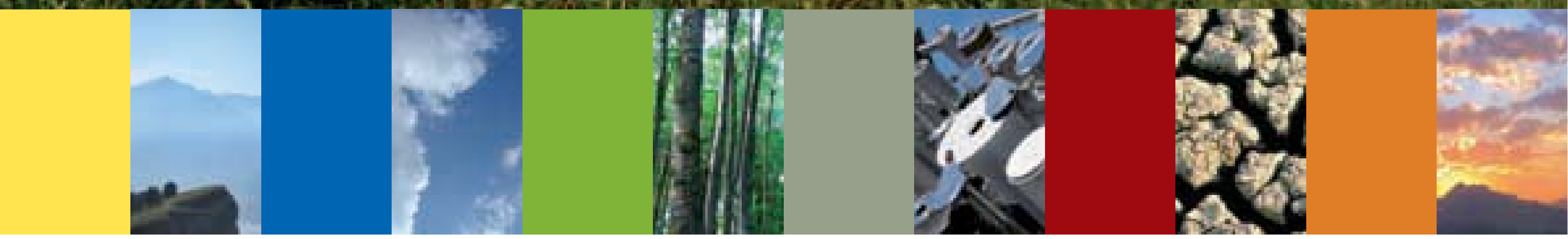
National Climate Observing System

Global Climate Observing System – GCOS Switzerland



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ProClim–
Forum for Climate and Global Change
Forum of the Swiss Academy of Sciences

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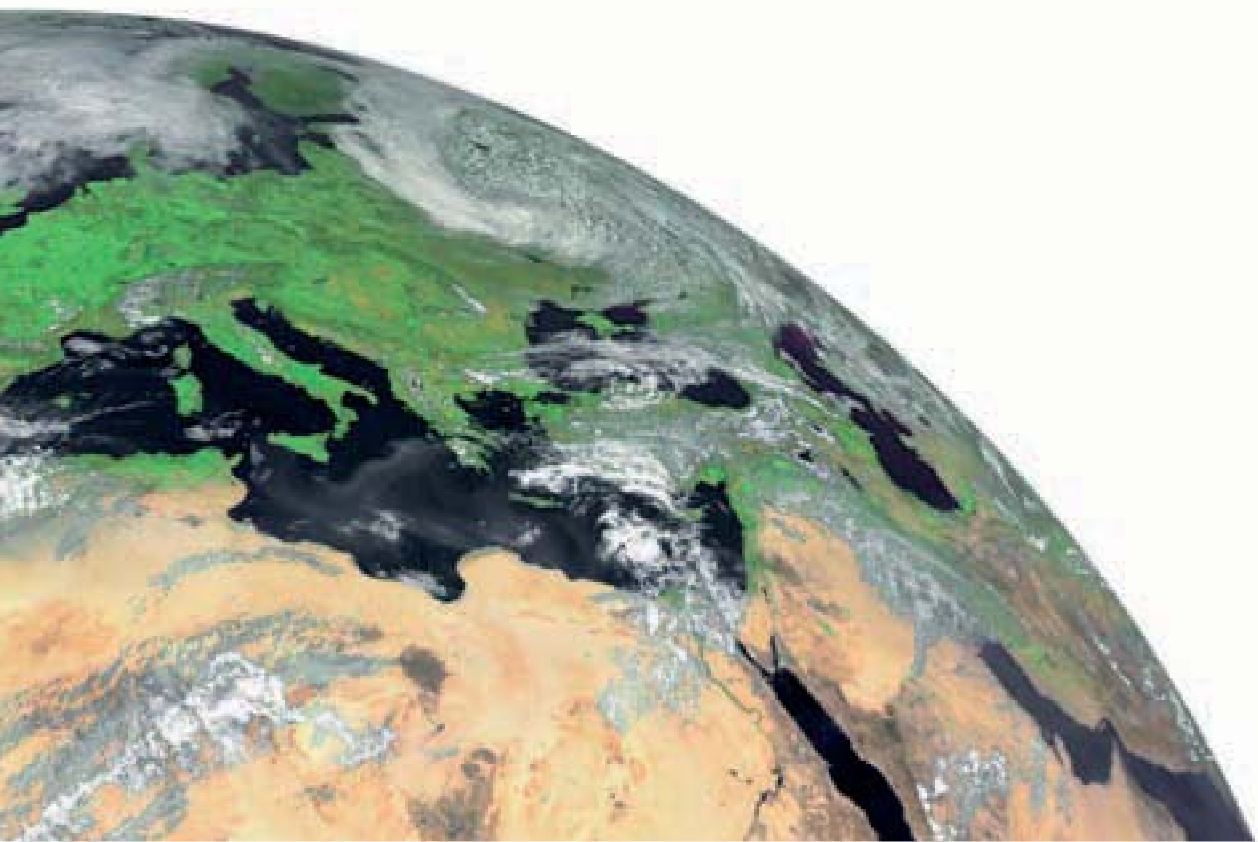
Global Climate Observing System – GCOS Switzerland



Imprint

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Citation
Seiz, G., Foppa, N., 2007. National Climate Observing System (GCOS Switzerland). Publication of MeteoSwiss and ProClim, 92 p.

Layout
BBG Werbung AG, Thalwil

Printed at
Schellenberg Druck AG, Pfäffikon ZH

Translation
Jeff Acheson

Foreword

Scientific data collection requires continuity. Trends and new developments cannot be detected with an isolated snapshot. Equally, sound conclusions as to how our climate is changing can only be reached on the basis of regular, standardized observations of different climate variables. As is strikingly demonstrated by the recently published Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the key findings and conclusions on the state of the climate are dependent on a correct assessment of the chronology of changes. If we were not able to place today's elevated atmospheric CO_2 concentrations – or the dramatic retreat of Alpine glaciers – within the detailed historical context of the past 50 years' developments, we would be unaware of the true interactions within this complex system.

In a country where lives are shaped by changes in the environment, there is a long tradition of systematic observation. Accordingly, Switzerland has numerous long-term data series, which are now part of the fundamental information on the climate system used by researchers and the authorities alike. The expertise acquired through these activities makes Switzerland an important partner in international climate observation programmes.

This report makes available for the first time a comprehensive inventory of the climate variables that have been observed in Switzerland for many years. It thus provides a starting point for the formulation of a financial and legislative strategy to secure the future of the national climate observing system.

Bern, October 2007

Thomas Stocker
ProClim President

Kathy Riklin
OcCC President

Summary

Switzerland has a long tradition of climate observation. Temperature and precipitation series of more than 150 years, the world's longest total ozone series, glacier measurements dating back to the end of the 19th century and the 100-year anniversary of the Physical Meteorological Observatory Davos are only a few of the highlights of Switzerland's contribution to global and regional climate monitoring.

The value of Swiss climate measurement series lies in their long-term continuity, systematic acquisition and remarkable quality. It should be borne in mind that if measurement series are interrupted, the loss of continuity is irrevocable. This report, prepared by the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss, provides, for the first time, a comprehensive overview of the most valuable long series of essential climate variables. For each variable, the report identifies any gaps regarding the legal basis, definition of responsibilities or availability of financial resources for the continuation of observations.

There is a clear need for action with regard to the cryosphere observations (glaciers, permafrost, snow): there is no legal basis and consequently, the funding of measurement series is not assured in the long term. In addition, funding is required for the CO_2 measurement series on the Jungfraujoch, for observations of lakes and phenology, and for three international data centres in Switzerland. The presented long-term measurement series of the National Climate Observing System (GCOS Switzerland) are crucial to our understanding of climate change, and for the planning and implementation of appropriate measures.

La Suisse a une longue tradition en matière d'observation du climat. Des séries de plus de 150 ans de mesures de la température et des précipitations, la plus longue série de l'ozone total dans le monde, des mesures glaciologiques depuis la fin du 19e siècle et cent ans d'activité de l'Observatoire physico-météorologique de Davos ne sont que quelques-uns des grands jalons de la contribution suisse au monitorage mondial et régional du climat.

La grande valeur des séries suisses de mesure climatiques tient à leur continuité, à des relevés systématiques et à une remarquable qualité. L'interruption de telles séries est donc irrévocable. Par ce rapport, le Swiss GCOS Office à l'Office fédéral de météorologie et climato-logie MétéoSuisse donne pour la première fois un large aperçu des plus précieuses des longues séries de variables climatiques essentielles. Cette synthèse examine pour chacune d'elles si des bases légales, des compétences ou des ressources financières font défaut pour assurer leur continuation.

Des dispositions sont requises notamment pour l'observation de la cryosphère (glaciers, pergélisol, neige) : il n'existe aucune base lé-gale à ce sujet, ainsi le financement de ces séries de mesure n'est-il pas assuré à long terme. Un besoin de financement existe aussi pour la série de mesure du CO_2 au Jungfraujoch, pour des séries d'observation des lacs et de la phénologie, ainsi que pour trois centres internationaux de données en Suisse. Les longues séries de mesure du système national d'observation du climat (GCOS Suisse) ici présentées, sont primordiales pour la compréhension du changement climatique et pour la planification et réalisation de mesures adéquates.

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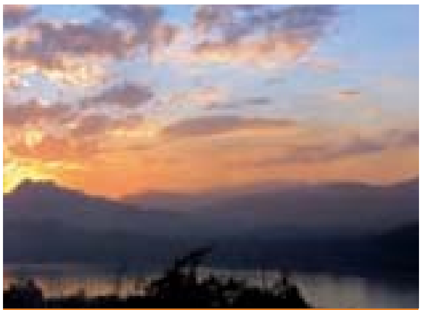

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1.0 Introduction

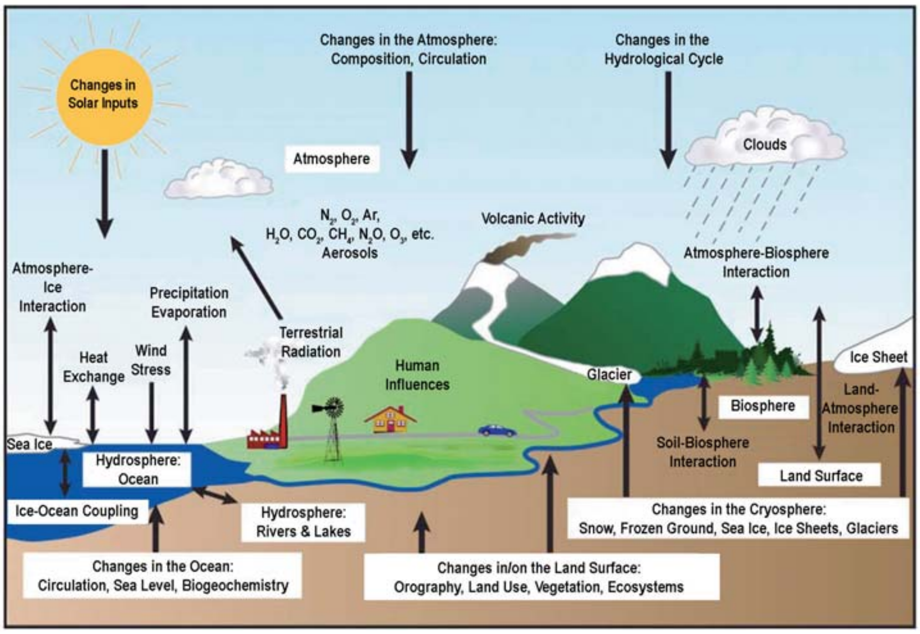
In recent decades – especially following the adoption of the Climate Convention in 1992 – the demand for observations of climate and climate change has steadily increased. For scientific conclusions on climate change, the attribution of anthropogenic influences and future climate scenarios, long-term, high-quality data series are essential.

Background

The recently published Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) summarizes the current state of knowledge on climate change and its global impacts. From a global perspective, Switzerland is relatively seriously affected by climate change.

By 2050, according to a recent report by the Swiss Advisory Body on Climate Change (OcCC, 2007), Switzerland will face autumn, winter and spring temperatures to increase by around 2 °C and summer temperatures by almost 3 °C. Precipitation levels are projected to rise by about 10 % in winter and to fall by about 20 % in summer. In addition, the frequency of extreme precipitation events is expected to increase, especially in the winter, possibly leading to more frequent floods and debris flows in certain regions. Management of climate change and its impacts thus represents a major challenge for the present and the future.

The climate system



The components of the climate system (IPCC, 2007).

Since the publication of the previous IPCC Assessment Report in 2001, researchers have made significant progress in understanding the climate system, current changes in the climate and their impacts on humans and the environment. To a considerable extent, this improvement in scientific understanding can be attributed to substantial improvements in the data base.

The close links between climate observation and climate research/modelling were recognized when the IPCC was first convened in the 1980s. This led to the establishment of the Global Climate Observing System (GCOS), as well as to the adoption of the UN Framework Convention on Climate Change (UNFCCC) in 1992. The aims and requirements of systematic observation are specified in Article 5 of the UNFCCC ("Research and Systematic Observation") and in Article 10 of the subsequent Kyoto Protocol.

GCOS is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of UNESCO, the UN Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS is designed to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. Building on existing networks and systems, GCOS encompasses the total climate system including observations of physical, chemical and biological properties of the atmosphere, the ocean and the land surface (see Figure).

Analyses of the climatological time series collected within the GCOS framework provide a key foundation for reports by international climate experts (e.g. IPCC Assessment Reports, WMO Assessment Reports on ozone). The Fourth IPCC Assessment Report makes reference to various papers concerning Swiss climatological time series, e.g. for precipitation (Schmidli and Frei, 2005), radiation (Philipona et al., 2005; Wild et al., 2005), snow (Scherrer et al., 2004), glaciers (Zemp et al., 2005), permafrost (Vonder Mühll et al., 2004) and phenology (Defila and Clot, 2001).

According to the GCOS Second Adequacy Report (WMO, 2003), systematic climate observations should support the following applications:

a) Characterize the state of the global climate system and its variability.
High priority is attached to the accuracy, homogeneity and continuity of data, so that climate signals are discernible from systematic biases, e.g. caused by changes in observing systems over the years. To characterize the climate system, many variables need to be observed simultaneously.

b) Monitor the forcing of the climate system, including both natural and anthropogenic contributions.
Over decades and centuries, variations in total solar irradiance and in volcanic aerosols have been the main natural drivers of climate variability and change. Anthropogenic contributions include greenhouse gases, aerosols and land use changes.

c) Support the attribution of the causes of climate change.
Along with systematic observations of the state variables and climate drivers ("forcings") described in (a) and (b), good models are required to be able to relate the expected change in state variables to the forcings.

d) Support the prediction of global climate change.
Climate predictions should consider not only the forcings, as described in (b), and their past history, but also the current state of the climate system. Long-term climatological series also play a key role in the calibration/validation of climate models.

e) Project global climate change information down to regional and national scales.
Impacts and adaptation will be apparent mostly on national and local scales, underscoring the importance of climate information on that level. Long-term observations are required in order to develop models for local climate scenarios and to understand the effects of the climate and climate variations on natural systems (e.g. glaciers, river discharge, ecosystems). There is thus a special need for detailed local information about the variables described in (a) and for an increased density of observations at the national level.

f) Characterize extreme events and assess their risk and vulnerability.
Data for characterizing extreme events (e.g. floods, storms, heatwaves) are important for impact assessment, policy development and adaptation.

To fulfil these requirements, GCOS has defined a set of essential climate variables (Table 1). This selection takes into account the scientific requirements as well as the measurability of climate variables on the global scale. However, additional variables are needed in order to understand the climate system as a whole. There are important additional climate variables systematically measured in Switzerland that should also be included in the national climate observing system (GCOS Switzerland).

The specified applications require more information than can be provided by the GCOS global monitoring networks alone. Therefore, as noted in the GCOS Implementation Plan (WMO, 2004), coordination is required at the regional and especially the national level to implement denser operational climate observing networks.

As far as possible, regional and national climate observing networks should be operated in accordance with the GCOS Climate Monitoring Principles (Table 2). Particular attention needs to be paid to, for example, metadata (Principle #3), quality assurance (#4) and data archival (#10). In addition, a variety of historical observations exist that are not yet available in digital form and should be digitized so as to further extend the most important time series.

Domain		Essential Climate Variables
Atmospheric	Surface	Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour
	Upper air	Earth radiation budget (including solar irradiance), Upper air temperature, Wind speed and direction, Water vapour, Cloud properties
	Composition	Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties, ***Pollen***
Oceanic	Surface	Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour, Carbon dioxide partial pressure
	Sub-surface	Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton
Terrestrial		River discharge, Lake levels, Ground water, Water use, ***Isotopes***, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover, Leaf area index, Photosynthetic activity, Biomass, Fire disturbance, ***Phenology***

Table 1. Essential climate variables as listed in the GCOS Second Adequacy Report (WMO, 2003), together with additional variables of relevance for Switzerland (in italics).

Switzerland has a long tradition in the observation of climate. Systematic observation programmes established by Swiss institutions make a significant contribution to the global climate observing system. The most important systematic observations concern the surface and upper air climate, Earth radiation budget, atmospheric trace gases, aerosols and pollen, hydrology, snow, glaciers and permafrost, and climate-related biosphere variables (land use, forest ecosystem, forest fires, phenology). The data collected are reviewed according to stringent quality criteria and transmitted to world data centres, where they are made available to the international scientific community for integrated analysis. In this connection, the data and calibration centres operated by Swiss institutions play an important role in the standardization of data and the international data exchange.

Following the ratification of the Kyoto Protocol by the Swiss Parliament in summer 2003, the national GCOS coordination was strengthened by the Federal Office of Meteorology and Climatology (MeteoSwiss). On 1 February 2006, the Swiss GCOS Office was established, building on the former GCOS Focal Point at MeteoSwiss. The Swiss GCOS Office is responsible for coordinating climatological observations carried out in Switzerland by federal offices, research institutes and universities/institutes of technology. This includes long-term planning to ensure continuous and representative observations, e.g. by identifying the risk of discontinuity ahead of time and engaging in remedial action. As far as possible, new measurement techniques are also considered in the integrated observation system. In addition, the Swiss GCOS Office identifies resource-related problems affecting the operation of international data and calibration centres in Switzerland and provides financial and technological support for selected observations abroad.

GCOS Climate Monitoring Principles

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems should be required.
3. The results of calibration, validation and data homogeneity assessments, and assessments of algorithm changes, should be treated with the same care as data.
4. A capacity to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information, should be ensured.
5. Consideration of environmental climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Uninterrupted station operations and observing systems should be maintained.
7. A high priority should be given to additional observations in data-poor regions and regions sensitive to change.
8. Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.
9. The carefully-planned conversion of research observing systems to long-term operations should be promoted.
10. Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.

Table 2. The ten principles adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999, and by the Congress of the World Meteorological Organization (WMO) through Resolution 9 in May 2003.

Motivation

Switzerland has a long tradition of climate observations. The long-term climatological data series are of high historical significance for the institutions concerned and are of major scientific value both for Switzerland and worldwide. Nonetheless, the continuation of valuable time series is frequently under threat. In addition, long-term observations are generally not supported by research funding.

The aim of this report is to present a complete inventory of climatological time series in Switzerland, and to identify significant time series whose continuation is threatened by inadequate resources.

The report primarily takes stock of the current situation. In cases where a legal basis or clearly defined responsibilities are lacking, plans for a future monitoring network should be elaborated and accompany requests for funding.

Procedure

In the spring of 2006, ProClim and the Swiss GCOS Office performed a survey among universities/institutes of technology, research institutes and federal offices based in Switzerland with the aim of documenting climatological series and identifying risks to their continuation.

The criteria were defined on the basis of similar studies for the selection of climatological stations (Müller, 1980; WMO, 1997). The main criteria specified were that a series should: (a) cover a period of more than 50 years, (b) be longer than comparable series abroad, or (c) concern recently introduced climate variables/observation methods. The secondary criteria included participation in international agreements/data centres, geographical representativeness, data quality and availability of metadata. Respondents were also asked to indicate their requirements for funding in order to ensure continued operation of stations.

Structure

The following two chapters give an account of the climate variables measured in Switzerland, under the general headings of atmospheric (Chapter 2) and terrestrial (Chapter 3) observations. The survey covered all the essential climate variables listed in Table 1 and also included three other variables of relevance for Switzerland (pollen, isotopes, phenology).

Chapter 4 presents the international data centres of essential climate variables that are operated by Swiss institutions. It also describes other international centres based in Switzerland that are of major importance for climate observation (e.g. international calibration centres). Chapter 5 focuses on valuable climatological observations outside Switzerland that are funded and/or carried out by Swiss institutions.

Chapter 6 summarizes the main conclusions of the report and looks ahead to the future of the national climate observing system (GCOS Switzerland).

2.1 Air temperature

Temperature is a key indicator of changes in the climate. As long time series of measurements of ground-level temperature in Switzerland are available, dating back to the mid-19th century, long-term trends can be analysed. These analyses provide a sound basis for investigating the contribution of anthropogenic factors to global warming.

§ **Legal basis**

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also to participate in the recording, exchange and analysis of international meteorological and climatological data. In addition, they are responsible for the provision of climatological information and for the implementation of measures contributing to the long-term preservation of an intact environment. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

Air temperature at ground level is now measured by MeteoSwiss at almost 130 stations. In some cases, these systematic measurements extend as far back as December 1863, when Switzerland's first nationwide meteorological observation network came into operation. Some monthly values are also available as paper records from earlier periods, e.g. for Basel (from 1755), Geneva (1768) or Grand St. Bernard (1817). Since 1980, a number of these stations have been automated (ANETZ). The roughly 70 ANETZ stations are currently being upgraded in line with the latest technological developments, and the other stations in the network are also to be converted to automatic operation by 2012 (SwissMetNet project). Alongside the MeteoSwiss stations, air temperature is also measured at numerous other weather stations by cantonal and communal authorities and private operators.

As well as meeting climatological needs, the MeteoSwiss stations provide services for other user groups, e.g. warnings, aviation weather, and data for civil protection, agriculture and tourism. The network of stations has been continually reviewed on the basis of analyses of requirements (Measurement Concepts 1980 and 2010), and the distribution of stations across the country and various altitudes has been optimized.

At each automatic MeteoSwiss station, values are recorded every 10 minutes and transmitted to the central database in Zurich. The temperature observations are used to calculate hourly, daily, monthly and annual means, together with medians, absolute extremes and numerous other parameters, such as frost days or heat days.

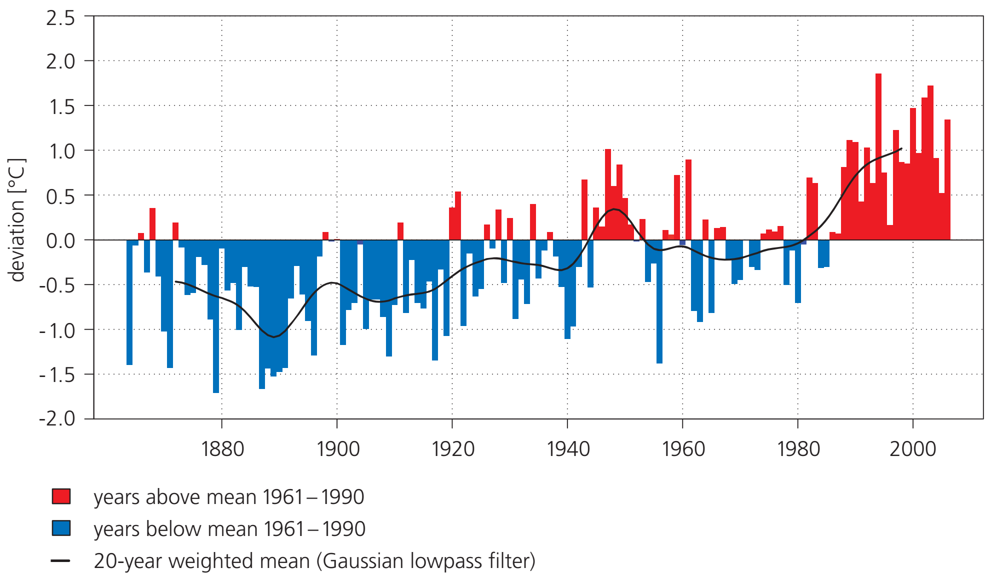
In order to understand changes in atmospheric temperature conditions, soundings are

Long time series and their importance

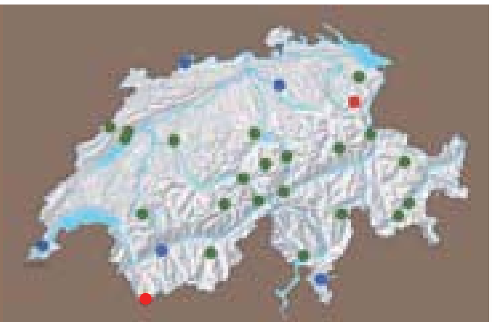
At many of the sites chosen in 1863, stations are still in operation today. In the NORM90 project, for each of Switzerland's twelve major climate regions, a station was selected where measurement data have been collected since at least 1900. These long time series were analysed for artificial discontinuities and trends caused, for example, by station relocation, change of instrumentation and calibrations, and homogenized. In order to increase the density of stations, particularly in the Central Alpine region characterized by large differences in altitude, 16 additional stations were selected with time series from at least 1900 (exception: Jungfraujoch only from 1930). These stations of the greatest climatological importance (28 in all) were designated as the Swiss National Basic Climatological Network (NBCN).

Temperature in Switzerland 1864 – 2006

Deviation of the annual mean from the 1961–1990 average



The deviation of the annual mean temperature in Switzerland from the multiyear average (norm 1961–1990) offers a striking example of climate change. The linear trend between 1864 and 2005 is + 1.1 °C per 100 years, yielding a total warming of + 1.5 °C from 1864 to 2005 (Begert et al., 2005). From a global perspective, temperature is the variable best suited for demonstrating the anthropogenic influence on the climate system. Long-term temperature series are therefore crucial for the observation, analysis and quantification of climate change.



Swiss National Basic Climatological Network NBCN. 2 stations belong to the GCOS Surface Network GSN (red) and 7 to the Regional Basic Climatological Network (red + blue).

carried out several times a day in addition to ground-based monitoring. Increasingly, these vertical temperature profiles are supplemented by ground- and satellite-based remote sensing measurements and in-situ sensors mounted on commercial aircraft (→ 2.7 Water vapour).

International Integration

Within the GCOS Surface Network (GSN), temperature and precipitation are measured at around 1000 stations worldwide and transmitted on a monthly basis to the GSN Monitoring Centres at the Japanese Meteorological Agency (JMA) in Tokyo (temperature) and the German Meteorological Service (DWD) in Offenbach (precipitation). At about a quarter of the stations, the data are additionally made available on a daily basis. In Switzerland, two NBCN stations were selected as GSN stations – Säntis and Grand St. Bernard. Seven NBCN stations (Säntis, Grand St. Bernard, Geneva, Sion, Basel, Zurich and Lugano) belong to the Regional Basic Climatological Network (RBCN) of the WMO.

