from one polygon map can be created. The relation to a database, in which all information of each polygon is stored, enables digital analysis of all geomorphological details obtained during the field study (Figure 2.5). For the Silvretta Nova ski area the attributes of interest have been process type (landslide, rockfall, earthflows, active torrents, etc.) and process activity (not active, less active, and active). The combination of these two results in a natural hazard map as presented in.

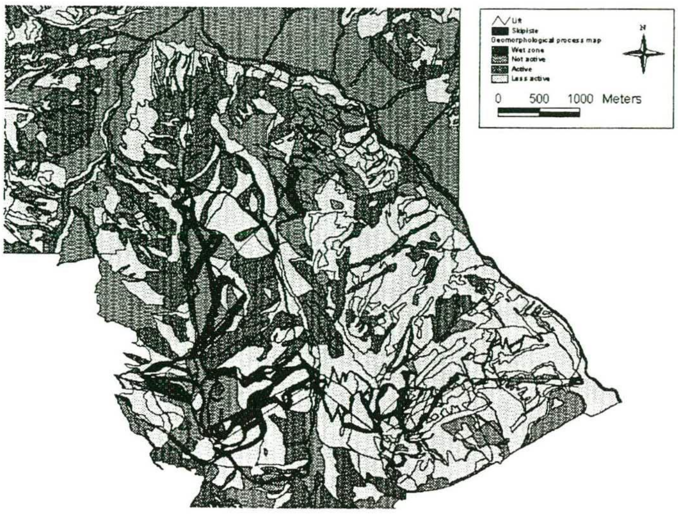


Figure 6.2 Map showing natural hazard zones in the Silvretta Nova area. Red: very active, yellow: active, green: not active, blue: wet, swampy zone. To this map GIS database is attached, therefore it is known which process type is active. The ski runs of Silvretta Nova are also shown on the map as dark polygons. Mapping was carried out by University of Amsterdam.

So beside a field study, the hazard map is based on digital orthophotos and 20-meter isolines printed on hardcopies that have been taken into the field. This assures a maximum displacement error of 1-2 meters for geomorphological maps at scale 1:10.000.

Despite the fact that the legend of the natural hazard map conforms to the 'Gefahrenzonenplanung' (danger zone planning), the scientific goal of a hazard map differs from a manager's goal. The earth scientist is interested whether or not a process occurs within a terrain-mapping unit. The manager is interested in the probability of the hazard occurrence and the extent of the hazard within the next 20 years.

7 IKONOS, detailed monitoring & high quality presentations

7.1 Introduction

IKONOS images with resolution of 4 meters in four multi spectral bands and even 1 meter in the panchromatic mode form a perfect possibility to perform high detailed monitoring of processes occurring at a local scale. Furthermore, the high quality of the images and high level of detail makes them very suitable for promotion purposes of for example ski areas, forestry companies and the whole tourist industry. Figure 7.1 presents some examples of both the multi spectral and the panchromatic mode of IKONOS images. The multi spectral image shows the natural colour as visible for the human eye. The panchromatic images illustrate very well the level of detail visible. In the upper image the 'buckle piste' can be clearly seen while in the lower image cars, houses and a ski lift are visible.

Since the launch of the IKONOS satellite was postponed several times it was not possible within the CARTESIAN project to receive IKONOS images in early stages of the project. Therefore, they have not been used for operations like change detection and hazard mapping. Instead, some high quality visualisations have been prepared for presentation and promotion purposes. These visualisations form an excellent data source as reference data and as background for planning purposes as well as promotion of the area. This application is very useful for both forestry organisations for forestry planning and ski areas. The images obtained within the ASMON project were actually used by the forestry and ski companies.

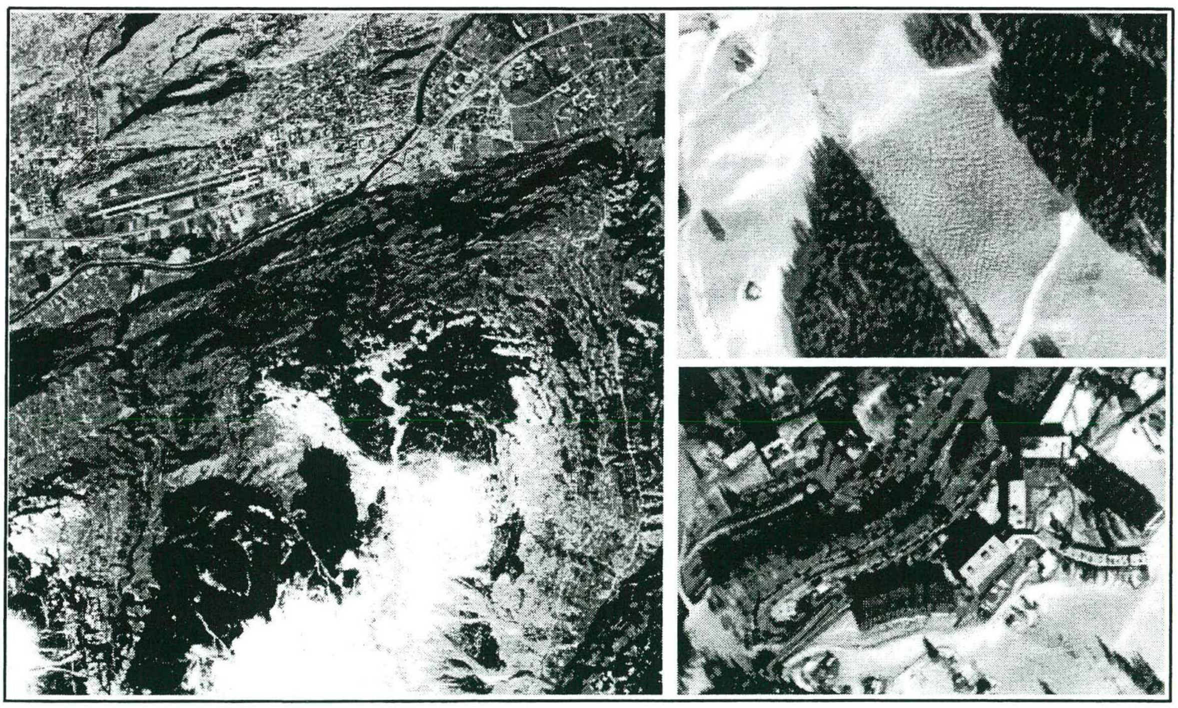


Figure 7.1 Example of IKONOS images in the multi spectral (left: Sion) and panchromatic (right: Les Arcs) mode.

In order to make use of both the high resolution of the panchromatic mode and the spectral information present in the multi- spectral bands a spectral merge was applied. This results in an image with the resolution of the panchromatic image and the colour information from the multi spectral images. In the following paragraph the applied merge techniques are illustrated in some more detail together with some examples of the merges.

7.2 IKONOS, resolution merge

A resolution merge is an effort to combine the advantages of spectral information with the high resolution of panchromatic images. Of course, there will always be a loss of spectral information when trying to convert to a higher resolution since some form of interpolation has to be performed. Therefore, several merging techniques have been developed. The experience until now is that the best technique for a given image depends very much on the features and the contrast present in the images. Examples of merging techniques are Principle Components, Brovey and RGB to IHS conversion. In the ASMON project all three were tested on all IKONOS images. For the Montafon the Brovey algorithm gave best result while for both Sion and Les Arcs the Principle Components gave better results.

The major problem for creation of good visualisations appeared to be the large difference in contrast between snow covered areas and forest. This gave problems in the merging algorithms and resulted in a loss of spectral information. Therefore, for presentation purposes several other image enhancements like brightness/contrast adjustment, stretching and histogram equalisation were applied. The final results were usually very satisfying as can be seen in Figure 7.2 that presents an example of an IKONOS merge.

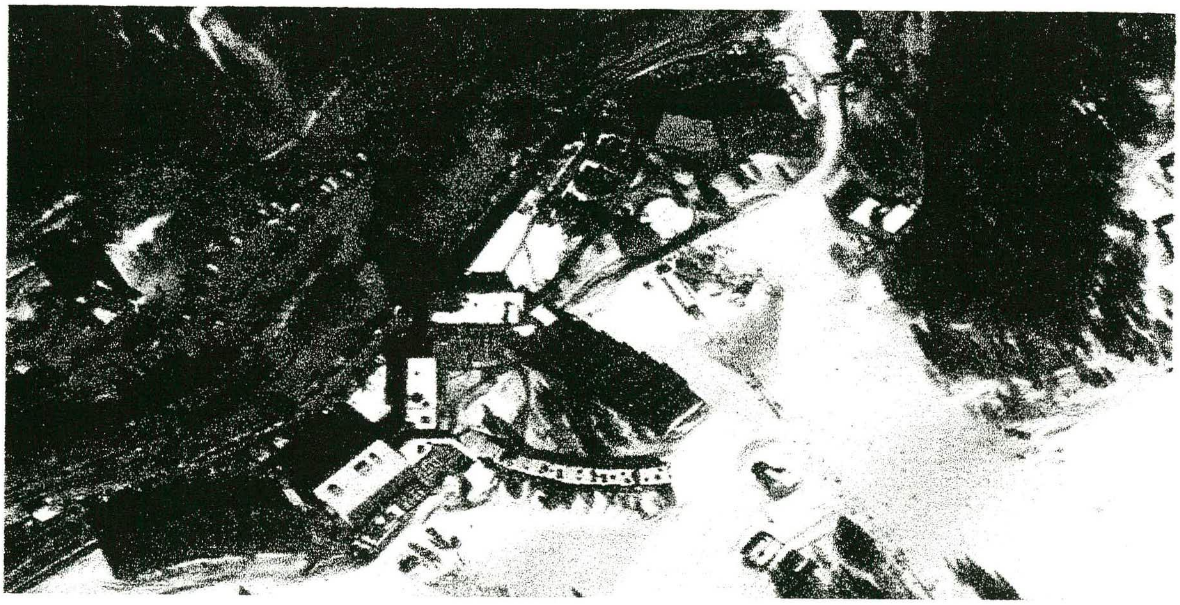


Figure 7.2 Detailed example of an IKONOS resolution merge.

7.3 IKONOS, other applications

The very high resolution of IKONOS images makes them very suited for many applications regarding detailed monitoring of environmental impacts. Detailed land cover maps can be created and change detection can be applied by comparison of subsequent classifications. This can be used for quantitative estimations of changes in forest cover but also of changes in heterogeneous natural land cover types. For example, where Landsat TM proved to contain insufficient detail to monitor the regeneration of vegetation on abandoned ski runs IKONOS is expected to give much better results. Unfortunately, within the ASMON project no time was available to actually apply such a change detection. Within the CARTESIAN project, running parallel to ASMON, a rapid assessment of land cover was made by a supervised classification (maximum likelihood classification with four bands, blue, green, red, near infrared). Selection of training areas was carried out by on screen digitising, with as background the false colour IKONOS image. The result of this classification is presented in Figure 7.3.

