Ground Data Associated with Snow Cover and Land Ice Monitoring

K. Seidel
Image Science Division - Communication Technology Laboratory ETHZ
Gloriastr. 35, CH 8092 Zürich, Switzerland
Tel: +41-1-632 5284 - Fax: +41-1-632 1251
Email: seidel@vision.ee.ethz.ch

and

M. Kennett
Norwegian Water Resources and Energy Administration (NVE)
P.O. Box 5091 Majorstua 0301 Oslo, Norway
Tel: +47-22-959595 - Fax: +47-22-959004
Email: mike@nve.no

Abstract -- Ground data on snow cover and land ice, together with related hydrological and meteorological data, exist for many areas of the world. This paper gives an overview of available data in Switzerland and Norway, where snow cover and glacier monitoring are of considerable scientific and economic importance.

A Worldwide Glacier Inventory compiled by the World Glacier Monitoring Service (WGMS) in Switzerland is available. Standardized data on the distribution and characteristics of a large number of glaciers all over the world have been collected, and access to a relational database system is now available using computer networks. In addition historical data on glacier mass balance and front positions have been collected for selected glaciers with long time series. Since 1930 ground measurements of snow cover have been collected regularly within a dense network in Switzerland. Data from hydrological and meteorological networks in Switzerland are also available in digital form.

Norway is covered by extensive current and historical glacier, snow cover, hydrological and meteorological ground data networks, largely as a result of hydropower requirements. Almost all of this data can be ordered in digital form for transfer over computer networks. Overviews of these data for browsing by network users should be available soon.

1. Introduction

Snow cover and glaciers are important components in hydrology and of interest therefore to the hydropower industry, for example. However both have come under increasing scientific scruting in recent years in connection with climate change. Glaciers are sensitive indicators of climate change, and snow cover has important climate feedback properties due to its high albedo. Remote sensing offers a valuable means of monitoring snow cover and glaciers due to the large areal coverage of snow, and the inaccessability of most glaciers.

The availability of ground data is of central importance in this respect. Historical ground data can be used independently for time series analysis. The data can also, for example, be combined with remote sensing data for calibration purposes, or with related ground data (primarily hydrological and meteorologacal data) for calibration and input to runoff models.

An overview of the type, amount and availability of ground data asssocated with snow cover and glacier monitoring in Switzerland and Norway is given below. The glacier, snow cover, hydrological and meteorological networks are presented, as well as the World Glacier Monitoring Service, located in Switzerland.

2. World Glacier Monitoring Service

In the framework of the Global Environment Monitoring Service (GEMS) a World Glacier Inventory (WGI) has been compiled by the World Glacier Monitoring Service (WGMS).

Glacier ice currently covers 10 percent of the Earth's surface, or some 15 million km^2. Although this resource contains 75 percent of the world's freshwater, most of it is stored far away from human habitat and action, in the massive ice sheets of Greenland and Antarctica.

The coordinated collection of information about glaciers began in 1894, to establish the relationship between glaciers and climate, and to improve the understanding of the Ice Ages. Until about 1950, most of the information collected related to glacier lengths, particularly in the Alps, Scandinavia and Iceland, and many of the observations were made in connection with hazards such as ice avalanches and outbursts from ice-dammed lakes.

Direct mass balance measurements began to be taken after World War II, first in Scandinavia and then elsewhere, many in conjunction with hydroelectric schemes. It was this work that really established the link between climate change and glacier fluctuations.