Resources required

Operation of the NBCN stations is assured under the legal mandate of MeteoSwiss. However, in the case of station renewals, it has been shown that budgets do not always cover the parallel measurements required for a 3-year period to meet GSN standards. Additional funds need to be set aside for such extraordinary tasks.

http://www.meteoswiss.admin.ch/web/en/climate/climate_since_1864/tt_rr_1864.html

2.2 Precipitation

Precipitation, together with temperature, is a key indicator of changes in the climate. As long time series are available for precipitation in Switzerland, dating back to the mid-19th century, long-term analyses can be performed. These are particularly valuable for assessing the effects of climate change on the water cycle and water balance.

§

Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also to participate in the recording, exchange and analysis of international meteorological and climatological data. In addition, they are responsible for the provision of climatological information and for the implementation of measures contributing to the long-term preservation of an intact environment. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

Precipitation is now measured by MeteoSwiss at more than 400 stations, some of which have been in operation since December 1863. In a number of cases, the measurements go back to the 18th century, although there are considerable gaps in some of the time series. Since 1980, a number of these stations have been converted to automatic operation (ANETZ). The roughly 70 ANETZ stations are currently being upgraded, and about 60 other stations (KLIMA, ENET) are also being automated (SwissMetNet project). While the remaining precipitation stations (NIME, totalizers) are not to be automated at present, the distribution of these stations is to be investigated in detail and reviewed in the coming years under a Precipitation Concept.

At each automatic MeteoSwiss station, precipitation is collected and measured at 10-minute intervals. These measurements are used to calculate total precipitation on an hourly, daily, monthly and yearly basis. At the NIME stations, the amount of precipitation is recorded once a day by the station operator, and records are sent in by post once a month. The NIME measurements are thus not available in real time.

To measure precipitation in mountainous areas, so-called totalizers are used. A totalizer generally measures precipitation for the water year (October 1 to September 30). Additional readings are sometimes taken during the year. However, owing to the poor accessibility of many totalizers, no more than one additional reading (in the spring) is usually taken. This at least makes it possible to determine the relative proportions of winter and summer precipitation.

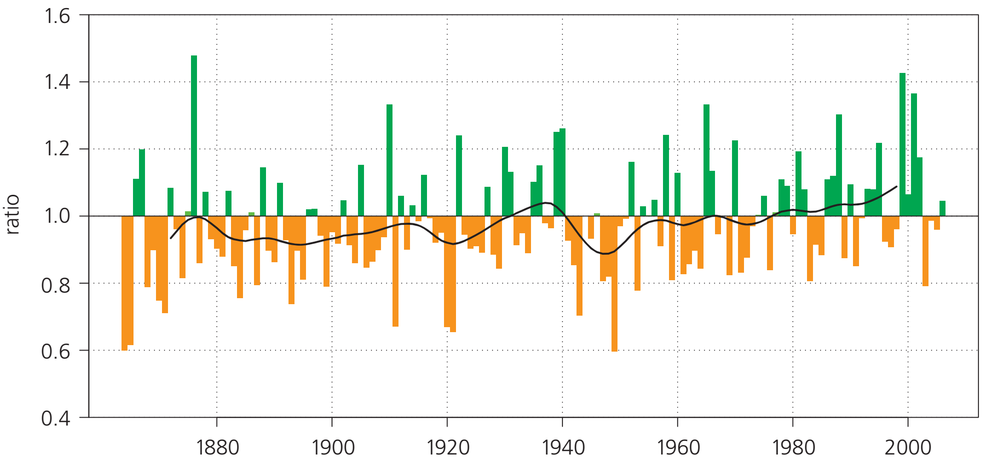
In addition to in-situ measurements, precipitation is also calculated indirectly on the basis of radar reflectivity with 3 precipitation

Long time series and their importance

Systematic recording of precipitation in Switzerland began in 1863 with the operation of, initially, about 70 weather stations equipped with a precipitation gauge. The total number of stations subsequently rose sharply, and by around 1900 precipitation was being measured daily at more than 300 locations. At many of the sites originally selected, stations remain in operation today. The most important sites are 27 of the 28 Swiss NBCN stations (→ 2.1 Air temperature); only at the Jungfraujoch NBCN station is precipitation not recorded. To complement the Swiss NBCN stations, the most important NIME stations with daily measurements are to be defined under the Precipitation Concept. In mountainous areas, the totalizer data represent important additional precipitation series with a low temporal resolution. From a climatological perspective, 8 of the totalizers are to be protected with Priority 1 and another 27 with Priority 2.

Precipitation in Zurich 1864 – 2006

Ratio of the annual total to the 1961–1990 average



years above mean 1961 – 1990
years below mean 1961 – 1990
20-year weighted mean (Gaussian lowpass filter)

Ratio of the annual total precipitation for Zurich to the multiyear average (norm 1961–1990) from 1864 to 2006. The data series shows a significant linear trend, with an increase of approximately 10% over 100 years. In particular, winter precipitation has increased (Begert et al., 2005). Long series provide a basis for understanding the broader context and permit conclusions concerning trends and recurrence intervals for extreme events (heavy rainfall and dry periods). Indirectly, they are valuable for planning flood protection measures and developing regional climate scenarios.

Red: Stations of the Swiss National Basic Climatological Network NBCN; green: MeteoSwiss precipitation radars; blue: 8 totalizers of greatest climatological significance.

International integration

Precipitation data from the GCOS Surface Network (GSN) stations Säntis and Grand St. Bernard are transmitted to the GSN Monitoring Centre at the DWD, and the WMO receives data from the Regional Basic Climatological Network (RBCN) stations Säntis, Grand St. Bernard, Geneva, Sion, Basel, Zurich and Lugano. The precipitation data from all MeteoSwiss stations are also transmitted to the GSN Monitoring Centre for precipitation in Offenbach.

Precipitation radar networks in Europe are coordinated by the EUMETNET Operational Programme for the Exchange of weather RAdar information (OPERA). All three Swiss precipitation radars are integrated into the OPERA programme. In addition, the INTERREG projects VERBANO and Franche-Comté are improving precipitation radar coverage in the border regions with Italy and France respectively.

radars (La Dôle, Albis and Monte Lema). These stations have been in operation since 1961 (La Dôle, Albis) or 1993 (Monte Lema), and the data have been systematically archived in digital form since 1991. The precipitation radar data thus represent potential long time series for future analyses.

Resources required

Operation of the NBCN and NIME stations is assured under the legal mandate of MeteoSwiss. However, budgets do not always cover the parallel measurements required for a 3-year period to meet GSN standards. The totalizers of greatest climatological significance are only guaranteed in the short term, as about half of the stations are funded by third parties; in addition, the commercial importance of the totalizer network is declining.

http://www.meteoswiss.admin.ch/web/en/climate/climate_since_1864/tt_rr_1864.html

2.3 Air pressure

Air pressure is an important component of the climate system, characterizing both local and large-scale atmospheric circulation. It is one of the key variables for backward modelling of long-term global meteorological datasets. Long-term observation of air pressure permits conclusions concerning, for example, variations in meteorological conditions.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also to participate in the recording, exchange and analysis of international meteorological and climatological data. In addition, they are responsible for the provision of climatological information and for the implementation of measures contributing to the long-term preservation of an intact environment. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

Surface pressure is now measured by MeteoSwiss at 90 stations. Systematic measurements began in 1864, when Switzerland's nationwide meteorological observation network came into operation. Early records for individual sites such as Basel or Geneva go back to the 18th century. However, as these data have never been processed, they are either not available in digital form or only as monthly averages.

Historically, air pressure was measured with mercury barometers. Since the monitoring network was automated, new methods of measurement have increasingly been used. At the automatic stations, air pressure is measured by means of an aneroid barometer – a metal box which expands or contracts in response to changes in air pressure. The introduction of a new type of instrument caused less significant inhomogeneities in the data series than the associated station relocations. As air pressure decreases with increasing elevation, measurements are strongly dependent on the altitude of the station. To allow measurements from different stations to be compared, the readings are converted to sea level pressure. At the automatic stations, air pressure is measured every 10 minutes, and these values are used to calculate hourly, daily, monthly and annual means. As well as being highly important for climate observation, these data are essential for description of the current state of the atmosphere, for weather forecasting and for modelling. Alongside the MeteoSwiss stations, air pressure is also measured at a number of other weather stations by cantonal and communal authorities and private operators.

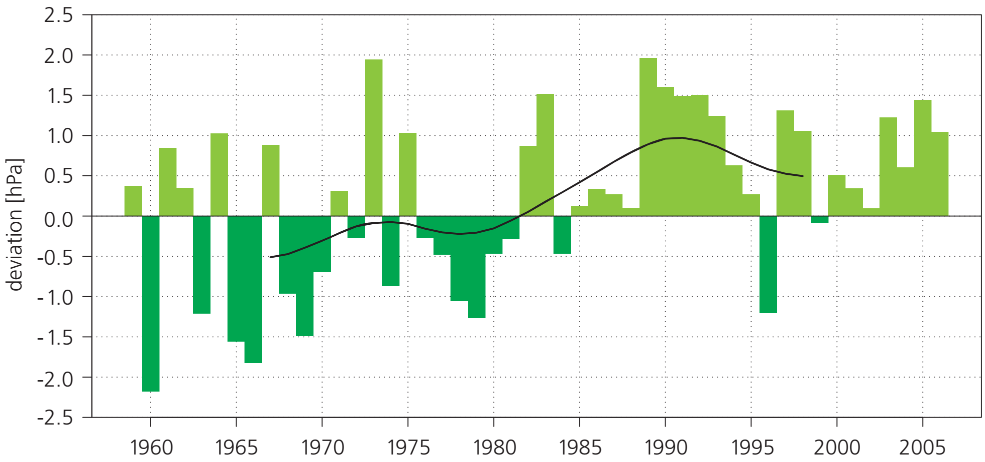
Surface pressure is one of the climate variables that cannot yet be measured operationally by satellites. The problem is primarily one

Long time series and their importance

From the Swiss meteorological network developed since 1863, 28 stations of climatological significance were selected so that Switzerland's climate would be represented and characterized as well as possible (→ 2.1 Air temperature). These Swiss National Basic Climatological Network (NBCN) stations also provide the most important long series of air pressure measurements, as most of the stations have recorded air pressure data continuously since 1863. It is not planned to homogenize all of the 28 time series, since air pressure shows strong regional correlations and the processing of a selection of NBCN series is thus sufficient to describe long-term trends in Switzerland.

Air pressure in Zurich 1959 – 2006

Deviation of the annual mean from the 1961–1990 average



years above mean 1961 – 1990

years below mean 1961 – 1990

20-year weighted mean (Gaussian lowpass filter)

Deviation of the annual mean air pressure in Zurich from the 1961–1990 average between 1959 and 2006. The trend correlates with that observed for air temperature, indicating the relationship between the frequencies of atmospheric circulation patterns and regional climate variability. Long-term air pressure series are valuable for the description of long-term variations in the frequency of atmospheric circulation patterns. In addition, they are the key input variable for the global and regional reanalyses used in the validation of climate models.

Swiss National Basic Climatological Network NBCN. 2 stations belong to the GCOS Surface Network GSN (red) and 7 to the Regional Basic Climatological Network RBCN (red + blue).

of accuracy, since the daily fluctuations to be measured are much smaller than the average air pressure values.

International integration

Of the Swiss NBCN stations, Säntis, Grand St. Bernard, Geneva, Sion, Basel, Zurich and Lugano belong to the Regional Basic Climatological Network (RBCN) of the WMO, which comprises 2600 surface stations worldwide. Two of the Swiss stations – Säntis and Grand St. Bernard – also belong to the GCOS Surface Network (GSN), which includes 980 stations worldwide. Air pressure measurement is not one of the minimum requirements (mean temperatures, precipitation) of the GSN. Measurement of this variable is, however, a target requirement. At the WMO, efforts are also under way to establish an international surface pressure database. In an initial global dataset, measurements of surface pressure (including Swiss RBCN data) have been processed for the years 1850–2004. This dataset comprises global data on a monthly basis with a spatial resolution of about 500 km.

Resources required

Operation of the NBCN stations is assured under the legal mandate of MeteoSwiss. However, in the case of station renewals, it has been shown that budgets do not always cover the parallel measurements required for a 3-year period to meet GSN standards.

http://www.meteoswiss.admin.ch/web/en/climate/climate_norm_values.html

2.4 Sunshine duration

In addition to temperature, precipitation and air pressure data, other meteorological measurements are required as indicators of changes in the climate. Among the most important additional variables recorded at weather stations are wind speed and direction, humidity, sunshine duration, global radiation, cloud cover and snow.

§

Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also to participate in the recording, exchange and analysis of international meteorological and climatological data. In addition, they are responsible for the provision of climatological information and for the implementation of measures contributing to the long-term preservation of an intact environment. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

The variables of greatest climatological importance are now measured by MeteoSwiss at almost 130 stations. In some cases, these systematic measurements extend as far back as December 1863, when Switzerland's first nationwide meteorological observation network came into operation. Since 1980, a number of these stations have been automated (ANETZ). The roughly 70 ANETZ stations are currently being upgraded in line with the latest technological developments, and the other stations in the network are also to be converted to automatic operation by 2012 (SwissMetNet project). Alongside the MeteoSwiss stations, some of the essential climate variables are also measured at numerous other weather stations by cantonal and communal authorities and private operators.

As well as temperature (→ 2.1 Air temperature), precipitation (→ 2.2 Precipitation) and air pressure (→ 2.3 Air pressure), this chapter describes the other important meteorological measurements – wind speed and direction, humidity and sunshine duration. Global radiation is covered together with other radiation measurements in section → 2.5 Radiation, cloud cover in section → 2.6 Clouds, and snow in section → 3.6 Snow cover.

At the ANETZ stations, humidity is measured every 10 minutes (current value) and sunshine duration (accumulated value) at 10-minute intervals. Wind speed/direction is measured continuously and on this basis mean values and gustiness are transmitted every 10 minutes. The 10-minute values are used to calculate the means for wind speed/direction and humidity, and the total values for sunshine duration.

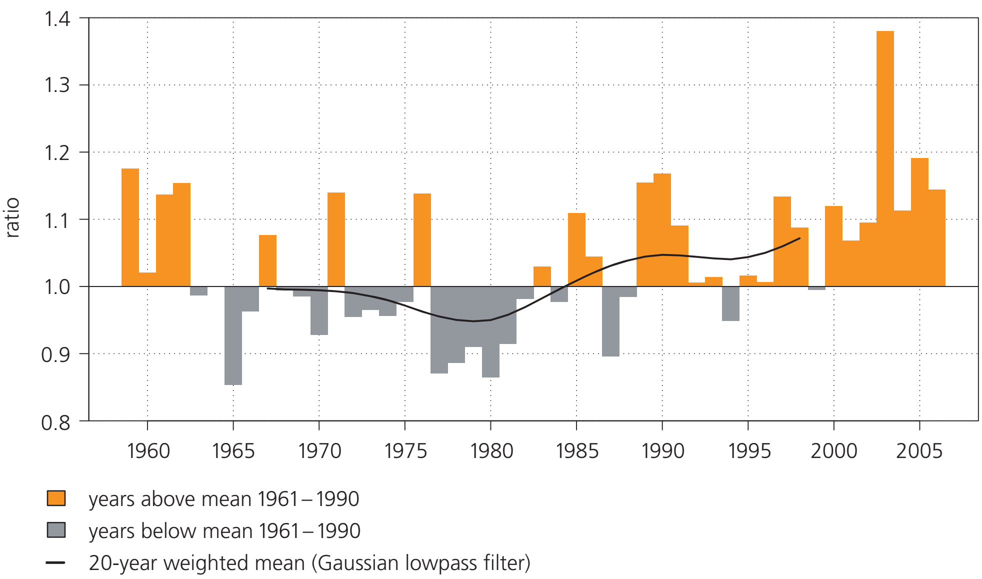
The surface measurements of wind speed/direction and humidity are supplemented by in-situ observations (soundings, airborne

Long time series and their importance

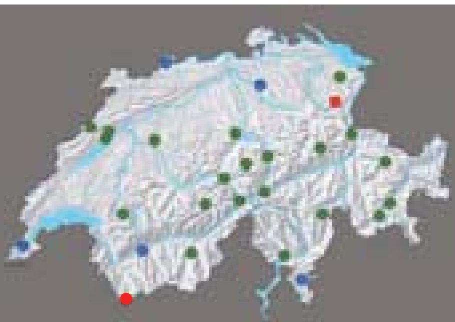
A permanent Swiss monitoring network was established in the second half of the 19th century. Recently, the 28 stations of the greatest climatological significance have been designated as the Swiss National Basic Climatological Network (NBCN) (→ 2.1 Air temperature). In most cases, time series for humidity go back to 1863. Measurements of sunshine duration began some years later, and only at selected locations. Before the network was automated (starting in 1981), wind speed and direction were measured three times a day. For this reason, wind data have only been systematically analysed since the 1980s. In addition to the 12 homogeneous temperature and precipitation series dating back to 1864, homogeneous time series are now available from 1959 for air pressure, sunshine duration, vapour pressure and cloud cover, and from 1981 for global radiation and wind speed.

Sunshine duration in Zurich 1959 – 2006

Ratio of the annual total to the 1961–1990 average



Homogenized data on sunshine duration in Zurich from 1959 to 2006. Homogenization is required because measurement conditions are not generally constant for long time series. Changes in measurement conditions (e.g. station relocations, environmental changes, new instruments) can lead to abrupt or gradual increases or decreases in readings, confounding trend analysis of time series. Statistical methods and assessments of station history are used in an attempt to identify and correct inhomogeneities in time series (Begert et al., 2003).



Swiss National Basic Climatological Network NBCN. 2 stations belong to the GCOS Surface Network GSN (red) and 7 to the Regional Basic Climatological Network RBCN (red + blue).

International integration

Of the Swiss NBCN stations, Säntis, Grand St. Bernard, Geneva, Sion, Basel, Zurich and Lugano belong to the Regional Basic Climatological Network (RBCN) of the WMO.

As part of the EU ENSEMBLES project, a European dataset was compiled for various observational series (minimum, maximum and mean temperature, precipitation, air pressure, snow depth, sunshine duration, relative humidity and cloud cover) from around 2000 stations and checked for inhomogeneities. This makes it possible to minimize the influence of variation in measurement conditions over time on subsequent trend analyses.

measurements) and increasingly also by measurements from ground- and satellite-based remote sensing instruments (→ 2.7 Water vapour).

Resources required

Operation of the 28 Swiss NBCN stations is assured under the legal mandate of MeteoSwiss. However, in the case of station renewals, it has been shown that budgets do not always cover the required 3-year parallel measurements.

http://www.meteoswiss.admin.ch/web/en/climate/climate_norm_values.html

2.5 Radiation

Radiation is the main factor in the climate system, accounting for seasonal and regional differences in climate. The effects of greenhouse gases and anthropogenic aerosols on the climate are directly manifested as changes in the radiation budget. These changes are measurable and allow a detailed study of changes in the climate.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are to support theoretical meteorology and climatology and to conduct applied research projects. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks. In addition, Switzerland is a member of the World Meteorological Organization WMO (SR 0.429.01) and participates in the WMO Global Atmosphere Watch (GAW) programme in accordance with the Federal Council Decree of 25 November 1994.

Measurements in Switzerland

In addition to the monitoring of global radiation at the automatic network (ANETZ, now SwissMetNet) stations, MeteoSwiss operates four dedicated stations for the measurement of radiation fluxes from the ultraviolet through the visible to the infrared portion of the electromagnetic spectrum. The Jungfraujoch and Davos stations are situated in the Alps, while the Payerne station is on the Central Plateau and Locarno-Monti lies south of the Alps. This network, known as CHARM (Swiss Atmospheric Radiation Monitoring), was supplemented in 1995 by another 10 stations of the Alpine Surface Radiation Budget (ASRB) network. At all the CHARM and ASRB stations, downward shortwave (solar) radiation and downward longwave (atmospheric) radiation are recorded. At three of these sites, reflected shortwave radiation and upward longwave (thermal) radiation from the Earth's surface are additionally recorded. CHARM and ASRB are attached to the WMO Global Atmosphere Watch (GAW) programme.
The Payerne station also belongs to the Baseline Surface Radiation Network (BSRN), which studies the global surface radiation budget (→ 4.2 BSRN). To this end, shortwave (direct, diffuse and global) and longwave radiation fluxes are measured in accordance with BSRN and GAW guidelines. In addition, individual spectral radiation fluxes are measured continuously with the greatest precision and at a high temporal resolution in order to determine the aerosol optical depth and water vapour content of the atmosphere. Various institutions are involved in the CHARM network: MeteoSwiss, the PMOD/WRC, the ETH and the University of Bern. The CHARM/BSRN and ASRB measurements are also used for the validation of satellite products. In the Eumetsat Satellite Applica-

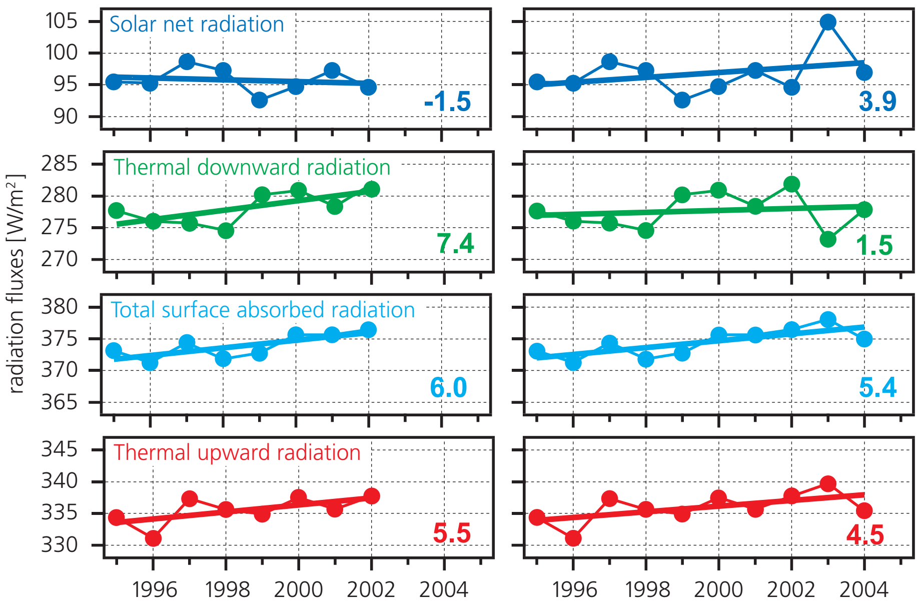
Long time series and their importance

Under the CHARM programme, radiation measurements were initiated at Davos in 1991 and at the Payerne BSRN station in 1992. The Jungfraujoch and Locarno-Monti sites were established in 1996 and 2001 respectively. In addition, radiation measurements have been carried out at ten ASRB stations since 1995. The CHARM and ASRB networks are designed for long-term monitoring and provide reliable radiation data, making it possible to study trends in the radiation budget specifically for the Alps. Outgoing radiation components are also recorded at four sites, although these measurements only began recently at individual stations.

The four CHARM stations Payerne, Davos, Jungfraujoch and Locarno and two ASRB stations (Cimetta, Weissfluhjoch) are located at ANETZ (now SwissMetNet) sites, permitting comparison with other variables. UV radiation has been measured at CHARM stations since 1995 (→ 2.8 Ozone).

Radiation budget in the Alps 1995 – 2004

Radiation fluxes in W/m²



Radiation budget measurements from the ASRB network in the Alps show how total absorbed radiation is rising, thereby producing an increase in temperature and upward longwave radiation. Net solar and downward longwave radiation show strong cloud-dependent variation. In cloud-free conditions, these measurements make it possible to study downward longwave radiation and thus changes in the green-house effect (Philipona et al., 2005).

The stations of the CHARM (red) and ASRB network (blue) monitor individual components of the surface radiation budget. At every CHARM site, there is also a ASRB station.

International integration

Data are supplied to the World Radiation Data Centre (WRDC) in St. Petersburg, one of five GAW World Data Centres, and to the World Radiation Monitoring Centre (WRMC) of the BSRN in Zurich. Under COST Action 726, the climatology of UV radiation over Europe is being studied in a European initiative with the participation of MeteoSwiss and the PMOD/WRC. The BSRN has been designated as the global baseline network for surface radiation within GCOS. The Payerne station is one of a total of 38 BSRN stations (→ 4.2 BSRN) and is also an official station for routine validation of CM-SAF products. The EUMETSAT CM-SAF is a joint project involving several European meteorological services, which aims to monitor climate variables using satellite data.

tion Facilities for Climate Monitoring (CM-SAF) project, a variety of radiation products are derived from European satellite data and validated specifically for the Alps.

Resources required

With the integration of the CHARM and ASRB stations into the MeteoSwiss-run SwissMetNet, their operation is assured both under the legal mandate of MeteoSwiss and through the Swiss GAW programme.

http://www.meteoswiss.ch/web/en/climate/global_climate_monitoring/GAW_CH_Allg.html

2.6 Clouds

The interaction between radiation and clouds remains one of the major sources of uncertainty in climate models. High priority is therefore accorded to measurement of the spatial distribution and microphysical properties of clouds. For this purpose, soundings and ground-based observations can be ideally supplemented by satellite data.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. This includes records of clouds in the atmosphere and the radiation balance at the top of the atmosphere. The federal authorities are also to participate in the recording, exchange and analysis of international meteorological and climatological data. Switzerland is a member of the European Organisation for the Exploitation of Meteorological Satellites EUMETSAT (SR 0.425.43). Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

At the MeteoSwiss monitoring stations (except for airports), cloud variables are not measured instrumentally, but estimated by observers at regular intervals. Currently, 54 stations belong to the visual observation network (OBS). The variables recorded include cloud cover, cloud type, cloud height, visibility, and present and past weather. Observations are made at least three times a day and transmitted by laptop. At the airports, in addition to human observers, present weather sensors are used to measure a number of cloud variables (e.g. ceilometer for cloud-base height) and visibility (transmissometer).

Comprehensive recording of the spatial extent and high temporal variability of clouds, including their microphysical properties, has only been possible since the first weather satellites were launched in the 1950s. Satellite measurements can be used to determine macroscopic variables such as cloud cover, cloud type (classified by various spectral properties), cloud-top height and cloud wind, as well as microphysical properties such as optical depth, droplet size distribution, cloud-top phase and liquid water content. Among the most important sensors for cloud observation over Europe are – on polar-orbiting satellites – AVHRR (onboard NOAA), MODIS and MISR (onboard Terra) and MERIS (onboard Envisat), and – on geostationary satellites – MVIRI (onboard Meteosat first-generation satellites) and SEVIRI (onboard Meteosat second-generation satellites).