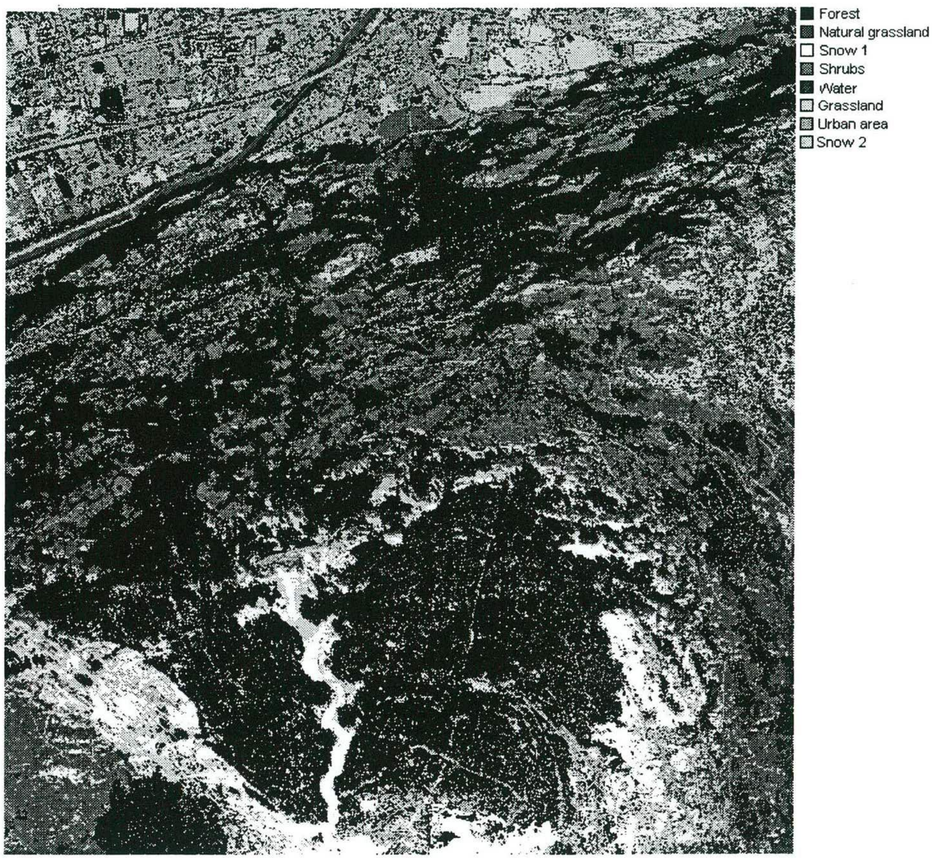


Figure 7.3 Example of a classified IKONOS image of the Sion study area produced within the CARTESIAN project.

Another application for which IKONOS images are especially suited is hazard mapping. The images provide sufficient detail to indicate hazard zones with respect to avalanches, rock fall and landslides, based on differences in vegetation coverage, vegetation type and even active zones can be recognised. This can function as a very relevant extension of the approach currently used for hazard mapping that is based on aerial photographs and field inventories. However, aerial photographs and field visits can not be replaced by the IKONOS images. Rather, IKONOS images should be used as an extra information source and a good possibility to extend analysis to larger surface areas and make rapid assessments.

8 3D Visualisations

8.1 Introduction

Images are a powerful medium to inform people. The expression that 'One image says more than thousand words' is often true. Thanks to the ongoing development in the computer industry, the possibilities to create computer images and animations are becoming more and more powerful.

Landscapes, and for this project ski areas, can realistically be visualised making use of 3D computer animations. Fast and easy manipulation enable the creation of realistic presentations and more importantly show the visual impact of possible measures such as the building of new ski lifts, slopes, roads, buildings, the cutting of forest and etceteras. This can be of great value to decision-makers. Besides this 3D images and 3D flights are a very attractive way to promote ski areas to the tourist industry. In the future it could even be possible that 3D computer animations partly replace traditional ski maps which are nowadays based on an artists impression.

8.2 World construction set

Resource Analysis has explored the present 'low end' possibilities to visualise landscapes. In this case 'low end' means 3D techniques suitable for personal computers in combination with dedicated GIS, 3D visualisation and audio/video software.

The GIS software is only used to manipulate and create the source data. This involves re-projection, conversion from vector to raster format and vice versa. The 3D-visualisation software like World Construction Set (WCS) is used to create realistic 3D landscapes from the source information. Below is a short description of the use of the World Construction Set to create the 'low end' 3D images and animations.

8.2.1 General description of WCS

With the World Construction Set, it is possible to create 3-D landscapes. For the ASMON project skiing areas are visualised using this tool. In order to make a visualisation with the WCS, first elevation of the landscape itself is derived from a Digital Elevation Model (DEM), which can be imported in WCS. The location of the ecosystems (forest, meadow, rock, snow, etceteras), which actually give the landscape its natural look, can be based on raster (i.e. classified aerial photos or satellite images) and vector input data (manually digitised ecosystems).

Each ecosystem can be assigned its own characteristics. It is possible to assign a mixture of plant species and vary the density and height. The location of man made features such as roads, buildings, parking places, ski lifts and ski poles is based on vector (point, line or polygon) data.

The features in the landscape itself (trees, buildings, ski lifts, etceteras) are also displayed in 3-D. It is possible to use and create real 3D features or flat images. It is for example easy to import an image of a characteristic ski lift gondola or restaurant in the area and assign this image to the vector, which represents this ski lift or building.

Depending on the available data (see Table 8.1) there are numerous ways to create a virtual representation of a ski area. The following is a description of the steps that have been taken for the Silvretta Nova area.

Table 8.1 List of the data used for the creation of the ski map in WCS.

DEM of the Silvretta Nova area (ArcView ASCII raster)
A classified orthorectified summer TM-Landsat image of the Silvretta Nova area (TGA)
Location and type of the ski lifts (ArcView shapefile)
Location and type of slopes (ArcView shapefile)
Location of roads (ArcView shapefile)
Location of buildings (ArcView shapefile)
Location of restaurants (ArcView shapefile)
Location of parking places (ArcView shapefile)
Images of features (trees, buildings, restaurants, different types of ski lifts and skilift poles)
A winter TM-Landsat image of the Silvretta Nova area (used for visual reference)
Paper tourist ski map of the area (used for visual reference).

8.2.2 *Step 1: Re-projection of geographic data*

In order to be able to use the data in WCS, the data must be re-projected from Gauss-Krüger to Lat/Long, since the WCS only supports Lat/long and UTM projections. The standard projection used for the Silvretta Nova area is Gauss-Krüger. The re-projection of vector (shapefiles) and raster data is done in Idrisi. The re- projection of vector files is straightforward. Only the projection parameters of the original and desired projection need to be given. For the raster data (DEM and satellite image) this information is also needed.

After the re-projection, the raster cells for at least the DEM should be square in order for WCS to place the data in the right dimensions. This can also be done within Idrisi by re-sampling the number of rows or columns so that the cells become square. Furthermore the DEM should be of a good quality (no stripes or other disturbing effects), as this will significantly affect quality of the end product. Sometimes it might be necessary to do a smoothing on the original DEM. The smoothing can be done in Idrisi using a filter operation. It may be quality and time rewarding to create two DEM's: one more detailed for the ski area itself (a resolution of +/- 25 m proved to give good results), and one less detailed for the surrounding area (the background).

Finally, after re-projecting all data to the Lat/Long projection, the DEM, raster and shapefile data can be imported into WCS.

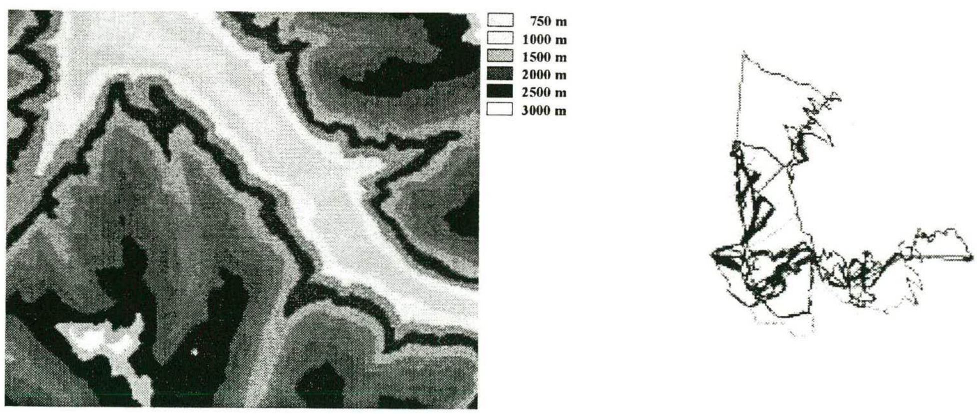


Figure 8.1 Step 1: DEM and location of ski lifts and slopes in the Silvretta Nova area.

8.2.3 *Step 2: Assigning ecosystems to colormap*

In order to get a nice representation of the landscape, it is necessary to assign specific characteristics to specific areas. For example, forest areas need to have trees, areas covered with snow need snow and bare or rocky areas also need to be represented that way. In WCS it is possible to get this result by assigning ecosystems to specific colours (classes) of a so-called 'colormap'. For this we can use remote sensing information of the Landsat TM satellite. The classified, orthorectified and re-projected Landsat-TM summer image is used as colormap and thus used to assign the terrain its ecological characteristics.

For the classification a summer Landsat-TM image is used in a supervised classification. In total six classes were identified as is illustrated in Figure 8.2.

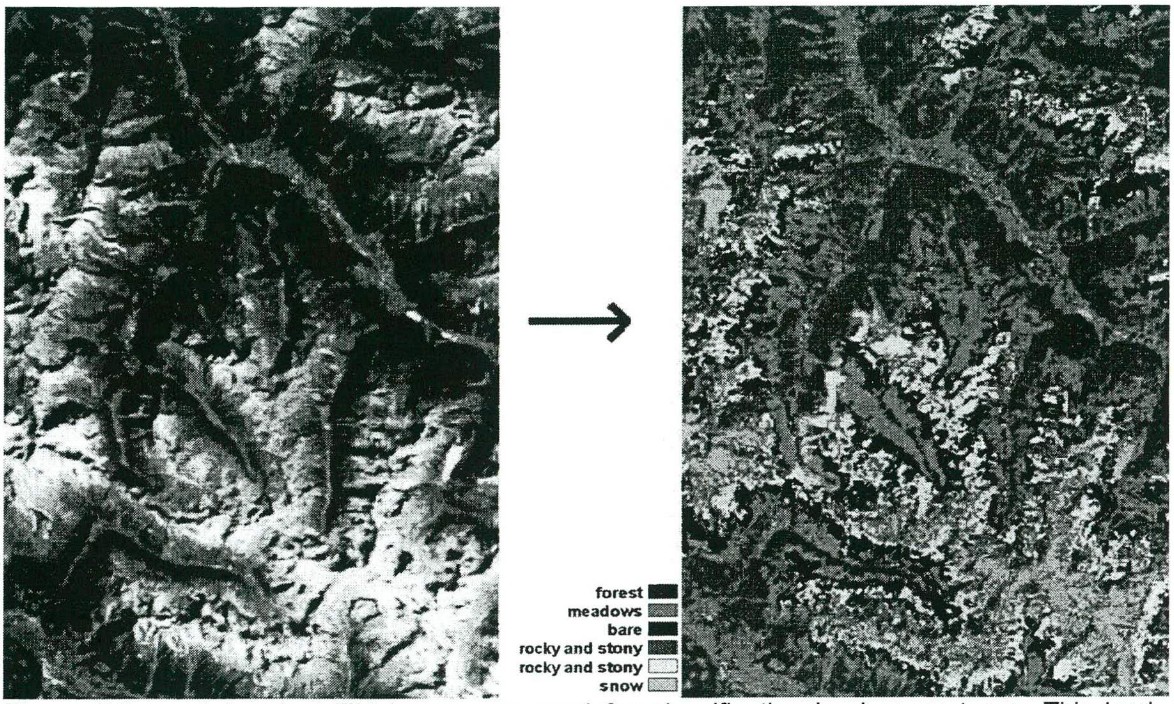


Figure 8.2 A Landsat TM image was used for classification land cover types. This land cover map is used as colormap in WCS indication of type of feature to be shown in 3D presentation.

