Periodic Report I

OMEGA

Operational Monitoring System for European Glacial Areas

Contract No. EVK2-CT-2000-00069

Reporting period: 1.10.2001 – 31.3.2002

Sections included:
Section 2, 3
Participants information

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31st May 2002

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Partner 3, Novosat Ltd. (NOVOSAT)
Partner 4, University of Innsbruck, Institute of Geography (UIBK)
Partner 5, Joanneum Research, Institute for Digital Image Processing (JR_DIB)
Partner 6, NORUT Information Technology (NORUT IT)
Partner 7, Norwegian Water Resources and Energy Directorate (NVE)
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SECTION 2: Executive publishable summary, related to reporting period (12 months)

Contract n°	EVK2-CT-2000-00069	Reporting period:	1.4.2001 – 31.3.2002
Title	Development of operational monitoring system for European glacial areas – synthesis of earth observation data of the present, past and future		

Objectives: To evaluate the full potential of airborne and satellite remote sensing for operational glacier monitoring.

Scientific achievements: Designing a processing chain for optical and radar satellite data in order to retrieve glaciological parameters from the image data, application of change detection methods on optical and radar satellite imagery over glaciers, and development of a relation and accuracy assessment methodology for comparison of digital elevation models generated from different data types.

Socio-economic relevance and policy implications: The current situation of glacier monitoring is assessed and the requirements for a glacier monitoring system is defined in User Requirement Document (URD). The monitoring system has to take account the local and regional characteristics and should be able to use different data types. The URD defines not just the technical aspects like accuracies, but also reminds about the usability of the system when the end user is not an experienced remote sensing specialist.

Conclusions: The data compilation and processing of the remote sensing data from different sources are straight forward tasks, but validation, comparability between the different data types and design of the monitoring system are challenging topics in the project.

Keywords: remote sensing, glaciers, change detection, multitemporal, multisensor

SECTION 3: Detailed report organized by work packages

Work package 1 – Preparation and requirements

Compiled by Kari Kajuutti and Petri Pellikka

All the consortium members were involved in this work package. The work package is divided into two different tasks:

WP 1.1 Definition of the current status and future requirements for glacier remote sensing
WP 1.2 Selection of glaciers and acquisition of existing data

The bulk of the work package was the preparation of the User Requirement Document, (Jackson et al., 2001), in which the definition of the current status and requirements for glacier remote sensing are presented. The other main task was to compile all the existing remote sensing, map and elevation data of the glaciers chosen for the study.

1. Objectives

The objectives of the work package were to define the current status and future requirements of glacier remote sensing in order to be able to understand the possibilities and needs of the monitoring system. This had to be done taking into account the local and regional characteristics. The final selection of study glaciers were to be done and the existing data sets compiled.

2. Methodology and scientific achievements

The major task was to compile different kinds of data sets already existing. The local contractors searched through the archives and the results of the search are presented in Tables 1 and 2. The new data collected during the project are also included. The data are then assessed in order to select the useable sets.

In accordance with the working plan University of Turku has acted as a lead contractor of the work package 1 and work package 1.2. The partners involved in the research have been partners 3, 4, 5 and 7 (lead contractor for WP 1.1).

University of Turku

University of Turku had active role in the negotiations and decisions about the study and test glaciers of the project. It also selected the Landsat images to be used in the project (Table 1) and put together the information of all found datasets for a database (Tables 1 and 2).

Helsinki University of Technology

HUT's contribution was in the work package 1.2. It chose the ERS radar satellite imagery, acquired existing digital elevation models (DEMs), old aerial photography and organised their scanning, digitising and processing.

University of Innsbruck, Institute of Geography

This partner contributed to the work package 1.1 (contributed the laser scanning part in the URD and was also involved in the end users and applications parts) and organised the laser scanner data acquisition on both study areas.

Joanneum Research

Joanneum Research contributed to the work package 1.1 and in the preparation of the URD. It prepared the specification of glacier variables and the summary of requirements to satellite monitoring of glacial areas in the Europe and provided general information on space borne radar methods (including SAR stereo and INSAR) for the glacier surface modelling and change detection. It also performed analysis of technical feasibility and perspectives for the use of those techniques in test areas. For the URD, Joanneum Research compiled principle applications of the output products, list of potential users and the list of available ERS-1/2-SAR data.

NVE

NVE was the lead contractor for the work package 1.1 and was also the responsible partner for compiling the URD. In it, NVE assessed especially the glaciological requirements for the monitoring system. NVE had an active role when negotiating and deciding the Norwegian study sites, searched for the archives in Norway in order to compile all kinds of old photogrammetric, glaciological, meteorological and topographical data over Svartisen (Table 2) and planned the data collection in Norway. Being the local Norwegian organisation and specialist in glaciology, NVE planned also the glaciological monitoring over Svartisen, especially fieldwork, and co-ordinated it with remote sensing data acquisition.

University of Innsbruck, Institute of Meteorology and Geophysics

This partner contributed strongly in both tasks of the work package. It planned the data collection in Austria, had an active role when negotiating and deciding the Austrian study sites and searched for the archives in Austria in order to compile all kinds of old photogrammetric, glaciological, meteorological and topographical data over the study area (Table 1). University of Innsbruck has also been digitising the old topographic maps into digital elevation models for glacier change analysis. Maps of Hintereisferner of the years 1984, 1920, 1956, 1969 and 1979 have been digitized, compared and analysed in a first approximation. It was possible to detect some errors on the first map of Hintereisferner (1:10000) of 1894. The change in volume between the different maps is now being investigated and compared with mass balance data.

The contributions from all the partners involved to the WP 1 have been successfully completed. In accordance with the request by other partners some research related with the selection and acquisition of available ERS-1/2-SAR data (WP 1.2) was performed by Joanneum Research spite of the fact that the Joanneum Research is not formally involved in this work package. In addition, NORUT has been acquiring ERS radar satellite data for its work in work package 3.

3. Socio-economic relevance and policy implication

OMEGA project's important contribution is to develop an accurate but cost effective monitoring system. This has kept in mind while selecting the study glaciers so that there are plenty of existing data available and they are suitable for testing different kinds of techniques in order to find out the most appropriate one(s) for long term monitoring. Human activities like hydropower production, tourism and farming are well represented in the study areas. Comparison of changes in glaciers dimensions and behaviour and on the other hand changes in human activities will offer ideas what kind of impacts future changes of glaciers may have for present and planned living conditions and business. The project is both on regional and global level supporting European Union's environmental policy.

4. Discussion and conclusion

The specification of the glacier variables and the present remote sensing methods have been defined taking into account the regional characteristics. Information of the possibilities of different methods for the glacier surface modelling and change detection have been provided. The technical feasibility and the requirements of the potential users for the monitoring system have been considered. The plan for collecting both remote sensing and glaciological data over study glaciers has been prepared taking into account the need of co-ordination with fieldwork and remote sensing data acquisition.

The collection of the already existing data sets pointed out quite clearly that there is plenty of data available from the study glaciers. The validation and putting the data together in a reasonable formula is and will be a challenging part for the project.

A User Requirement Document (URD) for glacier remote sensing was compiled with contributions from several partners. The included sections are aerial photography, airborne radar and satellite radar, digital camera imagery, laser scanning, optical satellite data and new techniques. The URD defines not just the technical aspects like accuracies, but also reminds about the usability of the system when the end user is not an experienced remote sensing specialist. The URD will serve the project as a guideline of the requirements to be fulfilled. The URD will be updated during the project.

5. Plan and objectives for the next period

Work package 1 is technically and successfully closed. However, the URD will be updated during the project and evidently more old data over the study glaciers will come up. The achievements of the technical plan and definition of the monitoring system requirements have already contributed and will contribute to the whole project. The compilation of the existing data will contribute especially to work packages 2, 3 and 4 making it possible to have both remote sensing and in-situ acquisition based on the historic knowledge of the glacier change.

Table 1. Data of Hintereisferner and Kesselwandferner.

Data type	Description	Year
Drawings		
	Das Ende des Hintereisferners	1847
	Mittlere Gruppe des Oetztaler Ferner	1852
Maps		
	Map of Ramblmayr and Gumpp	1681
	Atlas Tyrolensis	1774
	Die Zunge des Hintereisferners	1817
	Karte des Rofenthales	1848
	Der untere Abschnitt des Hintereisferners	1871/72
	Die Gletscher des Vernagtthales in Tirol und Ihre Geschichte	1846
	Untersuchungen über die physicalische Geographie der Alpen	1850
	Die Oetzthaler Gebirgsgruppe mit besonderer Rücksicht auf Orographie und Gletscherkunde	1861
	Hintereisferner, 1:10000	1894
	Hintereisferner, 1:10000	1920
	Hintereisferner, 1:10000	1939
	Hintereisferner, 1:10000	1953
	Hintereisferner, 1:10000	1964
	Hintereisferner , 1:10000	1967
	Hintereisferner , 1:10000	1969
	Hintereisferner , 1:10000	1979
	Hintereisferner , 1:10000	1997
	Hintereisferner, 1:25000	1939
	Hintereisferner, 1:25000 (US Military map)	1945
	Kesselwandferner, 1:5000	1971
	Kesselwandferner,1:10000 (only the accumulation area)	1914
	Kesselwandferner, 1:10000	1939
	Kesselwandferner, 1:10000	1958
	Kesselwandferner, 1:10000 (only the lower part of the glacier tongue)	1961
	Kesselwandferner, 1:10000	1979
	Kesselwandferner, 1:10000	1997
	Kesselwandferner, 1: 25000	1939
	Kesselwandferner, 1: 25000 (US Military map)	1945
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1905
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1914
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1917
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1918
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1919
	Confluence zone of Hintereisferner and Kesselwandferner, 1:10000	1922
Terrestrial photographs		
Olympus Camedia	Color digital, 1280 (H) x 1024 (V), Hintereisferner snout	September 2001
	B/W negatives, 93 images, scanned with 12,5 µm pixel size (subset of from 111 images, glass plates of size 120 mm x 160), Hochjochferner	July-August 1907
	Die Zunge des Hintereisferners	1884
	Photographs from the same viewpoint	almost annually
	Glacier de Kesselwand, Route du Hochjoch	1869
Aerial		