Figure 1: World Glacier Inventory: Status 1988

Table 1: Count of glaciers for each publication series
Y = data exist but not yet loaded into database
FoG fluctuations of glaciers
MBB Mass Balance Bulletin, regularily edited
WGI World Glacier Inventory

Country	**FoG**	**MBB**	**WGI**
Antarctica	39		
Argentina	10		Y
Australia	16		
Austria	142	7	925
Bolivia	2	2	
Canada	107	2	Y
Chile	36		Y
China	35	1	Y
Colombia	1		Y
France	11	2	1130
Germany	5		5
Greenland	14		45
GUS	176	13	Y
Iceland	62	3	Y
India	5		
Indonesia	6		Y
Italy	273	1	1376
Japan	2		Y
Kenya	13	1	Y
Mexico	2		Y
Nepal	12		130
New Zealand	4		3154
Norway	55	10	2998
Pakistan	37		69
Peru	10		Y
Poland	3		Y
Spain	25		31
Sweden	21	5	303
Switzerland	118	2	1828
Uganda	1		Y
United Kingdom	33		
United States	197	3	Y
Venezuela	1		Y
Total	1474	52	11994

The need for a worldwide inventory of perennial snow and ice masses was first considered during the International Hydrological Decade operated by UNESCO during 1965-74. Several countries started to compile glacier data and in 1976 a Temporary Technical Secretariat was established at the Swiss Federal Institute of Technology (ETHZ) in Zürich, Switzerland.

The original inventory was published in 1989 [1]. The aim was firstly to provide a snapshot of ice conditions on Earth during the second half of the 20th century. Glacier inventories were made worldwide, and then compiled to provide a statistical basis for the study of glaciers. As Figure 1 shows, all relevant glacierized areas of the world are now covered by some kind of inventory, most of them detailed but a few still preliminary. It is planned to fill the remaining gaps in the near future.

The work of the World Glacier Monitoring Service continues. The aims are to collect and publish data on glacier fluctuations every five years, and to complete and upgrade the original inventory. In addition, mass balance data are being published every two years because of the role of glaciers as key indicators within climate monitoring [2].

Glacier monitoring now attempts to provide several types of information. Observation of glacier lengths are the key for comparing today's glaciers with those of the past. The technical difficulties of glacier monitoring mean that remote glaciers must be monitored by aerial photography and high-resolution satellite imagery.

Table 1 indicates the relevant glaciers and what kind of information is available.

3. Swiss Networks

3.1 Permafrost Monitoring Network

A Permafrost Monitoring Network for Switzerland is being developped. Bore hole measurements (temperatures, deformations) will be included. Repeated photogrammetry and infra-red photography is used as a monitoring tool.

3.2 Swiss Meteorological Networks

The Swiss Meteorological Institute (SMA) offers a variety of databases containing a wide spectrum of measurements related to all kinds of meteorological parameters. Table 2 summarizes the most significant parts [3]. Data of some climate stations have been recorded since 1860.

Table 2: Station Summary of the SMA Observation Networks 1994

Network Type:	1.12.1993	1.12.1994
Automatic Measurement Network (ANETZ)	72	72
Complementary Automatic Network (ENET)	41	43
Conventional Stations Network	481	488
Air Traffic Stations Network	35	35
Storm-Wind Stations Network	35	34
Biometeorological Network	212	214
Aerologic Station (sounding ballon)	1	1
Radarstations	3	3
Total no. of SMA-stations	880	890