In the ecosystem editor of the WCS it is possible to create for every ecosystem its particular appearance. For a forest this consists of a mixture of different trees. It is possible to choose the type, colour, density and height of every desired specie. For the meadows a mixture of herbs and flowers is selected. For the rock classes a flagstone texture effect is assigned. For the bare and snow ecosystems the different shades of white are used.

8.2.4 Step 3: Creating ski lifts from vectors

In WCS it is possible to manipulate the appearance of vectors. In this way it is possible to assign a ski lift-look to the vectors that represent the ski lifts. Every ski lift has its own vector and therefore every lift can be assigned his own look. Different appearances are created for surface lifts, chairlifts and gondola lifts. This can be done by assigning different effects (images) to vectors.

To create a ski lift it is necessary to assign different effects to one vector: liftpoles (image), liftcarriers (image) and the liftrope (terraffactor; an effect of WCS which manipulates the source input). For the visualisation of a ski lift it is necessary to show liftpoles and carriers along the vector. Therefore there are points created along the vectors. Every point is assigned to an image of a pole or carrier. The size of the features can be set within WCS. The images themselves are derived from Internet or scanned from brochures.

Figure 8.3 Step 3: Visualisation of forest, a chairlift and a gondola lift in WCS.

Besides the effect used for the visualisation of the lift itself an other 'terraffector' is used, where necessary, to create a path for the ski lift in the forest.

8.2.5 Step 4: Adding other features, icons and text to the ski map

In order to create a realistic and useful virtual representation of a ski area, it is also necessary to visualise the locations of slopes, roads and houses. The best way to do this is to make use of existing digital (geo-referenced) vector information. All the existing vectors (ArcView shapefiles) are reprojected in Idrisi and imported in WCS.

The slopes are represented by polygons. To visualise the location and type of the slopes, every slope is represented by the colour (difficulty) of the slope. The roads are delivered as lines. In WCS it is possible to define the width of the roads. The houses are represented by points. A 'foliage effect' (mixture of images of houses) is used to represent the houses. The images themselves are derived from Internet. Images from the Internet and brochures are used to give the area the appropriate appearance (Figure 8.4)

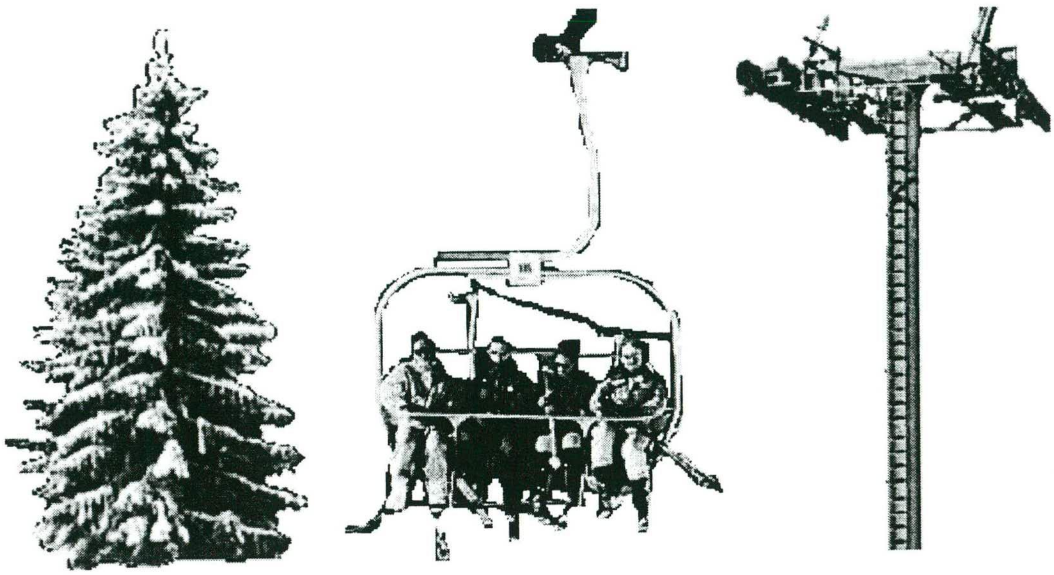


Figure 8.4 Step 4: Images from Internet and brochures are used to customise the appearance of the ski area.

Besides existing 'real world' features, it is possible to place text and icons in the landscape. This might be useful for showing important places in the ski area. This is done by digitising the locations of the different texts and icons as points. The digitising can be performed within WCS. This results in a vector for every different icon or text. A foliage effect (image) is assigned to these vectors. It is possible to change the size, the height above the ground, etc of the icons and text.

8.2.6 *Step 5: Creating an appealing view*

The power of WCS is that once all the features are correctly placed and given the appropriate characteristics, it is easy to create different looks of the ski area. For example it is possible to add clouds, haze, fog, a sun and moon image, change the colour of the sky, etcetera. Furthermore, it is easily possible to turn different features on or off (i.e. show icons and text or not). An example can be seen in Figure 8.6.

By changing the location of the camera position and the above-mentioned settings, it is possible to create fast and easy different impressions of the ski area. The most convenient image output size is BMP. Besides images it is also possible to create animations.

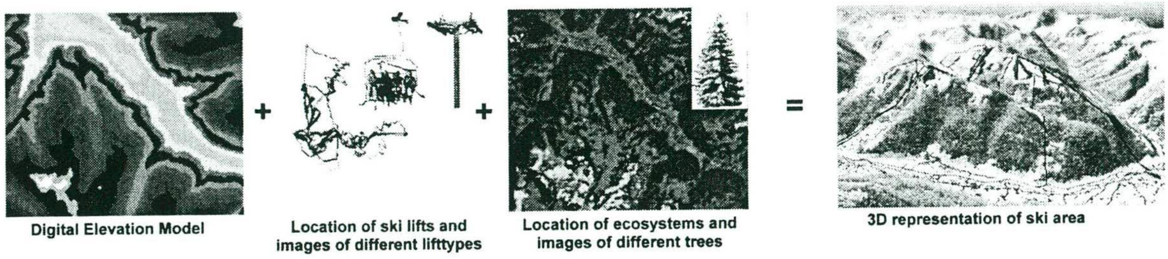


Figure 8.5 Schematic representation of the creation of a virtual 3D representation of a skiing area.

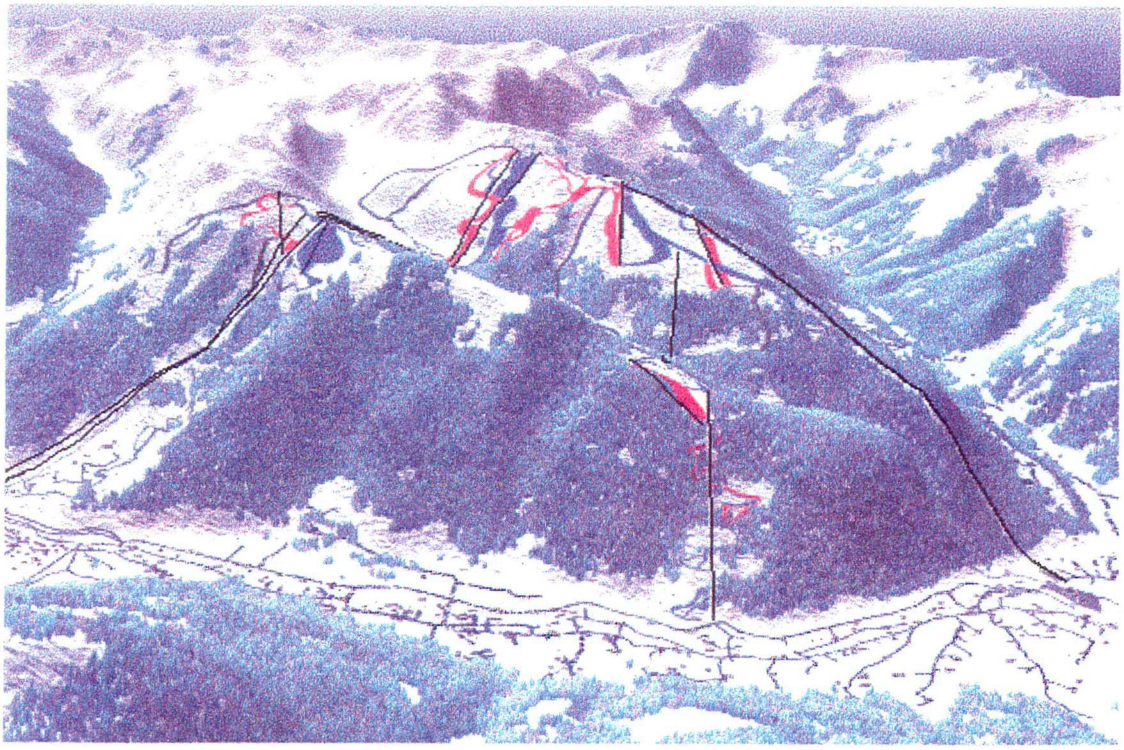


Figure 8.6 Step 5: Virtual representation of the Silvretta Nova skiing area made with the WCS.

8.2.7 *Step 6: Creating animations*

An animation consists of several images placed in a sequence. An animation should be kept fairly simple. The best effect is achieved by a relatively low flight over the terrain, because this way the details are viewed best.

An easy way to create flights is to sketch the flight path in WCS. It is also possible to customise the flight path more by setting the camera and target parameters separately. In this way, it is for example possible to fly backwards, circle around a point and strafe to a side.

The GIF Construction Set Pro (Alchemy Mindworks) is used to create an AVI-format movie of the sequence of BMP's. This program is used because it is capable of handling large amounts of images. The AVI file is then compressed with 'Windows Media On-Demand Producer'. This creates ASF files, which are approximately 10 times smaller than the AVI. These files can, if the animation is not too long and the size not too large, be played via Internet. It is worthy to select a good internet connection speed (100 KB to 1 MB), as this will significantly affect the size of the file and the speed of the playback (compress ratio).

8.3 Conclusion

Altogether, it takes a reasonable amount of time to create a nice virtual impression of the ski area. One of the main advantages of such a virtual impression above for example the traditional artist impressions is that it is easy to update the map with new lifts, slopes, restaurants and other features. It is also possible to change the appearance of the ski area. It is possible to create a summer and a winter image from the same data by adjusting the settings of ecosystem parameters.

Another advantage is that it is possible to use the virtual representation of the ski area for animation purposes. It is easy to make a little movie, complete with sunrise, sunset, flowing streams, evolving clouds, etc. A disadvantage of the virtual ski map is that it isn't possible to 'bend' the landscape in order to have a good view of all the ski lifts and slopes at the same time. The virtual ski map will therefore not fully replace the existing artists' impressions. It is however a powerful addition to visualise ski areas in a very attractive way.

9 Management Information System for ski areas.

9.1 Introduction

Since the wide availability of Personal Computers, software-instruments have been designed, implemented and applied in the field of resources management. In the ASMON project a monitoring and management information system (MIS) is developed to evaluate impacts of ski-resort activities on the environment (monitoring) and to support the sustainable management & tourism of the region. This system is based on Remote Sensing (Satellite information), geomorphological, ecological, change in land-use, socio-economic and policy information. Furthermore a special section on 'Eco Labelling', supplying information on future developments related to sustainable tourism, is implemented.

The MIS integrates:

- automatic access to a spatial GIS database containing e.g. remote sensing- and topographic information.
- a Management Evaluation tool based on MCA (Multi Criteria Analysis).
- advanced 3D visualisation tools to provide pre- recorded 3D animation's of the ski-resorts

A MIS can be used in several ways. In the first place, as an instrument to support communication between stakeholders involved in a process dealing with ski resort management. Typically, the MIS can be used in a workshop, showing management options and their impacts on several criteria such as environment and economic benefits. Secondly, the MIS can be used by an engineer as a stand-alone application for calculating the effects of constructing a ski lift. The MIS provides information on costs and environmental effects. Thirdly, the MIS is a clear marketing tool with 3D animations showing the resort from different viewpoints.