photographs		
	Aerial photography	1953
	Aerial photography	1969
	Aerial photography	1979
	Aerial photography	1997
Measurements		
	Velocity	1850
	Dendroclimatological mass balance reconstruction	since 1400
	Annual velocity on different sites	since 1894
	Fixed profile of velocity changes	since 1932
	Daily velocity measurements	1952/53
	Annual velocity measurements on the lowest part of Kesselwandferner	1895-1899
	Annual velocity measurements on 5 fixed profiles (stakes) on Kesselwandferner	since 1965
	Measurements of seasonal changes in velocity of two approximately 25m deep firn pits of Kesselwandferner	1967-1978 1983-1989
	Continuous measurements of changes in length of Hintereisferner	since 1894
	Continuous measurements of changes in length of Kesselwandferner	since 1965
	Climatological mass balance reconstruction	since 1934
	Mass balance measurements on Hintereisferner and Kesselwandferner	since 1952
	Meteorological data and GPR measurements	several years
Landsat scenes		
Landsat 1 MSS	Hintereisferner (Path/row 208/27) (snow cover or shadowed)	6.10.1972
Landsat 2 MSS	Hintereisferner (208/27) (snow cover or shadowed)	7.8.1975
Landsat 2 MSS	Hintereisferner (208/27) (snow cover or shadowed)	14.9.1978
Landsat 2 MSS	Hintereisferner (208/27) (snow cover or shadowed)	30.9.1980
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	29.10.1984
Landsat 4 TM	Hintereisferner (193/27)	30.9.1985
Landsat 4 TM	Hintereisferner (193/27)	3.10.1986
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	20.7.1988
Landsat 4 TM	Hintereisferner (193/27)	30.8.1990
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	17.9.1992
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	25.10.1994
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	15.9.1997
Landsat 7 ETM	Hintereisferner (193/27)	13.9.1999
Landsat 5 TM	Hintereisferner (193/27) (snow cover or shadowed)	25.10.2000
Spaceborne radar		
ERS 1	Hintereisferner area, Center coordinates 46,552N, 11,196E	30.6.1995
ERS 2	Hintereisferner area, Center coordinates 46,547N, 11,220E	1.7.1995
ERS 1	Hintereisferner area, orbit 23478, frame 927	10.1.1996
ERS 2	Hintereisferner area, orbit 3805, frame 927	11.1.1996
ERS 1	Hintereisferner area, orbit 23979, frame 927	14.2.1996
ERS 2	Hintereisferner area, orbit 4306, frame 927	15.2.1996
ERS 1	Hintereisferner area, Center coordinates 46,550N, 11,182E	5.4.1996
ERS 2	Hintereisferner area, Center coordinates 46,543N, 11,186E	6.4.1996
ERS 1	Hintereisferner area, orbit 23097, frame 2655	29.5.1996
ERS 2	Hintereisferner area, orbit 5802, frame 2655	30.5.1996
ERS 1	Hintereisferner area, Center coordinates 47,151N, 10,847E	10.3.1999
ERS 2	Hintereisferner area, Center coordinates 47,159N, 10,851E	11.3.1999
ERS 1	Hintereisferner area, Center coordinates 47,146N, 10,833E	14.4.1999
ERS 2	Hintereisferner area, Center coordinates 47,155N, 10,862E	15.4.1999
ERS 1	Hintereisferner area, orbit 49741, frame 927	30.4.1999
ERS 2	Hintereisferner area, orbit 21068, frame 927	1.5.1999
ERS 1	Hintereisferner area, orbit 42745, frame 927	17.9.1999

ERS 2	Hintereisferner area, orbit 23072, frame 927	18.9.1999
Laser scanner data		
Topscan	Hintereisferner and Kesselwandferner	10.10.2001
Topscan	Hintereisferner and Kesselwandferner	9.1.2002

Table 2. Data of Engabreen and Svartisheibreen.

Data type	**Description**	**Year**
Maps	Engabreen,. 1:20 000. Contour interval: 10 m.	1970 (glacier 1968
	Trollbergdalsbreen, 1:10 000. Contour interval: 10 m.	1970 (glacier 1968
	Høgtuvbreen, 1:10 000. Contour interval: 10 m.	1973 (glacier 1972)
Aerial photographs		
	Entire Engabreen glacier, Svartisheibreen. 1:35 000, B/W	1968, 1985
	Engabreen outlet below ca 1050 m a.s.l. 1:15 000.	1990-95
	Svartisheibreen	1995
	Engabreen outlet below ca 1050 m a.s.l. 1:15 000, B/W.	1997,1998, 2001
	Svartisheibreen, B/W, 1:15 000	25.8.2001
Terrestrial photographs		
Olympus Camedia	Color digital, 122 images, 1280 (H) x 1024 (V), processed to panoramic stereo images, 10 pairs	August 2001
Digital camera data		2001
NIKON D1	Engabreen and Svartisheibreen	24.9.2001
Digital elevation models		
	DEM of Svartisen, 25 m resolution	2002
	DEM of Svartisen, 100 m resolution	
Measurements		
	Engabreen front position: annual change in distance along fixed lines, measured in the autumn.	1903-2002
	Engabreen front position below 400 m a.s.l. from aerial photographs	1968, 1985, 1990-95
	Svartisheibreen front position in lake Heiavatnet by tachymeter	1988-2001
	Engabreen annual mass balance. Winter- summer- and net balance in 100 m elevation intervals, equilibrium line altitude (ELA).	1970–2001
	Svartisheibreen annual mass balance. Winter- summer- and net balance in 100 m elevation intervals, equilibrium line altitude (ELA).	1988-94
	Engabreen glacier velocity field in parts of the icefall for periods in summer derived from aerial photographs.	1990-95
	Engabreen velocity at stakes on lower part of glacier (< 400 m a.s.l).	1990-95
	Svartisheibreen velocity at stakes	1993–94

	Engabreen snow density in spring. 1-2 pits/cpres on the plateau each year	1999-2001
	Svartisheibreen snow density in spring. 1 pit 1030 m a.s.l.	1988-94
	Engabreen bottom topography measured with GPR, melt-drilling from surface, and rock drilling from rock tunnels underneath glacier.	?
	Svartisheibreen bottom topography measured with GPR	1989
	River discharge Engabrevatnet (7 m a.s.l.) (series not complete)	1969-2002
	Svartisheibreen jökulhlaup from lake level measurements	1991
Meteorological measurements		
Temperature		
	Tåkeheimen (1100 m a.s.l.)	June-August 1970-1981
	Glomfjord (ca 19 m a.s.l.)	1.1.1956 - 31.12.2001
	Skjæret (1364 m a.s.l.) (1 hour resolution)	12.01.1995 – 26.2.2002
Precipitation		
	Glomfjord (ca 19 m a.s.l.)	1.1.1974 – 31.12.2001
	Tåkeheimen (1100 m a.s.l.)	June-August 1970-1981
Landsat scenes		
Landsat 2 MSS	Engabreen (Path/row 214/13) (snow cover or shadowed)	15.8.1978
Landsat 2 MSS	Engabreen (215/13) (snow cover or shadowed)	16.10.1980
Landsat 3 MSS	Engabreen (Path/row 215/13) (snow cover or shadowed)	4.8.1982
Landsat 5 TM	Engabreen (198/13) (snow cover or shadowed)	30.9.1984
Landsat 4 TM	Engabreen (198/13) (snow cover or shadowed)	19.10.1988
Landsat 5 TM	Engabreen (198/13) (snow cover or shadowed)	1.10.1990
Landsat 5 TM	Engabreen (198/13)	25.8.1994
Landsat 5 TM	Engabreen (198/13) (snow cover or shadowed)	13.9.1995
Landsat 4 TM	Engabreen (199/13) (snow cover or shadowed)	6.9.1996
Landsat 7 ETM	Engabreen (199/13)	7.9.1999
Landsat 7 ETM	Engabreen (199/13) (snow cover or shadowed)	27.10.2000
Landsat 7 ETM	Engabreen (200/13)	19.9.2001
Spaceborne radar		
ERS 1	Svartisen area, orbit 226, frame 1341	1.8.1991
ERS 1	Svartisen area, orbit 269, frame 1341	4.8.1991
ERS 1	Svartisen area, orbit 312, frame 1341	7.8.1991
ERS 1	Svartisen area, orbit1215, frame 1341	9.10.1991
ERS 1	Svartisen area, orbit 1258, frame 1341	12.10.1991
ERS 1	Svartisen area, Center coordinates 66,452N 14,858E	7.6.1995
ERS 1	Svartisen area, Center coordinates 66,453N 13,422E	15.7.1995
ERS 2	Svartisen area, Center coordinates 66,459N 13,426E	16.7.1995
ERS 1	Svartisen area, Center coordinates 66,441N 14,124E	31.7.1995
ERS 2	Svartisen area, Center coordinates 66,457N 14,056E	1.8.1995
ERS 1	Svartisen area, Center coordinates 66,455N 13,413E	16.3.1996
ERS 2	Svartisen area, Center coordinates 66,466N 13,420E	17.3.1996
ERS 1	Svartisen area, orbit 24594, frame 1341	28.3.1996
ERS 2	Svartisen area, orbit 3242, frame 1341	29.3.1996
ERS 1	Svartisen area, Center coordinates 66,443N 14,142E	1.4.1996
ERS 2	Svartisen area, Center coordinates 66,449N 14,148E	2.4.1996
ERS 1	Svartisen area, orbit 29604, frame 1341	13.3.1997
ERS 2	Svartisen area, orbit 9931, frame 1341	14.3.1997
Laser scanner data		
Topscan	Engabreen and Svartisheibreen	24.9.2001

Work package 2 – Acquisition of in-situ data

Compiled by Miriam Jackson

Summary

Five of the consortium members were involved in this work package – University of Turku, Novosat Ltd., Joanneum Research, NVE (Norwegian Water Resources and Energy Directorate - work package leader) and the Institute for Meteorology and Geophysics at the University of Innsbruck.

The work package is divided into three different tasks:

WP 2.1 Glaciological and meteorological measurements
WP 2.2 Construction of a GCP network
WP 2.3 Radio-echo sounding

The bulk of the work package was the collection of glaciological data from the two study sites – Svartisen in northern Norway (Figure 1) and Hintereisferner in Austria (Figure 2). NVE concentrated on fieldwork on Svartisen whilst the University of Innsbruck collected data on Hintereisferner. The University of Turku performed fieldwork at both study sites. Joanneum Research and Novosat Ltd. were involved only in the construction of a GCP (ground control point) network. This network will provide an important framework for the different remote sensing techniques, as well as providing better positional control for some of the glacier measurements. Radio-echo sounding took place on Hintereisferner only. There already exists radio-echo sounding data for much of Svartisen, and this was compiled into an easily usable format.

1. Objectives

The objective of the work package is to acquire in-situ data and radio-echo sounding data of the glaciers studied and to construct a ground control point network.

2. Methodology and scientific achievements

University of Turku

The acquisition of in-situ data of the University of Turku was contribution mostly to work packages 3.1.1. and 3.3.1. In addition, some tasks for work packages 2.2 and 3.3.5. were made. University of Turku planned and carried out field campaigns on Engabreen and Hintereisferner during the first project year. The field campaign took place on Engabreen August 17-25 putting an emphasis on terrestrial photography. Research activities included also searching of training areas for the supervised classification of the Landsat TM data. Training areas were collected both from the glacier surface (snow, firn and ice) and from the land surface. University of Turku also assisted the University of Innsbruck in searching for GCPs in the study area and measuring the Halsa football field as a reference area for laser scanner data acquisition. The place for terrestrial photography was selected from a relatively flat part on the ablation area of Engabreen. The places of photography (tripod location) were located with a tachymeter from two fixed points of the GCP network. All the places were painted onto the bedrock in order to make it possible to repeat the photography on the following years.

Figure 1. Engabreen study glacier, Svartisen ice cap, Norway.

Figure 2. Hintereisferner study glacier, Ötztal, Austria, September 2001.

All the close-up views were taken with a digital camera and larger area photography with a non-metric 35 mm camera. The close-up photography was repeated after two days in order to find changes in the glacier surface over a relatively short period. Verifying the laser scanning data was also an intention for these images, but the flight was delayed several weeks because of unstable weather conditions. The 35 mm photography covers the glacier surface from the snout up to about 600 m a.s.l. However, these photographs were taken only from one side of the glacier leaving parts of the rough glacier surface out of sight (right hand side in Figure 1).