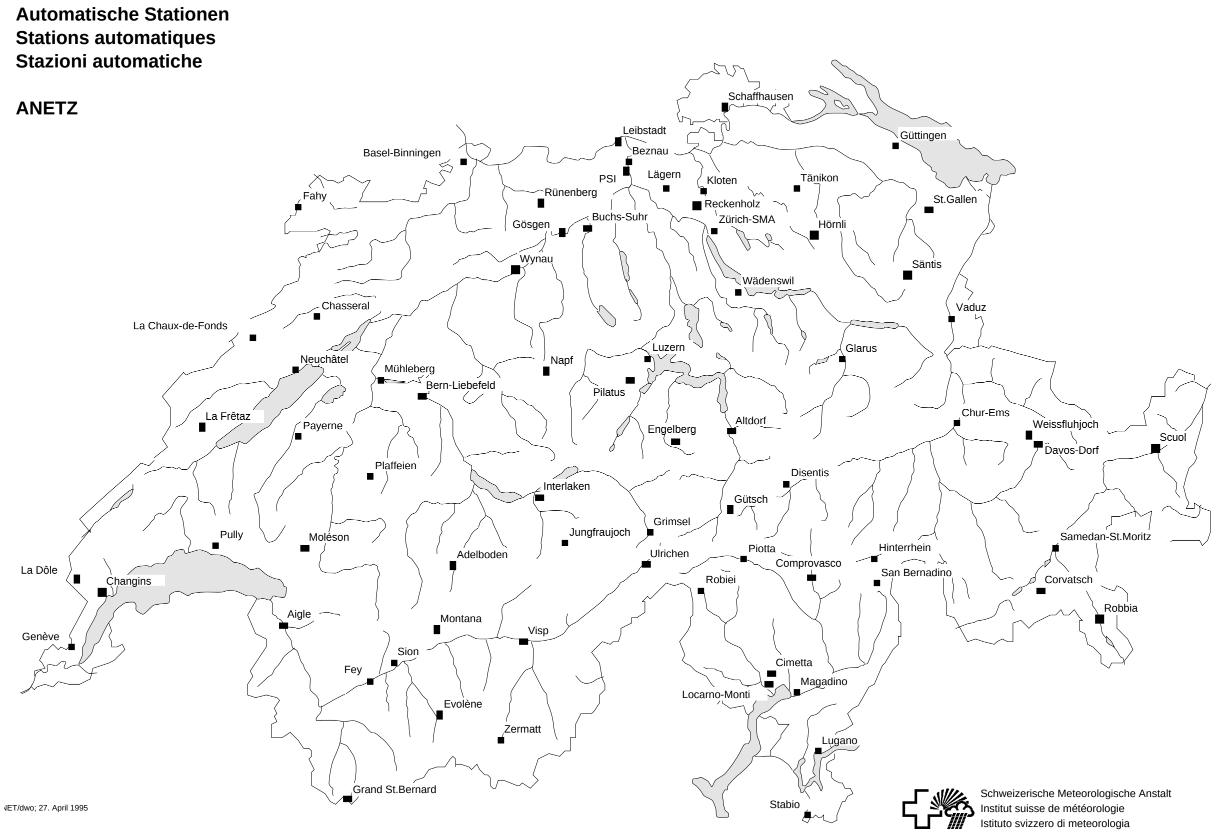

Figure 2: Swiss Automatic Measurement Network (ANETZ)

ANETZ - Automatic Measurement Network

Most important SMA network: generation of as many as 20 different measurements per station, locations in every region and altitude range of Switzerland (see Fig. 2). Fully automatic operation with measurement and data transfer every 10 minutes. At several stations, additional visual observations 3-8 times a day.

ENET - Complementary Automatic Network

Complements the ANETZ: measurements of wind at different locations,
otherwise very detailed measurement program, containing a maximum of 10 parameters,
e.g. measurement of snow at heights of 1900-3000 m. Fully automatic operation as well,
with data transferred every hour.

Conventional Stations Network

Contains the KLIMA-Network (measurement of the most important meteorological data with classical methods, completed with weather observations three times a day),
the Precipitation-Network,
the Snow-Measurement-Network,
the Frost-Network (stations operating usually in April-May in agricultural areas) and
the Totalizer-Network (collecting the precipitations over a whole year).

Air Traffic Stations Network

On larger airports. The number of measurements varies according to the air traffic density
between 4 and 47 a day.

Storm-Wind Stations

Automatic stations that ring an alarm if the wind intensity exceeds 25 knots
(the network is being terminated in 1995 and replaced by the ENET).

Biometeorological Networks

Contains the Phenologic Network (observation of plant development) and
the Pollen Measuring Network (only since 1993, data is reported weekly).