9.2 Elements within the MIS

The MIS contains three major knowledge elements:

1. knowledge of the Framework for Analysis: The "support part"

2. knowledge of ski-resorts Silvretta Nova and Les Arcs or proposed Olympic region of Sion : the "information part"

3. knowledge of the application of Remote Sensing "application part"

As might be clear, in the MIS three case studies are presented. The case study on the Silvretta Nova was carried out within the ASMON project. Both other case studies (Sion and Les Arcs) are part of the EU project CARTESIAN. All three case studies are presented in the MIS within the Framework For Analysis (FFA), though deal with different environmental studies and impacts.

The "support part", the framework in which all cases are presented, can be made fairly generic and constitutes the "core" of the MIS. For the "information part" it will be clear that it is unfeasible (e.g. cost-wise) to cover all ski areas or Olympic regions on Earth. Therefore, this part of the MIS is made modular. An interface has been designed which allows for the inclusion of so called "knowledge modules" which contain information on specific case study areas and which can be interrogated by the MIS core. The knowledge-modules determine the degrees of freedom the user has in interacting with the MIS: they are used to determine the effects of possible policy measures, but can only handle those measures that are covered by the model-equations of the supplied modules.

9.3 Potential users

In the three different case studies it becomes clear that there are numerous issues and problems in ski resorts on different scales in time and space that have to be dealt with. There are issues with a more technical origin, such as "what is the best location to build a ski lift?". This asks for a more technical tool with background information on the ski area. On a completely different level there are questions like "what is the best way to develop a ski area?". This goes more in the direction of vision creation and asks for a different approach. The MIS facilitates the solving of these questions.

On the other hand there is a lot of innovative and interesting information incorporated in the instrument which can be used for marketing purposes. The MIS, or a specific part of it, is therefore interesting and useful for technical planners, managers of ski areas, local communities, investors, other stakeholders, tourists, tour operators and other people that have interest in the skiing industry.

9.3.1 Introduction to Framework for Analysis

The generic part of the Management Information System is constituted around the "Framework for Analysis", a methodology to systematically analyse policy problems. This framework recognises the following 7 procedural steps:

1. issues and problems
2. objectives and criteria
3. scenarios
4. strategies, alternatives and visions
5. analysis
6. evaluation
7. presentation

After all these steps have been taken, it should be clear for the user which strategy or alternative is best to solve his or her problem.

Step 1: 'Issues and Problems' (what is going on?)
Within Step 1, the user comes in contact with a Document Information System (DIS). This is an information system, which shows the latest developments on issues and (potential) problems. The user gets an overview of the case study area: the geographical and socio-economic features, the processes that could influence the decision making process. In general, this step is meant to familiarise the user with the main subject and related issues.

Step 2: 'Objectives and Criteria' (what must be accomplished? how is this established?)
The user is offered a decision hierarchy that consists of the main objective and sub-objectives. Behind these objectives are criteria (supplied by the knowledge-modules in the MIS), which enable the measurement of the performance of his/her options (strategy/alternatives) regarding the (sub)objective(s);

Depending on the strategy the scores of the criteria will differ. Because people have different opinions on what criteria are important, the importance of the criteria have to be weighted.

The weights that are attributed to the criteria are derived from expert knowledge, but can be changed by the user. These weights symbolise the relative importance of a criterium compared to the other criteria.

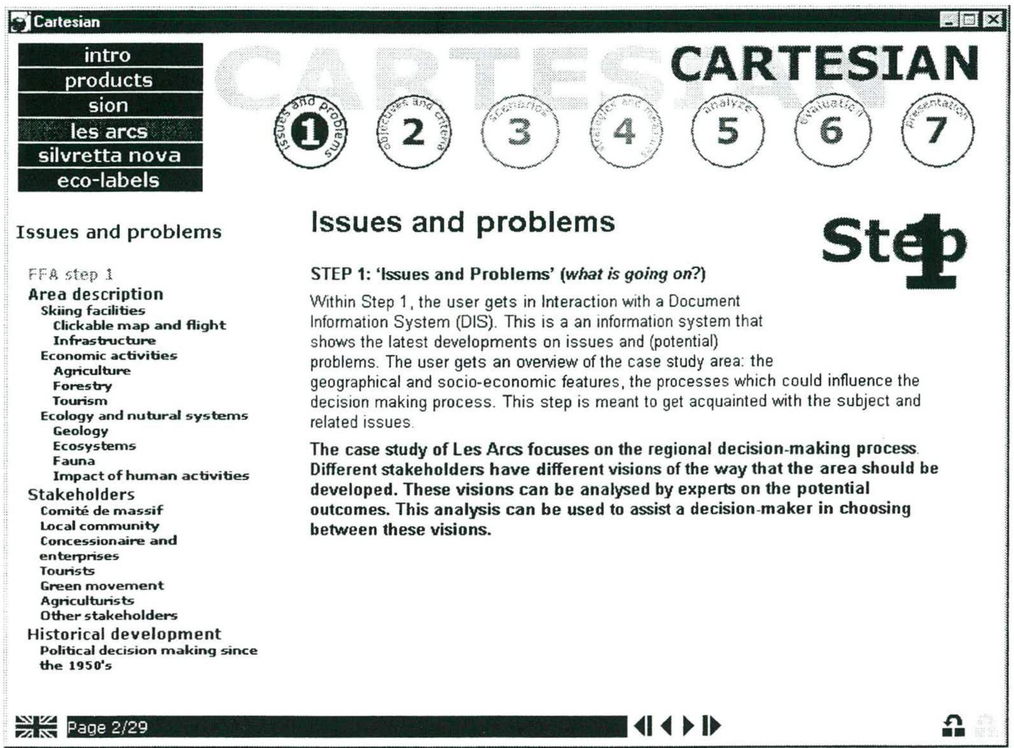


Figure 9.1 The structure of the seven steps of the Framework for Analysis is made clear by the 7 buttons on top of the screen.

Step 3: 'Scenarios' (what are the exogenous factors?)
A scenario is composed of exogenous factors that influence the outcome of a policy decision (climatic changes, change in tourism demand, change in international laws, change in infrastructure outside area, ...). In some cases the impact of scenarios is included in the model, for other cases it should only be kept in mind that exogenous factors could have a large effect on the outcome of measures.

Step 4: 'Alternatives, strategies and visions' (how can the problem be solved?)
In this step potential alternatives, strategies and visions are described or can be created by the user. By now the user has enough knowledge to create own strategies and alternatives. In the cases in which the alternatives, strategies and visions are (partly) predefined the policy options are described in order to get an insight in their advantages and/or disadvantages.

Step 5: 'Analysis' (analyse relevant combinations of scenarios and alternatives)
In the cases where the user can define an own policy, the scores on the criteria are calculated. For all cases the user is presented a scorecard with the scores of the different alternatives on the criteria. This helps in establishing the discriminating capacity of the criteria used, in the cases evaluated. Besides that it gives a first impression of what alternatives score good or bad.

Step 6: 'Evaluation' (which alternative/case/vision prevails?)
Within step 6, a Multi Criteria Analysis model will be used to analyse different alternatives.

In step 6, the different scores for the alternative strategies will be compared. A ranking of the alternatives, by using the weights given in step 2, is meant to find the 'best' alternative.

In this step, it is also possible to carry out a vulnerability analysis. It is possible to change the weight of the main criteria. If, by slightly changing the importance of criteria, the best alternative changes the user knows these criteria are very important for the final result. If, by changing the importance of criteria, the best alternative does not change the user knows that these criteria do not have an important impact on the outcome.

The difference between step 2 and 6 is that in step 2 you actually change the importance of the criteria while in step 6 you only evaluate if and how the criteria influence your outcome.

Step 7: 'Presentation' (what does it look like?)
The 'best' alternative, strategy or vision is presented in more detail. A visual impression of the situation after measures would have been implemented is presented.

9.3.2 *Case study Austria*

Both end users in of the ASMON project are users of the MIS: Stand Montafon and the skiing area of Silvretta Nova. The Austrian case study focuses on the Silvretta Nova skiing area. Information from the Stand Montafon is incorporated however.

The focus of the case study of Silvretta Nova is to display the effects of certain measures aimed at improving the competitiveness of a skiing area. The measures that can be taken are the construction of a ski lift, the construction of ski runs and the placement of artificial snow machines. A model has been developed to calculate the impacts of these measures on the environment, economy and hazards in the area.

The skiing area of Silvretta Nova is situated in the Montafon Valley in Vorarlberg, Austria, with over 100 km of ski runs, the Silvretta Nova skiing area in the Vorarlberg region is one of the best developed and most fascinating winter sport areas in Austria. Three feeder cable cars and a total of 28 lift systems open up the extensive Silvretta Nova skiing area. Thanks to its special location, the area, which includes the resorts of St. Gallenkirch, Gortipohl, Gaschurn and Partenen, is one of the best in Austria for guaranteed snow.

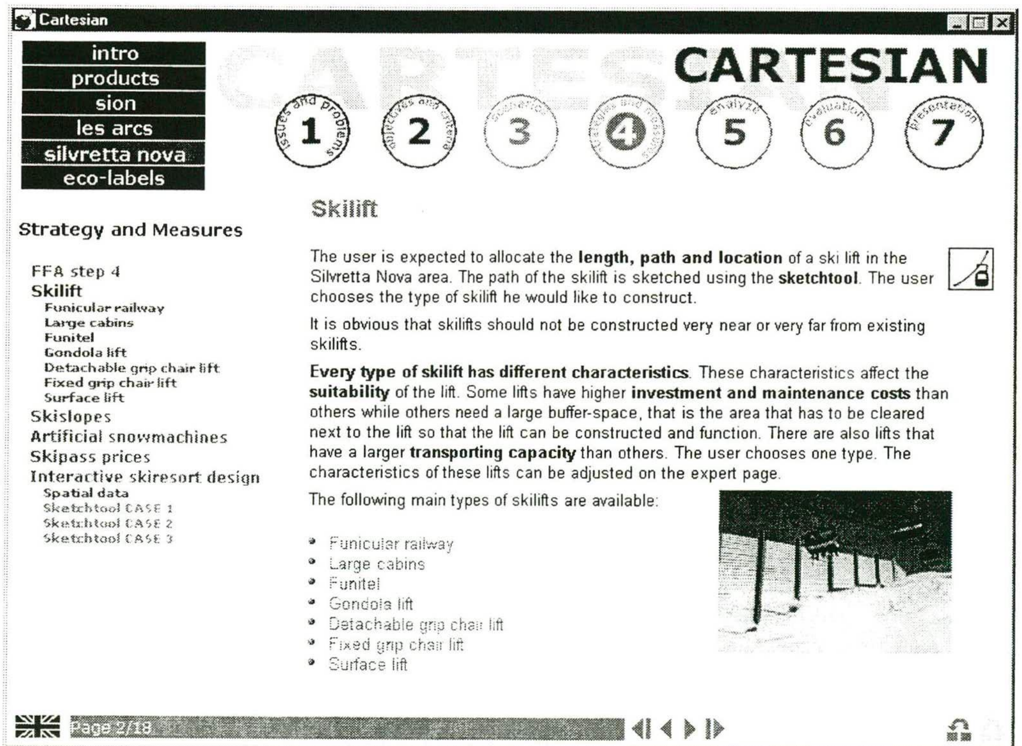


Figure 9.2 A page from step 4 (Strategies and measures) from the Silvretta Nova case study.

Despite the good present situation, it is always necessary to look at ways to improve the attractiveness of the skiing area. This is due to the combination of a decline in demand for skiing holidays and a very harsh competition between skiing areas. The case study of Silvretta Nova is facilitating the search to increase the competitiveness of a skiing area by technical improvements in a sustainable and safe way.