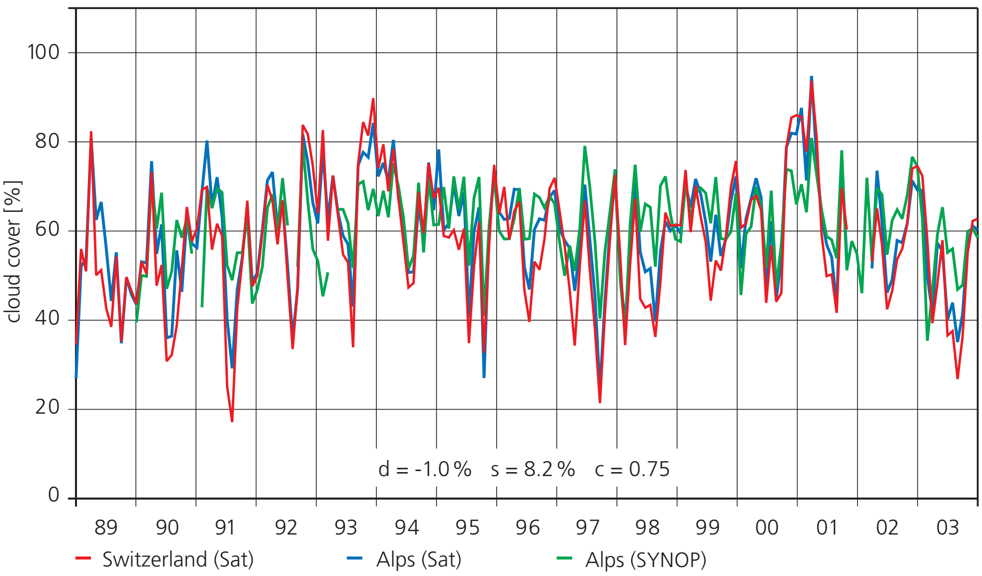
The Earth Radiation Budget is the balance between incoming solar radiation and outgoing longwave and reflected shortwave radiation at the top of the atmosphere. This value can only be directly determined by satellite measurements. No systematic analyses of satellite

Long time series and their importance

Visual observations from the 28 Swiss National Basic Climatological Network (NBCN) stations (→ 2.1 Air temperature) go back to the 19th century, as do meteorological measurements at many stations. However, in most cases the data have not yet been homogenized; i.e. they may contain inhomogeneities resulting from different observers, changing observation times or station relocations. In the NORM90 project, in addition to sunshine duration, cloud data from eight conventional NBCN stations (Andermatt, Bad Ragaz, Chaumont, Château d'Oex, Elm, Grächen, Meiringen and Sils Maria) were homogenized from 1961 onwards. At certain NBCN stations (e.g. Engelberg, Davos), the continuation of visual observations is not guaranteed.

Total cloud cover in the Alps 1989 – 2003

Area-averaged monthly total cloud cover from satellite data and surface observations



Monthly cloud cover from satellite data (NOAA/AVHRR) and surface observations (SYNOP), 1989–2003. The curves represent spatial averages for the Alps as a whole (blue; 46-47.8 N, 8-14 E) and for the territory of Switzerland (red; 46-47.5 N, 6.5-10 E). Also given for the Alps are the mean difference d (satellite measurement minus SYNOP), the standard deviation s of the differences and the correlation coefficient c. This analysis is part of the German Aerospace Center (DLR) European Cloud Climatology (ECC) study (Meerkötter et al., 2004).

The 28 stations of the Swiss National Basic Climatological Network (NBCN) where visual observations of clouds are carried out.

International integration

In addition to total cloud cover, the European Cloud Climatology (ECC) project included the variables "coverage of low, medium-high, high, and thin clouds", "liquid and ice water content", "cloud-top temperature" and "infrared emissivity" for the period 1989–2003 across Europe (34-72 N, 11 W-32 E) with a spatial resolution of approximately 1 km, derived from the NOAA/AVHRR data and evaluated climatologically. Globally, the results of the International Satellite Cloud Climatology Project (ISCCP) represent the most comprehensive cloud climatology analysis based on satellite data collected since 1983. However, the dataset for Europe in the initial years includes a number of major inhomogeneities which need to be duly taken into account.

In the EU projects CLOUDMAP and CLOUDMAP2, the derivation of various cloud variables from satellite data was studied in detail, and the value of data assimilation was tested for regional numerical weather prediction models.

Resources required

The funding of visual observations at the NBCN stations is assured; in individual cases, the continuation of observations could be threatened by staffing problems. Additional financial resources are required for systematic analysis of the satellite data on cloud variables and the radiation balance for Switzerland.

data are yet available for Switzerland (→ 4.1 GEBA).

http://www.meteoswiss.admin.ch/web/en/services/data_portal/monitoring_networks.html

2.7 Water vapour

As well as surface measurements, vertical profiles of key atmospheric variables (air temperature, air pressure, wind, water vapour) are of crucial importance for climate monitoring. They make it possible to investigate climate signals in various layers of the atmosphere. As a natural greenhouse gas, water vapour is of particular interest in this context.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also to participate in the recording, exchange and analysis of international meteorological and climatological data. In addition, they are responsible for the provision of climatological information and for the implementation of measures contributing to the long-term preservation of an intact environment. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for these tasks.

Measurements in Switzerland

Since 1942, Switzerland has a permanent aerological station at Payerne, which is operated by MeteoSwiss. Operations involving two soundings per day were commenced in 1954. Today, with four radiosondes launched per day, there are twice-daily continuous measurements of air pressure, temperature, relative humidity and wind speed/direction, and twice-daily measurements of wind speed/direction alone, up to an altitude of approx. 33 km. An exception is humidity, which is measured up to an altitude of approx. 12 km. In addition, ozone soundings (→ 2.8 Ozone) are carried out three times per week. From 1999, for control purposes and to provide additional humidity profiles, parallel soundings were performed experimentally using a chilled-mirror, dew/frost-point hygrometer ("SnowWhite"). Since 2001, these have been carried out about once a month.

Since 2000, a wind profiler installed at Payerne has continuously recorded vertical wind conditions up to an altitude of approx. 5 km. This system is part of the European Wind Profiler Network (CWINDE). For continuous recording of the vertical distribution of temperature and water vapour, other passive and active remote sensing systems (microwave radiometer, lidar) are currently being tested for subsequent installation on an operational basis. In future, these remote-sensing data can also be used for climatological analyses.

At the Institute of Applied Physics (IAP) of the University of Bern, a competence centre is concerned with research on water vapour in the atmosphere. For this purpose, a new observatory was built in Zimmerwald near Bern in 2006. Here, microwave radiometers, GPS receivers and spectrophotometers are used. Measurements of wind, temperature and, in

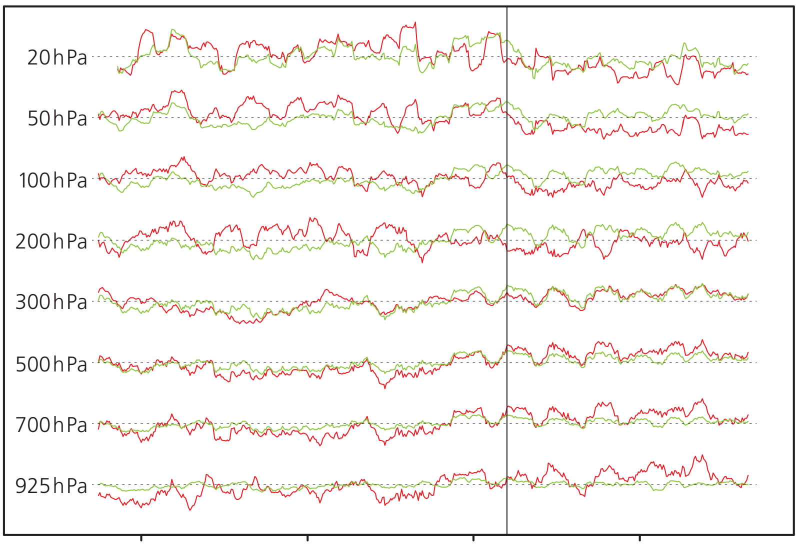
Long time series and their importance

The long and high-quality radio sounding time series of Payerne provides a valuable foundation for describing vertical conditions in the atmosphere. Analysis of data is possible from 1948 (one sounding per day) and 1954 (two soundings per day).

The University of Bern holds a globally unique data series on integrated water vapour content since 1994. Since 2003, water vapour profiles in the stratosphere have been determined operationally under GAW and NDACC (Network for the Detection of Atmospheric Composition Change) programmes. Water vapour measurements from across Switzerland are made available in a dedicated database (STARTWAVE) as part of an NCCR Climate work package. Total water vapour content has been estimated by analysis of GPS radio signals, initially (from 1999) on an experimental basis under the COST-716 programme, and since 2006 operationally at the swisstopo AGNES stations.

Payerne radiosounding 1967 – 2006

Temperature and geopotential height at eight pressure levels



Temperatures and geopotential heights from midnight soundings at Payerne (1967–2006). The start of the evaluation period coincides with the beginning of ozone balloon soundings (→ 2.8 Ozone). The smoothed relative deviations from the multiyear means are presented without units for 8 pressure levels at altitudes between 800 m and 26 500 m. The time series shown are homogeneous from 1992 (vertical line) (Aschwanden et al., 1996). Homogenizations of the Payerne soundings are to be found in Häberli (2006) and Haimberger (2007). These show long-term cooling in the stratosphere, and warming in the troposphere. They complete the trend results from Swiss surface measurements and are consistent with the results of satellite-based observations. The global radiosonde network is the only observation system to have monitored the free atmosphere for more than 60 years.

Stations carrying out upper-air measurements. Red: Payerne; blue: Bern and Zimmerwald.

some cases, humidity are also carried out on most commercial aircraft under the Aircraft Meteorological Data Reporting (AMDAR) programme. In addition, sounders installed on satellites can be used to retrieve temperature and humidity profiles from the infrared and/or microwave spectrum.

International integration

Payerne is one of the Regional Basic Climatological Network (RBCN) stations that transmit data from soundings on a daily and monthly basis to the WMO. About 150 of the 800 aerological stations worldwide are part of the GCOS Upper Air Network (GUAN), meeting higher quality requirements for long-term monitoring of the climate. From 1 January 2008, the Payerne station will also belong to GUAN. In addition, it is planned to operate selected GUAN stations with a broader range of instruments as the GCOS Reference Upper Air Network (GRUAN). Payerne has been listed as a potential GRUAN station. The Payerne radio soundings are transmitted to the GUAN Monitoring Centres at the ECMWF in Reading (UK) and the Hadley Centre in Exeter (UK). The data are archived at the Integrated Global Radiosonde Archive of the National Climatic Data Center (NCDC) in Asheville (US). The stratospheric water vapour profiles of the IAP are integrated in the global NDACC dataset with measurements from more than 70 research stations.

Resources required

Operation of the Payerne aerological station is to be regarded as assured under the legal mandate of MeteoSwiss. In addition, operation of remote-sensing instruments is assured in the medium term through project funding.

http://www.meteoswiss.ch/web/en/services/data_portal/monitoring_networks.html

2.8 Ozone

The ozone layer in the stratosphere filters out a large proportion of the sun's harmful ultraviolet rays. Monitoring of stratospheric ozone is therefore extremely important, especially in view of the rate of ozone depletion – which has however been reduced in recent years thanks to international agreements.

§ Legal basis

Since 1985, thinning of the ozone layer by ozone-depleting substances such as chlorofluorocarbons has been closely monitored under the Vienna Convention for the Protection of the Ozone Layer (Vienna Convention, SR 0.814.02) and the Montreal Protocol (SR 0.814.021). Worldwide, ozone measurements are coordinated by the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO). Switzerland is a member of the WMO (SR 0.429.01) and participates in the GAW programme in accordance with the Federal Council Decree of 25 November 1994. As the lead agency vis-à-vis the WMO, the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for Switzerland's contribution to the GAW programme.

Measurements in Switzerland

MeteoSwiss uses a variety of instruments to monitor ozone concentrations in the atmosphere over Switzerland.

At the Light Climatic Observatory (LKO) in Arosa, total ozone has been measured continuously since 1926 using Dobson and Brewer spectrophotometers. These instruments measure the transparency of the atmosphere to solar ultraviolet radiation at various wavelengths. This is used to calculate the total amount of ozone in the air column over Arosa. In addition, ozone profiles are derived using various methods of measurement and analysis. At Arosa, the Umkehr method (based on Dobson spectrophotometry) has been used since 1956 to obtain a rough ozone profile (6–9 vertical layers).

At Payerne, radio soundings have been used since 1968 to record ozone profiles directly with a high vertical resolution (approx. 50 m) up to an altitude of about 33 km. For this purpose, soundings are carried out three times a week, using an ozone sonde attached to an aerological balloon (→ 2.7 Water vapour).

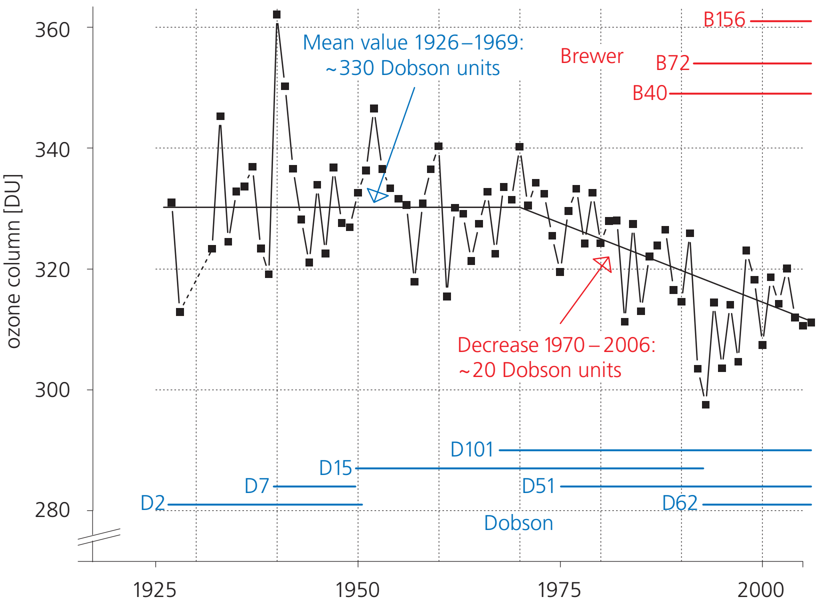
Since November 1994, the Institute of Applied Physics (IAP) at the University of Bern has operated a Ground-Based Millimeter Wave Ozone Spectrometer (GROMOS) to measure stratospheric and mesospheric ozone at altitudes ranging from 20 to 70 km. A second-generation instrument – the Stratospheric Ozone Monitoring Radiometer (SOMORA) – has been used operationally at Payerne by MeteoSwiss since 2002.

Satellite measurements play an important role in recording the global distribution of total ozone. For the application of satellite-based data in Switzerland, good spatial resolution is crucial. For example, the total ozone product, derived from Ozone Monitoring Instrument (OMI) data, offers a horizontal resolution of

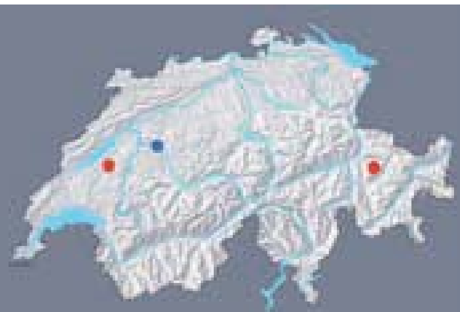
Total ozone
Long time series and their importance

Switzerland has a long history of ozone monitoring, going back to the first measurements at Arosa in 1926. Total ozone over Arosa has been determined on every sunny day virtually without interruption down to the present. Almost from the beginning of the time series, measurements have been carried out using the same type of instrument (Dobson). The global network for monitoring of the ozone layer is largely based on Dobson instruments. In the 1980s, a second type of instrument (Brewer) was developed in Canada. MeteoSwiss used its first Brewer device (B40) at Arosa in 1988. In subsequent years, two more Brewer instruments were installed. Total ozone over Arosa is currently measured by two Dobson and three Brewer spectrophotometers.
To date, the global networks of Dobson and Brewer instruments have maintained independent calibration procedures. The former is based on the US reference instrument D083 and the latter on the reference triad in Toronto. Both networks produce almost identical results, with minor differences (1–3 %) depending on the season and latitude. These differences remain a subject of current research, and the 20-year parallel measurements carried out with Dobson and Brewer instruments at Arosa are of great importance in this regard.

Total ozone Arosa 1926 – 2006
Annual means in Dobson units (DU)



Dobson spectrophotometers have been used to measure total ozone at Arosa for 80 years. The time series are mainly based on the three Dobson models D2, D15 and D101, and also on the redundant devices D7 and D62. The homogenized time series shown here was carefully derived using data from the various Dobson instruments (Staehelin et al., 1998; Zanis et al., 2006; MeteoSwiss, 2007). While the Dobson spectrophotometer still has to be operated manually, the Brewer device is fully automated (Komhyr, 1980). This is the world's longest time series based on Dobson instruments. It makes it possible to study the state of the ozone layer before and after the beginning of anthropogenic influences, as well as interactions between ozone and the climate.



Total ozone measurements and ozone profiles. Operational activities at Payerne and Arosa run by MeteoSwiss (red) and research activities at the University of Bern (blue).

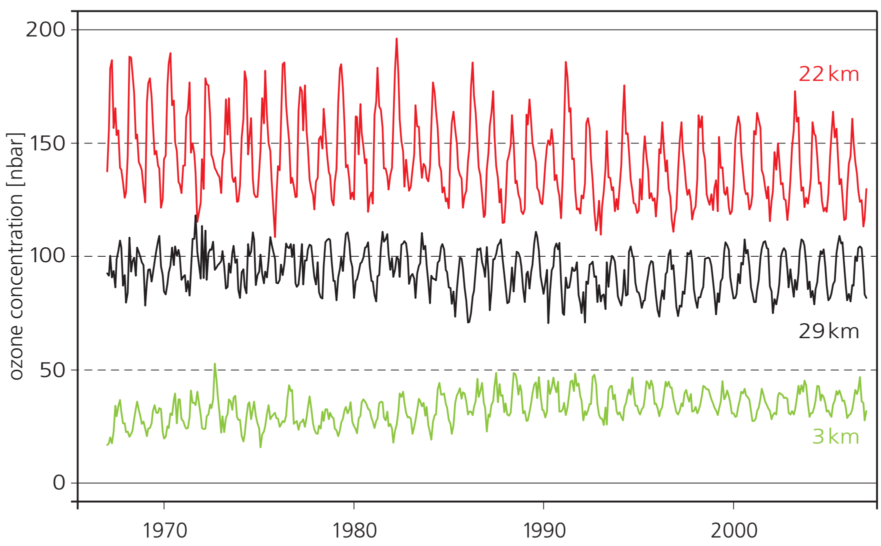
13 x 24 km. Swiss ozone monitoring data (Dobson/Brewer at Arosa, radio soundings at Payerne, microwave radiometry at Payerne and Bern) can make a decisive contribution to the validation of satellite-based data.

http://www.meteoswiss.ch/web/en/climate/global_climate_monitoring/GAW_CH_Allg.html

Ozone profile 0 – 33 km
Long time series and their importance

Information on the vertical distribution of ozone is important since the processes of ozone production and destruction differ markedly in the troposphere and the stratosphere. The first estimates of the ozone profile were obtained by means of special Dobson measurements in the 1930s. However, this so-called Umkehr method, which has to be performed as the sun rises or sets, is very elaborate. This method of measurement yields only 6–9 layers, at altitudes between approx. 5 and 50 km. In addition, highly complex mathematical processing is required. For this reason, measurements could not be carried out on an operational basis until the 1950s. At Arosa, the Umkehr ozone profile series was initiated with the Dobson D15 instrument. In 1980, the automated D51 instrument came into operation.
The Arosa Umkehr measurement series is the world's longest and at the same time one of the few sources of information on vertical ozone distribution in the years 1955–1970, before the start of satellite observations. Since 1988, the fully automatic Brewer B40 instrument has similarly produced Umkehr ozone profiles. Major efforts are currently under way to homogenize these multiyear parallel measurement series. In the late 1960s, ozone profiles were also determined in situ for the first time using small ozone sondes. Measurements were first performed for two years at Thalwil (1966/67), and since 1968 the ozone sondes have been combined three times a week (Monday, Wednesday, Friday) with the meteorological radiosonde balloon activity at Payerne. The ozone profiles obtained exhibit a high vertical resolution (currently about 50 m) between the Earth's surface and an altitude of 30–35 km.

Ozone soundings Payerne 1967 – 2006
Monthly ozone concentrations at three pressure levels

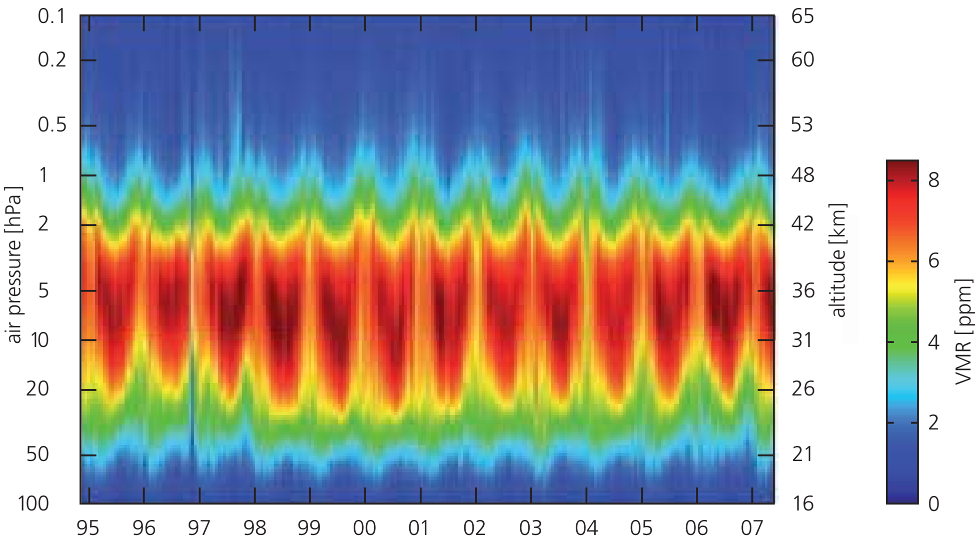


Time series of monthly ozone concentrations at various pressure levels for the period 1967–2006, measured by ozone balloon soundings (Jeannet et al., 2007). A similar series based on Umkehr measurements at Arosa extends as far back as 1956, and series generated by the new microwave radiometry technology at Bern and Payerne go back to 1995. The complementarity of these various series is unique, allowing vital cross-comparisons to be made so as to assure the best possible quality for long time series, including satellite-based measurements. Accordingly, the Swiss ozone series mentioned are often used in scientific publications worldwide, e.g. the Scientific Assessment of Ozone Depletion reports published every four years by the WMO/UNEP.

Ozone profile 20 – 70 km
Long time series and their importance

In the early 1990s, a microwave radiometer known as the Ground-Based Millimeter Wave Ozone Spectrometer (GROMOS) was developed at the Bern University Institute of Applied Physics (IAP). Since 1994, it has been used to determine the ozone profile about every 30 minutes. The second-generation Stratospheric Ozone Monitoring Radiometer (SOMORA) was tested in parallel to the GROMOS instrument at Bern from January 2000, and it has been used operationally by MeteoSwiss at Payerne since 2002. Covering an altitude range of 20–70 km and with a high temporal resolution, this time series extending over more than 10 years augments the sounding data, as it also permits conclusions concerning the balloon burst height and short-lived processes in the stratosphere.

Ozone profile microwave radiometry 1995 – 2007
Homogenized time series from Bern and Payerne



Homogenized time series of ozone profiles determined by microwave radiometry at Bern and Payerne under an NDACC (Network for the Detection of Atmospheric Composition Change) programme. The volume mixing ratio (VMR) of the trace gas ozone reaches its peak at an altitude of around 35 km during the summer season, with values of approx. 8 parts per million (ppm). The ozone profiles also vary on daily to monthly timescales as a result of atmospheric transport processes. The annual cycle is clearly apparent in the distribution.

International integration

Measurements from Arosa (Dobson and Brewer) and Payerne (ozone soundings) are routinely supplied to the World Ozone and UV Radiation Data Center (WOUDC) in Toronto. These data together with data from the two microwave radiometers (GROMOS and SOMORA) are also fed into the NDACC. All the time series described above will be of major importance for future ozone monitoring. Internationally, the in situ and satellite-based ozone measurements are increasingly being integrated into models for use in the Integrated Global Atmospheric Chemistry Observation (IGACO) Strategy of the GAW programme. Under the joint EU/ESA environmental monitoring initiative – Global Monitoring for Environment and Security (GMES) – global and regional ozone maps are generated daily by the ESA on a pre-operational basis in the GMES Service Element PROMOTE (PROtocol MOniToring for the GMES Service Element on Atmospheric Composition).

Resources required

Ozone monitoring operations at Payerne and Arosa are assured under the legal mandate of MeteoSwiss and through Switzerland's participation in the WMO Global Atmosphere Watch (GAW) programme.

http://www.iapmw.unibe.ch/

2.9 Carbon dioxide

Anthropogenic greenhouse gases are the main cause of global warming. Concentrations of greenhouse gases in the atmosphere have risen markedly since the industrial revolution. Levels of carbon dioxide CO_2 – the most important greenhouse gas apart from water vapour – are now at least 35 % higher than in the pre-industrial era.

§ Legal basis

Of relevance to Swiss climate policy at the national level are the emission targets specified in the Federal Act on the Reduction of CO_2 Emissions (CO_2 Act; SR 641.71). Of central importance at the international level are the emission targets of the Kyoto Protocol (SR 0.814.011), which is based on the United Nations Framework Convention on Climate Change (Climate Convention, SR 0.814.01). Under this national and international legislation, Switzerland is required to compile the latest statistics on greenhouse gas emissions annually. The Federal Office for the Environment (FOEN) is responsible for this task.

Measurements in Switzerland

The CO_2 Act is concerned solely with CO_2 emissions arising from fossil-based energy consumption. CO_2 emissions from these sources are to be reduced in Switzerland by 10 % by 2010, compared with 1990 levels. In this country, fossil fuels account for almost 80 % of total emissions of greenhouse gases, as defined in the Kyoto Protocol, which underlines the significance of the CO_2 Act for compliance with the Kyoto requirements.

In compiling the annual CO_2 statistics under the CO_2 Act and the National Greenhouse Gas Inventory under the Kyoto Protocol, emissions are not measured directly, but determined partly on the basis of statistics on the consumption of heating and motor fuels (overall energy statistics, Swiss Federal Office of Energy). The CO_2 emissions arising from the burning of fossil fuels are calculated by multiplying the total consumption of each fuel by the relevant emission factor.

In Switzerland, atmospheric concentrations of CO_2 have been measured by the Bern University Physics Institute on the Jungfraujoch since the end of 2000 and in Bern since October 2003. At the Jungfraujoch site, air samples are collected in 1 litre glass flasks each morning between 06:30 and 07:30. This guarantees measurement of carbon dioxide concentrations in background air, avoiding contamination of samples with more heavily polluted lower layers of air through vertical advection. In addition to measurements of the CO_2 mixing ratio, the ^{13}C fraction and the OC_2/NC_2 ratio of the samples is determined. The accuracy of the CO_2 measurements is better than ± 0.5 parts per million (ppm).