The field campaign on Hintereisferner took place on September 18-23. The terrestrial photography was carried out in a similar way as in Norway. The differences were on defining the places of photography. The locations were measured with a GPS receiver and from each place photographs were taken so that some fixed points of the GCP network were visible. Additionally distances from clearly visible objects were measured with a laser distance meter. The different zones of the glacier were also planned to observe but this was cancelled because the whole glacier was covered by new snow (Figure 2). The snow cover (which was unusual at this time of the year) also makes difficult the analysis of the terrestrial photography for surface model generation. Research activities included also searching of training areas for the supervised classification of the Landsat TM data. Training areas were collected only from land surface since the glacier surface remained snow-covered for the whole fieldwork period.

Helsinki University of Technology

The acquisition of in-situ data of HUT was contribution to work package 3.3.1. One member from HUT joined the team from the University of Turku in Svartisen for surveying the fixed points for terrestrial photography and for acquisition of terrestrial photography. The details of this work are reported under University of Turku. In addition, HUT assisted the University of Innsbruck measuring the Halsa football field as a reference area for laser scanner data.

Novosat

Novosat's contribution to WP 2 was the planning of the GCP networks on Svartisen and Hintereisferner (WP 2.2). The objectives were to provide reliable and precise geodetic control for glacier measurements, to provide an orientation basis and metric support for remote sensing data processing, to provide metric support for validation of the data collected, and quality control of positioning accuracy of remotely sensed data and map content review.

The current situation and future plans are described for each of the study sites separately. In general, there is a need for a tight and stable GCP network for aerial flights, as well as for VHR-satellite images.

The necessary data concerning existing points and study area limitations over Engabreen were received in digital from, which made the planning easy. Targeting and GPS measurement instructions were made and distributed before the field campaign started in Svartisen. The fieldwork was done by NVE during summer 2001. Checking of the measurements will be done by Novosat. For Hintereisferner there is a stable and dense GCP network from 1979. The measurements are precise and there will probably be no need for new measurements. The digital coordinates and precision level of the GCP network is provided by University of Innsbruck (partner 8) to Novosat.

Joanneum Research

Joanneum Research's contribution to WP 2 was the acquisition of GCP points from Austrian (1:25000) and Norwegian (1:50,000) topographic maps. All together 175 ground control points have been selected and identified in multitemporal INSAR data sets for Hintereisferner and Svartisen test sites separately for ascending and descending orbits. Set of 47 check points and 4 check profiles has been generated for the accuracy analysis of ERS-1/2-INSAR models.

NVE

NVE performed fieldwork entailing the collection of glaciological and meteorological data five times in the first year of the project. This included mass balance measurements on Engabreen and Svartisheibreen, velocity measurements, downloading meteorological data from a weather station, setting out the GCP signals and performing GPS measurements for the ground control network, GPS transects of the glacier surface and GDM measurements of the lower surface of Engabreen for calibration with the laser scanning. The fieldwork took place in May, August, September and October 2001 and February 2002.

Several kilometres of radio-echo sounding were performed in May 2001 in order to assess the winter mass balance. The sounding profiles are shown on the Figure 3.

Velocity measurements were made at stakes that were already part of the mass balance network, as well as some additional stakes being set out, such as those at EP11 and EP05. Positions of the stakes were calculated using differential GPS. Not all the stakes were re-measured during the autumn visits in September and October (partly due to fog) so the velocity data set is incomplete. Five points were also measured on Svartisheibreen. Sounding profiles were not done on Svartisheibreen.

Meteorological data from the meteorological station, Skjæret, at an elevation of 1364 m a.s.l. on Svartisen includes precipitation, radiation, wind direction, wind speed and air temperature at a resolution of one hour. The data set is incomplete, especially for the wind data, which is difficult to collect during the winter.

The topography of the lower surface of Engabreen was measured using GDM (geodetic distance metre). This was done within two days of the laser scanning flight (which was delayed by several weeks) and will be used to calibrate the topography as measured by the laser scanner. The topography of the upper elevations of Engabreen was measured in several places by performing GPS transects. It was hoped that these could be used to calibrate the topography measured by the other remote sensing methods, but the aerial digital photography and laser scanning did not take place until several weeks after this, and in the meantime, the glacier surface will have changed significantly.

Much of the glaciological measurements on Engabreen were performed concurrently with mass balance work performed in connection with a hydropower station in the Svartisen area. This meant that travel costs for the OMEGA project were considerably reduced, as well as additional data being available to the project at little or no cost.

Approximately thirty-seven points around Svartisen were used in the ground control network. GCP signals of white plastic measuring 1.2 x 1.2 m were placed at each point, and the position was measured using differential GPS. This entailed having GPS receivers recording at several points simultaneously.

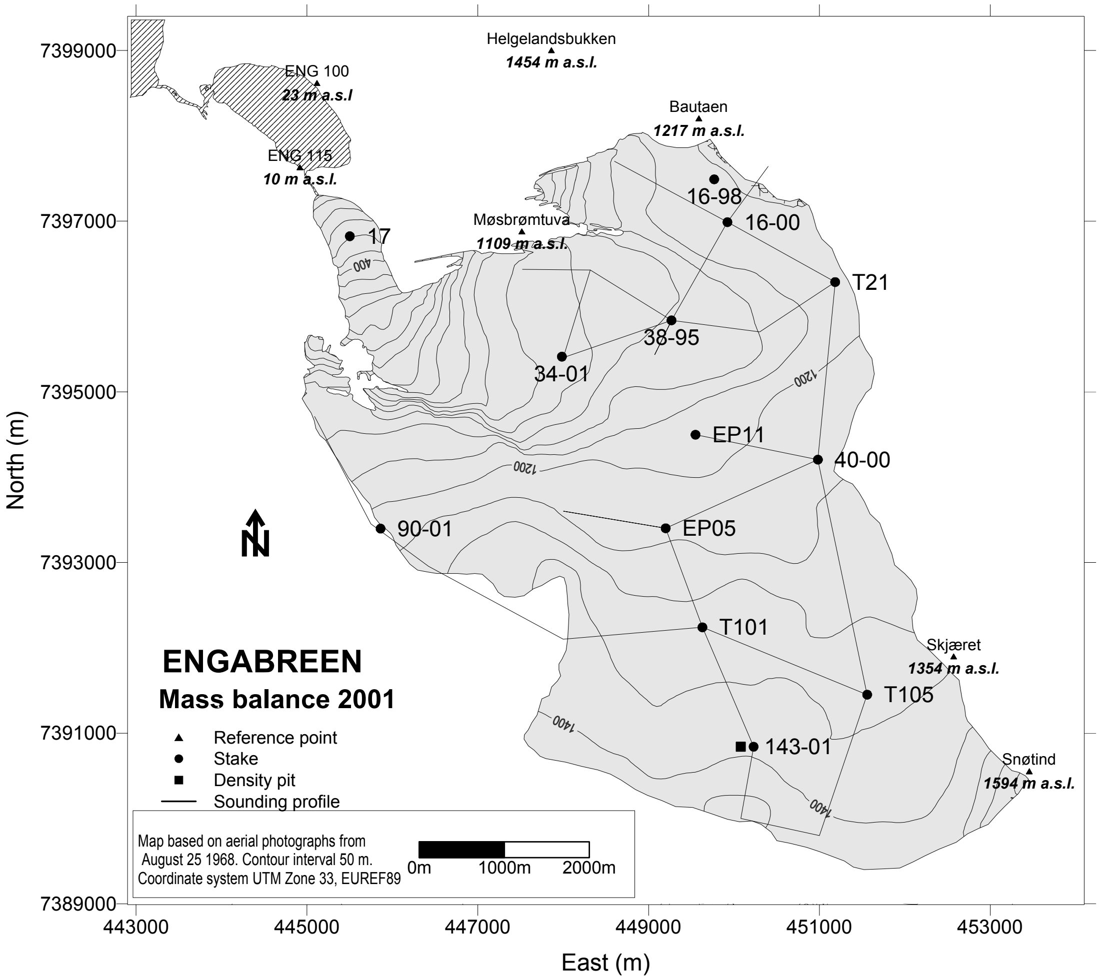

Figure 3. Sounding profiles and stakes used for velocity measurements in Engabreen, Svartisen, Norway in 2001.

University of Innsbruck, Institute of Meteorology and Geophysics

Velocity measurements have been carried out during summer and autumn 2001 on Hintereisferner (HEF) and Kesselwandferner (KWF). The velocity on the fixed cross profile "Line 6" is about 9 m a^{-1} and still decreasing. The velocities of KWF (five profiles) are in a range of about 2 to 17 m a^{-1}. In the upper firn area of KWF the thickness and movement have increased since three years following a short period with positive mass balance. The aerial photographs of the southern Ötztal Alps flight 1998 have been analysed and prepared for the development of a DEM.

The specific mass balance *b* and equilibrium line altitude *ELA* of 2000/2001 have been investigated for Hintereisferner and Kesselwandferner:

HEF: b = -173 mm ELA = 2955 m
KWF: b = 524 mm ELA = 3063 m

The data of all runoff gauges and meteorological stations in Ötztal have been collected and stored in existing data bases.

Radio-echo sounding has been applied on five cross profiles and one longitudinal profile on Hintereisferner in 2001. On almost all sites very clear signals have been detected and so it was possible to start with the construction of a DEM of the glacier bed of Hintereisferner.

3. Discussions and conclusions

In Svartisen, the work generally went well, although bad weather on Svartisen meant that the work entailed more visits than planned. Also, very little snowfall during the 2000/2001 winter meant that the work was more difficult to accomplish using snowmobiles and that helicopters were used more than expected whereas in a normal snowfall year, more of the work could have been done using snowmobiles. The bad weather also meant that the planned aerial photography of Engabreen did not take place, but will be done in late summer, 2002.

In Hintereisferner, the work went generally well, too. However, a very early snowfall in August made the acquisition of terrestrial photography and detection of glacier zones difficult. For the same reason, aerial photography and digital camera imagery was not acquired over Hintereisferner in 2001.

4. Plan and objectives for the next period

Some of the ground control work must be repeated again in 2002 year. In Svartisen, each ground control point must be revisited to see if the GCP signal is still in place, and if not, a new one must be set out. In Hintereisferner, the old GCP network has to be checked and repainted. Glaciological measurements will be repeated in both study areas in 2002.

The necessary additional GPS measurements in Svartisen can be done either during the first field campaign (weeks 21-22) or during the later one in (weeks 34 – 35) in 2002. The targeting for the new aerial photography acquisition will be done according to the instructions made for 2001 during the weeks 34-35 in 2002. For the VHR-satellite images a network will also be needed. These points can either be targeted points with very large signals or that kind of natural points, which can be identified on the pictures and in the terrain with no uncertainty.

In Hintereisferner, the targeting for the aerial photograph acquisition will be done during the field campaign in weeks 36-37 by University of Innsbruck (partner 8). The instructions for the targeting will be done with no delay, so that it can be controlled in the field during the earlier visits to the study area. VHR-satellite images will be ordered for the Austrian areas, too.

Terrestrial photography and fieldwork related to that will take place in weeks 21-22, 2002 in Svartisen and in weeks 36-37, 2002 in Hintereisferner.

Work package 3 - Remote sensing

Compiled by Kukka-Maaria Luukkonen, Henrik Haggrén and Petri Pellikka

Summary

Seven of the consortium members were involved in this work package – University of Turku, Helsinki University of Technology (work package leader), Novosat Ltd., Institute for Geography at the University of Innsbruck, Joanneum Research, NORUT IT and NVE (Norwegian Water Resources and Energy Directorate).