The core of this case study is the ski area design tool. This tool is described in more detail in the next paragraph. The entire Silvretta Nova case study can be found on the MIS CD-ROM. This CD-rom can be ordered by sending an e-mail to: Joris.de.Vente@resource.nl

9.4 Ski area design tool

For the Austrian case study a ski area design tool (Figure 9.3) has been developed. This instrument enables the simple spatial planning of ski areas. Behind a graphical interface is a simple model that calculates the effects of the measures the user designs.

The goal of the Austrian case study is to improve the competitiveness of the skiing area by creating new infrastructure as ski lifts and ski runs. The design tool is also developed with this purpose in mind and thus has limited use. With some modifications and additions, it is possible to use this instrument for any (simplified) spatial planning problem.

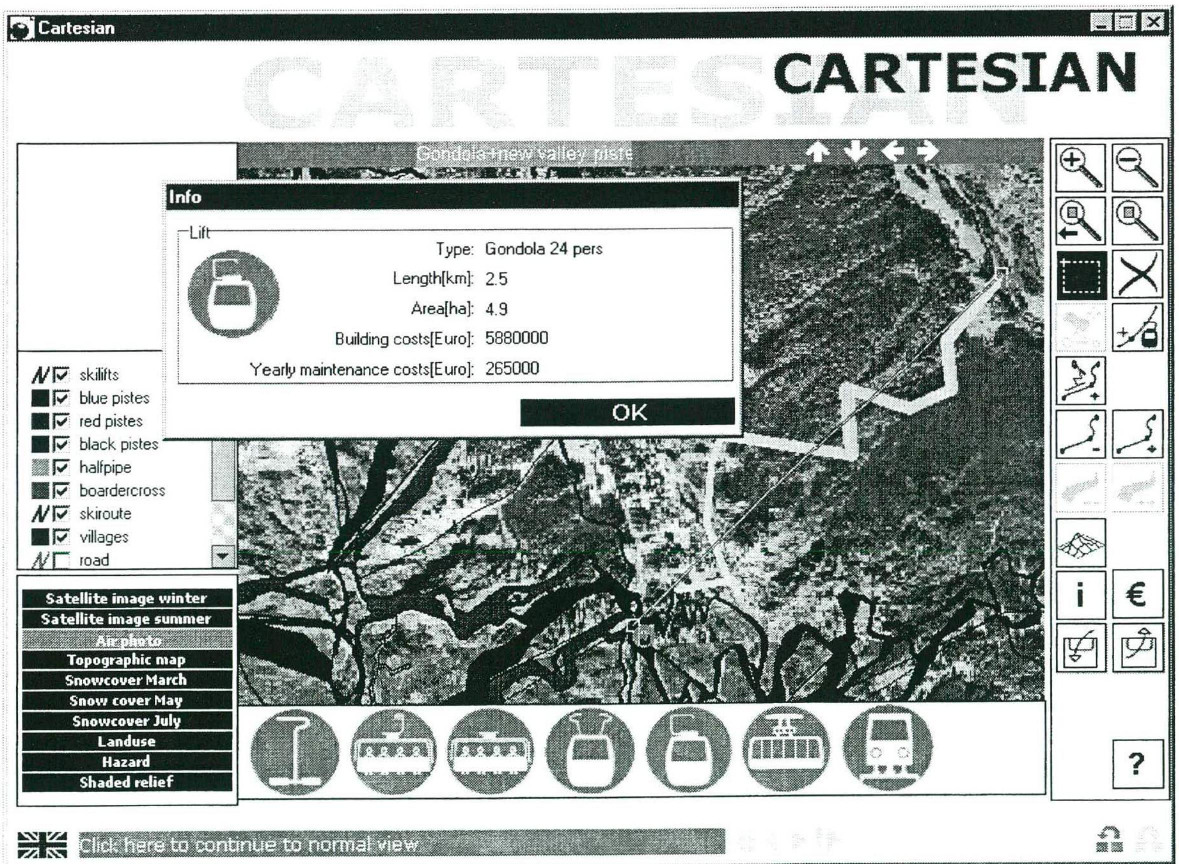


Figure 9.3 The ski area design tool. Design area is zoomed in on an aerial photo of the Silvretta Nova ski resort.

The following functionality is included at present:

- The construction of new ski lifts
- The construction of new ski slopes
- The placement of snow canons

In addition to this also all ski pass prices can be changed.

The user will decide where construction of the ski lift and ski slopes and the placement of artificial snow machines have to take place. The ski area design tool is used for the allocation and the selection of the path of the ski lift and ski slopes. The user can choose the type of ski lift he would like to construct. The design tool can also be used to place artificial snow machines on a ski run.

Every type of ski lift has different characteristics. These characteristics affect the suitability of the lift. Some lifts have higher investment and maintenance costs while others need a large buffer-space (the area that has to be cleared next to the lift so the lift can be constructed and function properly). There are also lifts that have a larger transporting capacity than others have. The characteristics of the different types of lifts can be adjusted easily to meet the local circumstances. For the current model the prices and characteristics per km were used as derived from Doppelmayr (1997)

Characteristics of the following main types of ski lifts are currently included:

- Funicular railway
- Large cabins
- Funitel
- Gondola lift (6, 8, 12, 16, 24 persons)
- Detachable grip chair lift (2, 4, 6 persons)
- Fixed grip chair lift (2, 4, 6 persons)
- Surface lift

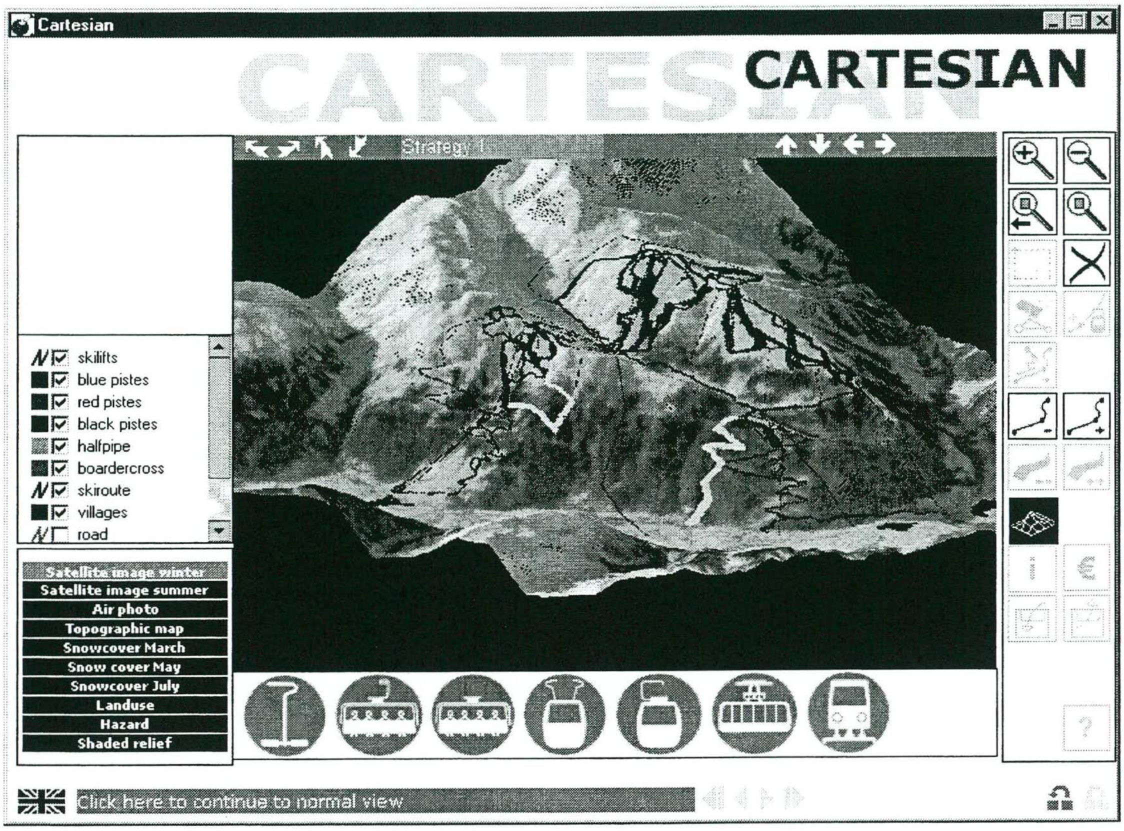


Figure 9.4 3D view of the newly designed measures in the Silvretta Nova skiing area.

In the design tool, the user can allocate several ski runs. The width of the run can be changed manually. The length and path of the run can be sketched into the area (on a 2-D map) using the design tool. The result of the sketching can be displayed in 3-D (Figure 9.4) to get a better idea of the location and path of the ski run.

In the design tool there are maps and other spatial information layers that the user can use as a background that helps the designing and allocation of the measures. Some of these maps also serve as input for the model behind the design tool. Dependent on the type and the location of the measures, there will be different impacts on the environment, risks and economy. These impacts are calculated based on the maps in combination with a simple model.

For the Silvretta Nova area the following maps (raster data) are available:

- *Summer and winter satellite images.* These are useful for visualising the area. It has no data attached to it, but shows the area as it is. The area can be displayed in summer and in winter.
- An *aerial photo* is included to get a detailed representation of the skiing area.
- A *topographic map* of the area is also included as background
- An *elevation map (DEM)*. This displays the elevation of the area.

- A *hazard map* contains information regarding the safety of the location. When constructing in the mountains, hazards such as avalanches and landslides have to be taken into consideration. The map displays 6 categories for danger (Figure 9.5):
  1) Not endangered
  2) Endangered by torrential streams.
  3) Endangered by rock fall
  4) Endangered by steep incision.
  5) Endangered by shallow landslides
  6) Endangered by deep-seated landslides

  Avalanches are displayed as vectors, but are taken into account in the calculation of the risks.

- A *land-use map* shows the land use type. This is an important map to determine the impact of a measure on the ecosystem of the area. The type of land use that is degraded determines the impact and possible damage on the ecosystem. The map displays 6 different categories of land-use:
  1) Forest
  2) Alpine meadow
  3) Grass / bare ground
  4) Bare ground / rock
  5) Rock
  6) Snow/water

- Three *snow cover maps* display the snow cover of the area in three month. If the run is located in an area that doesn't have snow in May the run might not be open for skiing the whole season. To ensure that a run can be used all season, the use of snow canons can be considered.

Apart from the raster data which cover the whole area and have a pixel or cell representation, it is also possible to display vector data, (shapefiles) for information to the user. Vector data can be presented over the raster data. It is also possible to view multiple vector layers at a time. The vector data available for the Silvretta Nova area are listed in Table 9.1.

For other areas or if other information is necessary, it is simply possible to include other maps and vector data, that serve as information for the user and as input for the simple model behind the design tool.

If the newly constructed runs are not covered by snow during the entire skiing season the runs will have to be closed part of the season. The placement of snow canons will ensure that the run can stay open for a longer period of time. This increases the attractiveness of the skiing area, and the number of visitors expected to come.

Table 9.1 Vector data available for the Silvretta Nova area.