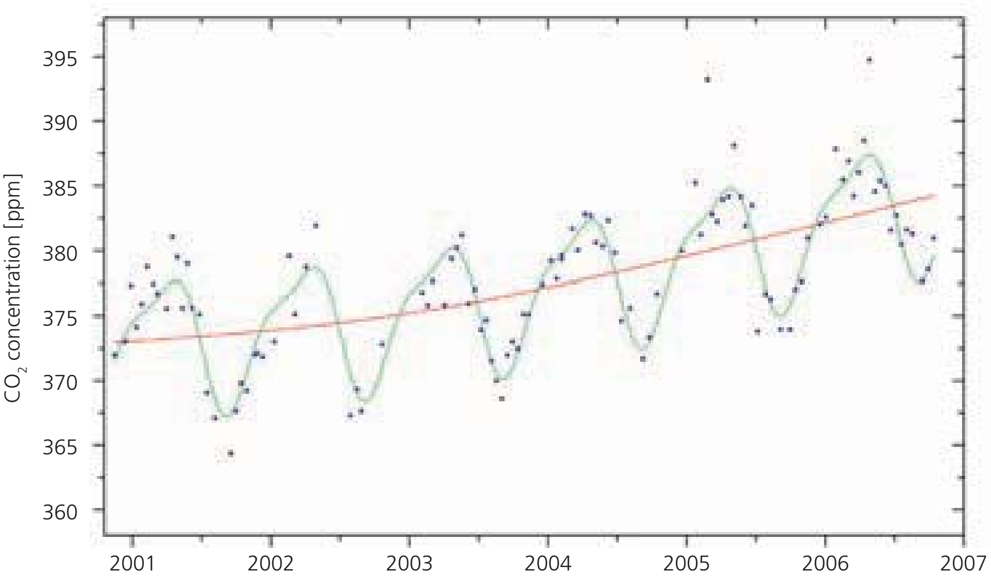
The Jungfraujoch and Bern stations are also of global importance. Despite the existence

Long time series and their importance

The increase in atmospheric carbon dioxide levels is a result of the rise in anthropogenic emissions from the burning of fossil fuels and changes in land use. The mixing ratio of CO_2 in the atmosphere is determined by the balance between emissions and uptake by the terrestrial biosphere and the oceans. Around half of emissions are absorbed by the oceans and terrestrial ecosystems. The calculation of ocean and terrestrial sinks and their temporal variability is important for an improved understanding of the biosphere as a carbon sink and of CO_2 uptake by oceans. Carbon absorption by the terrestrial biosphere and the oceans can be determined by combined measurements of O_2 (or O_2/N_2) and CO_2. The series of CO_2 and O_2 measurements initiated at the Jungfraujoch station in 2000 are thus of major importance for GCOS.

Carbon dioxide at Jungfraujoch 2000 – 2007

Concentration in parts per million (ppm)



Carbon dioxide concentrations measured at the Jungfraujoch station. Seasonal variation was found to be 11 ppm (green curve). A comparison with other stations suggests an amplified positive CO_2 trend (red curve) over the past three years (2003–2006) (Sturm et al., 2005; Valentino et al., 2008). Over this period, the rate of increase was clearly in excess of 2 ppm per year. Carbon dioxide is the most important greenhouse gas apart from water vapour.

Carbon dioxide measurements in Switzerland at the Jungfraujoch and Bern stations.

of various CO_2 monitoring stations around the world, additional, particularly continental, stations are required to reduce uncertainties in terrestrial carbon fluxes. Furthermore, there is a lack of concurrent atmospheric O_2 measurements over Europe.

International integration

Under the EU projects Airborne European Regional Observations of the Carbon Balance (AEROCARB), CarboEurope and CarboEurope-IP, monitoring of carbon dioxide in Europe has been and is being intensified. In the AEROCARB project, the Jungfraujoch station was one of the six ground-level flask air sampling sites where combined precision measurements of CO_2 and O_2/N_2 were carried out. The CarboEurope-IP network involves continuous ground-level monitoring, continuous tall tower monitoring, flask sampling and vertical aircraft profiles. The Jungfraujoch station is one of the 12 ground-level sites and one of the 24 flask sampling sites.

Resources required

The funding of carbon dioxide measurements at the Jungfraujoch station is assured until 2008 through the EU project CarboEurope-IP. Subsequently, long-term monitoring should be guaranteed by Swiss GCOS funding.

http://www.climate.unibe.ch/~mcl

2.10 Greenhouse gases

Apart from carbon dioxide, also methane, nitrous oxide and various synthetic gases contribute to the greenhouse effect. Concentrations of these gases are also steadily rising, further intensifying global warming. Long-term monitoring of greenhouse gases is therefore of major importance under international and national climate change legislation.

§ Legal basis

The Kyoto Protocol (SR 0.814.011), which is based on the Climate Convention (SR 0.814.01), covers not only CO_2 but also methane (CH_4), nitrous oxide (N_2O) and three synthetic gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Under the Kyoto Protocol, Switzerland has to reduce emissions of the six greenhouse gases by 8 %, compared with 1990 levels, by 2008–2012 (1st commitment period). The Montreal Protocol on Substances that Deplete the Ozone Layer (SR 0.814.021) is concerned with the ozone-depleting chlorofluorocarbons (CFCs) and their substitutes (hydrochlorofluorocarbons HCFCs). The handling of these substances is regulated by the Chemical Risk Reduction Ordinance (ChemRRV, SR 814.81).

Measurements in Switzerland

Since February 2005, atmospheric concentrations of the greenhouse gases methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6) have been measured by Empa and the Federal Office for the Environment (FOEN) at the Jungfraujoch station, which is part of the National Air Pollution Monitoring Network (NABEL). In addition, since 2000, Empa and the FOEN have also measured halogenated greenhouse gases such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) at the Jungfraujoch station as part of the System for Observation of Halogenated Greenhouse Gases in Europe (SOGE). CO_2 concentrations are also measured on the Jungfraujoch (→ 2.9 Carbon dioxide).

These continuous measurements, as part of a global monitoring system, make it possible to determine trends for these gases. At the same time, in conjunction with meteorological models, the measurements can be used to estimate Swiss and European emissions of these substances. This provides independent verification of the emission estimates calculated by individual countries under the Kyoto Protocol. Other greenhouse gases measured at the Jungfraujoch station are the fluorinated chlorinated hydrocarbons (CFCs, HCFCs) responsible for the depletion of stratospheric ozone. Here, the measurements can be used to identify any remaining diffuse emissions of these substances prohibited under the Montreal Protocol. The measurements carried out at the Jungfraujoch also make it possible to detect the use of these banned substances in Europe and identify sources.

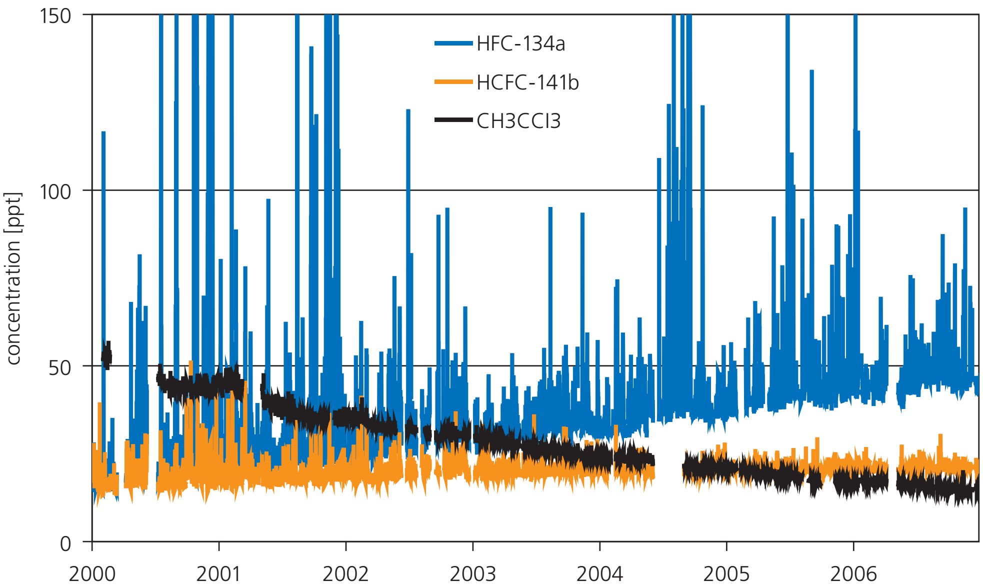
Halogenated greenhouse gases (CFCs, HCFCs, HFCs) are also measured at Dübendorf in campaigns carried out at intervals of several years in order to track emission trends. Here, it is possi-

Long time series and their importance

Thanks to its high-altitude alpine location at the centre of the heavily industrialized European continent and the low levels of local pollution, the Jungfraujoch is particularly suitable as a site for research on emissions of air pollutants. Although measurements of greenhouse gases (CH_4, N_2O) were only initiated at the Jungfraujoch station at the beginning of 2005, they represent extremely important future time series for GCOS. Likewise, measurements of the synthetic greenhouse gases have only been carried out operationally at this site under the SOGE programme since 2000, but they already provide an initial signal reflecting international efforts to phase out ozone-depleting substances in compliance with the Montreal Protocol.

Greenhouse gases at Jungfraujoch 2000 – 2006

Concentration in parts per trillion (ppt)



Concentrations of three greenhouse gases on the Jungfraujoch since measurements began in 2000. The decreased concentrations of trichloroethane (CH3CCl3, black), a solvent prohibited in the Montreal Protocol, clearly indicates the success of the ban (Reimann et al., 2005). Emissions of the second-generation foam blowing agent HCFC-141b (orange), banned since 2003, are also declining (Derwent et al., 2007). At the same time, marked increases are now observable for replacement products, e.g. the refrigerant HFC-134a (blue), which is a greenhouse gas (Reimann et al., 2004).

Stations where other greenhouse gases (apart from CO_2) are measured. Red: Jungfraujoch global GAW station; blue: Dübendorf NABEL station.

ble to estimate emissions at a site close to the source and to compare the results with measurements from the Jungfraujoch station.

International integration

As a global GAW site, the Jungfraujoch station plays an extremely important role in the monitoring of atmospheric composition. All GAW carbon dioxide and methane measurement stations are also part of GCOS. The data are transmitted regularly to the World Data Centre for Greenhouse Gases (WDCGG) in Japan. In addition, there is close cooperation between the Jungfraujoch station and the renowned Advanced Global Atmospheric Gases Experiment (AGAGE) network. As measurements are based on the same calibration scale and a similar method, the results are comparable and highly precise, with the same temporal resolution.

Resources required

Measurements of greenhouse gases at the Jungfraujoch station are financed through limited-term research projects. In future, they are to be incorporated into the NABEL monitoring programme (→ 2.11 Air pollutants).

http://www.empa.ch/climate_gases

2.11 Air pollutants

Trace gases with indirect effects on the climate (known as precursor gases) – such as carbon monoxide (CO), nitrogen oxides (NO_x) and volatile organic compounds (VOCs excluding methane) – only absorb infrared radiation to a limited extent, but they are chemically active in the atmosphere. They thus promote the formation and prolong the lifetime of climate-relevant trace gases.

§ Legal basis

Switzerland's air pollution control policy is based on the Federal Act on Protection of the Environment (USG, SR 814.01), which requires the federal and cantonal authorities to monitor environmental impacts and review the effectiveness of measures taken under this legislation. Under the Clean Air Ordinance (LRV, SR 814.318.142.1), the Federal Office for the Environment (FOEN) is responsible for determining the current state and development of air pollution on a nationwide basis. Swiss air pollution control policy thus complies with international accords (Geneva Convention, SR 0.814.32) and subsequent protocols.

Measurements in Switzerland

The National Air Pollution Monitoring Network (NABEL), a joint FOEN/Empa project, is an important element of Swiss air pollution control, forming the backbone for the monitoring of impacts in Switzerland. The NABEL network measures air pollution at 16 sites, representing key types of pollution situations: (a) city centre, heavy traffic (Bern, Lausanne), (b) city centre (Lugano, Zurich), (c) suburb (Basel-Binningen, Dübendorf), (d) rural, nearby autobahn (Härkingen, Sion), (e) rural, below 1000 m a.s.l. (Lägeren, Magadino, Payerne, Tänikon), (f) rural, above 1000 m a.s.l. (Chaumont, Davos, Rigi-Seebodenalp), (g) alpine (Jungfraujoch).

The NABEL monitoring programme covers gaseous pollutants (ozone O_3, nitrogen monoxide NO, nitrogen dioxide NO_2, nitrogen oxides NO_x, sulphur dioxide SO_2, carbon monoxide CO, volatile organic compounds VOCs, ammonia NH_3), particulate matter (PM10, PM2.5, PM1, particle number, particle size distribution and key constituents), as well as dust deposition and constituents in precipitation. The measurement programme is continually adapted to meet new requirements and to include new variables.

The long-term, precise and internationally comparable time series make it possible to assess air quality trends and to review the effectiveness of air pollution control measures. The time series can be used to estimate the impacts of gaseous air pollutants and aerosol particles on human health and the environment. NABEL thus provides essential information for policymakers. From the data collected, knowledge of sources, sinks and atmospheric chemical processes can also be obtained.

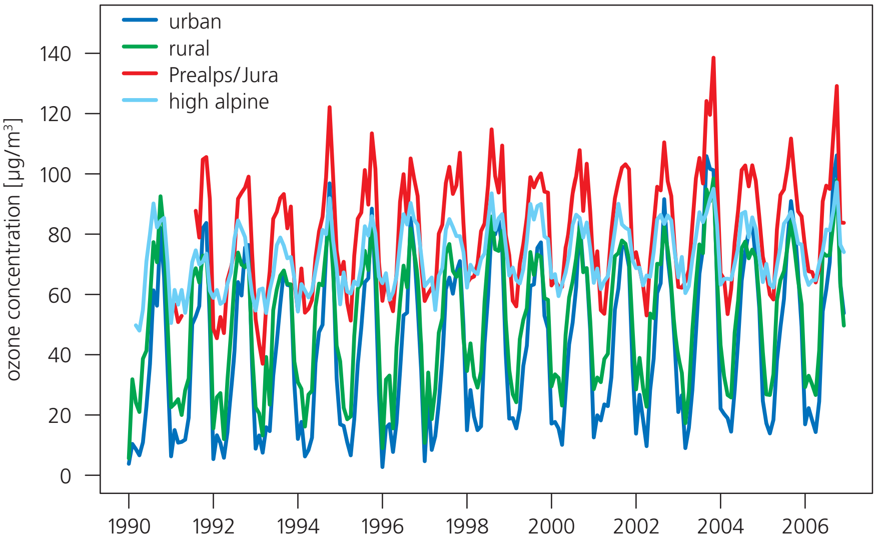
In future, measurements of air pollutants from satellite-based instruments (e.g. SCIAMACHY onboard Envisat, OMI onboard Aura, GOME-2

Long time series and their importance

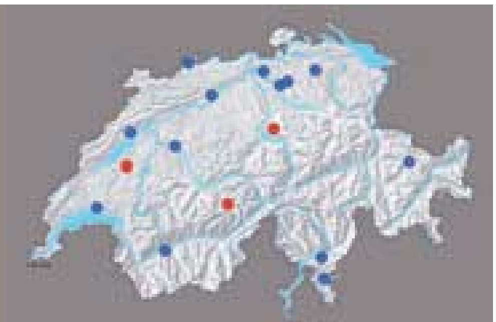
In 1969, monitoring of air pollutants was initiated by Empa at three stations in Switzerland (Dübendorf, Payerne, Locarno-Monti) under a joint international programme involving 11 countries. In subsequent years, measurements were also performed at the Jungfraujoch station. The NABEL network came into operation in stages from 1979. From 1989 to 1991, the network was modernized and expanded from 8 to 16 stations. The longest ongoing time series is that for SO_2 at Payerne (since 1969). Other long series include those for suspended particulates at the Dübendorf and Payerne stations (since 1973), and for SO_2 and suspended particulates at the high-altitude Jungfraujoch station (since 1973).

Ground-level ozone in Switzerland 1990 – 2006

Concentrations in micrograms per m³ for various settings



Ozone is the third most important anthropogenic greenhouse gas. The figure shows how ozone concentrations in the air have developed since 1990 (monthly means). For all four station types, the median values as well as the lower quantiles increase over this period. In the urban areas, the increase is to be expected given the reduction in nitrogen oxides. The rise in ozone concentrations at the rural and pre-Alpine stations suggests an increase in background levels of ozone from anthropogenic sources in the Northern hemisphere. Peak hourly values at the heavily polluted sites have decreased slightly since 1990. This trend is most evident in the south of the Alps (Ordoñez et al., 2005, 2007; Brönnimann et al., 2002).



NABEL stations. Red: NABEL stations participating in the Global Atmosphere Watch (GAW) programme and/or the European Monitoring and Evaluation Programme (EMEP).

onboard Metop) will become increasingly important. The initial results of validation experiments involving surface monitoring stations are highly promising.

International integration

The NABEL network regularly exchanges data with several international monitoring programmes. Since the start of monitoring operations, the rural Payerne and Rigi stations have been part of the European Monitoring and Evaluation Programme (EMEP), which investigates in particular the long-range transport of air pollutants across Europe. The NABEL measurements also contribute to the WMO Global Atmosphere Watch (GAW) programme: the Jungfraujoch site is a global, and the Rigi a regional GAW station. The NABEL network also supplies data to the European Air Quality Monitoring Network (EuroAirnet). EuroAirnet was established by the European Environment Agency (EEA) and includes in particular stations in urban and suburban areas across Europe. Measurements from the NABEL stations are also used for air quality forecasting and data assimilation purposes as part of the ESA PROMOTE project, a pilot project under the Global Monitoring for Environment and Security (GMES) programme.

Resources required

Funding of the NABEL network is assured for the long term through contributions from the FOEN and Empa.

http://www.bafu.admin.ch/luft/luftbelastung/index.html?lang=en
http://www.empa.ch/nabel

2.12 Aerosols

Aerosols have direct and indirect effects on the atmosphere. The magnitude of these effects, as regards warming or cooling, remains one of the most significant sources of uncertainty in climate models. When inhaled, aerosols can have adverse effects on human health.

§

Legal basis

Switzerland is a member of the World Meteorological Organization (SR 0.429.01) and participates in the WMO Global Atmosphere Watch (GAW) programme in accordance with the Federal Council Decree of 25 November 1994. As the lead agency vis-à-vis the WMO, the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for the GAW programme in Switzerland. Limits for anthropogenic aerosols are specified in legislation concerning air pollutants (→ 2.11 Air pollutants).

Measurements in Switzerland

As part of Switzerland's contribution to the GAW programme, continuous aerosol measurements are carried out by the Paul Scherrer Institute (PSI), on behalf of MeteoSwiss, at the High Altitude Research Station Jungfraujoch (HFSJ). The variables measured include the scattering, backscattering and extinction coefficients at various wavelengths, together with the number concentration, mass concentration (TSP: total suspended particulates; PM10: particulate matter <10 µm, PM1: particulate matter <1 µm) and size-resolved chemical composition. In some cases (TSP, PM10), aerosol measurements at the Jungfraujoch site are carried out under the NABEL programme (→ 2.11 Air pollutants). In addition, at the 4 CHARM stations (→ 2.5 Radiation) aerosol optical depth (AOD) is measured by spectrophotometers.

A further category consists of the AErosol RObotic NETwork (AERONET) stations. The AERONET programme, jointly established by NASA and the Centre National de la Recherche Scientifique (CNRS), currently coordinates a network of approx. 400 ground-based aerosol remote sensing stations (using identical automatic photometers measuring in different spectral ranges), operated by national agencies, research institutes or universities. Two AERONET stations are located in Switzerland, at Lägeren (since 2003; run by the University of Bern) and Davos (since 2005; run by the PMOD/WRC). The Federal Institute of Technology, Lausanne (EPFL), and the University of Neuchâtel are involved in the ground-based aerosol monitoring activities of the European Aerosol Research Lidar Network (EARLINET).

Valuable additional aerosol data (e.g. AOD) are provided by passive satellite measurements from AVHRR (onboard NOAA, Metop), SEVIRI (onboard Meteosat Second Generation),

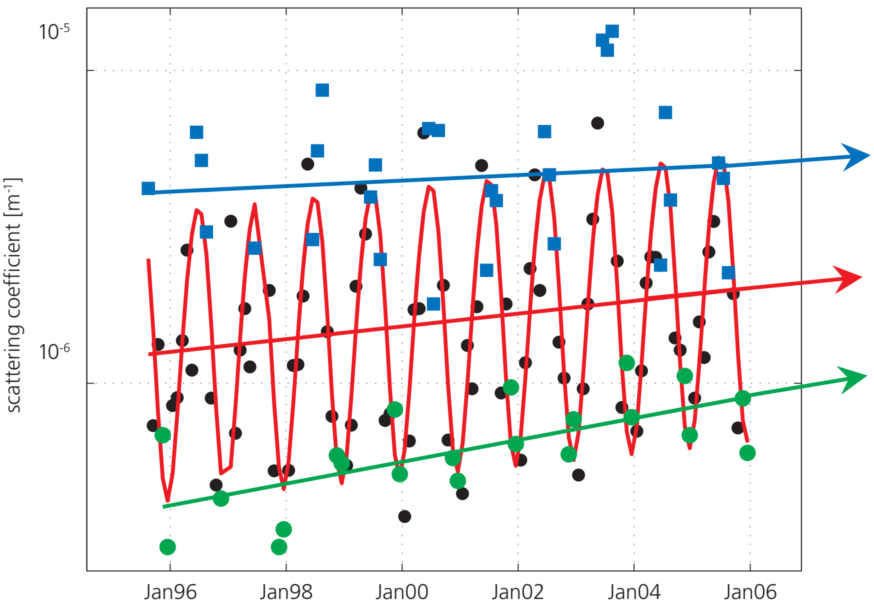
Long time series and their importance

From 1973, TSP mass concentrations were measured continuously at the Jungfraujoch station as part of the NABEL programme. In 2006, this series was succeeded by measurements of PM10 concentrations.

The PSI has carried out continuous measurements of aerosol variables at the Jungfraujoch site since 1988. The first variable measured by the PSI from the outset was the surface concentration of aerosol particles. In 1995, PSI monitoring was expanded to cover all other optical variables and integrated into the GAW programme. Chemical composition has been additionally measured since 1998. Over the past two decades, emissions of anthropogenic aerosols have declined in Europe as a result of improved air pollution control measures. Current observations, however, indicate a stabilization or increase of particulate concentrations.

Aerosol light scattering coefficient at Jungfraujoch 1995 – 2006

Scattering coefficient in m^{-1}



The trend analysis shows that the greatest increase in the scattering coefficient (monthly values, black) occurs between September and December (green), although the Jungfraujoch station is generally in the free troposphere during this period. In contrast, during the summer months from June to August (blue), measurements are strongly influenced by the planetary boundary layer. However, no statistically significant trend can be detected. The increase in the optical properties of aerosols observed in the autumn may be associated either with the greater influence of boundary layer air masses or with long-range transport from areas with increasing air pollution (Collaud Coen et al., 2007).

The main aerosol monitoring stations. Red: Jungfraujoch (GAW, CHARM); blue: Lägeren (AERONET), Davos (AERONET, CHARM), Payerne (CHARM), Locarno-Monti (CHARM).

MERIS (onboard Envisat), MODIS and MISR (onboard Terra), as well as the latest active satellite measurements from CALIPSO (lidar) and CLOUDSAT (cloud profiling radar).

International integration

Since 2006, the Jungfraujoch site has been one of the 25 global GAW stations worldwide. Aerosol measurements from the Jungfraujoch station are therefore regularly transmitted to the World Data Centre for Aerosols (WDCA) at the Joint Research Centre (JRC) in Ispra (Italy). In addition, the data are supplied to the Chemical Coordinating Centre of the European Monitoring and Evaluation Programme (EMEP) at the Norwegian Institute for Air Research (NILU) in Lillestrom. Key international partners for the PSI aerosol monitoring programme at the Jungfraujoch site are the German Aerospace Center (DLR; aerosol absorption coefficient), NOAA, Boulder (aerosol scattering coefficient) and TERA Environment (chemical analysis). In addition, measurement campaigns are frequently conducted at the station, especially to study the interaction of aerosol particles with clouds. The monitoring and research activities are integrated into various ongoing EU projects (e.g. ACCENT, EUSAAR, GEOMON).

Resources required

The funding of aerosol monitoring operations at the Jungfraujoch site is assured through the Swiss GAW programme. AERONET measurements at the Lägeren site and in Davos are funded by the University of Bern and the PMOD/WRC respectively.

http://www.meteoswiss.ch/web/en/climate/global_climate_monitoring/GAW_CH_Allg.html

2.13 Pollen

Pollen release and dispersal are controlled by meteorological conditions such as temperature, sunshine duration, precipitation and wind. Changes in airborne pollen levels, which may affect the prevalence of allergies or indicate the spread of new allergenic plant species, can be detected in good time by monitoring.

§

Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout the territory of Switzerland. They are also responsible for the implementation of measures contributing to the long-term preservation of an intact environment. Pollen counts are made available by the responsible agency, the Federal Office of Meteorology and Climatology MeteoSwiss. As a preventive measure, the Federal Office of Public Health also provides information on the spread of ragweed (Ambrosia artemisiifolia). The Federal Office of Agriculture (FOAG) and the Federal Office for the Environment (FOEN) are both involved in efforts to control this highly allergenic plant.

Measurements in Switzerland

From the late 1960s, airborne pollen was analysed at individual stations in Switzerland on a private basis. From 1982, pollen counts in Switzerland were coordinated by the Working Group on Aerobiology. Since 1993, MeteoSwiss assumes responsibility for operating the National Pollen Monitoring Network (NAPOL). This network comprises a total of 14 stations, covering the country's major climate and vegetation regions. Most of the stations are located near built-up areas and operate during the vegetation period each year, from 1 January to 30 September. Each measuring station is equipped with a volumetric pollen trap, which sucks in air. Each week, the pollen types are identified under the microscope at the MeteoSwiss laboratories (Payerne, Zurich), and daily pollen counts are determined, expressed as the number of pollen grains per m^3 air. Current research efforts are seeking to automate counting with the aid of optical processes and to make data available in nearly real time.

Of the numerous types of pollen found in the air, only a small number are responsible for the majority of pollen allergies. From spring to summer in Switzerland, the pollen types in question are from the following six plants: hazel, alder, birch and ash in the spring, grass in the early summer and summer, and mugwort in the late summer. These have recently been joined by ragweed pollen, increasing levels of which were detected at an early stage thanks to the NAPOL network. The most important type is pollen from grass, which can cause serious symptoms in more than 12 % of the population in May and June. Pollen counts vary according to the time of day and meteorological conditions, and from one region to another.