Table 3: Activities and Services at
the Swiss National Hydrological and Geological Survey (LHG)

Hydrological Data Bank Hydrological Yearbook	Hydrological Atlas of Switzerland LHG's Geographical Information System
Monitoring of waters Development of hydrometry in Switzerland Measurement of water level Determination of the discharge Use and calibration of current meters Discharge measurement under difficult conditions Sediment observation in waters Monitoring the state of waters Expansion of pollutants in rivers Investigation of floods Discharge forecasts and flood warning Long-term changes in the water balance	Geological Atlas of Switzerland 1:25'000 The national groundwater monitoring network Hydrogeological maps Hydrogeological properties of formation with low permeability Natural disasters and geology Textonic map of Switzerland 1:500'000

3.3 Swiss Hydrological Networks

The Swiss National Hydrological and Geological Survey (LHG), which is attached to the Federal Office of Environment, Forests and Landscape, is concerned with the detailed study of Switzerland's water cycle and geological subsoil. Its surveys and documentation, together with the data and basic information which is provided on these subjects, play an important part in planning and decision-making in an increasing number of areas [4]. These include, for example, the protection and use of surface and underground waters, protection against flooding, questions connected with waste disposal sites, the construction of buildings, roads and tunnels, land use planning and environmental impact assessment. The data collected by the LHG, in conjunction with monitoring of the atmosphere, soil and biosphere, form a vital basis for political decisions concerning long-term development, including possible rapid climate changes. Table 3 sumarizes the activities and the services. Table 4 and 5 give in addition an overview of the available data at LHG together with the time ranges of the recordings.

Table 4: Water level and runoff

	Water level[1)] (m a. s. l.)	Runoff ($m^3 s^{-1}$)	Specific Runoff ($l \cdot s^{-1} km^2$)	Runoff height (mm)
Permanent digital recordings	since 1974	-	-	-
Daily values	since 1964[2)]	since beginning (1869)	-	-
Monthly mean value	since 1964[2)]	since beginning (1869)	since 1974	since 1974
Monthly maximum	since 1964	since beginning (1869)	-	-
Monthly minimum	since 1964	-	-	-
Random samples	since 1976[3)]	-	-	-
Mean values over 1 or 2 weeks	since 1976	since 1976	-	-

1) Ground water, lakes, running waters
2) Large and medium lakes since beginning of the archived recordings in 1866
3) Two ground water stations in the transverse Rhein-Felsberg

Table 5: Further Parameters

	Water temperature (˚C)	Content of particles in suspension (mg/l)	pH; conductivity (uS/cm)	Oxygen content (mg/l)	NADUF[1] Programm
Permanent digital recordings	since 1974	-	since 1976	since 1976	-
Daily values	since beginning (1960)[2]	-	since 1976	since 1976	-
Monthly mean value	since beginning (1960)[2]	-	since 1976	since 1976	-
Monthly maximum	since 1974	-	since 1976	since 1976	-
Monthly minimum	since 1974	-	since 1976	since 1976	-
Random samples	-	since beginning (1962)	-	-	-
Mean values over 1 or 2 weeks	since 1976	-	since 1976	since 1976	since 1976

1) National program for the long-term analytical investigation of the swiss running waters (LHG, BUS, EAWAG). The program comprises geochemical and other parameters that are strongly influenced by civilization. All observed data is recorded.
2) Aare-Bueren Station 1887-1975

3.4 Snow Cover Monitoring

The Federal Institute for Snow and Avalanche Research (SLF) located in Weisfluhjoch/Davos reports on a regular basis about the situation of snow and avalanches in the Swiss Alps. Some of the data is collected automatically and included in the above mentioned databases (see SMA-ENET). The yearbook ‘Winterberichte’ [5] published by the institute contains extensive details. In Table 6 the respective categories are listed.