• Ski lifts	• Blue runs
• Red runs	• Black runs
• Half pipe	• Boardercross
• Ski route	• Villages
• Roads	• Restaurants
• Parkings	• Avalanches

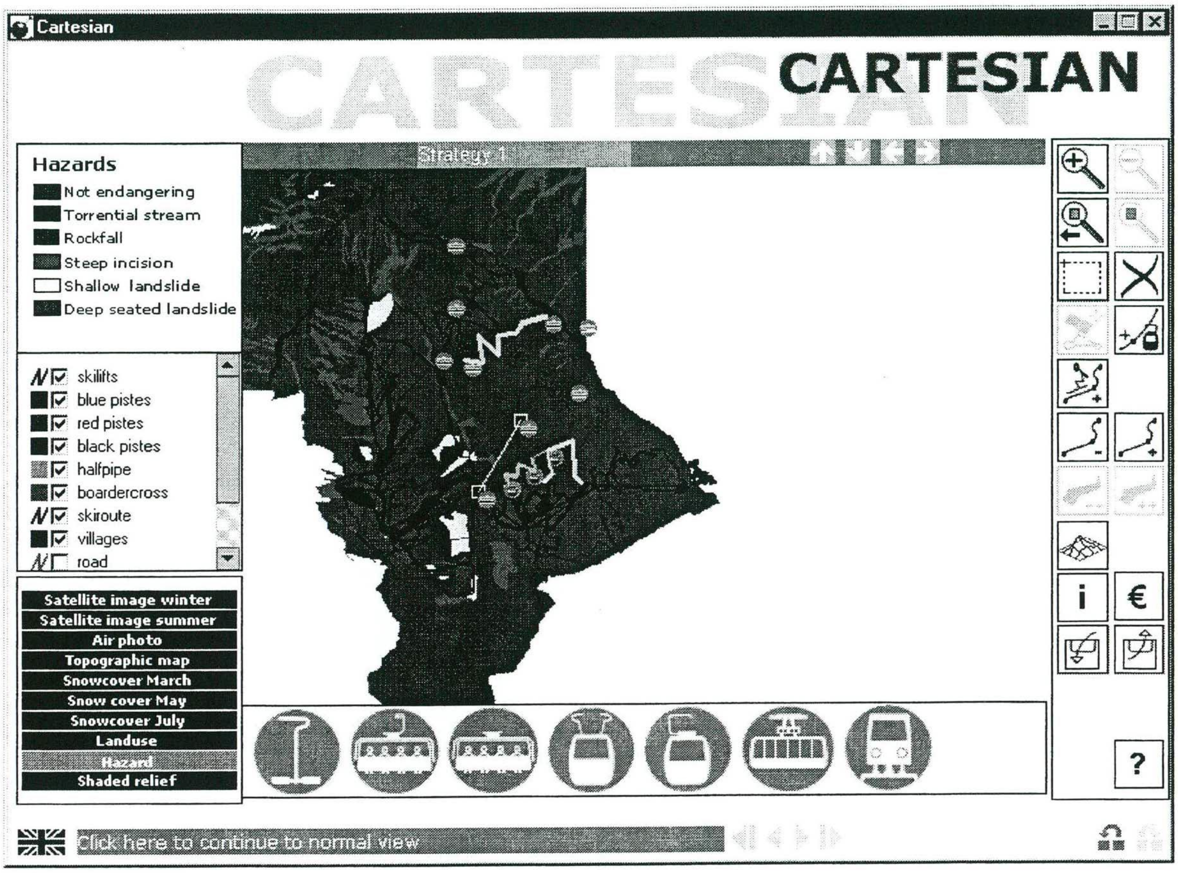


Figure 9.5 Hazard map of the Silvretta Nova skiing area used in the design tool.

A large part of the income of skiing areas is generated through the sale of ski passes. The user is able to adjust the price of the ski pass to analyse the impact of the price change on variables such as the income and the number of visitors in a ski area. Increasing the price too much will decrease the attractiveness of the area and thus the number of visitors to the area.

The ski area design tool is a very user friendly, attractive instrument to design different strategies (set of measures) and investigate in a very simple way the effects of those strategies on environment, risks and economy. The instrument is designed in such a way that it is very easy to use for other areas. By changing the model rules that are behind the design tool, it is possible to use the instrument for any simple spatial planning investigation.

10 Discussion & Conclusions

10.1 Results against objectives

ASMON started off with a thorough investigation on the requirements of the customers, being institutes and companies affiliated with the skiing industry. We have put forward several questions related to the type of issues and problems they encounter and the methods and techniques they currently use to tackle these problems. More specifically, we asked the customers to see what kind of spatial related issues they have to manage and what spatial techniques they currently use in this respect. Most of the identified problems were related to spatial planning issues, impact assessment studies and allocation of resources.

Thereafter, we have asked what kind of information and techniques they would like to improve or develop. Doing that, the focus was on the spatial data needed and the characteristics of this data. It appeared that spatial data has been used over the last 10 years, mostly in the form of aerial photographs. Furthermore, the digital storage of spatial data in a GIS is now starting to develop in the skiing industry and certainly seen as a promising tool for spatial data handling. This opened more easily the path for finding solutions using remote sensing information provided by satellites as the concept of satellite data provision has many resemblances with aerial photography.

One major conclusion that can be drawn after this study, is that the demand for spatial data within ski resorts increases rapidly: First, because areas expand through e.g. liaisons with other areas. Secondly, ski resorts have to become more efficient and careful with their natural resources because space becomes sparse and the alpine ecosystem is one of the most sensitive to disturbances. The spatial data request from the skiing industry is thus big and we therefore limited the data requirements of the customers to the following issues: (1) Land use and land use changes (2) 3D visualisation (3) Snow cover mapping and (4) hazard studies.

The main goal was to demonstrate how remote-sensing data can be used for providing the necessary spatial information for management issues. The ASMON project was carried out parallel to the CARTESIAN project where case studies were applied in Switzerland and France with generally the same objectives. A Management Information System (MIS) has been developed integrating both remote sensing products and decision-making techniques of all three case study areas. The MIS is available on CD-ROM and comprises all results achieved under CARTESIAN and ASMON.

10.2 Accuracy and results

Each of the four above-mentioned issues has been assessed using state of the art remote sensing technology. The accuracy and the temporal resolution required by the customer were a boundary condition in this respect. Let us discuss the results per item:

(1) Land use and Land use changes:

Land cover information could serve as a valuable base for forest cover management and ski facility extension projects. It furthermore serves as a integrative data source for the evaluation of the magnitude of land cover changes in connection with tourism and has to be seen in close contact with forest cover change. Furthermore, land cover data serves as a basis for long-term studies concerning environmental sociability of intensive winter tourism. Landsat TM images have proven to be useful for determining the different land cover types in an alpine region like the Montafon (approx. 600 km^2). Also, to give a quantitative indication of forest cover change, Landsat TM images are suitable.

A major issue for all customers was to quantify land use changes over the last 25 (possibly 100) years. The main satellite sensor, which has been used, was the Landsat TM with a resolution of 30 metersx30 meters. This is a resolution required by the customers, as all customers required a regional assessment study with respect to both land use mapping as well as change detection.

The assessment of long-term landscape changes such as carried out, requires the integration of data from various sources. In principle, this study shows that satellite remote sensing data is preferred above aerial photographs, considering the cost-effectiveness of upcoming studies. Considerable work input for pre-processing can thus be avoided. Still, as seen here, multispectral sensors with spatial resolution in the range of 20 to 30 m (e.g. IRS-LISS or Landsat-TM) hardly allow for the assessment of small changes which are often relevant in landscape evolution. Therefore, an important point is to evaluate where to put the focus of the study and determine the planned applications. If, for instance, a higher degree of detail is not needed for an assessment of forest changes, the choice must be space-borne remote sensing data. As first tests with IKONOS (1 by 1 m^2) have shown, recently launched or upcoming very high-resolution sensors have the potential to replace aerial photographs for small-scale landscape studies.

The study in the Montafon used additional MSS images with a spatial resolution 80 m^2. Main focus of this study was to detect forest changes. It appeared that land use mapping with Landsat TM resulted in very good figures on a regional scale. The detection however, of land use changes with both MSS and TM, resulted in relatively low regression coefficients mainly due to the lower resolution of the MSS sensor. Thus, to give a quantitative indication of forest cover change, Landsat TM images are suitable. However, if detailed changes have to be detected a higher resolution would be more appropriate. The most preferable case would be if at first the location of change were detected with satellite images, second the cause of a certain change in forest cover is known (e.g. landslide, reforestation, forest harvesting) and third the area would be analysed with high-resolution images (1*1 m^2) to define the exact spatial extent of the area.

(2) Snow cover mapping

The second request from the skiing industry was to classify snow cover during a skiing season. We have chosen to develop snow cover maps mainly based on Landsat MSS images. Remote sensing information proved to provide accurate information on snow cover. Snow cover mapping can be an important tool for climate change studies. On a local scale however, it is advised to use high-resolution sensors such as IKONOS.

(3) 3D Visualisation

Satellite information combined with a Digital Elevation Model (DEM) has been used to visualise a ski area for two reasons. (A) To visualise the region for attracting tourists possibly using the internet, and (B), to visualise impacts of management measures such as the clearing of forest for new infrastructure (e.g. ski runs). The requirement of the customers was to visualise the area as realistic as possible but at the same time, delivering products that are cost effective.

(4) Hazard studies

The Stand Montafon forestry institute in Austria required a detailed regional survey of rock fall and other hazards with respect to forest management in the area. Rock fall and hazard maps are produced by making use of the results of a geomorphological field study, a DEM and land use maps derived from Landsat TM. This results fulfil the requirements of the customer.

However, the following remark has to be made: the processes indicated on the hazard map are occurring at the moment or could occur in the future, with process rates that are hazardous to human lives and infrastructures. Especially for the processes that are not very active at present it is very difficult to give an indication in how many years these processes might cause problems. Therefore the polygons present on a hazard map indicate what process(es) are or were active or might activate in the (near) future. Thus, whenever a decision is made that might be influenced by a certain geomorphological process and its consequences, this has to be taken into account. If necessary the earth scientist can give a site-specific interpretation of the potential natural hazards, consequently a risk analysis can be made with the stakeholders involved.

10.3 Customer satisfaction and operational value of products

The feasibility of environmental monitoring with remote sensing techniques depends strongly on image quality, spatial resolution of the satellite images and accuracy of pre-processing and geo-referencing. The results obtained in the ASMON project showed that production of up to date land cover and snow cover maps as well as monitoring of land cover change can very well be carried out with Landsat images. Classification results are satisfying and detected changes in forest cover can be explained by processes occurring in the area. Only detection of changes occurring in very heterogeneous natural environments is always complicated by even slight differences in image quality.

Remote sensing information and especially high-resolution imagery, can play an important role in management of ski areas. Two main fields of application are monitoring of the state of the environment and the impact of the ski area management on the environment. Another important application is presentation purposes.

The overall satisfaction of the delivered products by the customers is high. At the beginning of the project, Remote Sensing was an unknown technique and the expectations were relatively low. It appeared that the intermediary and final products made the involved customers enthusiastic about the possibilities of remote sensing, especially on a regional scale. However, ASMON could profit from a flexible co-operation with Space Imaging providing new IKONOS information with a resolution of 1 m^2. Unfortunately, the images arrived in a late stage of the project, which made it impossible to spend much time in analysing the images. Still, the quality of the image is promising and will be used in the ongoing marketing campaigns. IKONOS clearly shows the use of remote sensing on a local scale.

A few remarks and suggestions can be made from the customer side:

- The temporal availability of snow cover maps must be high in order to have a good overview of real time snow reliability
- IKONOS images are valuable but still relatively expensive, especially orthorectified images
- 3D visualisations can be improved significantly with the use of 3D objects
- Because the products are based on satellite information, acquiring time - and availability of data might be a constraint for the temporal aspect of the requested product.
- Prices of material, that is satellite data, vary in time as new sensors are launched every year.

11 References

Campbell J. (1996). Introduction to remote sensing, Guilford Press, New York 622 pp.

Congalton R. (1991). A review of assessing the accuracy of classifications of remotely sensed data, Remote Sensing of Environment 37: 35-46.