The remote sensing work package is the largest work in the project. It is divided into four main tasks:

WP 3.1 Methodological development and techniques for image processing
WP 3.2 Processing of satellite imagery
WP 3.3 Acquisition and processing of terrestrial and airborne validation data
WP 3.4 Relation between DEMs

The bulk of the work package was the acquisition of terrestrial, airborne and satellite remote sensing data from the two study sites – Svartisen in northern Norway and Hintereisferner in Austria. University of Turku concentrated on acquiring Landsat data, and in methodological development for the preprocessing of Landsat data and for the retrieval of glaciological parameters from the Landsat data and processing the data from both study sites. HUT concentrated on acquisition of historical terrestrial and aerial photographs from both study sites, modern terrestrial and aerial photographs over Svartisen, and on developing methods for studying relation between DEMs generated with different types of data. Novosat concentrated on methodological development for image correction and calibration and change detection using Landsat data and ERS radar data. Joanneum concentrated on methodological development and processing of ERS radar data. NORUT IT concentrated on methodological development and processing of ERS radar data of Svartisen.

1. Objectives

The objectives of the work package are to develop refined cost-effective methodologies for glacier remote sensing using satellite remote sensing data, to generate DEMs using satellite and airborne remote sensing data, and terrestrial photography, and to compare their accuracy

2. Methodology and scientific achievements

Work package 3.1 - Methodological developments and techniques for image processing

University of Turku

WP 3.1.1 Glaciological interpretation of satellite imagery

The aim of the work has been to test available and develop new methodology to delineate glacier borders and distinguish glacier zones of snow, firn and ice using multitemporal optical satellite images. Reliable delineation of the glacier borders and classification of glacier zones enables the interpretation of the glaciological parameters, and furthermore, glacier change detection. The main data set consists of Landsat 4, 5 and 7 TM and ETM+ images.

The extreme elevation differences of Alpine glaciers cause geometric and radiometric distortions, such as relief displacement and slope and aspect effect. Dynamic range of most optical sensors is not optimised for high reflectance of snow, and sensor saturation often occurs. Therefore, much of the effort has been directed into geometric and radiometric pre-processing of the multitemporal Landsat images. Pre-processing steps include orthorectification to register image geometrically to reference coordinate system and with DEM. Saturated pixels distort later processing and hence more realistic DNs have been estimated by using a linear regression model. Different methods for topographic normalisation have been compared and a so-called c-factor method was found out to be the most suitable. The normalization is performed applying elevation model with 25 m spatial resolution in Hintereisferner and 100 m in Svartisen. However, the newly available elevation model of a spatial resolution of 25 m over Svartisen will be applied. Methods for multitemporal radiometric normalisation have included conversion of DNs into at-satellite reflectance and testing of different relative radiometric normalisation methods.

The glacier borders have been delineated by grey-level thresholding of ETM+ thermal infrared band and band ratio 3/5. ETM+ thermal infrared band was found especially efficient in the extremely shadowed Svartisen area. Traditional band ratio 3/5 is usable for TM data and particularly for less shadowed Ötztal study area. However, visual enhancements are usually needed for debris covered and shadowed parts of the glaciers.

Unsupervised and supervised classifications have been used to delineate zones of ice, firn and snow. Unsupervised Isodata classification can be used to find out spectral classes and to choose pixels for training phase of the supervised maximum likelihood classification. Because of the lack of simultaneous ground truth data for historical images, classifications are based on the visual interpretation of the image processor. However, some accuracy assessment can be carried out using annual snowline observations. The snow, firn and ice areas of Engbreen interpreted using Landstat TM from 1994, 1999 and 2001 are presented in Figure 4. The image processing chain is presented in Figure 5.

Figure 4. Snow (white), firn (light grey) and ice (dark grey/blue) in Engabreen in 1994, 1999 and 2001 from the right to the left.

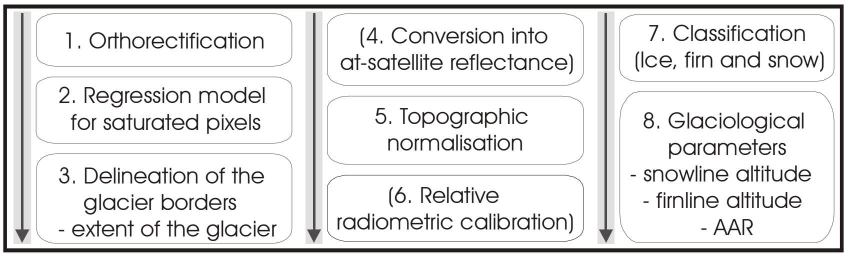

Figure 5. Image processing chain of the Landsat TM/ETM+ data.

Novosat

WP 3.1.1 Glaciological interpretation of satellite imagery

There is a need to calibrate satellite images radiometrically in order to do change detection directly from image comparison. Generally, calibrations should not be run blindly for every image, because there are different cases, and image parameter quality varies. Standard processes can still be designed. Landsat 7 produces cost-effective data and is suitable for future operative monitoring. Novosat has studied Landsat 7 radiometric issues and suitable calibration approaches in ERDAS Imagine environment.

Novosat has been in co-operation with the University of Turku in relation to topographic normalisation techniques and relative radiometric normalisation of optical images. One of the implemented ideas was to perform the matching in two phases, excluding the altered areas in the second phase, enabling a better fit. Also the extrapolation of the saturated pixels, using the unsaturated bands, was proposed to the University of Turku, who implemented it. Different kinds of shadows in Landsat images are still hard to compensate, especially up north in Engabreen area.

For older images like Landsat 4, radiometric calibration is possible mainly relatively, since no one really knows which calibration coefficients to use. Using the relatively calibrated optical images, Novosat has produced multispectral difference images with fixed look-up tables. There, gray means no change, and different colours reveal the various change types (from firn to ice, ice to soil, etc.). Changes that occur in bright snow areas (snow to firn) are much better detected than from original bright image areas (Figure 6).

Novosat has studied absolute radiometric calibration into ground reflectance. An interface for the COST method for Landsat 7 ETM+ images has been implemented. COST requires no external information about atmospheric conditions. Landsat 7 is said to have a 5% nominal accuracy for the DN to Top-of-Atmosphere Radiance coefficients. European Space Agency (ESA) uses the calibration parameters updated at least every 90 days by United States Geologic Survey (USGS). We studied one scene where gain change from high to low gain occurred on band 4. Using the coefficients given for various gain modes, we transformed the south part of image into high gain DN's: $DN_S' = DN_S * 1{,}515 + 0.0$. We noticed that water areas remained brighter on the southern side than on the northern side. When DN values from both sides of the border were gathered and sorted, a regression gave a transformation $DN_S' = DN_S * 1{,}45 + 6.0$, which gives better results also for water areas. This gives us an estimate on the limitations of Landsat 7 radiometric calibration. There have been difficulties in the internal calibration systems, and external earth target areas are mainly used. These correction methods seem also to have difficulties because glaciers are extremely bright. There is also a lot of scattered light.

Future: Novosat will still test change detection methods like AutoChange and possibly atmospheric corrections using weather data, or temperature retrieval. We are interested in defining how the results from single images could contribute for defining the general trend of glaciers; we seldom get an image exactly from the optimal late summer date just before the snow comes.

WP 3.1.2 Spatial modelling of glacier surface via image data

Nvosat has been in contact with Joanneum Research in relation to the development of the used methods, especially concerning the processing phase of WP 3.2 to enable the modelling of the glaciers. The methods of JR_DIB (e.g. DEM generation via Slope Maps) have been added on the RSG software. Novosat has a test licence for this software and gave JR_DIB access of its own InSAR software. Considering the DINSAR methods, Novosat has so far had to rely much on the tools from Joanneum Research. There is no need to overlap the research activities too much. They are aware of this and aim to share their knowledge and include the tools into the RSG.

Future: Novosat is improving the system documentation of its InSAR software, easing the maintenance and development of new applications, possibly the coherence/feature tracking for finding where the ice has moved (when interferometry does not work), detection of coherence changes. We will examine ENVISAT possibilities, e.g. whether the different frequency with ERS-2 can be compensated for InSAR applications. Orthorectification of coherence images is also essential (also by using an existing DEM, when there is no need to produce an own DEM for the image pair via phase unwrapping or Slope Map). We will consider synthetic interferograms (from a DEM and satellite orbit data) to enable comparisons of various interferograms to the one of our reference DEM, and alignment and subtraction of satellite-derived interferogram from synthetic DEM to ease the phase unwrapping.

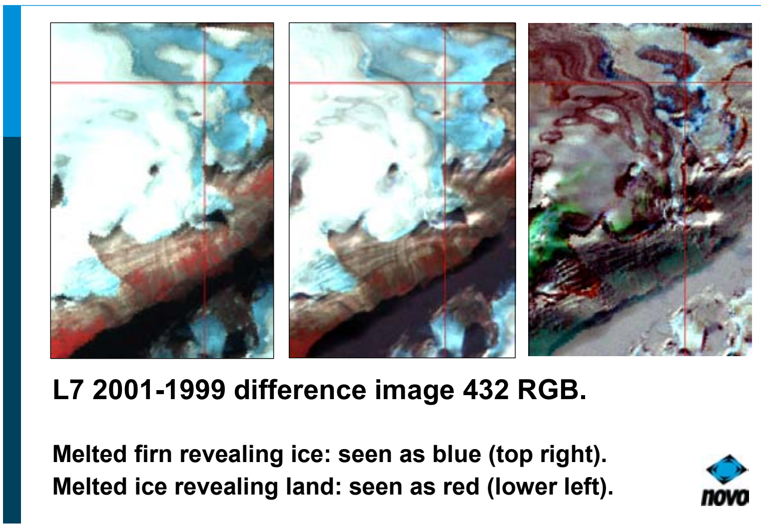

Figure 6. Multispectral difference images expressing glacier changes in Svartisen, Norway.

Joanneum Research

WP 3.1.1 Glaciological interpretation of satellite imagery

Theoretical backgrounds on multiple microwave backscattering at the stratified glacier surface have been studied and basic metric relations between the function of microwave backscattering and basic parameters of glacial topography were formulated. An initial simplified 3-layer-backscattering model for the reliable description of coherent microwave interactions within the stratified glacier surface including the effect of multiple-ray interference has been discussed and developed. Preliminary interpretation of physical interactions related with coherent microwave backscattering and interferential effects at the multilayer glacier surface have been performed in actual ERS-1/2-SAR imagery. Comparative visual analysis of multitemporal ERS-1/2-INSAR data sets taken over the Svartisen and Hintereisferner test sites during three different seasons (winter, spring, summer) has been performed and the behaviour of amplitude and coherence values in response to environmental changes (air temperature, melting onset) has been studied. An original technique for the unsupervised glacier change detection based on differencing between INSAR slope maps has been devised and tested. High sensitivity to glacier changes has been verified.

WP 3.1.2 Spatial modelling of glacier surface via image data

Non-conventional gradient-INSAR (GINSAR) technique for the glacier surface modelling was designed, programmed and tested using the ERS-1/2-INSAR data obtained over the Svartisen and Hintereisferner test sites. An original transferential approach was devised and tested for the accurate measurements of glacier frontal velocities in single SAR-interferograms. Method of unsupervised glacier-change detection based on differencing between INSAR slope maps was devised and tested. High sensitivity to glacier changes was verified. GINSAR algorithmic singularities were defined and estimated metrically. An efficient methodology for the glacier motion measurement and the longitudinal strain estimation via multitemporal INSAR topograms was designed. Basic principles for the selection of GCPs for geocoding INSAR products (topograms) were developed. New kind of GCPs was offered. Daily INSAR velocities of several outlet glaciers in Svartisen Ice Cap were determined.