Table 6: Data available at the Federal Institute for Snow and Avalanche Research (SLF)

Observations:	Point Measurements:
Observation period Depth of new snow Total snow depth Weather phenomena and their intensity Wind direction and its intensity Atmospheric temperature Snow temperature, at 10 cm under the snow surface Shape of the snow surface Sink-in depth Avalanche observation data Estimation of the avalanche threat Water equivalent of the new snow Plain text: unusual events reported as shorttext	Depth of new snow Total snow depth Weather phenomena (only in case of rain) Water equivalent of the new snow Stations with 14-days snow profile recordings: Ram-profile with ram-probe SLF Sequence of layers for the total snow cover, specifying for each layer: Shape of grains Dimension of grains Hardness Humidity Temperature profile over the whole snow depth range Total water equivalent Sliding-block test and its interpretation

In addition, Table 7 compares the number of ground stations supervised by the various institutes, whilst Table 8 shows a list of the measured variables and the frequency of the measurements. The map in Fig. 3 shows how the stations for snow cover observations are distributed in Switzerland.

Table 7: Snow gauging stations operated by different institutions, distributed by altitude zones

Elevation [m a.s.l.]	SLF SLF/SMA	SLF/ETH SLF/ETH/SMA	ETH	SMA	WSL	Total
>2500	4			1		5
2500 - 2000	7	2		5		14
1999 - 1500	22	27	1	9		59
1499 - 1000	22	27		20	17	86
999 - 500	9		5	41		55
<500	2			42		44
Total	66	56	6	118	17	263

Actual stations with at least 5 years of observation and cancelled stations with at least 10 years of observation are considered. Supervisory Institutions:

SLF = Federal Institute for Snow and Avalanche Research
SMA = Swiss Meteorological Institute
ETH = Federal Institute of Technology
WSL = Federal Research Institute for Forest, Snow and Landscape