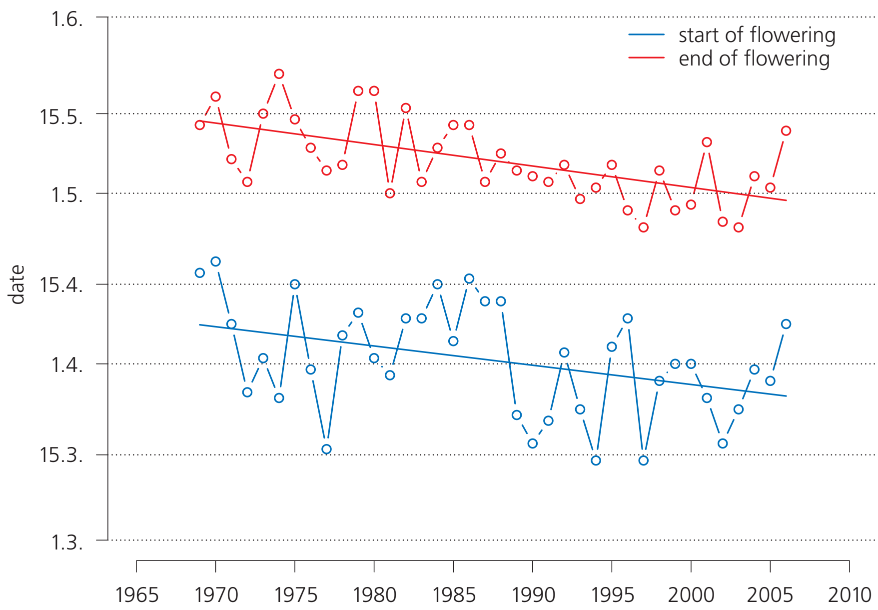
Long time series and their importance

Switzerland's first pollen analyses were carried out in Basel in 1969. Since the 1980s, pollen counts have been determined at the Neuchâtel, Davos and Lugano stations for the most important allergenic plants in Central Europe: hazel, alder, birch, ash, grasses, mugwort and the highly allergenic invasive species ragweed. In Switzerland, these pollen types are responsible for about 95 % of pollen allergies.

Coverage of the various climate and vegetation regions is provided by a selection of measurements from the following NAPOL sites: Basel (Northern foot of Jura Mountains), Neuchâtel (Central Plateau), Davos (Alps) and Lugano (Southern Alps). The even distribution of these four representative sites is important so as to permit detection of future changes in pollen dispersal.

Birch pollen in Basel 1969 – 2006

Start and end of flowering



The beginning of the birch pollen season depends on temperature levels in February and March. The higher the air temperature, the earlier the onset of birch flowering. Rising temperatures have brought forward birch flowering by a significant amount (13 days) since 1969. Over the same period, the end of flowering has been brought forward by 14 days. Over the past 40 years, the length of the birch pollen season has remained unchanged; however, it has been brought forward by about two weeks (Clot, 2003; Gehrig, 2004). Pollen grains are the main cause of allergies. The intensity and duration of the pollen season are highly dependent on environmental factors, with meteorological conditions being among the most important. The long time series are key indicators of the effects of climate change on the main trigger of allergies.

National Pollen Monitoring Network (NAPOL). The selection of 4 (red) of the 14 sites provides coverage of the various climate and vegetation regions.

International integration

As pollen dispersal is independent of national borders, it calls for international data exchanges. To this end, the European Aeroallergen Network (EAN) database was established in 1988. The EAN pollen database now has 152 users from 48 countries including Switzerland.

Incorporating pollen count data for 170 pollen types from 557 stations across Europe, it is available for research purposes. This collection of data provides valuable information on spatial and temporal trends in airborne pollen concentrations over Europe.

Resources required

The continuation of pollen monitoring is assured under the legal mandate of MeteoSwiss. Automation of the measurement network is planned for the coming years, to replace manual pollen counting methods. Renewal of the network will involve higher investment costs.

http://www.meteoswiss.ch/web/en/weather/health/pollen.html

3.1 River discharge

Changes in climate affect the water cycle in various ways. In turn, possible shifts in hydrological variables, including lake and river water levels and discharge, have consequences for water management sectors such as water resource use, water protection and flood control.

§ Legal basis

Under the Federal Water Protection Act (GschG, SR 814.20), the federal authorities are required to carry out surveys of national interest on hydrological conditions. The Federal Office for the Environment (FOEN) is responsible for these tasks.

Measurements in Switzerland

The Swiss river discharge monitoring networks currently consist of around 200 federal stations, about 300 cantonal stations on smaller surface waters and a number of privately operated stations. The FOEN monitors water flows and – in cooperation with the Swiss Federal Institute of Aquatic Science and Technology (Eawag) and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) – water quality in Swiss waterbodies. Data collection takes the form of continuous measurements at permanent hydrometric stations and individual measurements at temporary sites.

Surface water measurements fall into the following categories: the basic monitoring network, the National River Monitoring and Survey Programme (NADUF), water temperature and sediment transport.

The basic monitoring network, which records water levels and discharge, goes back to the mid-nineteenth century. It now comprises some 260 gauging stations on surface waters (rivers and lakes). In this network, 90 % of all stations have automatic remote retrieval facilities.

Under the NADUF programme, which is designed to assess the state of Swiss watercourses, concentrations of nutrients and pollutants have been continuously measured at selected stations since the mid-1970s. Continuous sampling combined with discharge measurements permits accurate calculations of substance loads.

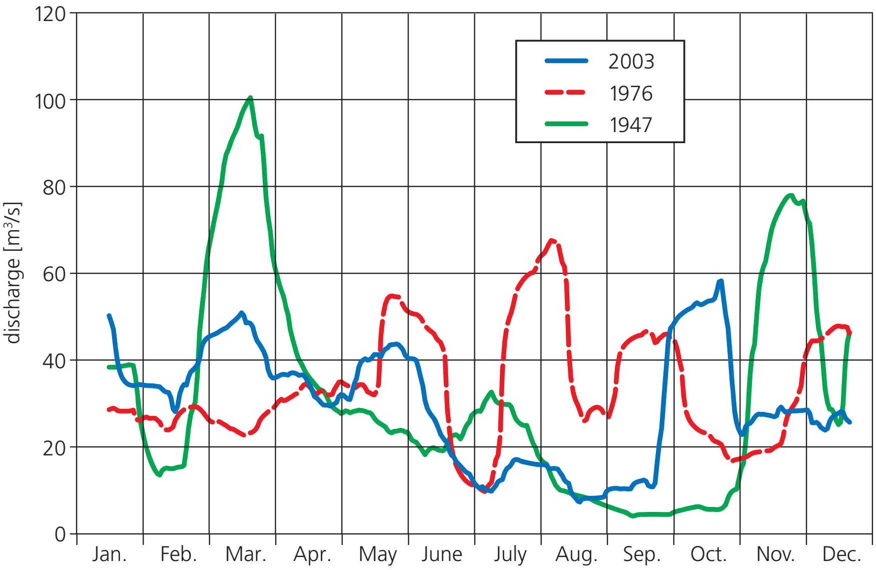
In the 1950s, hydrological study areas (HUG) were first designated in Switzerland; over the years, further catchment areas have been added. The gauging stations in these areas are part of the basic monitoring network. The aim of the HUG studies is to observe long-term changes in the water regime in near-natural catchment areas across the country's various

Long time series and their importance

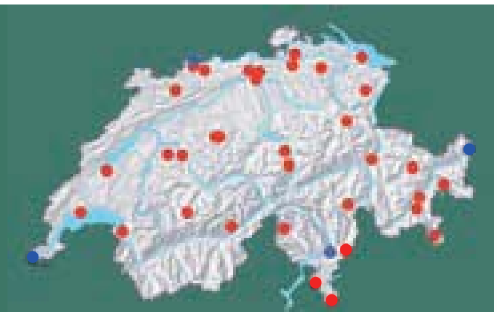
In the Hydrological Yearbook of Switzerland, data (including discharge) from all the gauging stations operated by the FOEN has been published since 1917. The longest continuous daily discharge series come from stations on the Rhine (1891 Basel), the Thur (1904 Andelfingen) and the Birs (1917 Münchenstein). Among the oldest gauging stations are four border stations (Rhine-Basel, Rhône-Chancy, Ticino-Bellinzona, Inn-Martinsbruck), which record discharge from Switzerland and, in some cases, belong to the NADUF programme. The HUG gauging stations belonging to the basic monitoring network have an average time series length of 40 years. The HUG areas were selected with a view to covering all types of hydrological regime in Switzerland.

Thur discharge for 1947, 1976 and 2003 in Andelfingen

Discharge rates averaged over 30 days, in m³/s



The precipitation periods of March and November 1947, July 1976 and October 2003 are evident from the discharge curves. Also clearly apparent are the low-water periods of varying duration (FOEN, 2004). Fluctuations in discharge are indirectly influenced by meteorological variables and by the storage capacity of snow cover, glaciers, soils, groundwater and lakes. Discharge data provide an important basis for the analysis of runoff estimates generated by hydrological modelling. A long-term change in the discharge regime will have consequences for various aspects of water management.



The selection of Switzerland's most important discharge series comprises various monitoring networks (red + blue), including border stations (blue).

climatic regions. They therefore cover runoff depth and area precipitation for about 50 catchment areas.

International integration

A selection of stations (12) with long discharge series participate in the Global Runoff Data Centre (GRDC). Daily river discharge data from a total of 27 Swiss stations is supplied to the GRDC, representing an important contribution to international data exchange. The GRDC is part of the Global Terrestrial Network for Hydrology (GTN-H), which is supported by GCOS, GTOS and the WMO Hydrology and Water Resources programme. The European Terrestrial Network for River Discharge (ETN-R) is a GRDC contribution to the European Flood Alert System (EFAS), facilitating medium- to long-term flood forecasts.

Resources required

It can be assumed that, given the existing legal basis, measurements of discharge and continuous monitoring of surface waters will be continued. In the medium term, funding is to be regarded as assured for the long-term observation programmes jointly supported by the FOEN, the Eawag and the WSL. These programmes are fundamental to flood control and water protection efforts.

http://www.bafu.admin.ch/hydrologie/index.html?lang=en

3.2 Lakes

Lakes may react sensitively to changes in climate, depending on the type and size of waterbody concerned. Among the effects are changes in the temperature of surface and deep waters, in the temporal dynamics of plankton and in the duration of ice cover. Historical records of freeze and thaw dates for lakes permit valuable inferences about past regional climatic conditions.

§ Legal basis

The goals and requirements for the observation of lake variables are specified in the Federal Ordinance (GSchV, SR 814.201) accompanying the Water Protection Act (GSchG, SR 814.20). With regard to water temperature, one of the requirements specified for standing waters is that natural temperature regimes are not to be detrimentally altered as a result of human interventions. Other relevant provisions are to be found in the federal legislation on environmental protection (USG, SR 814.01), nature and cultural heritage protection (NHG, SR 451) and the exploitation of hydroelectric power (WRG, SR 721.80).

Measurements in Switzerland

The basic monitoring network operated by the FOEN Hydrology Division, comprising a total of around 260 hydrometric stations, includes more than 30 stations on Swiss lakes. These lake stations measure discharge, which depends directly on lake water levels. The vertical and horizontal differences in temperature occurring in the lakes are not, however, recorded by the FOEN temperature monitoring network. Measurements of lake water temperatures are carried out as part of comprehensive water quality studies by cantonal water protection agencies, international commissions and the Swiss Federal Institute of Aquatic Science and Technology (Eawag). For example, Lakes Murten, Neuchâtel and Biel are monitored in a joint project by the competent authorities of Cantons Bern, Fribourg and Neuchâtel. Monitoring of Lake Constance is coordinated by the International Commission for the Protection of Lake Constance (IGKB). The lakes of Canton Ticino are monitored by the Joint Commission for the Protection of Italian-Swiss Waters (CIPAIS), and Lake Geneva by the International Commission for the Protection of Lake Geneva (CIPEL).

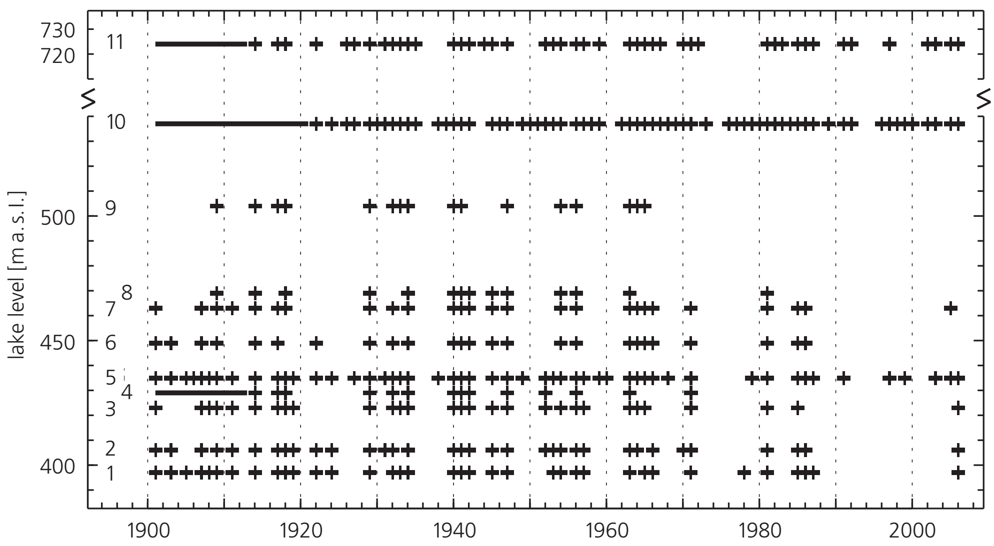
Lake water temperature profiles are determined, in some cases, from boats at a high resolution, with the aid of probes. Temperatures are usually measured once or twice a month at various depths between the lake surface and bottom. Monthly measurements are required for an understanding of the development of lake temperatures over time. In addition, for larger lakes, water surface temperature can be derived from satellite data. This is done operationally for various Swiss lakes using NOAA AVHRR data (at the University of Bern).

Long time series and their importance

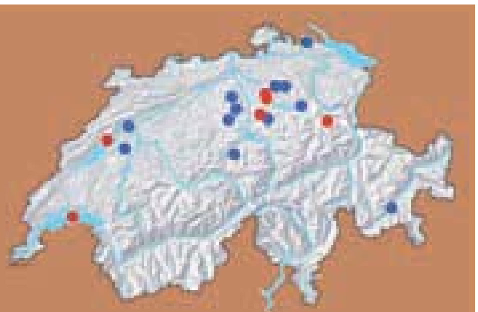
Water temperature is an important variable for regional climate modelling. Monthly water temperatures have been recorded by the Zurich water utility at the Thalwil site on Lake Zurich, with some interruptions, since 1936. Over this period, the number of depths per profile varies. Since 1977, weekly observations have been made by the University of Zurich (Limnological Station, Institute of Plant Biology) in the middle of the lake between Küsnacht and Rüschlikon. Measurements have been carried out at different temporal resolutions and at various depths on Lake Zug (since 1950), Lake Greifen (since 1956), Lake Geneva (since 1957), Lake Neuchâtel (since 1963), Lake Pfäffikon (since 1972), Lake Walenstadt (since 1972) and Lake Aegeri (since 1975). As the measurements in these series have been carried out differently over the years, a degree of inconsistency both within and between the time series is inevitable.

Freezing of lakes on the Swiss Central Plateau 1901 – 2006

Data compiled for 11 lakes as a function of altitude above sea level



Data on ice cover for alpine lakes contain relevant climatological information, since ice cover and winter temperature are closely related. Cross: complete ice cover. Line: years for which no data are available. Lakes: 1 = Untersee, 2 = Upper Lake Zurich, 3 = Lake Murten, 4 = Lake Biel, 5 = Lake Greifen, 6 = Lake Hallwil, 7 = Lake Baldegg, 8 = Lake Sarnen, 9 = Lake Sempach, 10 = Lake Pfäffikon, 11 = Lake Aegeri. From these data, ice cover can be shown to have declined over the past 40 years. This trend is particularly marked for lakes that freeze rarely (Hendricks Franssen and Scherrer, 2007).



Water temperatures have been measured at various sites since about the middle of the twentieth century (red). Freeze and thaw dates have been observed for more than 100 years (blue).

International integration

Historical records of freeze and thaw dates for lakes permit valuable inferences concerning the past regional climate and provide additional information on winter temperature patterns. These observations are not carried out systematically across Switzerland and come from various sources (including newspapers and personal records). The longest time series available in Switzerland is for Lake St. Moritz; starting in 1832, it extends without interruption up to the present. This dataset is unique for central Europe. The freeze and thaw dates for alpine lakes are the only lake variables transmitted to an international data repository. The Global Lake and River Ice Phenology Database at the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, archives observations from Lakes St. Moritz, Silvaplana and Sils. Observations are no longer being updated for the two last-named lakes.

Resources required

Lake vertical temperature measurements are carried out by various institutions across Switzerland in an uncoordinated manner. Likewise, freeze and thaw dates are not systematically observed. As no legal basis exists for long-term observations of this kind, these time series are not guaranteed.

http://www.eawag.ch/organisation/abteilungen/wut/schwerpunkte/umweltisotope/

3.3 Groundwater

More than 80% of Switzerland's drinking and industrial water is sourced from groundwater. Groundwater recharge is influenced not only by precipitation and dry periods but also by human activities. Quantitative and qualitative monitoring of groundwater is therefore required nationwide to ensure the long-term preservation of these resources.

§ Legal basis

Under the Federal Act on the Protection of Waters (GschG, SR 814.20), the federal authorities are required to carry out surveys of national interest on hydrological conditions and on water quality in surface and groundwaters. The Federal Office for the Environment (FOEN) is responsible for these tasks.

Measurements in Switzerland

The National Groundwater Observation Programme (NAQUA) operated by the FOEN is designed to provide a representative picture, in both qualitative and quantitative terms, of the state and development of Swiss groundwater resources. It thus facilitates (a) the protection, long-term preservation and sustainable use of natural groundwater resources and the elimination of existing damage and (b) the protection of the public against excessive pollution (harmful organisms and substances).

NAQUA provides reliable information on (a) the main types of aquifer relevant to groundwater use in Switzerland (karstic or fractured rocks and unconsolidated sediments); (b) the main aquifers used as sources of drinking water in Switzerland; (c) aquifers in the various major climatic and landscape regions of Switzerland, e.g. Jura, Central Plateau, Pre-Alps, Alps and south of the Alps; and (d) the most important natural and anthropogenic factors influencing Switzerland's groundwaters.

NAQUA comprises four modules: TREND for tracking long-term developments in groundwater quality (50 stations), SPEZ for studies of specific pollutants (500 stations), QUANT for observing groundwater quantity (100 stations), and ISOT for observing isotopes in the water cycle (23 stations) (→ 3.5 Isotopes).

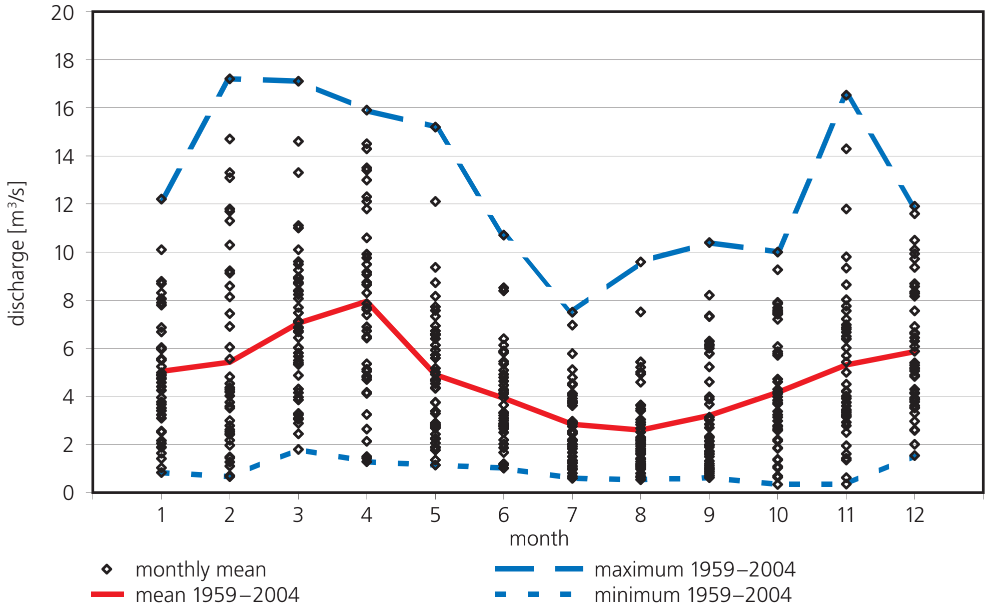
Groundwater quality and quantity is also monitored at numerous sites by various institutions (universities, water utilities, cantons). Altogether, groundwater levels and spring discharges are currently observed at around 900 stations. Measurements of groundwater levels are generally carried out manually or automatically in a perforated tube installed in the aquifer. Spring discharge is measured as close as possible to the spring using a natural cross-section or with the aid of an artificial overflow.

Long time series and their importance

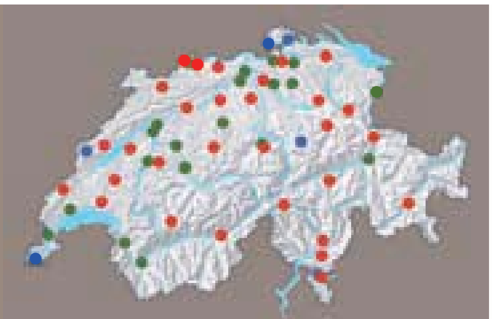
To better assess the possible consequences of climate change, NAQUA pursues an integrated approach, aimed at increasingly recording groundwater quality and quantity at the same stations over time. Under the NAQUA programme, the FOEN is therefore collaborating closely with the cantons. The longest groundwater level data series in Switzerland (from around 1900 to the present) are available from water utility pumping wells. Since the end of the 1970s, groundwater levels have been continuously monitored nationwide, e.g. on the Rhine (Maienfeld, since 1975), Arve (Soral, since 1975) and Vedeggio (Lamone, since 1980). The discharge of the Areuse spring in St-Sulpice has been measured continuously since 1959, representing one of Switzerland's longest spring discharge time series.

Discharge of Areuse spring in St-Sulpice 1959 – 2004

Mean monthly discharge in m³/s



Mean monthly discharge of the Areuse spring in St-Sulpice for the observation period 1959–2004. These data contribute significantly to our understanding of climate variability. Such fluctuations may differ widely as a result of Switzerland's small-scale diversity, but they are not currently quantifiable. The impacts of climate change on groundwater can only be reliably estimated with sufficiently long time series on groundwater quality and quantity (Schürch et al., 2006).



Switzerland's National Groundwater Observation Programme NAQUA: selected stations from TREND (green) and QUANT (blue) modules, and stations belonging to both modules (red).

International integration

Groundwater observations are coordinated internationally by various networks. The International Groundwater Resources Assessment Centre (IGRAC), a joint UNESCO/WMO initiative for global information exchange, belongs to the Global Terrestrial Network Hydrology (GTN-H). The data and information network responsible at the European level is EUROWATERNET, which is operated by the European Environment Agency (EEA).

Resources required

The operation of monitoring stations under the NAQUA programme can be regarded as assured, at least in the medium term. However, especially in connection with the instrumentation of springs, the technical and financial resources required for station equipment and data transmission have proved to be substantial in some cases.

http://www.bafu.admin.ch/hydrologie/index.html?lang=en

3.4 Water use

Water resource availability is essential for the provision of supplies to the public and for various economic sectors. With rising temperatures, longer dry periods and seasonal fluctuations, climate change affects water supplies and demand. A knowledge of water consumption is therefore of great importance.

§ Legal basis

Among the aims of the Federal Water Protection Act (GSchG, SR 814.20) are to ensure economic use of drinking and process water and to protect agricultural irrigation from adverse impacts. The legislation also includes provisions on residual flows, restricting water withdrawals from surface waters. Concessions or licenses granted by the cantonal authorities are required where water is used for irrigation. In contrast, drinking water abstraction has priority in the exploitation of groundwater resources. The legal basis is provided by cantonal water management legislation.

Measurements in Switzerland

The natural geography of the Alps makes Switzerland a water-rich country.

In Switzerland, water consumption data are collected by different agencies to different extents and with varying degrees of regularity. For example, data on the withdrawal, treatment and supply of drinking and process water are collected by the Swiss Gas and Water Industry Association (SVGW) and determined by utilities that supply water to about 50 % of the population. The main source of drinking water in Switzerland is groundwater, which is accordingly of great importance and subject to systematic qualitative and quantitative monitoring (→ 3.3 Groundwater).

Water consumption associated with Swiss agriculture is confined to relatively small areas and essentially to extremely dry areas and vegetable farming. Scant information is available on the distribution and extent of agricultural irrigation. This is due to Switzerland's federalist structures, which explain the lack of uniform data. Quantitative values concerning irrigated areas are determined with the aid of surveys conducted by the Swiss Farmers' Union and the Federal Office for Agriculture (FOAG). In the spring of 2007, the FOAG carried out a survey on irrigation. Here, data were compiled at the cantonal level, providing an updated estimate of consumption compared with the previous survey (2002).

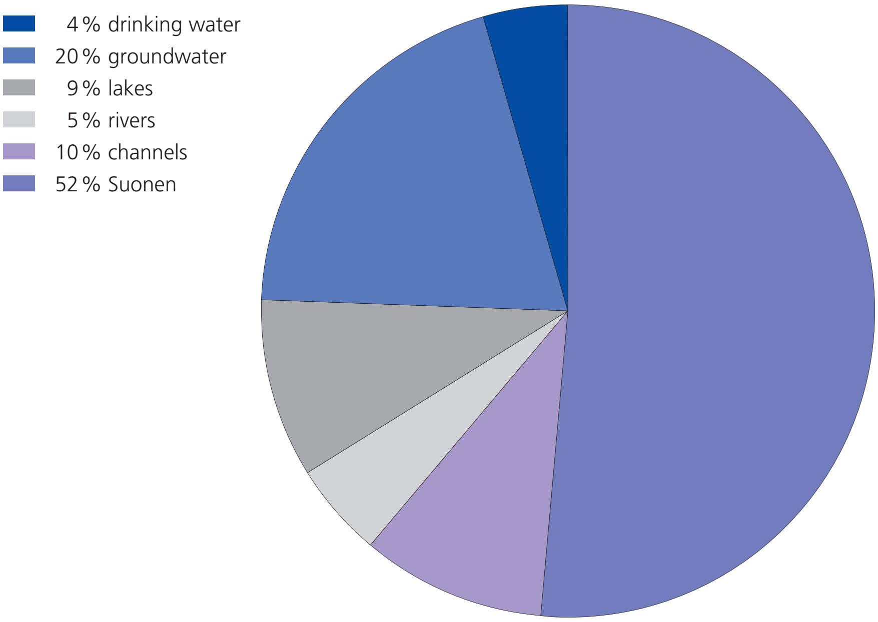
Graubünden is the first canton to have developed a concept defining areas that require irrigation. This study was carried out with expert support at the suggestion of the Graubünden farmers' union and was mainly funded by the canton. According to the FOAG, a nationwide study of irrigation water consumption has the backing of about half of all cantons.