NORUT IT

Norut is involved in WP 3.1.1, WP 3.1.2 and WP 3.2. Norut is responsible for WP 3.1.1. Problems with getting firm commitments from Airborne SAR operators have delayed the acquisition in work package 3.1.1. Work has been started on analysis of Spaceborne SAR data for glacier facies detection and DEM evaluation.

WP 3.1.1 Glaciological interpretation of satellite imagery

Three ERS data (winter, spring and summer) from Svartisen have been recalibrated, absolute calibrated and geometrically corrected using the NORUT geocoding software. Interpretation of the results indicates that the last years firn line is visible in the winter images for parts of the glacier.

WP 3.1.2 Spatial modelling of glacier surface via image data

The NORUT geocoding software performs recalibration, absolute calibration and geometric correction of ERS data using external DEM. The software has been modified and verified for ERS data from Svartisen glacier using ERS data with 100 x 100 m^2 DEM.

Work package 3.2 - Processing of satellite imagery

The objectives of the work package are to select the appropriate satellite image data, conduct interferometric modelling of study sites (DEM) via complex radar imagery (ERS-1/2, Radarsat SLC), determine glacier dynamics using SAR interferometry and interpretation techniques, generate of DEMs using VHR data, and to use the optical remote sensing data (Landsat TM) for the mapping of the aerial extent of the glaciers and to distinguish between snow, ice and firn. The partners involved in WP 3.2 are partners 1, 3, 5, and 6.

The processing of satellite images in WP 3.2 is partly executed interactively with methodology development in WP 3.1. On the optical Landsat data the glacier borders have been delineated by grey-level thresholding of ETM+ thermal infrared band and band ratio 3/5. Unsupervised and supervised classifications have been used to delineate zones of ice, firn and snow. Height extraction by means interferometry takes advantage of one of the unique qualities of SAR images: distance information from the sensor to the ground is recorded for every pixel in the SAR image. If two SAR images, which cover the same area from slightly different vantage points, are available, the phase of one can be subtracted from the phase of the other to produce the proper "noiseless" distance difference of the two SAR images.

University of Turku

The methods to pre-process and delineate glacier borders and classify glacier into glacier zones (WP 3.1) have been applied processing the available Landsat data. The methods can give the borders of the glacier during different years. The location of the firn and snowline and areas of ice, firn and snow can be determined from the classifications, which are the desired input for WP 4.1.

Novosat

All the possible 14 ERS pairs have been checked. The ones that could be processed (8 pairs) have been processed. Pairs are phase unwrapped and orthorectified to map coordinate system. True maps and DEMs of target area are used as reference.

For the processing the Insar-tool is used. Insar is a program developed by Novosat and VTT, National Research Center of Finland. It has been used already earlier successfully in several DEM projects all over the world.

In this Insar-tool the phase unwrapping (definition of the order number) is a manual process, which is often time demanding (Figure 7). In low coherence areas interferometric fringes get mixed. It is up to the operator to determine these areas, to define logical routes of fringes and to solve interferogram properly.

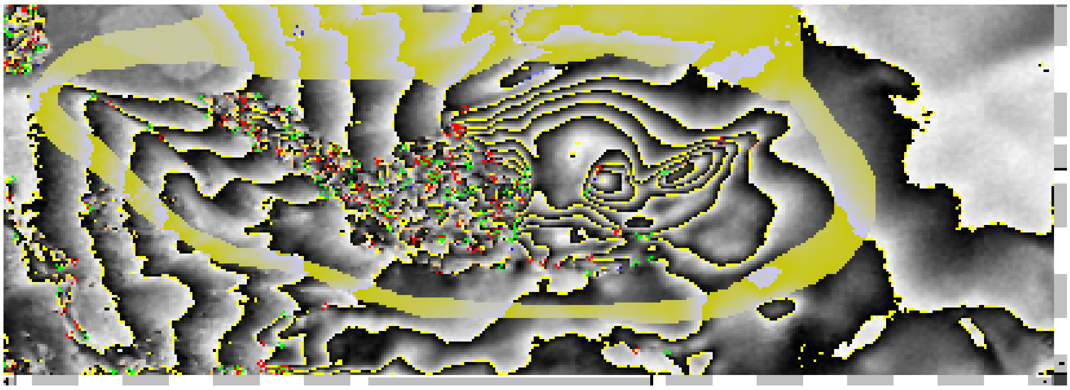

Figure 7. Phase unwrapping in Engabreen.

Five SAR image pairs were collected with longer time gap and in those the coherence is too low for processing. These pairs can be used for interferometric velocity mapping but not in DEM production by traditional interferometry.

The target areas are quite extreme with high mountains and low valleys. Elevation differences are strong and slopes are very steep. There are small streams and other elements that cause some moisture in radar image in the valleys. Wetlands and steep slopes in front of a satellite instrument causes problems, and basically makes some holes in DEM. There are only quite few image pairs that can realistically be expected to form a decent DEM.

Joanneum Research

Several maps of test sites were obtained and studied. Geographic peculiarities of the test sites were analysed and the ERS-1/2-SAR data availability was determined. Meteorological situations for the preliminary analysis of radar interferometric (INSAR) data from available archives were determined for both test sites using meteorological maps and NOAA-data.

8 INSAR DEMs of the test areas were generated using traditional INSAR approach with two different software packs (RSG 3.50 and ARCTUR). The positional accuracy of INSAR DEMs was evaluated via 47 checkpoints and 4 check profiles and by comparing (differencing) with the reference DEM obtained from the Austrian topographic maps at 1:25000 scale (Figure 8).

6 INSAR slope maps of the test areas were generated using the GINSAR approach with the RSG 4.0 software pack.

2 change images (velograms) for Svartisen Ice Cap and 1 change image (velogram) for Hintereisferner were generated and the preliminary interpretation of these INSAR products was performed.

NORUT IT

Several ERS Tandem data have been used to generate DEM of Svartisen glacier using Atlantis interferometric software.

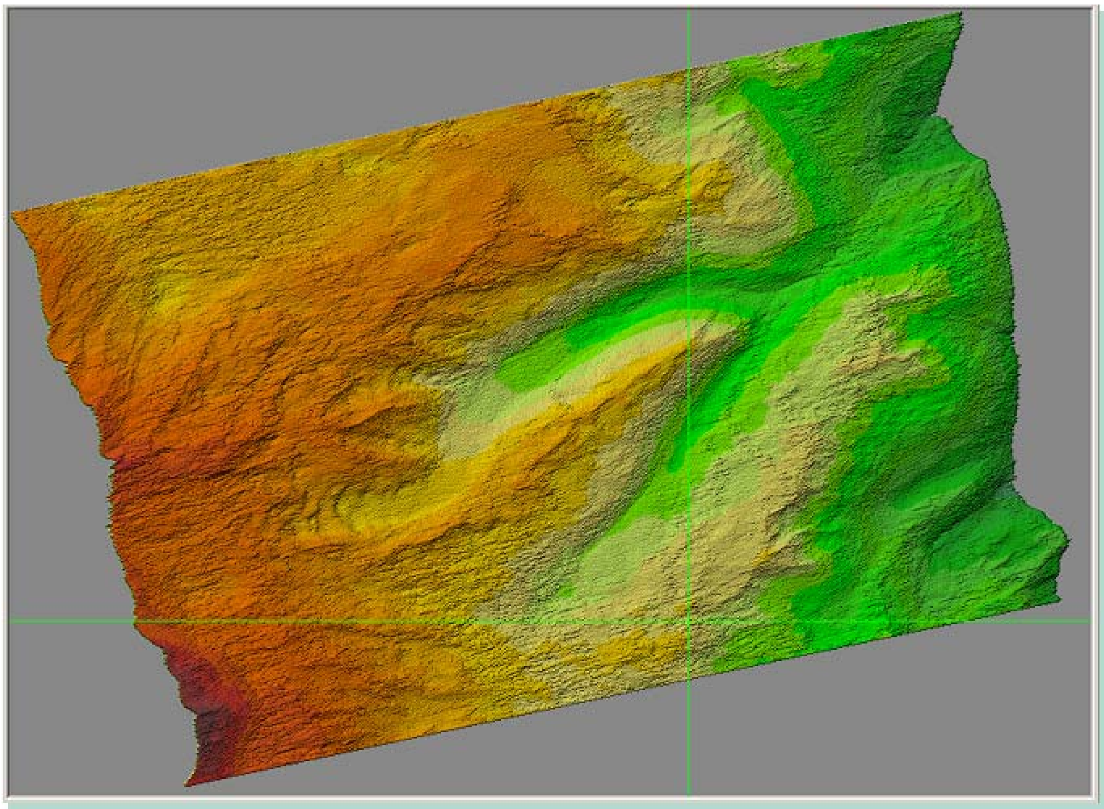

Figure 8. INSAR DEM over Hintereisferner, Ötztal, Austria, 14/15 May 1996.

The coherence is found to be high in the winter images. In the summer image the coherence is low due to the temporal decorrelation caused by melting of snow/ice.

During winter the glacier and snow surface are more stable resulting in high coherence. Preliminary analysis of the accuracy of the DEM derived using interferometric techniques with existing DEM shows results varying from +/- 20 meter to several hundred meters. The vertical accuracy in the space borne SAR DEM does not fulfil the user requirements, which are in the order of 0.2 meter.

Work package 3.3 - Acquisition and processing of terrestrial and airborne validation data

The validation data for the monitoring procedure is collected by terrestrial photography, aerial photography, digital camera imagery, airborne radar data and airborne laser scanning. Digital elevation models (DEMs) are processed by each alternative method deriving necessary data for ice volume estimation. These image data are also used for interpretation and derivation of area data as far as it concerns the coverage of ice, snow, moraine, bedrock, etc.

WP 3.3.1 Acquisition and processing of terrestrial photographs

The work in this work package is carried out by the University of Turku and Helsinki University of Technology. University of Turku is responsible for the acquisition and glaciological interpretation of the terrestrial photographs and HUT for the processing. Terrestrial photography is used for two types of validation. First, old terrestrial photographs are reprocessed in order to validate the old topographic map data. The data is the same original data, but now it will be processed using the newest photogrammetric knowledge and technology. Second, new terrestrial photographic data are used for local validation of any airborne topographic data as far as it concerns the geometric formation of ice surface geometry.

During the field campaigns of summer 2001 terrestrial photographs were taken on Engabreen and on Hintereisferner with with both a digital and a 135-size film camera. The ground control was measured on Engabreen with a tachymeter and on Hintereisferner using GPS. Close-up stereoscopic pairs of panoramic digital image sequences were recorded on the Engabreen ablation area, which consists of blue ice and bedrock. The photography was repeated twice with an interval of two days. All the images (122 pieces) were sorted and grouped into panoramic sequences. On a selected set of images, optical distortions and chromatic variations were corrected. Ten panoramic stereo pairs were transformed to Intergraph's tiled format and oriented by ZI software. The first stereo pair was oriented absolutely using ground control points and approximately known camera orientation. The stereo pair was used for triangulation of further new control points and for collection of DEM. An experimental DEM was made from an area of about 5 x 5 meters using a regular 20 cm grid of 800 points. The main purpose for this imagery will be to compose a very close-up DEM of the glacier surface and to verify the airborne laser scanner DEM. The 35 mm photographs have demonstrated that the rough surface of Engabreen is not very suitable for analysis of larger areas. Making a wider DEM from these photographs has been postponed for the time being. On Hintereisferner all the photography was disturbed by the fresh snowfall covering completely the glacier. The photography was, however, done as planned but is considered to be of secondary importance. The film based photographs have been digitized, because the area seems otherwise suitable for terrestrial photography analysis. In the future, the timing of photography will have a major emphasis on field campaign planning. Regarding the verification of airborne laser scanner DEM, a simultaneous data acquisition with terrestrial digital camera is of utmost importance.