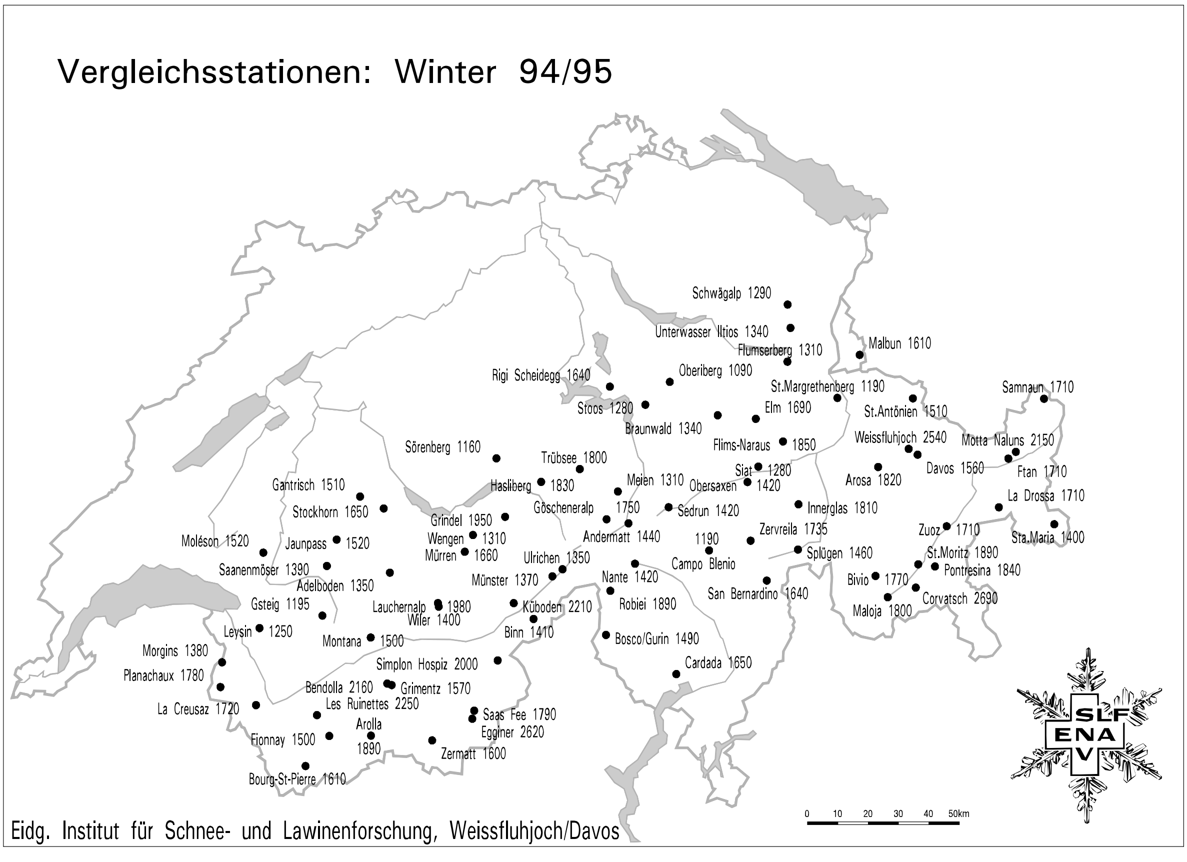

Figure 3: Stations for observation of snow cover properties in Switzerland

Table 8: Assessment of the snow gauging network with regard to the measured variables: New snow depth, total snow depth, water equivalent of the new snow, water equivalent of the total snow cover

Number of stations	Variables measured:
4	Total snow depth (daily)
23	Water equivalent of total snow cover (every 2 weeks)
162	Total snow depth, depth of new snow (last 24 hours)
7	Total snow depth, new snow depth, totl snow water equivalent
67	Snow depth (total and new snow), Water equivalent (total and new snow)
263	

4. Norwegian Networks

Norway is heavily dependent on hydropower, since 99% of its electricity is produced in this way. The need for economic and environmental assessment of power stations all over the country has led to extensive hydrological and associated networks. Snow is important since it accounts for over 50% of the yearly precipitation in many areas, and many catchments have a significant proportion of glacier cover, thus well established snow cover and glacier networks exist in Norway. Data from the meteorological network is also used in power planning and production.

The hydrological, glacier and snow cover networks are managed by the Norwegian Water Resources and Energy Administration (NVE). NVE is currently transfering these data to a new database, but most of the data are already available in digital form over Internet. The Norwegian Meteorological Institute (DNMI) is responsible for the meteorological network, and these data are also available over Internet. Both organisations have standad prices for digital data. Once ordered the data series are transfered to a directory which the client can access over Internet. NVE and DNMI are considering providing data overviews for browsing via Internet.

The Norwegian ground data networks are described below. Also described is an AVHRR archive which can be used in conjunction with these ground data.

4.1 Norwegian Glacier Network

Norway (excluding Svalbard) has 1627 glaciers covering 2609 km^2 [6]. Glacier inventories have been compiled for northern Scandinavia (1973 [7]) and southern Norway (1969 [8] and 1988 [6]), and much of this data is available digitally. A total of 30 maps have been produced since 1951 for 24 glaciers, mostly at a scale of 1:10 000 [6].

Mass balance has been measured on 31 glaciers for a total of 388 glacier-years and at several elevations on each glacier [6]. These series vary in length from 2 - 47 years, and include the world's 2nd longest series, Storbreen, which has been measured continuously since 1949. Five additional series are longer than 30 years. Mass balance is currently measured on 10 glaciers. These data exist in published or internal reports, but will be transfered to NVE's hydrological database in 1995/6.

Glacier front position series exist for 35 glaciers [6], of which 32 were started in 1910 or before. Ten glaciers are currently monitored. These data are available digitally.

4.2 Norwegian Snow Cover Network

Snow fields are monitored by power companies 1 or 2 times per year, mostly since the 1940's, although some series stretch back to the 1920's. The network covers 29 snow fields, each with stations consisting of either "point swarms" (ca. 20 per field) or snow profiles (ca. 10 per field). Point swarms are many snow depth probings within a few m2 around fixed points in the snow field. The average depth for each station is recorded. Snow density is also measured. Snow profiles are straight lines of typically 1 km length between fixed points. Snow depth is probed every 25 m or so, and snow density is measured. A total of ca. 20 000 station years is archived in the NVE hydrological database.