Long time series and their importance

In Switzerland, estimates of agricultural water use have been prepared and transmitted to international organizations since the early 1990s. The estimated irrigated area rose from 25,000 ha in 1995 to 30,000 ha in 2000 and 38,000 ha in the 2007 survey. The total area of 38,000 ha refers to regularly irrigated land, two thirds of which is to be found in the cantons of Valais and Graubünden. In contrast, other cantons appear to lack precise data on irrigated areas. In addition to the areas irrigated regularly, another 12,000 ha of land is irrigated occasionally. There are major regional differences in the efficiency of water use, which depends on cultivation methods and irrigation technologies.

Irrigated areas of Switzerland by source of withdrawal

Cantonal estimates for 2006



Agricultural water consumption data are based on estimates from the majority of cantonal agencies. Irrigated areas can be classified by the type of crop and source of withdrawal, and by the type of system used. Grasslands in the Central Alpine dry valleys of Valais and Graubünden supplied with water from traditional open channels (Suonen) account for about half of the total irrigated area (personal communication, A. Schild, FOAG). The extent of irrigated areas will probably increase in future. However, water demand could be met more efficiently than is currently the case by using appropriate cultivation methods and irrigation technologies.

The extent of agricultural water consumption is based on estimates; these involve uncertainties, making it impossible to determine areas reliably.

International integration

Per capita water consumption is a standard international environmental indicator used by the OECD and FAO in various studies to assess sustainability. The FAO maintains a global information system on agricultural water use, particularly in developing and emerging countries (AQUASTAT). AQUASTAT is part of the Global Terrestrial Network for Hydrology (GTN-H), to which the global networks on river discharge (GRDC) and groundwater (IGRAC) also belong (→ 3.1 River discharge and → 3.3 Groundwater). The information on water consumption in Swiss agriculture supplied to the AQUASTAT database is based on FOAG estimates.

Resources required

In view of the growing demand for water arising from climate change and associated changes in production conditions, there is a clear need for systematic data collection efforts so as to estimate the cantons' irrigation requirements.

http://www.blw.admin.ch/themen/00010/00071/00230/index.html

3.5 Isotopes

Serving as natural tracers, isotopes of oxygen and hydrogen leave a "fingerprint" in numerous components of the climate system. Accordingly, in addition to their use in groundwater management and protection, long-term isotope data series provide necessary reference values for climatological studies.

§ Legal basis

Under the Federal Act on the Protection of Waters (GschG, SR 814.20), the federal authorities are required to carry out surveys of national interest on hydrological conditions and on water quality in surface and groundwaters. The Federal Office for the Environment (FOEN) is responsible for these tasks.

Measurements in Switzerland

The signature left by isotopes in the water cycle is mainly due to isotope fractionation during the formation of precipitation. Most naturally occurring elements have stable isotopes; other isotopes are radioactive (unstable) and decay over time. The stable isotopes oxygen-18 (^{18}O) and deuterium (^{2}H) and the radioactive hydrogen isotope tritium (^{3}H) are constituents of the water molecule. They are measured by various institutions at about 135 stations across Switzerland in water samples from precipitation, rivers, lakes, glaciers, snow and groundwater. In 1992, as part of the National Groundwater Observation Programme (NAQUA), a new module was established for the observation of isotopes in the water cycle (ISOT).
The ISOT network currently comprises 23 sites distributed throughout Switzerland: 13 precipitation, 7 surface water and 3 groundwater stations. At these stations, the isotope ratios of oxygen-18, deuterium and tritium in water are measured. The FOEN operates the ISOT network in cooperation with the Climate and Environmental Physics group at the University of Bern. The ISOT precipitation stations are spread across the various climatic regions of Switzerland. Monthly composite samples from a precipitation gauge emptied daily are used for isotope measurement. Stations belonging to the discharge monitoring network (basic monitoring network) or the National River Monitoring and Survey Programme (NADUF) were selected as ISOT surface water stations. At these sites, composite samples are collected automatically each month or spot samples are taken manually. At the ISOT groundwater stations, spot samples are collected monthly for isotope analysis, and water temperature, electrical conductivity and spring discharge/groundwater levels are also determined.

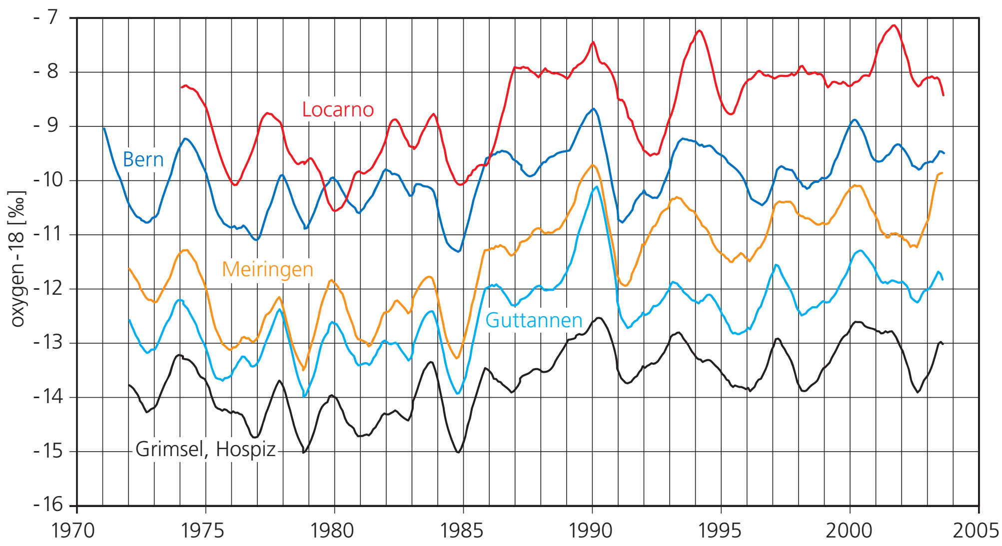
Long time series and their importance

At the monitoring stations in Bern, Meiringen, Guttannen, Grimsel and Locarno, monthly composites of daily precipitation samples have been used for isotope analysis since the early 1970s. Time series from these five sites are the longest available in Switzerland and together form a NW/SE profile through the Alps from Bern (541m a.s.l.) across the Grimsel Pass (1950m a.s.l.) to Locarno (379m a.s.l.).

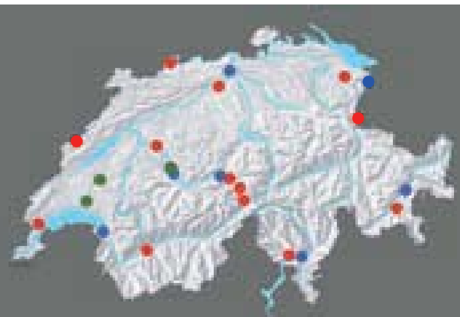
Most of the stations are located close to climatological stations operated by MeteoSwiss, where additional variables, such as temperature and relative humidity, are measured. Isotope observation in rivers dates back to the mid-1980s (Rhine at Diepoldsau, Rhône at Porte du Scex and Inn at S-chanf). These measurements thus cover Switzerland's major rivers.

Oxygen-18 isotope in precipitation 1971 – 2003

Moving monthly averages in per mille at five ISOT sites



The moving monthly averages of the oxygen-18 isotope in precipitation, 1971–2003, reveal the climate trend over the past three decades, which is also apparent from the discharge of large Swiss rivers. The signature left by isotopes in the water cycle is due to the hydrometeorological conditions prevailing during the formation of precipitation – from the original source of humidity to the final rainfall at the collection point (Spreafico and Weingartner, 2005).



The isotope observation network (ISOT) measures the ratios of oxygen-18, deuterium and tritium in precipitation (red), in surface waters (blue) and in groundwater (green).

International integration

Since 1992, data from selected ISOT stations have been transmitted to the database of the Global Network of Isotopes in Precipitation (GNIP) operated by the International Atomic Energy Agency (IAEA) and the WMO. The ISOT network thus makes an important contribution to internationally coordinated isotope programmes, with data being used in research as reference values or for calibration purposes. Together with Germany and Austria, Switzerland has a dense monitoring network with long time series, as compared with other countries. This makes the ISOT series particularly valuable, e.g. for international research programmes.

Resources required

Operation of the ISOT stations is integrated into the National Groundwater Observation Programme (NAQUA). As the tritium content of water samples declines, the number of costly tritium analyses is being continuously reduced.

http://www.bafu.admin.ch/hydrologie/index.html?lang=en

3.6 Snow cover

As well as playing a key role in the climate system, snow cover is a vital economic factor in sectors such as tourism, water management, hydropower, agriculture and transport. With long time series for snow variables, conclusions can be drawn concerning past and future regional trends.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data throughout Switzerland and to provide weather hazard warnings. Under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), the implementing agency is the Federal Office of Meteorology and Climatology MeteoSwiss. Under the ETH Board Ordinance on Research Institutes of the ETH Domain (SR 414.161), the Swiss Federal Institute for Snow and Avalanche Research (SLF), as part of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), is responsible for issuing avalanche warnings and information on the development of snow and avalanche conditions in Switzerland.

Measurements in Switzerland

The most important observations for snow climatology are snow depth, new snow depth, and water equivalent of new and total snow cover. Snow depth and new snow depth are recorded by measurement networks operated by the SLF, MeteoSwiss and other cantonal and private institutions.

The SLF network comprises both automatic and conventional stations (measuring points MS and comparison stations VG). At the roughly 100 conventional stations, the variables are measured manually by observers each day. Most of the stations are located at medium altitudes between 1000 and 2000 m a.s.l.

By contrast, the 39 automatic (ANETZ, now SwissMetNet) and 11 conventional (KLIMA) snow measurement stations operated by MeteoSwiss are evenly distributed across Switzerland, also covering altitudes below 1000 m a.s.l. Since 1996, the SLF and MeteoSwiss stations have been supplemented by the approx. 70 automatic stations of the Intercantonal Measurement and Information System (IMIS), located at altitudes between 2000 and 3000 m a.s.l. This network was established in cooperation with the FOEN under an intercantonal agreement.

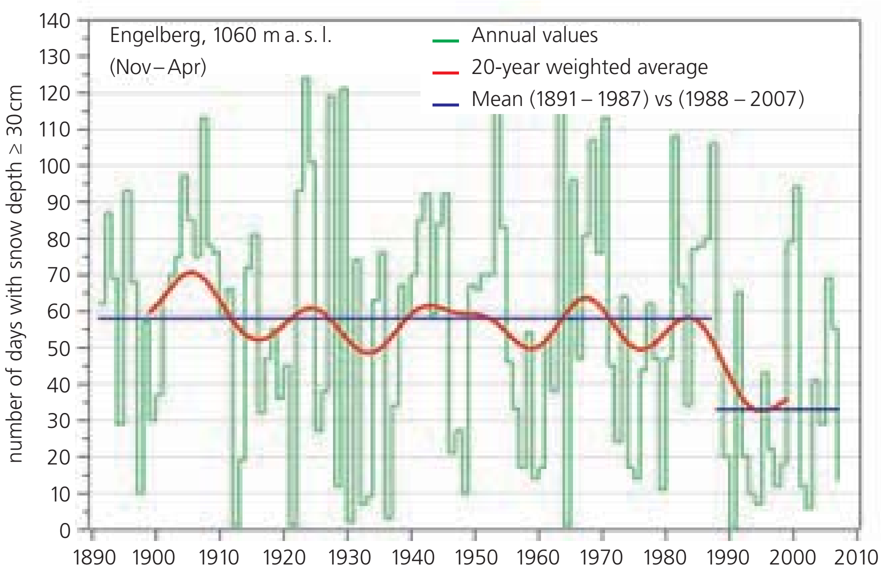
At the 10 mountain stations of the automatic ENET network, observations required for avalanche warnings are jointly carried out by MeteoSwiss and the SLF. At about 75 % of the roughly 340 precipitation stations in the MeteoSwiss NIME network, daily measurements of total and new snow depth are carried out manually. Unlike at the conventional and automatic stations, these data are not recorded digitally. Satellite data are being used operationally to determine snow cover, e.g. from NOAA AVHRR (by the University of Bern) and Meteosat Second Generation (by MeteoSwiss).

Snow depth
Long time series and their importance

Compared with the automatic measurement networks, the advantage offered by the conventional stations is that the available time series are sufficiently long for climatological purposes (> 50 years). In most cases, the most important measurement series for total snow depth are shorter than for new snow depth. This may be associated with the early initiation of precipitation measurements (→ 2.2 Precipitation). The longest total snow depth series go back to the 1890s – Säntis (1890), Engelberg (1890) and Davos (1896). At other stations, measurements also began around 1900, but the frequency of measurement varied widely from year to year and from station to station. At most sites, continuous observations of total snow depth began at the earliest in the 1930s (e.g. Weissfluhjoch, Trübsee, Andermatt, Ulrichen). Total snow depth has also been recorded since the 1930 at stations in a number of

Snow cover in Engelberg 1891 – 2007

Days with snow depth of at least 30 cm for the November-April period



The development over time illustrates the clear decline of snow cover at valley elevations. The green curve shows the large natural fluctuations typical of snow cover. The 20-year average highlights a decrease in the number of snow days – from the late 1980s to the present – never previously observed since measurements began. In the winter of 1989/90, for example, a snow depth of 30 cm or more was not recorded on a single day. This decline over the past 20 years is also associated with a sharp decrease in the total number of winter snow days – an important figure for tourism – from 58 to only 33. The decrease in snow days observed at virtually all stations below 1300 m a.s.l. over the past 20 years is already having a major impact on winter tourism (Laternser and Schneebeli, 2003).

Stations with the longest and most important time series for snow depth (>50 years) and new snow depth (>100 years).

(Continued on page 52)

Swiss towns on the Central Plateau. However, given the high degree of variability in snow depth associated with small amounts of snow at this altitude, time series from these sites are difficult to interpret.

Data on snow depth were only recorded more or less regularly following the introduction of measurement instructions from 1893 onwards. In many cases, the data collected before 1930 are only available in the original analogue form and therefore require additional processing and digitization if they are to be used in analyses.

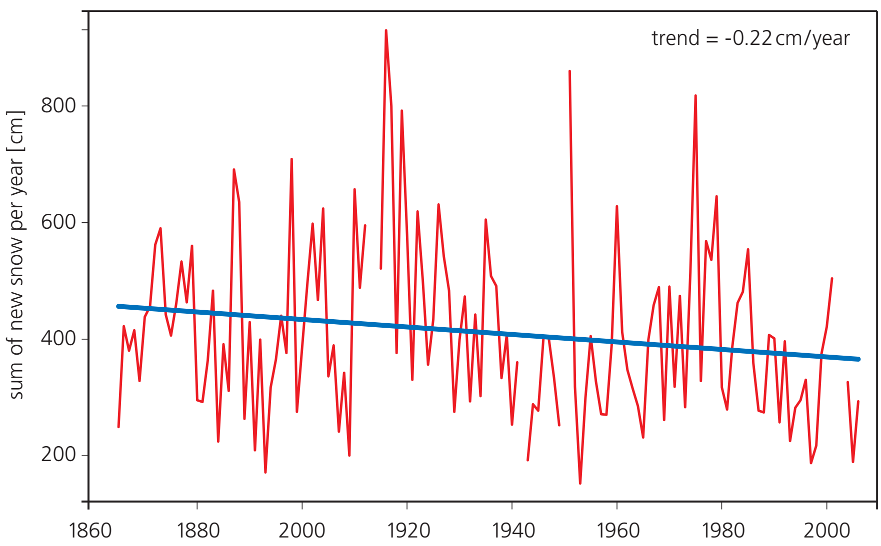
http://www.slf.ch/research/snowtrends/snowtrends-en.html
http://www.meteoswiss.admin.ch/web/en/services/data_portal/monitoring_networks.html

New snow
Long time series and their importance

Altogether 15 stations have new snow records dating back to the 19th century. Either MeteoSwiss or the SLF is responsible for these measurements. At 7 stations, new snow has been recorded since around 1880 – Sils Maria (1864), Guttannen (1877), Elm (1878), Lucerne (1883), Airolo (1885), Chur (1888) and Arosa (1890). The amount of new snow per day and the number of days with new snow are variables of climatological importance, making it possible to analyse the influence of warmer winter temperatures (i.e. more rain than snow) and the predicted increase in winter precipitation (i.e. more snow in summit regions). New snow depth is also important for avalanche warning operations, winter tourism and snow clearance services.

New snow in Sils Maria 1864 – 2006

Yearly total in cm



Yearly totals for new snow in Sils Maria, 1864–2006. The blue line illustrates the linear trend for the entire period. However, the trend of -0.22 cm total new snow per year is not statistically significant. Sils Maria has the longest new snow series available in Switzerland, going back as far as 1864. Measurements for 6 individual years are incomplete (1913, 1914, 1942, 1950, 2002 and 2003), with no data at all for 1913 and 1914. In the other cases, data for at least one winter month (December, January, February) are missing, so that it is not possible to calculate plausible yearly totals for new snow. The maximum yearly total (930 cm) was recorded in 1916, and the minimum (152 cm) in 1953.

Measurements in Switzerland (2)

Long-term data on snow water equivalents (SWE) are also of interest from an engineering perspective, as these values are used in construction standards (SIA NORM 261) for the maximum snow load on structural elements. The SWE is recorded by various institutions and measurement networks across Switzerland. Compared with measurements of snow depth, SWE is determined at a lower temporal resolution.

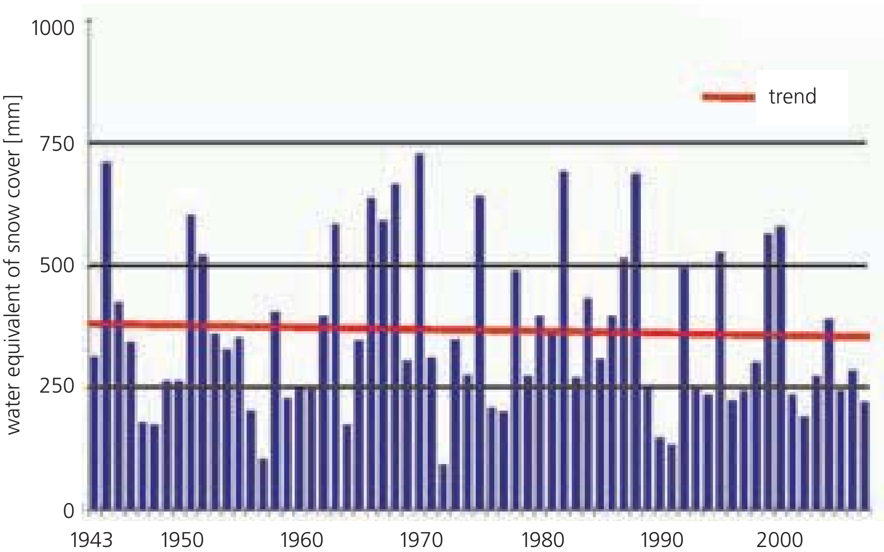
The first regular observations of SWE within a measurement network were carried out in 1943 by the ETH Zurich (Hydrology Division of the Laboratory of Hydraulics, Hydrology and Glaciology/VAW) in cooperation with the electricity sector. This network was subsequently largely integrated into the SLF network, and since then the sites concerned have served as comparison stations (VG). The SWE data collected at VG stations from 1943 onwards were digitized for the period 1943–1985. Since 1998, after an interruption of more than 10 years, data have again been recorded in digital form. At present, the water equivalent of the snow depth is determined by observers twice monthly at half of the roughly 80 VG stations. Measurements are mainly performed between November and April, and the data are digitally archived. Additional isolated measurements are carried out by hydropower plants and private companies, supported by Cryospheric Commission (EKK) of the Swiss Academy of Sciences (SCNAT). Thus, as part of the observation programme on the Claridenfirn and the Silvretta, Basodino, Gries and Aletsch glaciers, measurements of the water equivalent of accumulated firn are carried out in the spring with EKK support. As well as ground-based and conventional measurements of SWE, additional methods are used for research purposes: for example,

Snow water equivalent
Long time series and their importance

The SLF operates VG stations where measurements of SWE go back to the 1940s – Weissfluhjoch (1937), Davos (1947), Klosters (1948) and Zuoz (1951). Of particular importance with regard to total SWE are the various stations in the Wägital valley. They account for the world's longest SWE series for a catchment area (since 1943). The series includes 11 SWE and 28 snow depth sites where measurements are performed in the spring and the average SWE of the snowpack is determined for the catchment. This network, originally operated by the Hydrology Division of the VAW at the ETH Zurich, is now being run by Meteodat GmbH with financial support from the SLF. Meteodat GmbH is currently continuing the measurements carried out at the Garichte and Sihlsee stations since 1943.

Snow water equivalent in the Wägital 1943 – 2007

Area-averaged SWE in mm for the whole catchment as of 1 April



On the basis of point measurements at each site, the water reserves stored in the snowpack are combined into an area-averaged SWE as a function of elevation band. Variation in SWE can thus be shown for the entire catchment area. The red line shows the trend for the long-term average on 1 April. Winter precipitation at lower and medium elevations is likely in future to increasingly take the form of rainfall rather than snowfall. Among the consequences would be greater snowpack compaction (Rohrer et al., 1994). SWE is therefore expected to show a less pronounced negative trend with climate change than snow depth.

The longest water equivalent series go back to 1940: individual stations (green) and groups of stations in catchment areas (red: Wägital, Garichte, Sihlsee; blue: Alptal).

International integration

As part of the European avalanche warning system, snow data from stations close to the border are exchanged with foreign avalanche warning services. In the Alptal valley, hydrological and climatological studies have been carried out by the WSL on snow courses in various subalpine subcatchments for almost 40 years. Individual hydrological measurements form part of the NADUF programme (→ 3.1 River discharge). SWE values determined at 14 sites in the Alptal on a weekly to monthly basis serve as reference measurements for the validation of numerical models in the international Snow Model Intercomparison Project (SnowMIP2) conducted on behalf of the International Association of Cryospheric Sciences (IACS).

Resources required

Continuation of the longest time series is largely assured. Whether certain long-term SLF series (including Engelberg) will be continued is uncertain, since the climatological measurement sites have been outsourced from the avalanche warning service and the current support by the FOEN and ETH is open. The valuable measurements in the Wägital catchment are only assured in the short term. To guarantee their continuation, additional financial resources will be required from 2008.

SWE is determined using equipment such as snow pillows, flat band cable sensors, microwave systems and gamma ray spectrometers.

http://www.wsl.ch/forschung/forschungsprojekte/hydrology_subalpine_watershed/

3.7 Glaciers

The predominantly negative mass balance of Alpine glaciers over the past 25 years is one of the clearest signals of a significant recent increase in the Earth's surface temperature. Long-term changes in mass balance and glacier length are taken as key indicators demonstrating changes in climate.

§ Legal basis

No clearly defined legal basis exists for long-term climate-related glacier monitoring. At present, national legislation provides for regular measurement of glaciers only in the Federal Department of Defence, Civil Protection and Sport Technical Ordinance on Cadastral Surveying (TVAV, SR 211.432.21). Under Art. 7b of the TVAV, the information layer "Ground cover: 6. unvegetated areas" is subdivided into the following categories: (a) rock, (b) glacier / firn, (c) debris/sand, (d) extraction/landfill and (e) other unvegetated areas. In addition, trends that can be derived from glacier observations are relevant as a basis for the assessment of natural hazards in mountain regions (Art. 12c of the DETEC Organizational Ordinance/OV-UVEK, SR 172.217.1).

Measurements in Switzerland

The variables studied (mass balance / volume change, length change, glacier inventory, firn temperature and flow velocities) are currently being reviewed by the Cryospheric Commission (EKK) of the Swiss Academy of Sciences (SCNAT). The aims are to integrate existing measurements into the Global Terrestrial Network for Glaciers (GTN-G), to define future strategy with regard to relevant issues (research, public affairs) and to incorporate modern technologies (satellite data, geoinformatics, numerical models) into the monitoring programme. With regard to GCOS and the GTN-G tier system, data can be integrated as follows: mass balance in Tier 3, length change in Tier 4 and glacier inventories in Tier 5. These three glacier variables are described in detail below.

The mass balance of a glacier – the net result of the accumulation of snow and the loss of snow or ice mainly caused by melting (ablation) – is an area-averaged value, based on measurements taken across the entire glacier. The mass balance is determined by the direct glaciological method; i.e. measurements are performed at least once a year using snow pits and a number of stakes drilled into the glacier surface. These in situ measurements need to be calibrated at intervals of about 10 years by the geodetic-photogrammetric method (production of a digital elevation model), in which changes in volume are determined on the basis of spatial changes across the surface of the glacier. The direct method is currently used to determine area-averaged mass balances for three glaciers and long-term volume changes for 25 glaciers. The mass balance measurements are carried out and financed by the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the ETH Zurich, with support from the EKK,

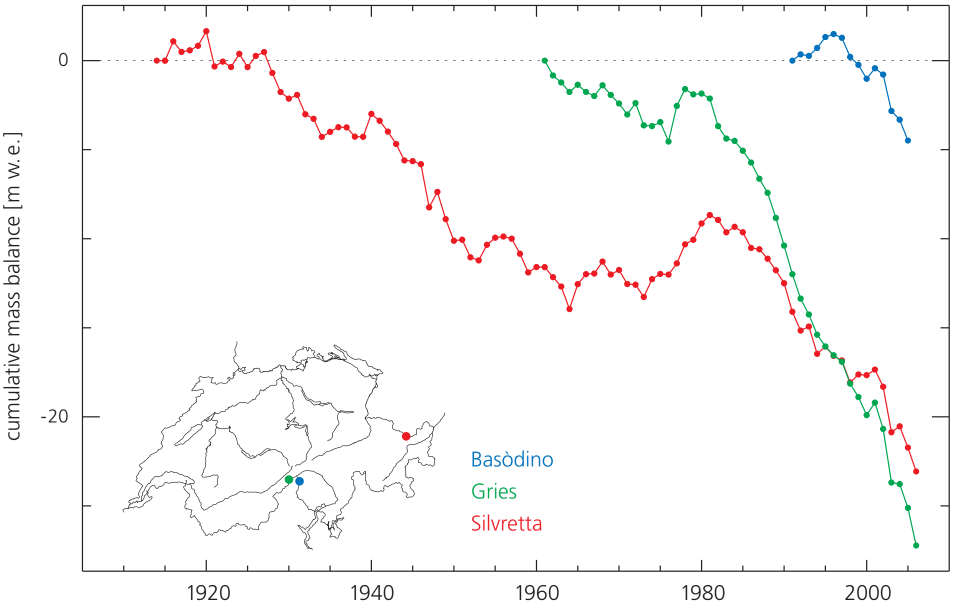
Mass balance
Long time series and their importance

Measurements of mass balance were first carried out on the Rhône glacier in the period 1884–1910. Long-term in situ measurements of mass balance go back to 1914 for the Silvretta glacier, and to 1947 for the Limmern and Plattalva glaciers; however, measurements on the two last-named glaciers were discontinued in 1985. Thus, measurements are currently still being carried out on the glaciers Silvretta (since 1914; since 1959 with a denser network), Gries (since 1961) and Basòdino (since 1991). Measurements from individual stakes are available for the Claridenfirn (since 1914) and Grosser Aletsch (since 1918) at seasonal resolution, and for four other glaciers (Giétro, Corbassière, Allalin and Schwarzberg) at annual resolution. For about 25 glaciers, data are available allowing long-term volume changes to be calculated for the past 100 years at intervals of 10–30 years.