During 2001 old existing terrestrial photography was searched by Bavarian Academy of Sciences related to the OMEGA test areas of Hintereisferner and Vernagtferner. The most covering set of the historical glass plates found was the one of Hochjochferner next to the Hintereisferner. However, this data can be used for validation of the technology. The glass plates, being 93 in total and each of size of 120 mm x 160 mm, were scanned by University of Bundeswehr in Munich with a pixel size of 12,5 microns. The DEM will be processed by HUT in 2002 and compared to the topographic map data published by Otto Gruber in his dissertation from 1907.

WP 3.3.2 Processing of terrestrial and aerial photographs

The work is carried out by Helsinki University of Technology. Until recently aerial photography has been the only practical alternative to produce topographic models of large areas. As far as it regards past records, the DEMs will be produced either by digitizing the topography from old analog maps, or by digitizing the DEMs directly from old original films copied as diapositives. These will then act as reference data for monitoring the change of ice volume and coverage from previous times. In 2001 only the test area of Svartisen, namely Svartisheibreen could be photographed. Both Engabreen and Hintereisferner/Vernagtferner could not be photographed due to weather conditions. The flights in Svartisen were operated by Fotonor AS on August 25, 2001 (flight no. 01139). The 1:15000 scale photography was made in b/w. In Svartisen, also copies of old b/w photographies from August 25, 1968, August 19, 1985 and August 15, 1997 by Fjellanger & Wideroe AS were purchased. These are all in scale of 1:35 000. The DEM of Svartisheibreen from the 2001 photography was produced by Mittaustekniikka Oy. The work included two parts, the aerial triangulation and the stereointerpretation of the glacier surface. It was done with analytical plotter Wild BC2. The aerial triangulation was based on minimal, or even poor ground control, and had to be supported by GPS-based camera observations and by control pass points derived from a topographic map. The DTM was interpreted as triangles and break lines. The points were coded to classes of moraine, bedrock, snow, and ice. Additionally, the borders of snow and ice covered areas were drawn. Later on, the photographs were scanned.

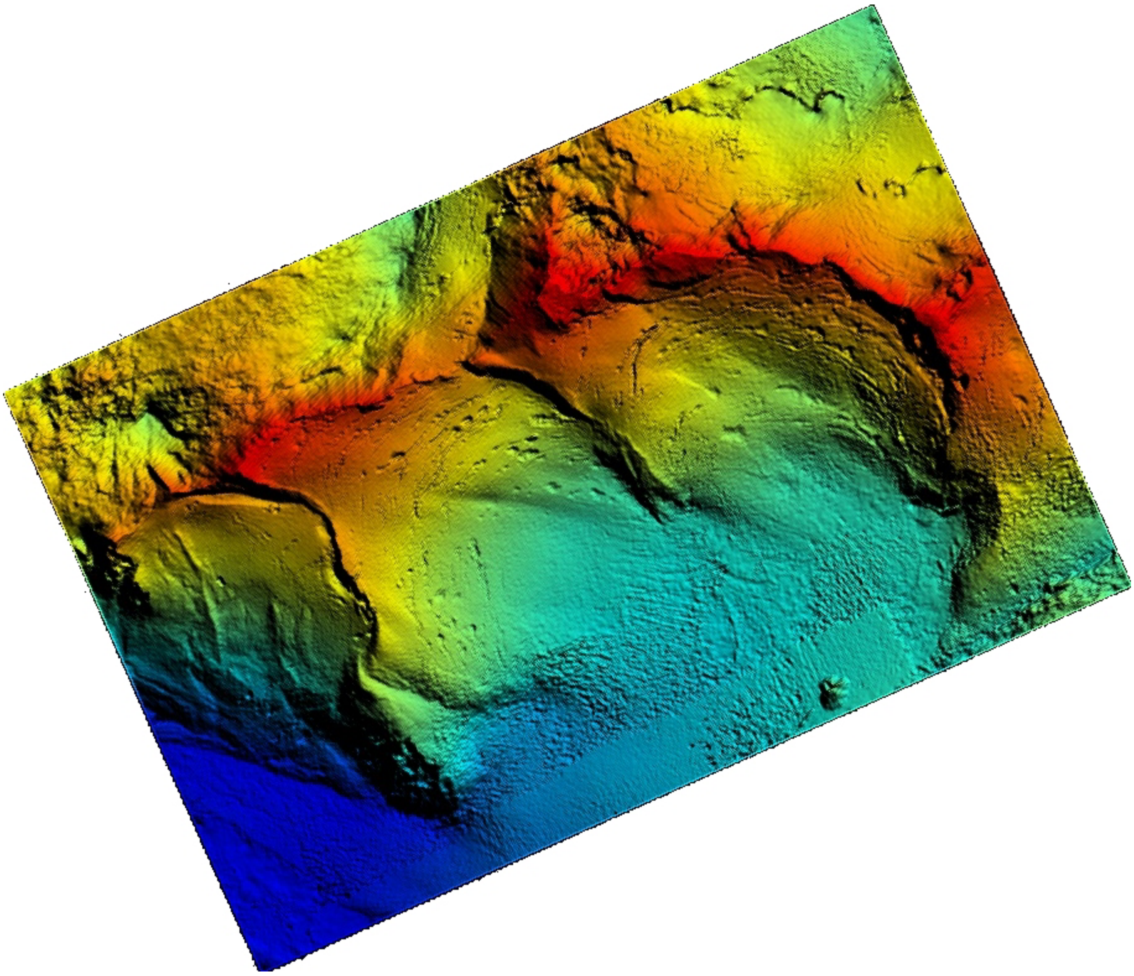

Figure 9. Digital elevation model generated over Svartisheibreen, Svartisen, Norway using digital camera imagery applying global block adjutsment approach, 24 September 2001 .

WP 3.3.3 Acquisition and processing of digital camera data

The work is carried out by the University of Turku. The digital camera data was acquired on Svartisen on September 24, 2001 simultaneously with the laser scanner data. The camera was a Nikon D1 digital camera owned by StoraEnso Forest Development, Finland. The image size was 1324 x 2012 pixels and the calibrated focal length 1298 pixels, which corresponds to a field of view of 60 degrees. The flying altitude above ground was 900 to 1000 m which corresponds to a ground resolution of 70 to 80 cm. A total of 559 frames were recorded in 35 strips with 60% image overlap and 40% sidelap. The imagery covered Engabreen completely and Svartisheibreen for its northern part. The camera was calibrated afterwards. In 2002 a DEM of 5 m ground resolution and respective orthomosaic of 1 m ground resolution was processed on Svartisheibreen (Figure 9). This block of 41 images was processed based on an innovative global block adjustment approach and respective software called Cobra, recently developed by Inpho Gmbh.

WP 3.3.4 Acquisition and processing of the airborne SAR data

The work is carried out by NORUT IT. The acquisition of in-flight airborne SAR data is planned to take place only on the Svartisen glacier, Norway. The optimum time for in-flight airborne SAR to derive the DEM from Svartisen is between the end of ablation and before the beginning of snowfall (estimated to be the last week of August). Since the airborne systems uses in-flight interferomertric techniques, there is no problem with temporal decorrelation, as reported for spaceborne repeat pass. Currently two operators (Aerosensing and EMISAR) have been contacted. So far, however, it has been impossible to get access the sensors at the optimum time. In order to ensure that airborne SAR data becomes available in 2002 the airborne campaign is planned for week 22. For the same week a laser scanner flight is planned which would enable synchronized data acquisition. As the glacier and snow cover is likely to dry the penetration depth will result in a bias of the DEM. During the campaign several corner reflectors will be deployed and in-situ measurements will be performed. By using these data the bias may be removed.

WP 3.3.5 Acquisition and processing of laser scanner data

The work is carried out by University of Innsbruck, Institute of Geography. The main objectives of using airborne laser scanning are the mass balance calculations and other glaciological applications as well as the provision of calibration data for other remote sensing data. Therefore 10 laser scanning acquisition flights are planned for the Austrian test site (Hintereisferner) and 3 laser scanning flights are planned for the Norwegian test site (Svartisen). The first two data acquisition flights at Hintereisferner took place on October 10, 2001 and January 9, 2002. The preprocessing of the data, i.e. integration of GPS and INS measurements and calculation of coordinates for each data point in WGS84, has been done for both flights. The absolute calibration of the data is in progress. For the first flight a DEM with a grid size of 1 m has been calculated and is delivered as input for WP 3.4 and 4. Furthermore a triangulated irregular network (TIN) from all data points has been calculated and visualised for certain areas for first interpretation. At Svartisen, the first data acquisition flight was done on September 24, 2001 simultaneously with the acquisition of digital camera imagery, as the sensor could be mounted on the same plane. Data were acquired both from Engabreen and Svartisheibreen. The preprocessing of the data, i.e integration of GPS measurements and INS measurements, absolute calibration of the system, calculating coordinates for each data point in WGS84, has been done for both flights. A DEM with a grid size of 1 m has been calculated and is delivered as input for WP 3.4 and 4. Furthermore a triangulated irregular network (TIN) from all data points has been calculated and visualised for certain areas for first interpretation (Figure 10).

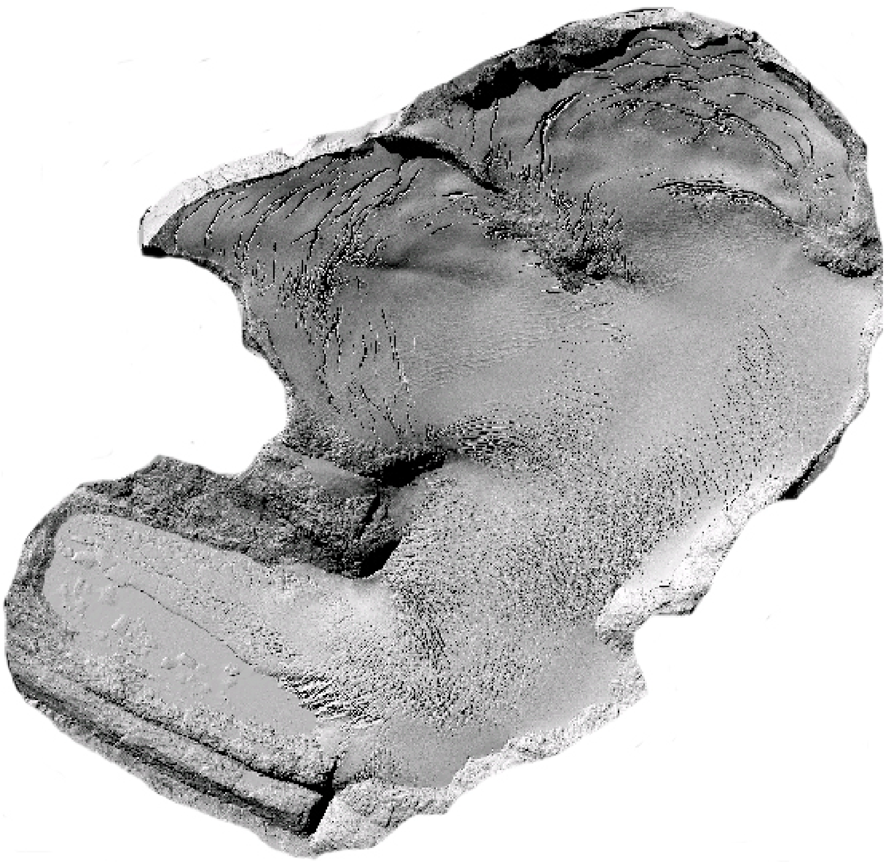

Figure 10. TIN over Svartisheibreen, Svartisen, Norway generated from laser scanner data acquired on 24 September 2001.