De Boer, M, De Vente J., Mücher, S., Nijenhuis B., Thunnissen H.M.A. (2000). INDAVOR Instrument for detecting land cover change for Europe. NPRS-2 project no. 4.2/DE-03. Resource Analysis report RA/00-409, 98pp.

Ehrler, C. (1996). Analyse des Ausaperungsmusters in ausgewählten Regionen der Schweizer Alpen, basierend auf dem Konzept der Schneebedeckungseinheit (Snow Cover Unit). Einsatz von Geographischen Informationssystemen und Fernerkundung in der Umweltanalyse, edited by K. Brassel, K. I. Itten and E. Schmitt (Geoprocessing Reihe, Geographisches Institut der Universität Zürich), 35-42.

Graaff, L.W.S. de, M.G.G. de Jong, J. Rupke and J. Verhofstad (1987). A geomorphological mapping system at scale 1:10,000 for mountainous areas. Z. Geomorph. N.F. 31(2): 229-242.

Hall, D. K., Martinec J. (1985). Remote Sensing of Ice and Snow. Chapman and Hall, London - New York.

Ingram, K., Knapp, E. and Robinson, J. W., 1981. Change Detection technique development for improved urbanized area delineation, technical memorandum, CSC/TM-81/6087, Computer Sciences Corporation, Silver Springs, Maryland, USA.

Jensen J.R. (1986). Introductory digital image processing: a Remote Sensing perspective. Englewood cliffs, Prentice Hall, pp. 89-91.

Jongman R.H.G. (1996). Ecological and landscape consequences of land use change in Europe. Proceedings of the first ECNC seminar on land use change and its ecological consequences (the Netherlands February 1995), ECNC publication series on Man and Nature, Volume 2.

Lillesand T.M., Kiefer R.W. (1994). Remote Sensing and image interpretation. John Wiley & Sons, New York 750pp.

Martinec, J.,Seidel, K., Burkart, U., Baumann, U. (1991). Areal modelling of snow water equivalent based on remote sensing techniques. Snow, Hydrology and Forests in High Alpine Areas. Proceedings of the Vienna Symposium. IAHS Publ. no. 205.

Seidel, K., Burkart, U., Baumann, R. Martinec, J., Haefner, H., and Itten, K.I. (1989).Satellite data for evaluation of snow reserves and runoff forecasts. Hydrology and Water Resources Symposium: 24-27. Christchurch. New Zealand.

Singh A. (1989). Digital Change Detection techniques using remotely sensed data. International Journal of Remote Sensing 10(6): 989-1003.

Seijmonsbergen, A.C. (1992). Geomorphological evolution of an alpine area and its application to geotechnical and natural hazard appraisal in the NW. Rätikon and S. Walgau (Vorarlberg, Austria), including map series at 1:10,000 scale. PhD Thesis, University of Amsterdam: 109 pp.

Whetton, P.H., Haylock, M.R. and Galloway, R. (1995): Climate change and snow cover duration in the Austrian Alps. Climatic Change, 32: 447-479.

Appendix A Remote sensing based methods in perspective. Summary of a feasibility study.

Goal of the feasibility

As part of the ASMON project a feasibility study was carried out. The goal of this feasibility study was to evaluate the applicability of remote sensing based monitoring of environmental impacts related to the tourist industry in the Montafon, Austria. These monitoring and presentation techniques were compared to alternative techniques such as extensive field campaigns and measurements for monitoring and traditional promotion media such as booklets and artist impressions of the area. The evaluation and comparison focuses especially on the following topics:

- Spatial and temporal scale of interest
- Cost and time investments
- Reliability, accuracy and reproducibility
- Attractiveness for promotion
- Information content and effort for updating

In addition to these criteria, the applicability of the current methodology and final products for other environmental monitoring purposes like other tourist regions (e.g. with other types of activities and impacts) is a criteria in the feasibility study. In the main text of this report the applied methodologies for monitoring, like land cover classification, change detection and visualisation were described in detail. This should give a good idea of the effort required with a remote sensing based methodology. In this Appendix alternative approaches will be introduced and compared with the remote sensing based methodology on the basis of different criteria. In the end some of the basic conclusions are presented.

Alternative methods

Within the ASMON project several remote sensing based products have been developed. It is evident that there is not one alternative method that can provide all this information comparable to the information provided in this project. For some of the products there even does not exist a reasonable alternative, like for example the highly detailed visualisations with IKONOS images. Still, some approaches are seen as possible alternative methods for environmental monitoring. These alternative methods are:

- 'Groundtruth method': Extensive field campaigns for land cover mapping and snow cover measurements.
- 'Statistical method': Comparison of land cover map with older topographical maps for change detection.
- 'Artist method': Artist impressions for 3D visualisations.

The first two methods refer to the production of land cover-snow cover maps and change detection. The third method refers to production of 3D presentations. The first alternative is a large groundtruth data collection program in the study area for land cover mapping. Information on land cover obtained during field campaigns would be used to update existing land cover databases for change detection. In this way changes relative to the source year of the original land cover database will be demonstrated. Also photographs taken at the exact locations where already historical photographical material is available can contribute to change detection. The second alternative for construction of a land cover map and change detection is the reconstruction of up-to-date land cover maps based on digitised historical land cover maps together with statistical data from forestry organisations and cadastral information.

Spatial and temporal aspects

An important consideration for the applicability of land cover information for most studies is that the information should cover large contiguous areas and that data should be easily reproducible and updated which makes especially the remote sensing technique useful. However, when for a study very detailed information is required at a fine scale a groundtruth field campaign can provide more detailed data. The advantage of the groundtruth method is also that the data can be collected just according to the needs of a specific project. In contrast, the information as provided by remote sensing is usually of a generic nature. This makes the information less specified but on the other hand it also makes it applicable for a much wider range applications.

An important advantage of the groundtruth method is the high spatial resolution and a relatively high accuracy of the information for the locations where actual observations are made. However, the groundtruth method is best applicable in case of relatively large homogeneous areas, since heterogeneous areas require an enormous amount of field visits, which is expensive. Furthermore, up-scaling of information from a groundtruth data collection is very difficult. With the groundtruth method extrapolation is complicated, aggregating land cover types into bigger classes will not reduce the amount of field sites necessary and the method will still come up with unsatisfactory information (even in case of a large number of sites). Altogether, the groundtruth method can be a very useful tool when there is a need for very detailed data on land cover and land cover change for limited areas.

In contrast to the groundtruth method, both the remote sensing based technique and the statistical method are able to deal with larger surface areas at a time. However, both methods are confined to only a fixed resolution, which is usually lower than the resolution of groundtruth information and independent of the spatial variability. Furthermore, the groundtruth method has to deal with the fact that especially in Alpine regions many locations are very difficult to be reached for mapping purposes. This considerably complicates the process to cover the whole region.

The advantage of the statistical method is that it can probably provide information on a variety of land cover types. However, the method requires an extensive and detailed statistical database on current land cover and changes occurring in it with a high level of detail. Further, a historical database on land cover and its source year are needed. Another large disadvantage of the statistical method is that often large differences exist between representation of maps and statistical information sources (e.g. different scale, different legends). Furthermore, the accuracy of a historical map is not always clear and the analysis is confined to the spatial resolution of the statistical data and the historical maps. Finally, in statistics on land cover change often the total amount of change per region is available but the actual distribution of the land cover types with geographical co-ordinates is not available. This complicates the construction of accurate maps.

As was explained in detail in this report, Landsat TM images have proven to be useful for determining both snow cover and the different land cover types in an Alpine region like the Montafon (approx. 600 km^2). Also, to give a quantitative indication of forest cover change, Landsat TM images are suitable. Still, since Alpine regions consist mainly of natural environments that have complex structures and are very heterogeneous a more detailed change detection is hampered. For detection of more detailed changes related to natural environments a higher resolution would be appropriate. The most preferable case would be if at first the locations of change were detected with Landsat images, second the cause of a certain change in forest cover is known (e.g. landslide, reforestation, forest harvesting) and third the area would be analysed with high-resolution images (5m*5m) to define the exact spatial extent of the area.

To improve knowledge in snow cover change through the winter season more images are needed than were used in the current study. Especially a better image sequence during the beginning of the ski season (October, November) and in the end (March, April, May and June) would be helpful. Analysing such a sequence every 5 years could be a start in monitoring snow cover change. However, acquiring useful satellite images for these months is difficult because of cloudiness. But the increase of commercial satellites might be a solution for this problem, as the amount of available and hopefully useful images per month is increasing.

Finally, the Artist method for creation of 3D impressions of the area can be seen as an alternative for virtual 3D views. The major advantage of the artist impressions is that very easily a whole ski area can be represented by adjusting slightly the perspective and so enabling an overview of the whole area in one image. With a DEM there will always be the problem of representing the ski area behind another slope. The disadvantage of the artist impressions is that the representations are static and it is not possible to show the evolution of the area over the season in one image like with virtual movies.

Cost and time investments

At the end of this Appendix some tables are presented with the costs related to different products delivered with different methods. First Table below presents the summarised costs related to the products as produced with the remote sensing method. The costs of the statistical method and the groundtruth method are related only to production of a land cover map and change detection analysis, not to visualisation or snow cover mapping. Costs include both material and labour costs. Of course the costs depend very much on the surface area of interest. Therefore, the current comparison only focuses on an application for the study area as presented in this report. The costs of a change detection are difficult to compare since it depends on how long monitoring will continue. Therefore, only the costs related to a comparison between two years are presented. Costs related to additional application for more years vary largely between the different approaches.

Analysing the application for change detection between two years it seems that especially the groundtruth method is relatively expensive due to the large costs related to the field data collection programme. Especially the labour costs for the field campaign are relatively high. The remote sensing based method and the statistical method show comparable overall costs. For the statistical method the labour costs are somewhat higher.

Costs related to production of different applications based on remote sensing.

Product	Price	
Land cover classification	F 40.300,-	
Change detection (In addition to costs related to LC classification)	F 28.200,-	*Total CD*: F 68.500,-
Snow cover maps	F 58.200,-	
3D views	F 23.100,-	
3D flights (In addition to costs related to 3D views)	F 3.000,-	*Total 3D*: F 26.100,-
IKONOS visualisation	F 14.800,-	

The main advantage of the remote sensing based technique is that for an extension of the method for a multi-annual application, costs are reduced considerably. Time invested to develop the change detection methodology and classify images can be reduced substantially. So the most important costs will be the acquisition of new images. In the statistical method costs will also be reduced slightly in a multi-annual application since less time will be needed for map classification to uniform legend units and digitising maps. However, when the representation of statistical information changes, this also has a result for the costs to be made to make information fit with existing information. For the groundtruth method the only cost reductions that can be made are in the materials, but this reduces total costs only marginally.

A comparison between the artist method and creation of visualisations with remote sensing techniques reveals that the artist impressions are significantly more expensive. This difference is especially due to higher labour costs and time needed for preparation of the artist impression. Important time investment is the combination of the artist impression with infrastructure information on pistes and ski lifts.

Altogether, total costs of the statistical and the remote sensing based method are comparable, while the costs of the groundtruth method are much higher. Moreover, for a multi-annual application, the costs for the groundtruth database are equal every year while for the other two methods the costs reduce significantly. The most important reason for this is that the groundtruth method is very time consuming and requires much labour efforts. Finally, the artist impression is much more expensive than a remote sensing based approach.

Reliability, accuracy and reproducibility

The level of accuracy of the remote sensing based technique depends strongly on the quality of the satellite images and accuracy of pre-processing and geo-referencing. Furthermore, the available amount and accuracy of the reference data determine the quality of the result and accuracy of the validation procedure. As was mentioned before, the accuracy of the classification of Landsat TM images was very satisfying with a total accuracy of 93.8%. The forest cover change detection can also be regarded as satisfying especially since most changes in forest cover could be explained by processes of change like landslides or forest harvest.

