Plate 3.1[2] Cryosphere-Measuring Networks: Snow, Glaciers, Permafrost

Introduction

Recent changes in the cryosphere-measuring networks have necessitated a revision of plate 3.1. While the snow-measuring networks have on the one hand been extended and on the other automated, the traditional glacier-measuring network has been modified and expanded. An entirely new feature is the permafrost-measuring network, which was first launched in 2000 as a pilot project. The Cryosphere Expert Committee that was set up by the Swiss Academy of Sciences (scnat) in 2006 is now responsible for coordinating the individual measuring networks.

Snow

In Switzerland, snow measurements are carried out mainly at the measuring stations operated by the Swiss Federal Institute for Snow and Avalanche Research and the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss). In addition, there are single stations and smaller measuring networks of a local character. These are used for research and winter tourism, as well as to assess the operational safety of mountain transport systems or to estimate the volume of water available to power stations [5,7,14].

The maps, tables and figures in this plate provide an overview of the locations of measuring stations and the characteristics measured, and indicate the degree of completeness of the measurement series provided by the individual snow-measuring networks. Any analysis of the actual measurement results (see for example [3,8,11]) needs to take into account the fact that only part of the data has been checked, adjusted and interpolated, and that the missing years indicated refer to snow depths. There may be further gaps in data referring to other characteristics. In addition, certain stations may have been transferred from one network to another. The present plate shows the network composition as per 2006. The plate lists a total of 581 snow-measuring stations, of which 311 were in operation in 2006 (see table 1). It includes only those stations where data are available in digital form on request from a database of the institution operating them.

Snow characteristics

The three most important snow characteristics dealt with in this plate are snow depth (HS), new snow depth (HN) and snow water equivalent (SWE) (see table 2). The snow depth is read off from a graduated pole or determined automatically using ultrasound. New snow is measured every 24 hours at around 7 a.m., the depth of snow that has fallen since the previous observation being measured on a board. The board is then wiped clean and placed on the surface of the snow again. This characteristic cannot be measured using a sensor. The snow water equivalent corresponds to the depth of the melted snow of the snow cover.

At automatic stations, the density and the water equivalent of the new snow can be deduced using a model, providing that in addition to snow depth measurements also include radiation, atmospheric humidity, wind direction and speed, air temperature and snow temperature at various depths.

Snow-measuring networks

The automatic ANETZ network is the high-temporal-resolution ground-based measuring system operated by MeteoSwiss. It was set up between 1977 and 1982 and comprises a total of 72 stations throughout the country which automatically record a broad selection of meteorological data every 10 minutes (see plate 2.1[2]). Conventional snow measurements are carried out at 34 of these stations. Since 2005, the stations have been gradually transferred to the new automatic SwissMetNet and equipped with automatic snow-depth gauges [10].

The complementary ENET network was set up between 1990 and 1994 [9], replacing the so-called Gfeller storm-warning network belonging to MeteoSwiss. ENET comprises 44 stations in all, of which 10 are located at high altitude and take snow measurements. All of these are double stations consisting of a summit station (heated anemometer, air temperature thermometer with air intake, radiation sensors in some cases) and a nearby flat-ground station where snow depth and snow temperature on and below the surface are measured.

The Intercantonal Measuring and Information System (IMIS) was set up between 1992 and 2006. The 99 stations included in this system also consist of two stations each, a summit station and a nearby flat-ground station. Apart from the characteristics recorded by the ENET network, the IMIS stations also measure atmospheric humidity and reflected short-wave radiation. These data can be used to operate the SNOWPACK model [1], which simulates the characteristics of the different snow layers, the drift index, the surface hoar index, new snow depth and the snow water equivalent.

The so-called comparative network (VG) is the basic monitoring network for avalanche warnings and comprises 80 stations. Apart from snow characteristics, the observers working here also report any avalanches that occur and estimate the avalanche risk for their area.

Glaciers

The main purpose of the measuring programme for obtaining long-term documentation about changes in glaciers is to collect and make available a representative database for a broad range of users. Apart from research into the relationship between climate and glaciers, the measuring programme satisfies demands from the business sector (hydro-electric power, tourism) and the public sector (information, education) as well as being used for identifying and assessing natural hazards.

Systematic annual measurements were started as early as 1880, when researchers hoped to use them to explain the ice ages among other things. Over the years, the research aims of glacier measurements have changed, and new measuring methods have been developed. Today the emphasis is on combining new technologies (for example remote sensing, geo-information) with traditional measuring techniques (e.g. field measurements). Simultaneously, the results obtained contribute to international glacier-change documentation projects.

Characteristics measured

The glacier-measuring network is structured in such a way that it enables changes in glaciers to be analysed at both a global and a regional level. The monitoring programme includes annual records, or records covering a number of years, of changes in glacier length, mass and volume, flow speed and firn temperature, as well as the periodic recording of glacier characteristics (cf. table 3).

Changes in the length of some 100 glaciers are measured each year in late summer by observing the shift in the position of the end of the tongue. This relatively easy task can be carried out in a number of ways, either on the spot (measuring tape, theodolite, GPS) or by evaluating aerial photos. Changes in the length of glaciers are a delayed and diluted sign of climatic change, depending on the size, geometry and flow dynamics of the glacier (cf. plate 3.7). The dense measuring network includes glaciers of all sizes and provides a good overview of regional fluctuations (fig. 7,[6]). Some 9100 individual observations have been made since records began in the 19th century, producing measurement series of an average length of 71 years.

At present, the mass balance, made up of accumulation and ablation (in particular ice-melt) is determined at the end of the winter (normally mid-May) and the end of the balance year (normally the end of September) for three glaciers. This involves labour-intensive direct glaciological measurements using gauge poles and snow-shafts. These detailed records are completed with annual local measurements taken of several other glaciers, as well as long-term measurements of total volume change in 25 glaciers [2]; figure 8 shows selected results.

Surface velocity depends on the thickness of the ice, the gradient and the mechanics of how the glacier glides over the ground beneath it. It is recorded once a year using terrestrial measurements involving gauges and cross-profiles, along with photogrammetric analyses of aerial photos. Firn and ice temperature measurements, which are limited to individual glaciers, are not included in this plate. Finally, records include periodic surveys of the entire glaciated area of the Swiss Alps and the extrapolation of further characteristics (see plate 3.10).

Permafrost

Permafrost is an important indicator for environmental change at high altitudes, and research into this field has become more important over recent years. Following a development phase of several years, a concept for PERMOS (PERmafrost MOnitoring Switzerland) was implemented in a pilot phase between 2000 and 2006 [12,13]. This made it possible to secure existing measurement series and refine the methodology for monitoring permafrost.

Together with the evaluation of periodic aerial surveys, the information obtained through PERMOS enables scientists to make a more accurate assessment of natural hazards originating in permafrost areas (e.g. processes causing mud-slides and rock-falls). The programme focuses on the following characteristics:

- Thickness of the thawing surface, permafrost temperatures in drill cores: Observations show that it takes around 6 months for a temperature signal to penetrate to a depth of 10 m. At this depth, short-term fluctuations (e.g. day/night) can no longer be detected, whereas the influence of seasonal variation is more apparent (see fig. 6).
- Ground surface and rock temperatures: Temperature sensors just below the surface record the effects of air temperature, solar radiation, snow cover and the movement of air between large blocks, if appropriate, on the temperature of the surface of the ground. Some of these temperature sensors have been inserted into near vertical rock walls where no snow accumulates, while others have been set up in flat areas. In this way it is possible to deduce the different influence of various characteristics such as air temperature, radiation, snow and air circulation and to observe any changes over time (see fig. 5).

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