Work package 3.4 - Relation between DEMs

This work package has two objectives. The first is to estimate the accuracy (bias and precision) of long-term change in the volume of a glacier as a function of time. The second is to compare DEMs of a glacier produced using different methods and different data but acquired at the same time. The second objective is an addition to the original DoW and it is intended for finding out which method is most suitable for DEM production in glacial areas. First comparisons were made for INSAR DEMs with refrence to topographic map data.

Helsinki University of Technology

Theoretical studies have been carried out for the first objective. It has been realized that the accuracy depends primarily on discretization errors as the volume integral is approximated by a sum. The discretization errors can be estimated using known mathematical formulas typically expressed in terms of ground resolutions and higher order derivatives of the DEM surface. The estimation will thus require analyzing the shape of the surface. Secondly, the accuracy depends on measurement errors given as vertical accuracies and accuracies of georeferencing. It currently seems that a bottleneck may be to obtain a reliable estimate for the georeferencing of data from the past.

The second objective has been addressed by developing techniques for DEM comparison with data from a mountainous region in Jordania. The test data included a

DEM generated from TK-350 satellite images and georeferenced using on-board equipment (stellar cameras, precision laser altimeter and positioning system). The DEM had been obtained from State Research Institute of Aviation Systems in Russia. The second DEM had been produced by SITO Oy (subcontractor for partner 2) from aerial images. This DEM had been georeferenced using a map of 1:50,000 (tops of hills provided the shift in z and the location of a temple gave the shift in x and y). The third DEM produced by HUT from terrestrial images had been georeferenced via tachymeter measurements which had also been measured by HUT and georeferenced using GPS.

The comparison has showed that there are systematic errors between tachymeter measurements and the DEM from terrestrial images. These deformations have most likely resulted from the accumulation of errors as the georeferencing of the tachymeter measurements could not be performed directly to the GPS points when the measuring was moved to the next area but via measurements in the areas recorded previously. The deformations have been corrected by an affine transformation, the parameters of which were estimated by minimizing the distance from the tachymeter points to the DEM surface.

The comparison has also indicated that the DEM from aerial images is located approximately 7–8 meters above the DEM from terrestrial images. Furthermore, the DEM from satellite images is clearly shifted and located more than 100 meters below when compared to the DEM from aerial images. These errors have been corrected by registering the DEMs using a surface matching algorithm without exactly known corresponding points between the data sets. The algorithm iterates the determination of corresponding points compatible with respect to the orientation of the surface normal and distance between candidate points and the estimation of the parameters of a rigid body transformation that minimizes a weighted least squares distance between the established corresponding points.

Joanneum Research

The relation between traditional INSAR DEMs and the reference DEM generated from available Austrian topographic maps has been evaluated. The positional accuracy of INSAR DEMs has been evaluated by 3 independent experts using 47 check points. The root mean square height difference was given as 25–40 meters depending on the test site and the coherence of original INSAR data. The maximum height errors exceeded 100 meters. Main sources of modelling errors were recognised and it has been revealed that the imperfection in interferometric phase unwrapping leads to the significant areal error propagation. The mistakes caused by glacier melting and radar penetration into dry snow could be minimised by the appropriate selection of INSAR data. Significant albeit local modelling errors due to the glacier motion are very difficult to compensate. It has been revealed that, in traditional INSAR models, nearly 80% of the information contents at high spatial frequencies is getting lost due to the phase unwrapping with preliminary low-pass filtering. In contrast, in GINSAR models, 75% of original information contents is preserved. The modelling (positional) accuracy of the GINSAR technique was verified via check profiles as well as by comparing with the slope model resulted from the reference DEM. The root mean square slope difference was given as 0.5° and the mean difference was estimated as less than 0.1°.

3. Socio-economic relevance and policy implication

For the right interpretation it is very important that the optical satellite images that are used are taken just before the new snow is falling on the glacier. To meet this requirement seemed to be very difficult for two main reasons:

1) It is difficult to predict the exact time of new glacier year start as the variability from year to year can be great.
2) It has also proved to be impossible to see this from quick look's of the satellite data that image distributors are providing.

If one want to be able to use e.g. Landsat data in this kind of approach, there is a need of some changes in the service chain of images distributors. There must be more flexible and tailor-made way of choosing the suitable images.

For SAR-processing the result today is not completely meeting the user requirements. The suitable technique exists; it is a questions of not always getting data good enough. However, during the coming years we are expecting new radar satellite missions, which are better designed even for interferometry. E.g. RADARSAT 2 and 3 will be flying within a 30 second time gap, which removes a major part of image pair difference problems. Also the resolution of images will increase significantly.

4. Discussion and conclusion

Due to the above mentioned facts there were not that many Landsat images to be processed, interpreted and combined. This is not saving any time as it is making the procedure limited and more complicated. However, with better knowledge of the meteorological situation and field conditions (snow cover, new snow) more suitable images can be ordered. With this knowledge, some new images have been and will be ordered. Also the images from 2001, 2002 and 2003 are of great interest.

Although the ERS tandem mission cover the whole earth, there occur certain problems, because the temporal availability is limited between years 1995 and 1997 and the 24 hours time gap within a pair causes temporal decorrelation that makes many of otherwise possible image pairs not usable. The changes of imaging conditions (weather, climate, wind etc.) are in many cases too large for traditional SAR interferometry. The GINSAR from JR_DIB gives us an interesting new tool to work in interferometry and it might solve some of the decorrelation problems.

The low coherence of glacier areas during summer strongly limits the possibility to derive DEM using tandem and in particular repeat pass SAR interferrometric techniques. It is particularly important to note that the penetration depth of C-band in dry snow/ice is several tens of meter. Thus the scattering centre location will be several tens of meter below the actual glacier surface. This will lead to a bias of the DEM derived using interferometric techniques.

DEMs processed with Insar-tool will not reach the precision level that is, in general, seen to be necessary for glacier monitoring. There will however be also need for overall covering serving as a basis for the more precise, but often area limited, measurement and DEMs, such as processed from VHR-image pairs.

Airborne remote sensing (especially multisensor) is a problematic field of data acquisition due to weather requirements, the availability of aircraft and sensors, and unexpected factors, such as aircraft or sensor malfunction. The problems with weather are increased in mountainous areas, since they are often covered by clouds, which make optical remote sensing worthless and flying dangerous. A problematic factor related to remote sensing of glaciers is that the monitoring should take place at the end of glacier year, i.e. when the snow has melted as much as possible and the new snow has not arrived yet. The problem with all the other factors is that this timeframe for the most favourable data acquisition period is short.

The remedy is synchronised data acquisition in year 2002. This will be achieved by making the subcontractor contracts early enough and enlargening the timeframe available for both glacier areas. However, this will not remove the problem related to weather. A prerequisite in the selection of the subcontractor is that the subcontractor should guarantee the availability of the sensor, aircraft and personnel during the proposed timeframe. Therefore, it is evident, that the cost of the subcontracting is not the only primary issue if aiming for a synchronized acquisition of data.

5. Plan and objectives for the next period

5.1. New satellite data and satellite data processing

Very high resolution (VHR) image pairs will be ordered for both study areas next autumn. The pairs will be processed stereoscopically. Some free ASTER images have also been retrieved from the study areas. ASTER images are quite interesting data since their spatial resolution is 15 m. Those images will be processed in the same way as the Landsat data. 2–3 Envisat ASAR scenes will be acquired from both study areas from different seasons. They will be used for analysis of backscattering response from ice surfaces and from dry, wet and very wet snow surfaces. The funds for Envisat scenes will be transferred from the funds reserved originally for ERS and Landsat TM data.

Different change detection method procedures will be implemented and tested for the optical (Landsat) images. For Insar – DEMs processing to combine the single ones to multi-data source is executed to find out the possibilities of filling “the holes” in DEMs. During the processing some interesting information was found. The coherence images can give us more information in glacier classification as the radar interacts strongly with snow (Figure 11).

The VHR data processing chain and utilization is under consideration by the partners. The data to be purchased will be EROS A1 data since since two stereopairs of that data of each study area can be acquired and therefore the risks of getting cloudy data are minimised. Only one stereopair could be obtained with the cost of IKONOS or Quickbird.

However, there is no proper tool at hand for extracting elevation models from EROS A1 stereopairs at the moment. According to investigations, some commercial software suppliers are going to prepare some tools for processing EROS A1 data, but their schedule is still open. The properties needed for processing are: 1) image orientation by using proper EROS A1 imaging model, 2) automatic DEM extraction from oriented EROS A1 stereopairs, 3) visual DEM editing and checking in digital photogrammetric workstation / 3D-viewing system.

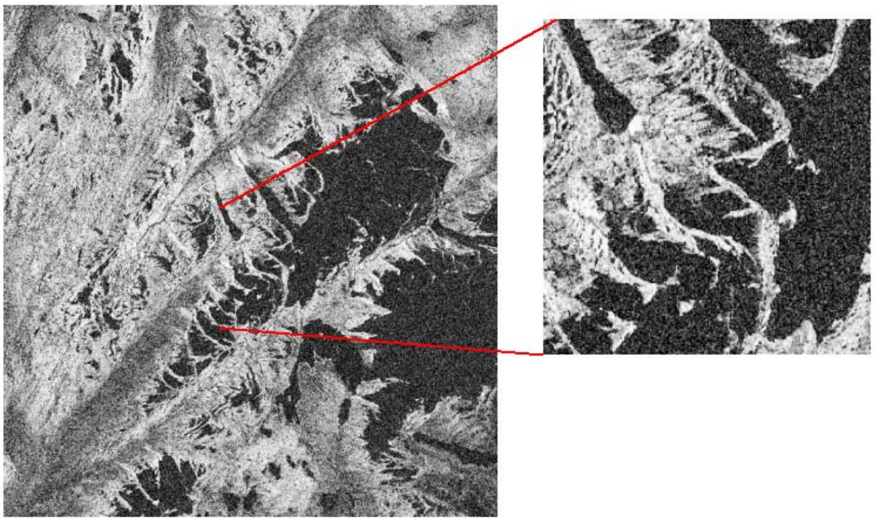

Figure 11. Dark areas indicate low coherence on glaciated areas.

There are several options for how to deal with the current situation: 1) wait that commercial software suppliers put EROS A1 processing tools into market and then Novosat could utilize those tools in its processing, 2) have a third party developer produce proper software tool for processing, 3) a partner, or partners, inside OMEGA group develops tools for processing EROS A1 stereoimages. The main tasks will be: establish EROS A1 geometric model, tailor automatic DEM calculation routine and attach image geometry model into some commercial stereoviewing system.

A decision between these alternatives will be made during next period. Inquiries will be made continually for potential software suppliers about their plans. Also some estimation of resources for developing methods and software tools withing OMEGA will be made. The decision will be affected also by the material (EROS A1 images and ground control points) available for method development.