Snow water equivalent is also logged continuously using snow pillows at 6 stations in Norway. Additional snow cover data is recorded at some meteorological stations by DNMI.

4.3 Norwegian Hydrological Network

This consists of a total of 771 discharge stations and 640 reservoir level stations. Of these, 50 stations transmit data in real time to NVE headquarters. A total of ca. 50 000 years of daily values of discharge/waterlevel are currently stored in the NVE database, some as old as 1840. Many stations have a high time resolution (1 hour or less), and some of these series start in the 1930's. The data is subjected to standard quality control procedures.

Other hydrological data includes groundwater (1200 series, but only a few of these series are current), water temperature and sediment concentration. Some hydrological stations record other parameters such as water quality and meteorological data. Altogether 13 million new data are added to the database each year.

4.4 Norwegian Meteorological Network

The network includes a total of 565 manual precipitation stations (where amount and type of precipitation are registered), 173 manual weather stations (air temperature, wind velocity, humidity and cloud cover), and 55 telemetry stations (precipitation, air temperature, wind velocity, humidity, air pressure and incoming radiation). Additional snow depth and snow cover parameters are measured at some manual stations. The data passes standard quality control procedures and is archived in the DNMI database.

4.5 AVHRR archive

A total of 221 cloud free or partially clouded full resolution 5 channel AVHRR scenes covering southern Norway have been selected and archived at NVE - 1 or 2 every month since 1979. This data is available digitally.

5. Conclusions

Extensive current and historical data series from glaciers in many parts of the world are available from the World Glacier Monitoring Service in Switzerland.

Both Switzerland and Norway are well covered by current and historical glacier, snow cover, hydrological and meteorological ground data networks, due to the importance of these parameters here. Almost all of this data is already stored digitally, and can be ordered at fixed or rates for delivery over Internet. Data overviews could be freely available over Internet if the demand for data is considered sufficient.

Data collected at ground stations refers to point measurements. The extrapolation from these measurements to areal information is of limited reliability. Regional snow cover and glacier information can be derived from remote sensing satellite imagery. It would be a significant advantage to develop the technique for operational usage as a tool for snow cover and glacier monitoring in high mountain areas.

6. References

[1] IAHS (ICSI)/UNEP/UNESCO, World Glacier Inventory: status 1988 (edited by W. Haeberli, H. Boesch, K. Scherler, G. Oestrem and C.C. Wallen), Nairobi, 1989.

[2] IAHS (ICSI)/UNEP/UNESCO, Glacier Mass Ballance Bulletin No.2, 1990-1991, WGMS/ETH, Zürich, 1992.

[3] SMA, Konzepte Netze 1993, SMA Publikationen, No. 181, 1995 (Schweizerische Meteorologische Anstalt, Krähbühlstr. 58, Ch-8044 Zürich).

[4] LHG, The Swiss National Hydrological and Geological Survey - Activities and Services, Puplished by: Federal Office of Environment, Forest and Landscape (BUWAL), CH-3003 Bern, 1993.

[5] SLF, Schnee und Lawinen in den Schweizer Alpen Winter 93/94, Winterbericht des Eidg. Institutes für Schnee- und Lawinenforschung, Weisfluhjoch/Davos, Nr. 58/1995.

[6] Norwegian Water Resources and Energy Administration, Atlas of glaciers in South Norway, publication no. 61, Hydrology Department, 1988.

[7] University of Stockholm, Glacier atlas of northen Scandinavia, publication no. 46, Department of Physical Geography, 1973.

[8] Norwegian Water Resources and Energy Administration, Atlas of glaciers in South Norway, publication no. 20, Hydrology Department, 1969.