The accuracy of the groundtruth method is in general very high, but only for the locations where actual observations are made. The overall accuracy depends directly on the amount of observations made. For change detection and comparison with existent databases the accuracy depends on the accuracy of the initial land cover database. Interpolation of information between field sites results in high uncertainties. Finally, compared to the remote sensing technique the uncertainty of the statistical method is expected to be larger. The reliability of topographic maps differs considerably between maps because of scale and source. Furthermore, statistical information on land cover changes is often limited available, sources are often difficult to check and not for each land cover type statistics are available with the same level of detail and accuracy. For example a forest organisation maintains a database with harvested forest but this contains no information on other land cover types.

Applicability for monitoring studies and ease of updating

Monitoring land cover is very important for environmental monitoring in Alpine regions. It can serve as a valuable base for arguing in forest cover management, ski facility extension projects and other tourist or infrastructure related topics. It furthermore serves as an integrative data source for the evaluation of the magnitude of land cover changes in connection with tourism and has to be seen in close contact with forest cover change. Furthermore, land cover data serves as a basis for long-term studies concerning environmental sociability of intensive winter tourism.

One of the major advantages of the remote sensing technique is that it can relatively easy be used repeatedly. With the analysis of changes in the spectral response between different years changes in land cover characteristics can be detected much easier than with one of the other two methods. A disadvantage of remote sensing is the relatively high price of the images and the dependence on high image quality. Notwithstanding, satellite images provide information on large continuous areas and the change detection and classification methodology only need to be defined once. The relatively high starting costs makes the remote sensing based method especially suited for monitoring applications.

Another advantage of the remote sensing method for both snow cover monitoring as land cover classification is that there is no problem with the accessibility of the area. With the groundtruth method many areas in the Alps can hardly be reached especially in winter on steep slopes with much snow cover.

The approach of change detection through comparison of databases also seems to be suited for a monitoring approach since updating of information should not be too time consuming. However, the disadvantage is that with this method you are always dependent on (changes in) the format of presentation of statistical information and on the reliability of the data sources. The groundtruth method does not seem to be a feasible option for prolonged monitoring at a regional scale since it is a very time consuming activity and needs the same investments every year. For monitoring of specific locations near tourist industries it can be an option since the quality of information is very high.

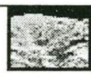
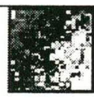
The power of the WCS for creation of 3D views is that once all the features are correctly placed and given the appropriate characteristics, it is easy to create different looks of the ski area. Different seasons can easily be represented by adding snow, clouds, sunshine, moon and each required location of the observer can be defined on request. These options are all available within WCS. Besides that it is easily possible to turn different features on or off (i.e. show icons and text or not). In contrast, the artist impression is much more static since the whole underground can not be changed after preparation. Only new ski lifts or pistes can be added but no different seasons or locations of the observer can be made easily.

Conclusions

The remote sensing based methodology for land cover classification and change detection as presented in the ASMON project certainly has many advantages over other possible methods to provide a database of land cover and land cover change. The same counts for production of snow cover maps. First of all, the remote sensing based method results in a contiguous database for the whole area of interest, which is relatively easy to update and especially suited for monitoring studies. Secondly, the spatial resolution of 30 meter *30 meter is high enough for most monitoring purposes. For purposes that require more detail, IKONOS images can be used, which is expected to provide good results as well. Another advantage of the remote sensing method is that it can provide information on ecosystem dynamics during the growing season. With the statistical; method this is not possible and with the groundtruth method it will not be feasible for logistical reasons. Furthermore, the remote sensing method is relatively cheap, especially for a multi annual application. Another major advantage of the remote sensing based methodology compared to the more traditional way of statistical data gathering is that a great range in temporal and spatial resolutions can be achieved for a large geographic area over a long period of time. In contrast to a methodology based on statistical information with remote sensing the data gathering and interpretation methodology is consistent over the study area and no problems exist in different availability of data for different regions or different moments in time. So, although a statistical approach seems to be feasible in terms of costs, monitoring possibilities and application for large areas, the major problem remains the accuracy and dependence on the availability and level of detail of information.

An extensive groundtruth data collection program in order to update existing databases seems to be the least feasible option for a pan European application. However, a groundtruth data collection program would be a very good way to provide accurate data at a high spatial resolution for limited areas. In that way, a field survey can form an important contribution to for example the validation of information in areas with a heterogeneous land cover or areas of interest that are not sufficiently represented by statistical or remotely sensed information.

Visualisations of an area through virtual 3D presentations (views or flights) have proven to provide a very attractive alternative for traditional presentation and promotion means. The 3D views and movies can also be integrated with HTML pages on the Internet. In an extended application as clickable maps the information content of the application can even be extended significantly. Furthermore, when the virtual map suits the wishes and purposes it is easy to update the map with new lifts, pistes, restaurants and other features and it is also possible to change the appearance of the ski area. It is possible to create a summer and a winter from the same data by adjusting the settings of ecosystem parameters. All these are large advantages compared to traditional artist impressions and booklets for promotion of ski and other tourist industries. A disadvantage of the virtual ski-map is that it isn't possible to 'bend' the landscape in order to have a good view of all the skilifts and pistes at the same time, even if in reality they are covered by other features or a slope. The virtual ski-map will therefore not fully replace the existing artists' impressions. It is however a powerful addition to visualise ski areas in a very attractive way. Finally, IKONOS images form a very attractive presentation of an area. The images, processed for optimal presentation, can be used for promotion but also as reference information for forestry organisations.

Product				Site	Labour (1)	Material (2)
		No.	View		[Days]	[Euro]
3D Animations	3D View	1		Silvretta Nova	10	* 3000
	3D Movie / Flight (extra on top of No. 1)	2		Silvretta Nova	2	-
Snow Cover	Snow cover (6 maps) 30x30m2	3		Montafon	30	6000
Land Use	Land use map 30x30m2	4		Montafon	20	**4000
	Landscape Change analysis	5		Montafon	10	**6000
IKONOS	Full color image (1x1 m2 resolution, 10 * 10 km)	6		Montafon	4	4000

Prices are indicative
1: 'Labour' is the number of days needed to make the product. The labour cost is dependent on the institute that will carry out the order.
2: 'Material cost' is the cost of material (satellite images, air photos, etc.).
Total price of the product = (number of days * labour cost) + material cost.
* GIS Database should be available (costs ca. 700 Euro).
** Ground control points should be available for best results (costs ca. 700 Euro)

Estimated costs related to monitoring with statistical based methodology.

Materials	***Costs***
Topographic maps one year	*f* 1.500,00
Land cover database	*f* 1.500,00
Statistical database	*f* 1.000,00
Windows NT workstation and digitizer	*f* 10.000,00
RS/GIS software	*f* 5.000,00
Subtotal materials	*f 19.000,00*
Labour	***Costs***
Map classification to uniform legend (10 days)	*f* 15.000,0
Digitising maps (15 days a *f* 1.000,00)	*f* 15.000,00
Set-up of land cover statistics database (10 days)	*f* 10.000,00
Calculation of updated land cover database (15 days)	*f* 15.000,00
Subtotal labour	*f 55.000,00*
Total	***f* 74.000,00**

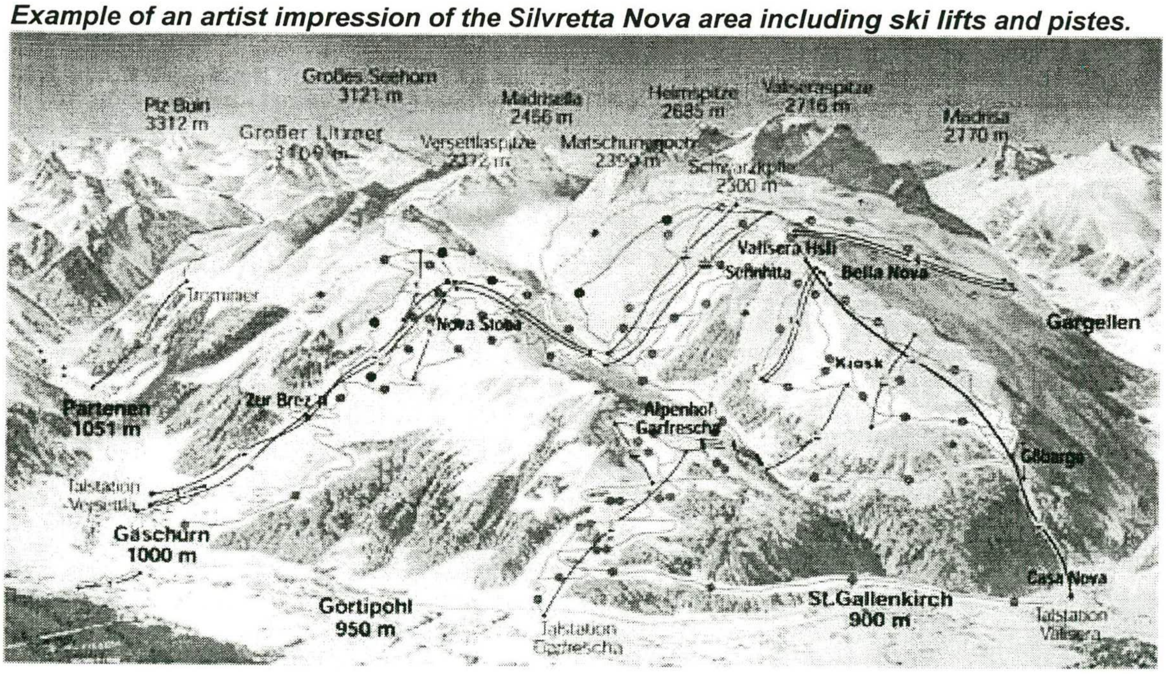
Land cover classification and change detection with the Groundtruth method

Materials	***Costs***
Travel costs	*f* 7.500,-
Overnight stay (45 days, 2 persons *f* 100,00 pppn)	*f* 9.000,00
Topographic maps	*f* 1.500,00
Land cover databases	*f* 1.500,00
PC, Laptop + GIS software	*f* 15.000,00
Global Positioning System (GPS)	*f* 5.000,00
Subtotal materials	*f 39.500,00*
Labour	***Costs***
Field campaign (45 days a *f* 1200, 45 days à *f* 1500,00)	*f* 121.500,00
Dataprocessing (15 days)	*f* 18.000,00
Subtotal labour	*f 139.500,00*
Total	***f* 179.000,00**

Visualisation by artist impressions

Materials	***Costs***	
Travel costs	*ƒ* 2.000,00	
Overnight stay (15 days, *ƒ* 100,00 pn)	*ƒ* 1.500,00	
Topographic maps including lifts and pistes	*ƒ* 1.000,00	
Painting material	*ƒ* 1.500,00	
Subtotal materials		*ƒ 6.000,00*
Labour	***Costs***	
Field visit (15 days à *ƒ* 1500,00)	*ƒ* 22.500,00	
Merge painting with features (lifts/pistes..) (10 days)	*ƒ* 15.000,00	
Final painting (15 days)	*ƒ* 22.500,00	
Subtotal labour		*ƒ 60.000,00*
Total		***ƒ 66.000,00***

Example of an artist impression of the Silvretta Nova area including ski lifts and pistes.



The National Remote Sensing Programme 1990-2000, (NRSP-2) is implemented under the responsibility of the Netherlands Remote Sensing Board (BCRS) and coordinated by the Ministry of Transport and Public Works.

The objectives of the NRSP-2 are: to secure the long-term integration of the operationel use of remote sensing through temporary stimulation in the user-sectors of government and industry, to strengthen the development of remote sensing applications and the expansion of the national infrastructure.

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