5.2. Acquisition of terrestrial and airborne remote sensing data in 2002

The terrestrial and airborne data acquisition in the next field season period (1.4. 2002 – 31.9. 2002) are:

<u>Hintereisferner</u>	
May 2002	Laser scanner
June 2002	Laser scanner
July 2002	Laser scanner
August 2002	Laser scanner
September 2002	Laser scanner, Terrestrial photography, Digital camera imagery, Aerial photography, EROS, Envisat , Landsat ETM, Field spectrometry
<u>Svartisen</u>	
May 2002	Airborne radar, Laser scanner, Terrestrial photography
August 2002	Laser scanner, Aerial photography

Work package 4 - Analysis
Compiled by Petri Pellikka and Aleksey Sharov

Summary
Five of the consortium members were involved in this work package – University of Turku, Helsinki University of Technology, Joanneum Research (work package leader), NVE and Institute of Meterorology and Geophysics at the University of Innsbruck.

The work package is divided into two tasks:

WP 4.1 Glacier change detection using remote sensing methods
WP 4.2 Interpretation and analysis of remote sensing data and glaciological and meteorological records

The planned start of the work package was month 16. However, some analysis has been conducted by the University of Turku, Joanneum Research and University of Innsbruck since the work packages 4.1 and 4.2. are continuations from work packages 3.1 and 3.2.

1. Objectives

The objectives of the work package are to analyse glacier changes using the spectral data and DEMs produced and to compare them with the glaciological and meteorological records.

2. Methodology and scientific achievements

University of Turku

WP 4.1 Glacier change detection using remote sensing methods

The optical satellite data give the borders of the glacier, positions of firn and snowline and the extent of the accumulation area. The late summer snowline altitude is comparable to the equilibrium line altitude (ELA), which is highly correlated to the net-balance of the glacier. The extent of snow zone corresponds to accumulation area of the glacier. The ratio of the accumulation area and area of the glacier (AAR) is as well related to the net balance and can be detected out of classifications.

Snowline altitude and AAR were derived for Engabreen over three different kinds of net-balance years. The interpretations were compared to the net-balance measurements based on direct glaciological method. The results showed a good fit between assessed snowline altitude and measured ELA. The assessed AAR could detect spatial patters of annual ablation better than AAR derived from mass-balance gradient. The observed differences in parameters were well explained by the meteorological conditions between the time of image recording and the end of mass-balance year. The changes in the glacier borders were also assessed in relation to front-position measurements. According to small data, spatial resolution of the Landsat data is coarse but suitable for monitoring long-term changes in the glacier extent, for example, in the time scale of decades.

The preliminary studies in one outlet have shown that optical satellite data have potential to give estimates of glaciological parameters over larger areas. Especially AAR can give qualitative information about the glacier net-balance. Therefore, the study areas will be divided into separate glacier outlets or drainage areas, and glaciological parameters defined for them. This allows detecting spatial patterns of glaciological parameters and glacier change in the study areas.

Joanneum Research

WP 4.1 Glacier change detection using remote sensing methods

Multitemporal INSAR slope maps of the Svartisen and Hintereisferner test sites were co-registered, merged and subtracted. Main areas of glacier changes / motion were determined in 3 change images and represented in the form of false colour composites (velograms). Basic principles on volumetric measurements in INSAR change images were designed. One fragment from the Svartisen change image has been converted to the glacier-motion field (Fingerbreen Glacier).

University of Innsbruck, Institute of Meteorology and Geophysics

WP 4.1 Glacier change detection using remote sensing methods

Preparation of numerical models of energy balance, mass balance, and ice flow is started. These models will be used to assess glacier reaction to IPCC climate scenarios in WP 6.1. Runoff models to be used for the same purpose are now being tested in the framework of the Glowa-Danube project for the alpine tributaries to the river Danube above Passau.

3. Discussion and conclusion

The preliminary results show that optical and radar satellite remote sensing data are useful for the retrieval of glaciological parameters if pre-processing is conducted well. However, more data and more analysis are needed for.

4. Plan and objectives for the next period

The future plans will follow the DoW. More input from WP 3 is needed to start analysis.

Work package 5 – Implementation
Compiled by Tore Guneriussen

Summary
All the consortium members were involved in this work package the leader being NORUT IT. The work package is divided into four tasks:

WP 5.1 System design (and implementation)
WP 5.2 Testing
WP 5.3 Implementation (building) of the glacier database
WP 5.4 Cartographic representation and visualisation of the results (implement visualisation)

The planned start of the work package was month 24. However, the scheduled start of the work was shifted to month 6 (August 2001) due to the need for an early available first version of the system to be modified during the project.

1. Objectives

The objective of the work package is to implement the glacier information and monitoring system, the glacier databases and to visualise glacier changes.

2. Methodology and scientific achievements

NORUT IT

NORUT IT has established the end user requirements for the prototype software system based on the URD (Miriam Jackson et al., 2001), interviews with end users, in particular NVE. A first version of the User and operational requirements for the OMEGA prototype (Sylvarnes & Indregard, 2002; Appendix 4) has been generated and distributed in the consortium. The baseline design has been agreed.

WP 5.1 System design and implementation

The scheduled start of work in month 18 was shifted to month 6 (August 2001). The user requirements for a prototype glacier monitoring system have been discussed with the OMEGA partners. A separate meeting has been held with NVE and during the Biannual Progress Meeting in Galtür (October 2001) the design baseline was discussed.

The design is based on the assumption that the OMEGA system will consist of all the software and hardware used in the process of generating reliable glacier information. Included here is particularly the different algorithms used for processing raw data and the software for distributing the information between the partners. But the core OMEGA system to be realised in WP 5 takes care of the storage, retrieval, distribution and visualisation of glaciological data.

OMEGA prototype users

The potential users of the OMEGA project results are listed in the URD (Jackson et al., 2001) and can be grouped in two main groups:

- Advanced users who want to view and process datasets (including all participants in this project)
- Public users who seek information about glaciers, i.e. just viewing results

These will all use the browser software, but public users will only have restricted output. In addition, all participants in the project will generate data and become users of the system.

Design baseline

An interchange system will be developed based upon Microsoft Windows NT/2000 platforms. By using CORBA (which is middleware for reusable code on different operating system) the interchange system is expandable to other systems (Linux, UNIX). The prototype implementation of server, manager and browser software will be done for Windows. Free database software such as (Postgress, MySQL etc.) or simple database (MS Access) are candidates.

Analytic and processing software

The OMEGA monitoring system will not be a complete software package with common GUI (graphical users interface) where all results and remote sensing analysis are available, but rather a distributed system where the different datasets are saved and processed by the owner of the data. Then the datasets are made available for the others through a common interface. ArcView 8.1 is chosen as the visualisation tool. Users without ArcView 8.1 will only be able to receive the data as files, while users with ArcView 8.1 will have a closer integration with the OMEGA browser. The rest will have to rely on the their own software or software developed in work package 5.4. ESRI Shape format will be used for vector data and GeoTIFF for raster data. Other formats like MrSID will be considered.

The design ambition for the prototype system

Server:
- Store and retrieve raster data and vector data with all available properties such as acquisition date, owner etc. through the CORBA API developed in GIN.

Manager:
- Parse and load SHAPE files into the database
- Load GeoTIFF-files into the database
- Control the access rights for the data in the database

Browser:
- Search for data of a certain area, time, owner, dataset type, vertical accuracy, horizontal position accuracy, horizontal resolution accuracy, grid size
- Preview / Quick look of vector data
- Preview / Quick look of raster data (a small GeoTIFF image which could be used to pick the right dataset before the much larger image dataset is transferred)

Catalogue:
- Give a common access point for localising servers
- Keep updated information on available geodata resources at any given time
- Provide some level of metadata information about feature collections available

WP 6 – Demonstrations
Compiled by Petri Pellikka

Summary
All the consortium members were involved in this work package the leader being the Institute of Meteorology and Geophysics of the University of Innsbruck

The work package is divided into two tasks:

WP 6.1 Considerations and scenarios
WP 6.2 Promotions and disseminations

The planned start of the work package was month 31. However, the work in work package 6.2 has started immediately from the start of the project by disseminating the project itself in newspapers, scientific conferences, and scientific journals and by implementing project web-site at the University of Turku and several of those among partners.

1. Objectives

The objectives of the work package are to promote and market the glacier information and monitoring system and to complete academic dissertations.

2. Methodology and scientific achievements

University of Turku

The OMEGA project was represented by the University of Turku in two conferences in 2001. In *Climate Change and Variability in Northern Europe* held in Turku, Finland, 6-8 June 2001 and in *International Workshop on Geo-Spatial Knowledge Processing on Natural Resource Management held in* Varese, Italy, 28-29 June 2001.

The preliminary scientific results over assessing glaciologial parameters using Landsat data were presented in EARSeL workshop in March 2002: *Observing our Cryosphere from Space: techniques and methods for monitoring snow and ice with regard to climate change*, held in Bern, Switzerland, 11-13 March 2002.

Three general papers have been written by the coordinator in workshop proceedings and in Finnish scientific magazines (Pellikka et al, 2001; Pellikka & Luukkonen, 2001; Pellikka 2002). In addition, four newspaper articles in Finnish newspapers have been written about OMEGA (TS, 2001; Hakkarainen, 2001; Niitemaa, 2001; Hakkarainen, 2001).

One scientific paper has been submitted (Heiskanen et al., 2002a) and two abstracts have been submitted to scientific workshops and conferences (Pellikka & Hendriks, 2002; Heiskanen et al., 2002b).

University of Innsbruck, Institute for Geography

The preliminary scientific results over the use of laser scanner technology for quantifying glacier mass balance were presented in two meetings: Alpine Glaciology Meeting in February 2002, and in EARSeL workshop in March 2002 (*Observing our Cryosphere from Space: techniques and methods for monitoring snow and ice with regard to climate change*, 11-13 March 2002, Bern, Switzerland). The scientific paper is submitted to be published in the EARSeL workshop proceedings (Geist & Stötter, 2002).

Joanneum Research

Preliminary scientific results of the OMEGA project obtained by were presented at the 21st EARSeL Symposium in Paris, in May 2001 and at the Second ACD Workshop in Potsdam, in November 2001. Four papers describing the project results have been prepared and published or transferred to publishing: Sharov & Gutjahr (2002), Sharov et al. (2002a), Sharov et al. (2002b) and Sharov (2002).

A guest lecture based on the project results with a title “Glacier Change Detection Using SAR Imagery” was prepared and given by Aleksey Sharov to students at the Department of Geography, University of Turku on April 18, 2001. The lecture was part if the Seminar in Geoinformatics organised by professor Pellikka. A report “New solutions to traditional problems in polar remote sensing” including own project results was given by Aleksey Sharov to the appointment commission at the TU Graz on May 23, 2001. A lecture with a title “Why and how do we study glaciers?” was presented by Aleksey Sharov on September 16, 2001 during the field campaign on board the ship “Hydrologist”.

NVE

The preliminary scientific results over assessing glaciologial parameters using Landsat data were presented together with the University of Turku in EARSeL workshop in Bern (Heiskanen et al., 2002a).

University of Innsbruck, Institute for Meteorology and Geophysics

Contact has been established with the European Environmental Agency Project "Climate Change State and Impact Indicators in Europe. The possible use of the public relations networks of IGBP Mountain Initiative and of the Austrian Glacier Inventory for the promotion of OMEGA results is being investigated.

3. Plan and objectives for the next period

The project staff and partners will publish their results in scientific conferences and journals. Academic theses will be completed. The project will be presented at the International Glaciological Society Nordic branch meeting to be held in Oslo in November 2002.

4. Dissemination of the project

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