From a GTN-G perspective, measurements should be continued primarily on the three Tier 3 glaciers. For the other long time series, priority should be given to developing further methods to enhance utilization of these records. One promising approach lies in the combination of mass balance models and remote sensing data for spatio-temporal extrapolation of isolated measurements. In addition, long-term series of this kind can be extrapolated with climate data to reconstruct the past and assess future developments.

Mass balance series for three Swiss glaciers

Cumulative mass balance in m water equivalent



Cumulative mass balance (in m water equivalent) for the glaciers Silvretta, Gries and Basòdino glaciers, determined by the glaciological method. The three mass balance series presented provide the essential basis – in conjunction with additionally determined volume changes – for preparing homogenized mass balance time series for a larger sample over the past 100–150 years (Huss et al., 2008).

Swiss Glacier Monitoring Network. Red: glaciers with mass balance measurements (3 glaciers); blue: additional glaciers with volume change measurements (22 glaciers).

federal offices, power generation companies and private bodies.

(Continued on page 56)

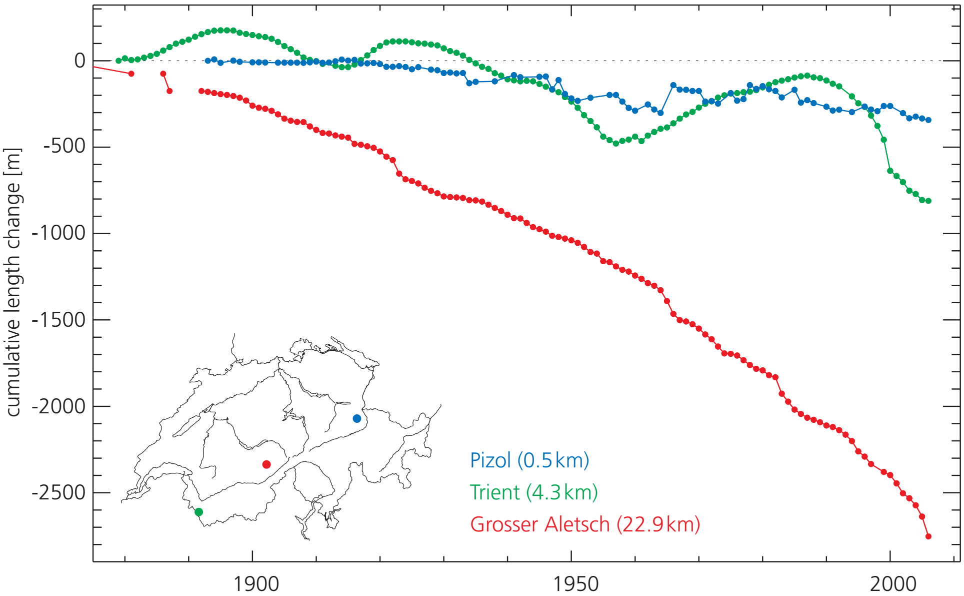
http://glaciology.ethz.ch/swiss-glaciers

Length change
Long time series and their importance

The first regular glacier observations in the Swiss Alps began in 1880 with annual measurements of changes in length. Since 1893, these data have been systematically collected in an internationally coordinated manner. Thanks to the continuous efforts of numerous observers, Switzerland has one of the world's most extensive monitoring networks. According to the glacier evaluation report, monitoring is to be continued for at least 97 of the 120 glaciers currently surveyed (including 73 assigned priority 1). However, as a result of the increasing disintegration of many glacier tongues in recent years, unequivocal determination of length change is sometimes problematic, and the continuation of individual series should be critically reviewed in each case. To address the methodological challenges now arising, the use of new technologies should increasingly be considered.

Changes in length of three Swiss glaciers 1880 – 2006

Cumulative annual measurements in m



Cumulative annual measurements of length change (in m) for three glaciers of different sizes (length in km) showing different responses and adaptability to changes in climate. The figure illustrates how the size of a glacier influences the extent and duration of fluctuations. Thus, Switzerland's larger glaciers (Grosser Aletsch) have retreated continuously since observations began. In contrast, steeper mountain glaciers (Trient) show decadal variations, while small glaciers (Pizol) show low-amplitude yearly variations (Glaciological Reports, 1881–2006).

Measurements in Switzerland (2)

The monitoring network established in Switzerland over the years includes length change measurements for glaciers of all sizes and types, ranging from the small glacier patch through cirque and mountain glaciers to large valley glaciers. While glaciers of the last two types are well represented, small glaciers are substantially underrepresented given their actual numbers (according to the glacier inventory, 80 % of the glaciers are smaller than 1 km²). The length change measurements are carried out by the VAW in cooperation with the cantonal forest agencies, federal offices, hydropower companies and private bodies, with financial support from the EKK. Changes in length continue to be determined mainly by field measurements, carried out by local residents. Among the approaches used are simple methods involving measuring tapes and portable distance meters (e.g. binoculars) or more complex theodolite or GPS surveys. In addition, remote sensing systems (aerial photography and satellite imagery) are increasingly being used. To date, the aerial photographs produced by swisstopo at regular intervals for several decades have not been available for use in systematic analysis. In the future, field measurements will still be required for calibration of remote sensing data.

Glacier inventories represent Tier 5 observations in the GTN-G system, recording the characteristics of each glacier according to a standardized scheme. In addition to the name, coordinates and hydrological catchment, these include details of the area, length, lowest and highest point, aspect and survey time, as well as a morphological classification. Inventories allow individual measurements (e.g. of mass balance) to be extrapolated to an entire sam-

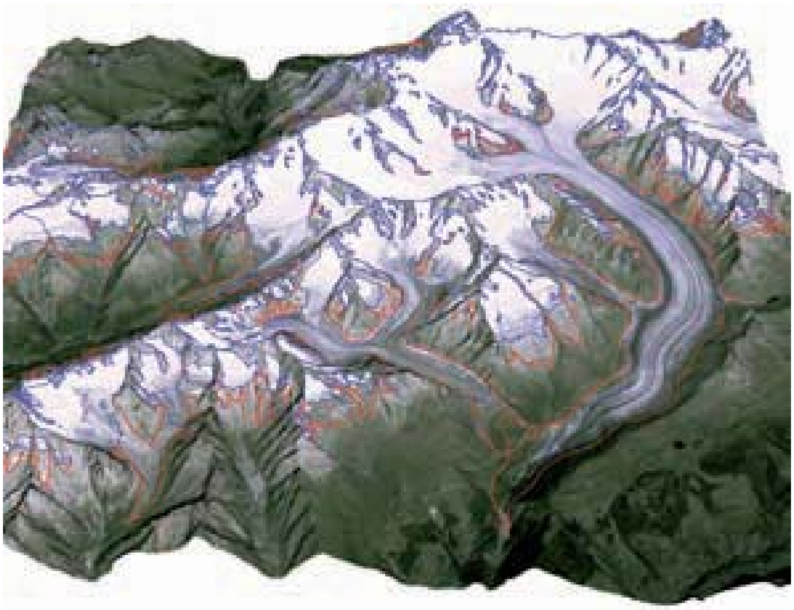
http://glaciology.ethz.ch/swiss-glaciers

Inventories
Long time series and their importance

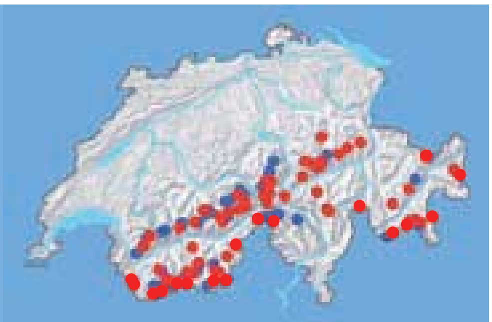
A Swiss glacier inventory (SGI) was compiled from aerial photographs taken in the autumn of 1973. Supplementing this publication was an inventory from around 1850, reconstructed from contemporary plane-table sheets, surveys and analysis of aerial photographs. For the 1998/99 period, a new inventory (SGI 2000) was compiled from multispectral satellite data, covering about 85 % of the remaining glaciated area. To determine changes in individual glaciers resulting from climate change, knowledge of the precise glacier boundary (outline) is required in each case. In various projects, the glacier outlines from 1850 and 1973 were digitized and these have now been published in the Digital Atlas of Switzerland. The SGI 2000 glacier outlines, integrated into the Global Land Ice Measurements from Space (GLIMS) database, are freely available.

Retreat of glaciers in the Aletsch region

Glacier boundaries according to Swiss glacier inventories of 1850 and 1973



Comparison of the 1850 (red) and 1973 (blue) Swiss glacier inventories for the Aletsch region. Glacier inventories record basic data for the largest possible sample of glaciers at a given point in time. They provide an essential basis for numerous glaciological, hydrological, climatological and geomorphological investigations and should be repeated at intervals of several decades (Paul et al., 2004). In the area of natural hazards, the inventories make an important contribution, e.g. by allowing hydrological modelling to take account of currently glaciated areas. Digital terrain model: swisstopo; satellite data: NPOC/Eurimage.



Length change measurements within the Swiss Glacier Monitoring Network. Red: 73 priority 1 glaciers; blue: the rest of the 120 glaciers surveyed.

ple and thus enable changes to be assessed nationwide (e.g. loss of ice volume). According to inventory data, the total glaciated area was 1340 km² in 1973 and only 1050 km² in 2000.

International integration

The methods developed for the Swiss glacier inventory SGI 2000 – automatic glacier classification based on multispectral satellite data and subsequent derivation of inventory data using geographical information systems – are now applied worldwide, e.g. in the GLIMS project. This project, which aims to complete the global glacier inventory using satellite data, is soon to be officially responsible for Tier 5 of the GTN-G.

The measurements at the three Tier 3 glaciers (Silvretta, Gries, Basòdino), together with the measurements of changes in volume (25 glaciers) and length (120 glaciers), represent Switzerland's contribution to global observations of glaciers, which are collated, archived and published by the World Glacier Monitoring Service (→ 4.3 WGMS).

Resources required

Owing to the lack of a legal basis, the funding of glacier measurements is not assured in the long term. At present, they are largely conducted on a voluntary basis without long-term guarantees. Additional financial resources are also required for the acquisition of satellite and aerial images. Glacier monitoring should therefore be assured in the long term through Swiss GCOS funding.

http://www.glims.org

3.8 Permafrost

Permafrost reacts sensitively to changes in climate such as the rising air temperatures currently observed. Thawing leads to increased ground instability at high altitudes, which may have adverse impacts, e.g. on cableways, hiking paths, pass roads and mountain villages.

§ Legal basis

Permafrost monitoring is only provided for indirectly in national legislation, in connection with the natural hazards arising from changes in permafrost. Under Article 12c of the DETEC Organizational Ordinance (OV-UVEK, SR 172.217.1), the federal authorities are required to ensure protection against natural hazards. The Federal Office for the Environment (FOEN) is responsible for this task. Under Article 3d of the ETH Board Ordinance on Research Institutes of the ETH Domain (SR 414.161), the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is also active in the area of permafrost.

Measurements in Switzerland

"Permafrost" is the term used to describe a subsurface layer where the temperature does not exceed 0 °C throughout one year. In the Alps, permanently frozen soil and rocks of this kind mainly occur above the treeline.

Permafrost lies below the active layer, which is up to several metres thick and has positive or negative temperatures depending on the season. It exists unseen in rock faces and across summit areas or scree slopes. In polar regions, permafrost can be more than a kilometre thick, while its thickness in our latitudes ranges from decametres to several hundred metres. It is estimated that permafrost underpins about 5 % of the area of Switzerland, i.e. about twice the area covered by glaciers.

Observations of permafrost are coordinated by PERMOS (Permafrost Monitoring Switzerland), based at the University of Zurich. Measurements are carried out by various partner institutions. PERMOS, currently still under development, comprises stations on alpine scree slopes and at rock sites of varying slope and aspect. Measurements are performed in various ways: (i) at 16 sites, temperature depth profiles are determined using boreholes, allowing measurements at depths of up to 100 m (these indicate the thickness of the active layer and changes in the temperature of permafrost); (ii) in 5 areas, ground surface temperatures are measured, permitting conclusions as to temperatures underground and thus the occurrence of permafrost; and (iii) in 8 areas, aerial photographs are regularly taken and analysed.

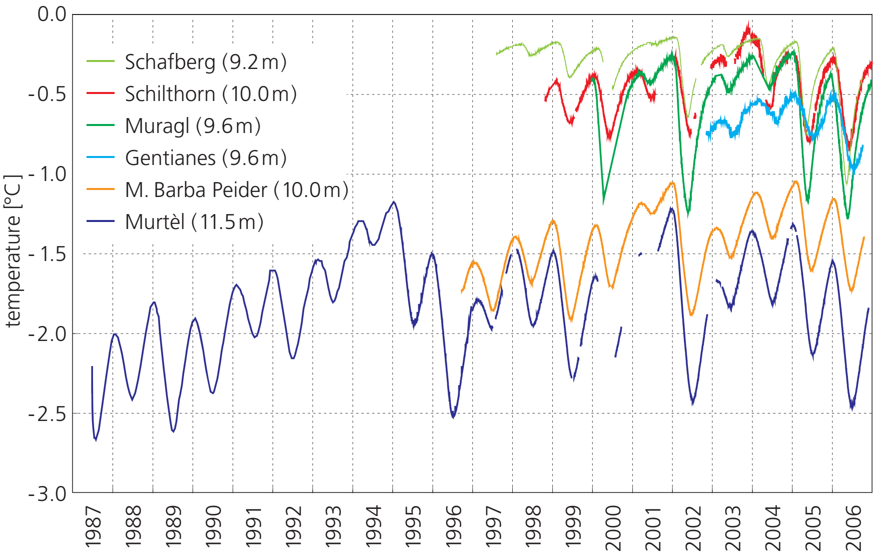
The measurement sites are divided into three categories: A sites have been included in the PERMOS programme and operations will continue; B sites will initially continue to be operated and will be re-evaluated in 2009; C sites are no longer included in PERMOS.

Long time series and their importance

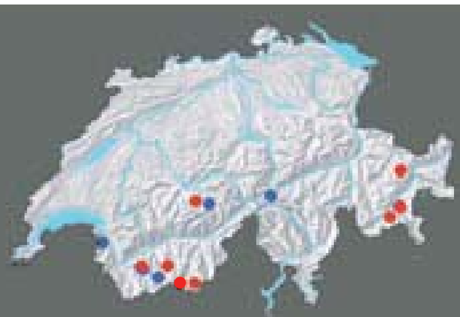
PERMOS was established by a number of university-based partner institutes in the 1990s. The longest time series are long, even compared internationally. The stations operated within the PERMOS network are of major importance for the Swiss GCOS Office, as the quality and long-term continuation of measurements is assured at these sites. The existing stations were mainly set up in the course of research projects addressing process-related questions, but they are also available for monitoring purposes. This also explains the division into categories: A sites are being maintained as a priority and methodologically and technically standardized, while B sites are to be operated until 2009 and then re-reviewed. Expansion of the network is planned for the medium term in connection with various activities. Ideally, there should be at least two PERMOS stations in each alpine climate region.

Permafrost temperatures from six boreholes 1987 – 2006

Monthly average in °C at a depth of around 10m



These series of permafrost temperatures measured at a depth of around 10m in six selected boreholes reveal three periods of warming, with interruptions in 1995/1996 and 2002. It takes about half a year for the signal to penetrate to this depth. As short-term daily fluctuations are not noticeable at this depth, seasonal variation is clearly apparent. Permafrost temperatures depend in particular on winter snow conditions and summer air temperatures (Vonder Mühll et al., 2007).



The permafrost monitoring network PERMOS. A sites (red); B sites (blue). As the stations were a product of research projects, their distribution is geographically heterogeneous.

International integration

In the context of international research and monitoring activities, PERMOS is a component of the Global Terrestrial Network for Permafrost (GTN-P), which is currently being established within GCOS/GTOS. Here, in addition to in situ measurements, increasing use is to be made of remote sensing data and numerical modelling in space and time.

The EU Permafrost and Climate in Europe (PACE) project also contributed to GTN-P. This project involved studies at nine boreholes, including three Swiss sites.

Resources required

The funding of PERMOS measurements and of the coordination office is assured until the end of 2010 under an agreement between FOEN, SCNAT and MeteoSwiss. Subsequently, the proportion of permafrost measurement sites required for climate monitoring is to be funded by the Swiss GCOS Office.

http://www.permos.ch

3.9 Land use

Each year, about 4000 ha of land in Switzerland undergoes a change of use. This transformation influences the regional climate. The climate system is affected by the release or uptake of greenhouse gases associated with changes in land use. Information on historical and current conditions is needed to determine the effects of land use change on the climate.

§ Legal basis

Under the Federal Statistics Act (BStatG; SR 431.01), the federal authorities are required to obtain representative data, in a scientifically independent manner, on the state and development of the population, economy, society, land and environment in Switzerland. The Federal Statistical Office (FSO) is the national responsible agency. The principles governing the collection of statistical data are specified in the Ordinance on the Conduct of Federal Statistical Surveys (SR 431.012.1).

Measurements in Switzerland

The FSO Land Use Statistics record changes in land use every 12 years on average. For this purpose, aerial photographs produced by the Federal Office of Topography (swisstopo) are analysed. As of spring 2007, results of the third survey period (2004–2009) are available for 16 % of the total area of Switzerland. The latest survey employs 46 different categories of land use and 27 of land cover. Comparability with earlier data is assured by the definition of 72 basic categories. The first two surveys, conducted in 1979–1985 and 1992–1997, are being reviewed according to the current method and adapted to the new nomenclature.

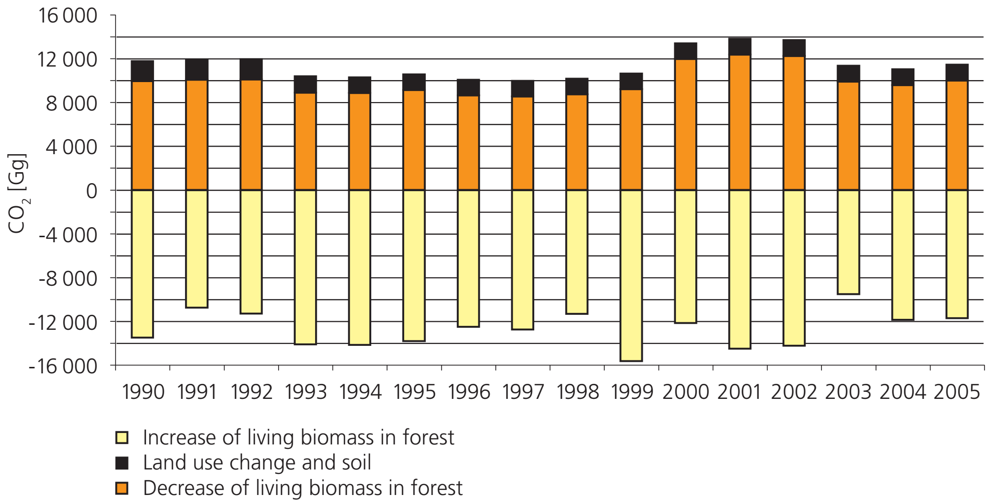
As transboundary environmental policy calls for a reliable, objective and comparable information base, the 1979/85 Swiss Land Use Statistics were integrated into the European CORINE (Coordinated Information on the Environment) Land Cover 1990 statistics. The datasets differ in the definition of land use types, nomenclature and spatial resolution. With the CORINE Land Cover 2000 project CLC2000, supported by the European Union and the European Environment Agency (EEA), an updated database on land use and land use changes across Europe is now available. The Swiss Land Use Statistics are to be integrated into the CLC2000 database. With support from the European Space Agency (ESA), CLC2000 is being updated with satellite data from the GlobCover project, part of the Data User Element programme. At the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Land Resource Assessment Unit compares CORINE data with forest inventory data and global satellite products. In order to preserve nationally protected ecosystems, landscape surveys are conducted by various project partners (e.g. WSL) on behalf of the FOEN.

Long time series and their importance

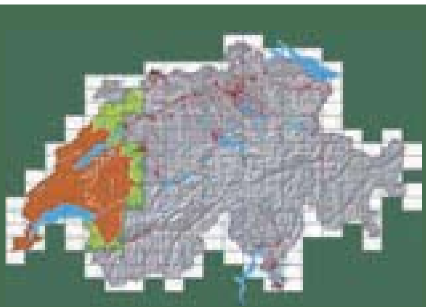
Swiss land use surveys were previously carried out in 1912, 1923/24, 1952 and 1972. However, owing to inconsistencies in these surveys, changes in land use cannot be reliably determined over these periods. The re-analysis of the 1979/85 and 1992/97 Land Use Statistics according to the methodology used for the current survey makes all three datasets directly comparable with each other, permitting statistically based conclusions on land use changes over a lengthy period (1979–2009). This also provides an excellent basis for determining carbon balances for the Greenhouse Gas Inventory.

CO_2 balance for land use changes in Switzerland 1990 – 2005

Sources and sinks in gigagrams



CO_2 emissions (+) and removals (-) associated with land use, land use change and forestry (FOEN, 2007). The greenhouse gas balances calculated show that, on average, land use has acted as a sink in Switzerland since 1990. However, there are large variations from year to year, determined by two factors in particular: (a) the occurrence of severe storms (windthrow) and (b) the occurrence of hot and dry summers (little new growth). In future, the use of energy wood for heat and power production will be a decisive factor.



Status of the 3rd survey period (July 2007) of the Swiss Land Use Statistics (2004–2009). Orange: cantonal data (15 %); light green: communal data (19 %); dark green: geographical data (21 %).

International integration

As a signatory to the UN Framework Convention on Climate Change (UNFCCC), Switzerland has a commitment to compile a national inventory of sources and sinks of greenhouse gases each year, taking 1990 as the base year. The FOEN is responsible for this task. A greenhouse gas balance for "Land Use, Land Use Change and Forestry" (LULUCF) has to be prepared in the greatest possible detail according to guidelines issued by the IPCC. A particularly precise carbon balance is required for the forest sector. This is based on data from the Land Use Statistics and the National Forest Inventory.

Resources required

The latest available data are published in the Land Use Statistics and made available to various users as geographical basic data. These data, broken down by region, are indispensable for LULUCF. These activities are governed by the Statistics Act.

3.10 Forest ecosystem

Forests are not only a natural resource – they also fulfil protective and recreational functions. A changing climate affects forests by altering the length of the vegetation period – affecting the future distribution limits of individual tree species. With long-term observations, impacts on the forest ecosystem can be assessed.

§

Legal basis

With the partial revision of the Federal Forest Act (WaG, SR 921.0), the Federal Council intends to safeguard the forest's protective function and natural diversity over the long term. Federal forest policy is based on the Swiss National Forest Programme (WEP-CH) from 2002/03. The Forest Act and Ordinance are further elaborated in circulars addressed to the cantonal enforcement authorities. The Federal Office for the Environment (FOEN) supports forest monitoring projects developed by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). Under the ETH Board Ordinance on Research Institutes of the ETH Domain (SR 414.161), the WSL is responsible for forest ecology activities.

Measurements in Switzerland

Since 1985, the state of Switzerland's forests has been documented by the Sanasilva Inventory, which focuses on tree health. These surveys are carried out in July and August, using a 16 x 16 km sampling grid (approx. 50 study sites). The main characteristics assessed are (a) crown transparency, (b) crown discoloration and (c) mortality; growth rates are studied by the National Forest Inventory (LFI).

Under the federal Long-term Forest Ecosystem Research (LWF) project, more intensive and wide-ranging studies have been pursued since 1994 as part of an integrated approach to forest monitoring. At 18 monitoring sites (LWF plots) in Switzerland, (a) external anthropogenic and natural influences (air pollution, climate) are evaluated, (b) changes in important components of the forest ecosystem are assessed, (c) forest health indicators are developed, and (d) comprehensive risk assessments are conducted under various stress scenarios. To this end, numerous site-specific variables are permanently monitored. On the LWF plots, meteorological measurements are carried out automatically according to international standards, with one station located in the stand and a second in a nearby unstocked area. In addition, stand, vegetation, soil and nutrient data are collected at varying temporal resolution (hourly to yearly). At the Seehornwald research station (Davos), microclimate and tree physiological data have been recorded for two decades. Covering a period of about 10 years, almost continuous records of gas exchange rates are available for a forest patch and for individual trees and branches. Over the same period, stem radius changes and sap flow rates have also been continuously measured.

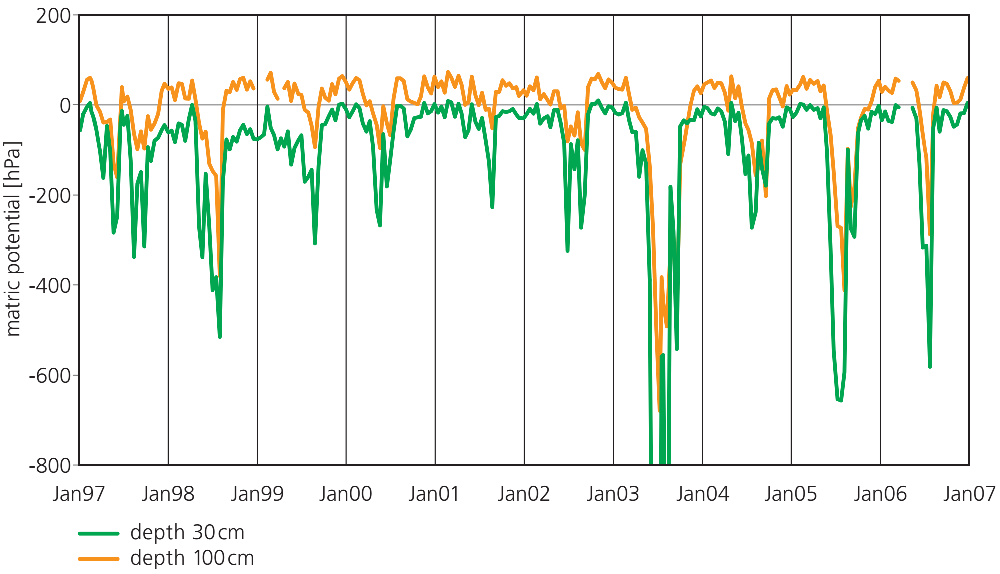
Other specific areas are being studied as part of forest fire ecology projects (→ 3.11 Forest fires).

Long time series and their importance

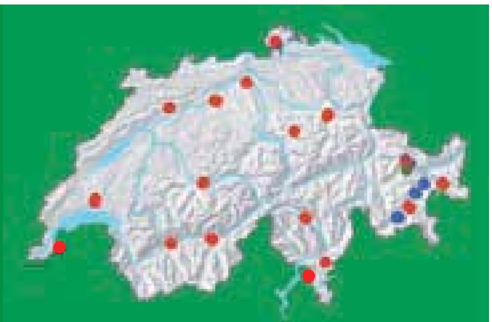
The LWF project, involving permanent monitoring and experimental sites, improves our understanding of the impacts of air pollution and climate change. The systematic sampling grid of the Sanasilva Inventory has become less dense over the years. Around 8000 trees were surveyed at 700 points in a 4 x 4 km grid in the period from 1985 to 1992; around 4000 trees in an 8x8 km grid in 1993, 1994 and 1997; and around 1100 trees in a 16 x 16 km grid in 1995, 1996 and from 1998 onwards. In addition to the measurements at these sites and the LWF plots, bioclimatological studies are carried out at the subalpine experimental afforestation site on the Stillberg mountain near Davos. Here, microclimatological variables have been studied at four plots since 1975. In larch stands in the Engadine and near Davos, measurements of needle growth have been performed since the 1960s to determine how the development of this tree species is affected by the larch bud moth and by climate change.

Water availability for vegetation 1997 – 2006

Soil matrix potential in hPa at the LWF Vordemwald site (Central Plateau, 480 m a.s.l.)



Water availability for vegetation at the LWF Vordemwald site, 1997–2006. The lower the values, the more difficult it is for trees to extract water from the soil. On the LWF plots, the matrix potential is measured to study the effects of drought on trees. The drier it became in 2003 (an exceptionally hot year), the greater the decrease in tree growth compared with the wet 2002 (Graf Pannatier et al., 2007). With long-term monitoring of the matrix potential, it is possible to demonstrate the effects of climate change on soil water availability for vegetation.



The 18 LWF research plots (red), the Stillberg experimental afforestation site (green) and the larch sites in the Engadine (blue).

International integration

The aims of the LWF project are in agreement with those of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). This programme was launched in 1985 under the Convention on Long-range Transboundary Air Pollution (CLRTAP) of the United Nations Economic Commission for Europe (UNECE). The various measurements are submitted yearly to the Joint Research Centre (JRC) at Ispra (Italy) and to the ICP Forests Programme Co-ordinating Centre in Hamburg. Other data are used for reporting to the Ministerial Conference on the Protection of Forests in Europe (MCPFE) Criteria and Indicators. The LWF is part of the International Long-Term Ecological Research Network (ILTER).

Resources required

Continuation of the LWF and Sanasilva surveys is assured in the medium term. Depending on the resources available, the Stillberg site can be studied more or less intensively. The larch studies are guaranteed over the long term.

http://www.wsl.ch/forschung/forschungsprogramme/target/oekologie/index_EN

3.11 Forest fires

Forest fires may be caused either by human activities or by natural factors. The effects of a lack of precipitation and insufficient moisture can persist over several years. Fires impair the protective function of forests. The regional forest fire risk may be affected by changes in climate.

§

Legal basis

Under Article 77 of the Federal Constitution (SR 101), the federal authorities are required to ensure that forests can fulfil their productive, protective and welfare functions. According to the Forest Act (WaG, SR 921.0), forests must contribute to the protection of human life and assets. Under the Forest Ordinance (WaV, SR 921.01), the cantons are required to take measures against causes of damage that may endanger forests, including the establishment of permanent fire prevention facilities. Cantonal forest services monitor forest fire risk levels and prohibit fire lighting in or near forests. Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the Federal Office of Meteorology and Climatology (MeteoSwiss) is responsible for issuing forest fire risk warnings.

Measurements in Switzerland

Forest fire statistics are an indispensable instrument for forest and fire services planning fire-fighting facilities and prevention measures. With forest fire data going back years or even decades, analyses of various kinds can be carried out: (a) to identify areas or forest types particularly susceptible to forest fires, (b) to assess the forest fire risk on the basis of meteorological conditions (risk index) as an aid to decision-making concerning fire bans, (c) to optimize prevention measures, and (d) to assess the historical effectiveness of changes in forest fire control. In general, forest fire behaviour can be classified into four types: surface fire, crown fire, spot fire and ground/root fire. In 1993, as part of the National Research Programme NRP 31, the WSL established a forest fire database for southern Switzerland (canton Ticino, southern Simplon region and Graubünden southern valleys). By 2006, information on more than 6600 forest fire events had been stored in this database, in some cases dating back to the 19th century. From 1980, forest fires were also systematically recorded by canton Graubünden (approx. 350 records by 2004). In the cantons of Valais and Uri, data on the most relevant forest fires since the beginning of the 20th century were compiled through archive research carried out by the forest and fire services. The database is centrally managed by the WSL, so that data can be used in particular for research purposes.

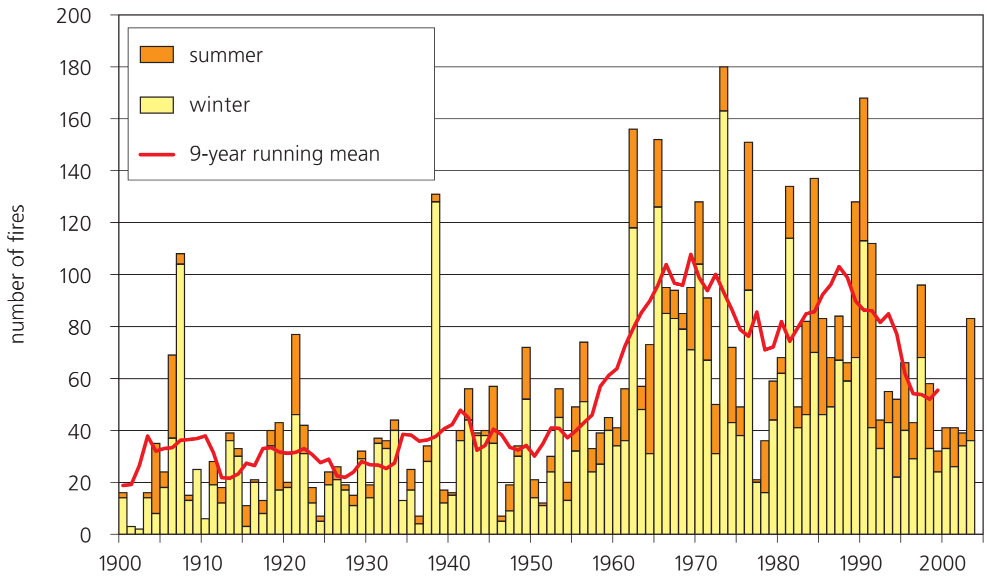
Global forest fire maps are produced using satellite data and integrated into the World Fire Atlas. It is based on data from the radiometers ATSR and AATSR onboard the ESA satellites ERS-2 and Envisat. The Standard Forest Fire Product based on MODIS data is a contribution to the GTOS programme Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD).

Long time series and their importance

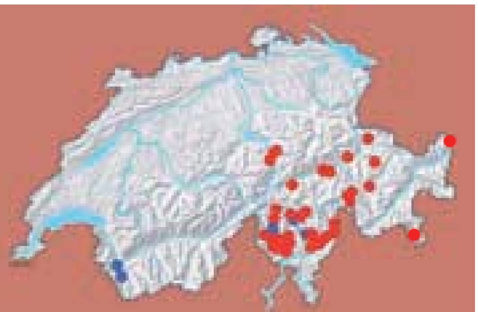
The long-term forest fire statistics held in the central WSL database are valuable for analysing forest fire trends for specific regions over lengthy periods. Ultimately, data is to be recorded nationwide. One such analysis, albeit restricted to 20 years, concerns the distribution of lighting-induced fires in the Alps. A spatial distribution pattern also provides information on fire perimeters and the fire regimes in the region concerned. At the same time, the distribution of a specific type of forest fire can be analysed, e.g. the points of origin of lightning fires in the hot summer of 2003. In a WSL project designed to study ecological resilience after fire in Central Alpine valleys, the forest fire patch of Leuk is the subject of a long-term monitoring study. Here, local weather conditions have been recorded since 2004, as in LWF monitoring (→ 3.10 Forest ecosystem), and vegetation and biodiversity have also been studied.

Forest fires in southern Switzerland 1900 – 2003

Number of fires, by season



The yearly statistics for the period 1900–2003 come from the database on forest fires south of the Alps. In the 20th century, the average number of fires per year occurring south of the Alps increased from 30 to 80 from the 1960s onwards. Since the 1990s, the number of forest fires has declined again. The exceptional events of 1973 led to a reorganization of the Ticino fire service. Thanks to this reorganization, the yearly burned area decreased markedly from 1980 (Conedera et al., 1996).



Starting points of forest fires caused by lightning in the summer of 2003: high (red) and low (blue) degrees of certainty as to the time of inception.

International integration

The Global Fire Monitoring Center (GFMC) provides early warnings and monitoring of fire events and archives global fire information. The GFMC is based at the Max Planck Institute for Chemistry at Freiburg and is supported by the German Federal Foreign Office, the Federal Ministry for Education and Research, and the UN International Strategy for Disaster Reduction (ISDR). The GFMC publication International Forest Fire News regularly includes reports from the WSL. In addition, the WSL is a new member of the European Commission's Forest Fire Expert Group.

Data from the European Forest Fire Information System (EFFIS) are published by the European Commission.

Resources required

Routine maintenance of forest fire statistics is assured by the WSL. Upgrading or expansion of the database is carried out in projects requiring separate funding.

http://www.wsl.ch/waldbrand

3.12 Phenology

Plant growth and development are strongly influenced by climatic conditions. Accordingly, the trends observed in phenological time series are largely attributable to climate warming in recent decades. The results of phenological observations are in particular applicable in healthcare (pollen forecasts) and in agriculture.

§ Legal basis

Under the Federal Act on Meteorology and Climatology (MetG, SR 429.1), the federal authorities are required to record meteorological and climatological data continuously throughout Switzerland. In addition, they are responsible for the implementation of measures contributing to the long-term preservation of an intact environment. The Federal Office of Meteorology and Climatology (MeteoSwiss), which is responsible for these tasks under the Federal Ordinance on Meteorology and Climatology (MetV, SR 429.11), conducts detailed phenological observations. Also involved in phenological aspects of biodiversity, agriculture and healthcare are the Federal Office for the Environment (FOEN), the Federal Office for Agriculture (FOAG) and the Federal Office of Public Health (FOPH).

Measurements in Switzerland

The first phenological observation network in Switzerland was created in 1760 by the Economic Society of Bern. About 100 years later, from 1869 to 1882, the Forest Agency of canton Bern carried out a phenological observation programme in forests.

A national phenological monitoring network was established by MeteoSwiss in 1951. This now comprises some 160 stations, distributed across various regions and elevations of Switzerland. The lowest-lying station is located in Ticino (Vira) at 210 m a.s.l., and the highest-altitude station is in the Engadine (St. Moritz) at 1800 m a.s.l.

Each year, observers record the dates of leaf unfolding (needle appearance), flowering, fruit ripening, leaf colouring and leaf fall for selected wild plants and crops. These observations cover 26 plant species and 69 phenophases. In 2001, MeteoSwiss also took over the forest phenology programme initiated by the FOEN.

Trees, shrubs and herbs are taken as the most significant indicators of climatic changes: beech, hazel, larch, spruce, lime, wood anemone, dandelion and daisy. Observations are passed on to MeteoSwiss at the end of the year for use in studies on the long-term effects of the climate on plant development. To permit conclusions on the current state of vegetation, data are submitted immediately for certain phenophases. These provide a basis for reports on vegetation status.

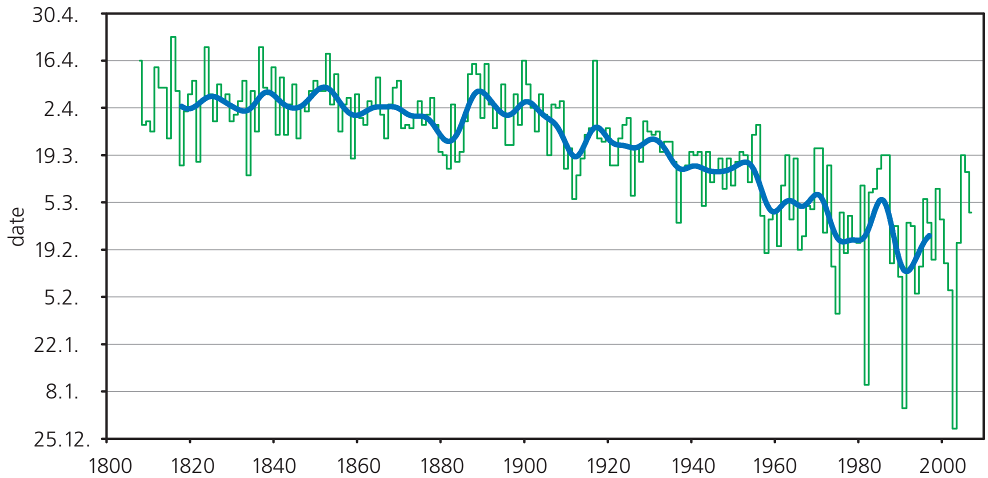
Observations of pollen distribution – another phenophase – are of major public health relevance. They are carried out by the National Pollen Monitoring Network NAPOL (→ 2.13 Pollen).

Long time series and their importance

Since 1808, the bud burst date for horse chestnut has been recorded in Geneva. This is Switzerland's longest phenological time series. Of equal importance is a second historical series – cherry tree flowering dates at the rural Liestal station – which goes back to 1894. Observations from the stations of the national phenological monitoring network are more recent, going back to the beginning of the 1950s. The selection of the country's most important observation sites includes a wide variety of regions and elevations, taking into account the quality of observations of tree, shrub and herb phenophases, preferably of long duration. Twelve of the most important sites are Liestal, Davos, Enges, Murg, Prato-Sornico, Rafz, Sarnen, St. Moritz, Trient, Valsainte, Versoix and Wildhaus.

Horse chestnut bud burst Geneva 1808 – 2007

Dates of onset and running average



The onset of horse chestnut bud burst in Geneva varies widely. In 1816, for example, it was observed on 23 April, while for 2003 it was already recorded on 29 December 2002. From around 1900, a clear trend towards earlier onset is obvious. This is attributable not only to global climate change, but also to changes in the local city climate (Defila and Clot, 2001). Given the strong temperature dependence of plant development, phenological time series are good indicators of the impacts of climate change.

The main sites for phenological observations in Switzerland, covering a variety of regions and elevations, where long observation series of tree and shrub phenophases are available.

International integration

Switzerland is part of the European Phenology Network (EPN), and the Birmensdorf WSL site participates in the European International Phenological Gardens (IPG) observation programme. In addition, under COST-725, joint efforts are being undertaken to harmonize observation guidelines and to build a European reference data set. The Global Observation Research Initiative in Alpine Environments (GLORIA) aims to establish a worldwide long-term observation network of sites collecting data on vegetation in Alpine environments. Switzerland is contributing to this initiative with two sites – one in the National Park and one in Valais.

Resources required

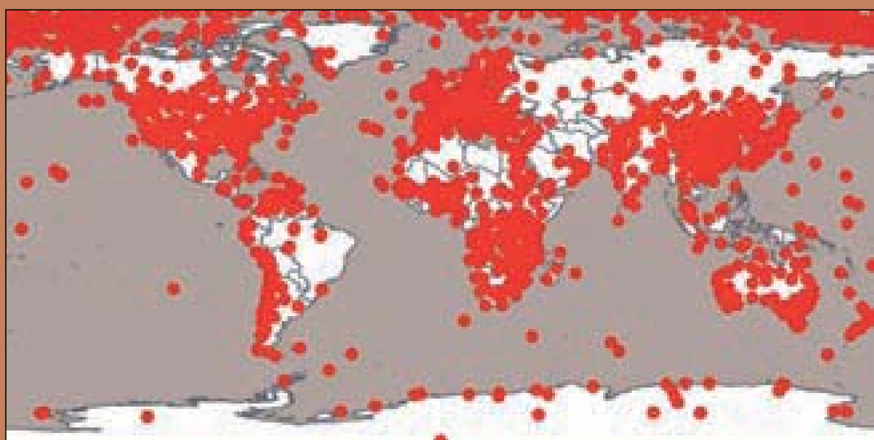
The Geneva and Liestal sites are not part of the phenological monitoring network; as they are operated on a voluntary basis, the observations are not considered to be guaranteed. In contrast, the continued operation of the twelve main phenological stations is assured under the legal mandate of MeteoSwiss.

http://www.meteoswiss.ch/web/en/climate/climate_since_1864/phaenologie.html

4.1 GEBA

The Global Energy Balance Archive (GEBA) systematically stores data on energy fluxes from around 1600 stations worldwide. Energy fluxes at the earth's surface largely determine global heat transport and atmospheric circulation. To understand the climate and climatic changes, therefore, a detailed knowledge of the variations in the energy balance is essential.

Global measurements



The GEBA database holds about 250,000 records of monthly mean energy fluxes measured at 1600 stations worldwide.

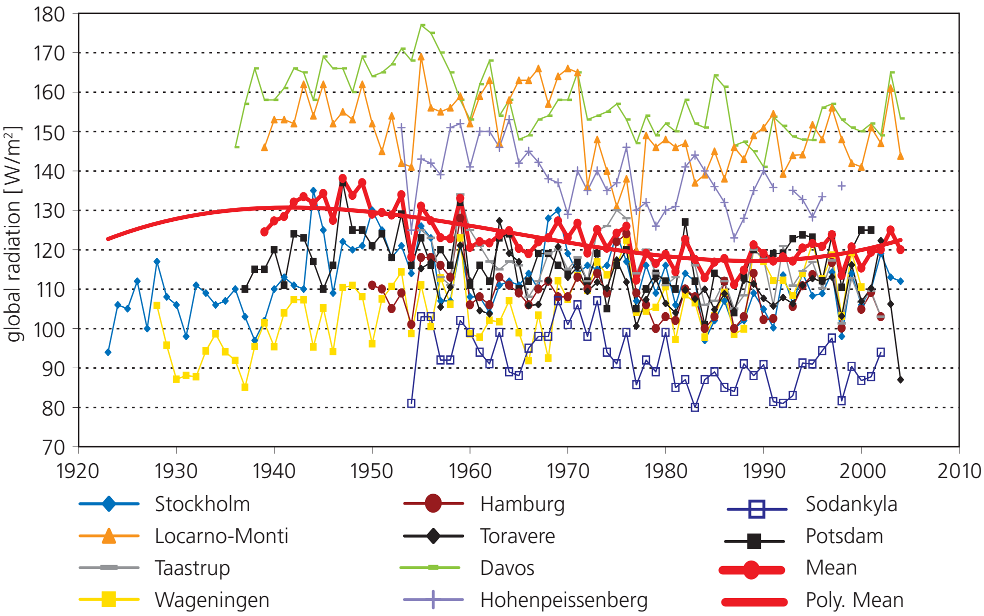
The first version of the Global Energy Balance Archive (GEBA) database was implemented at the ETH Zurich in 1988. In 1991, the database was first made available to the global scientific community. In 1994/95, GEBA was redesigned and a large amount of data was added. The

Importance for GCOS

The data stored in GEBA serve a variety of important functions in climate research: (a) validating radiation products derived from satellite data, (b) validating surface energy fluxes simulated by general circulation models, (c) studying absorption of solar radiation by clouds and (d) evaluating the impact of aerosols released from forest fires in equatorial regions. The longest energy flux data series come from European sites – Stockholm, Wageningen, Davos, Potsdam and Locarno-Monti. At these five stations, radiation measurements began before 1940. To date, observations have already been analysed from 380 stations worldwide with time series covering more than 40 years. The GEBA energy balance components are of fundamental importance in understanding other processes in the climate system (including the cryosphere).

Global radiation at 10 European stations from the GEBA database

Annual means in W/m²



Changes in annual mean global radiation at 10 European stations included in the GEBA database where radiation measurements are available going back at least 50 years. The analysis shows that between 1960 and 1990 solar radiation at the Earth's surface declined by several per cent (global dimming), and that this trend has been reversed over the past 10–15 years (global brightening). The two longest data series (Stockholm and Wageningen) show an increase in global radiation of about 20 W/m² between 1922 and 1952 (Ohmura, 2006).

database is regularly updated, with great importance being attached to a series of quality control procedures. The archive currently contains 250,000 records of monthly mean energy fluxes measured at 1600 stations worldwide. GEBA incorporates various energy balance components, with a total of 19 different variables. These include, for example, global radiation, short- and long-wave radiation and turbulent heat fluxes.

It should be noted that the values have been and are measured using different instruments. In addition, at most sites, instruments have been replaced over the years. Data consistency and details of changes in instrumentation are integrated into GEBA as station history data – an important element in data analysis.

Responsibility

Since November 1986, the Global Energy Balance Archive (GEBA) has been a World Climate Programme (WCP) project under the lead of the World Meteorological Organization (WMO), UNESCO and the International Council for Science (ICSU). The database is located at the Institute for Atmospheric and Climate Science (IAC) at the ETH Zurich.

Resources required

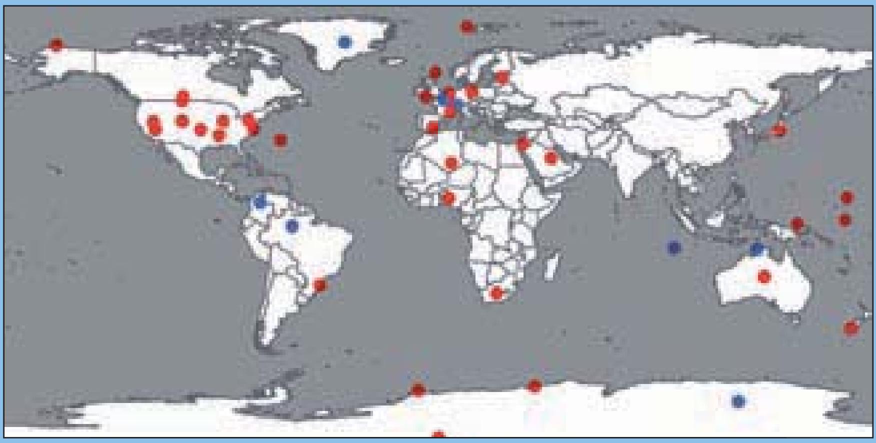
Continued operation of GEBA at the ETH Zurich is no longer assured from 2008. Swiss GCOS Office funding will be required to maintain and regularly update the GEBA database and to ensure that it is readily accessible for the scientific community.

http://bsrn.ethz.ch/gebastatus

4.2 BSRN

The Baseline Surface Radiation Network (BSRN) is the global baseline network for monitoring the radiation field at the Earth's surface. Global changes in radiation fluxes can only be reliably determined on the basis of consistent, long-term, high-quality observations – hence the importance of systematic archiving of data.

Global measurements



Baseline Surface Radiation Network (BSRN) monitoring sites. Red: operational BSRN stations; blue: planned BSRN stations.

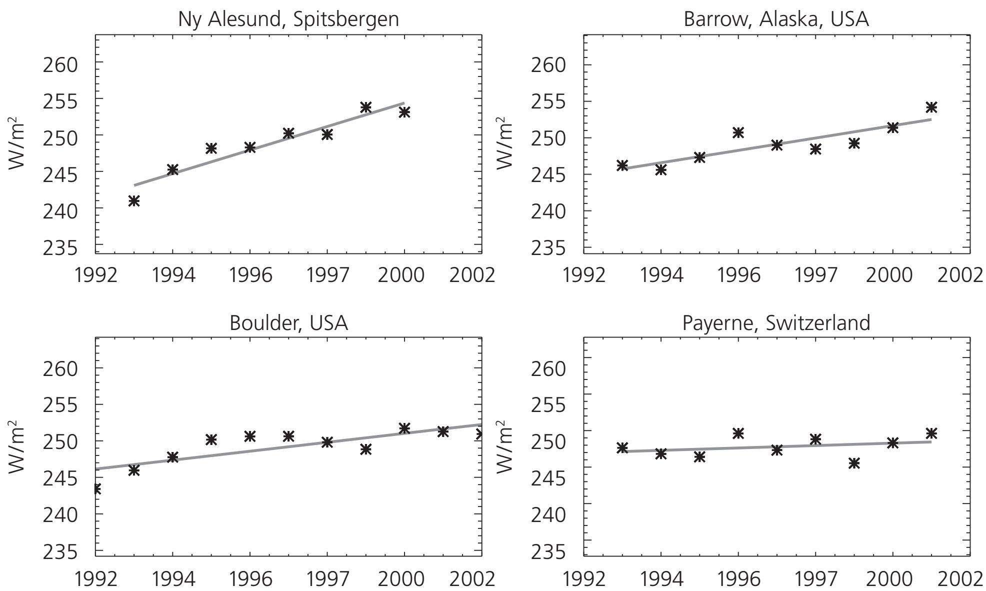
At 38 BSRN stations distributed across all climatic zones, at latitudes between 80° N and 90° S, all the components of solar and atmospheric radiation are measured. These measurements are carried out with instruments and methods providing the greatest possible accu-

Importance for GCOS

The combination of global operational observations and continuous quality control and archiving offers a unique potential for studying climate-related questions. These global datasets can be used for calibration and validation of satellite products (e.g. for surface radiation fluxes, → 2.5 Radiation) and of global climate model simulations. In addition, local measurements can be used in the derivation of regional radiation climatology. The BSRN permits continuous recording of changes in the radiation budget caused by natural and human factors. Since the BSRN has been designated as a GCOS baseline network, efforts are being made to ensure that the GCOS monitoring principles are increasingly applied (e.g. establishment of new BSRN stations in underrepresented regions of the world).

Solar radiation at four BSRN stations 1992 – 2002

Annual means in W/m²



Changes in solar radiation observed at selected BSRN stations over the period 1992–2002. Analysis indicates that the reversal in the surface solar radiation trend observed since the mid-1980s (global brightening) is confirmed by BSRN measurements carried out worldwide since the early 1990s. Studies at 19 BSRN stations show an increase of 0.47 W/m² per year for the period 1992–2004. This reversal may be attributable not only to changes in cloud cover but in particular to widespread improvements in air quality (Wild et al., 2005).

racy, so that data can be collected with a temporal resolution of one minute.

The global BSRN measurements are stored at the World Radiation Monitoring Center (WRMC), which is based at the Institute for Atmospheric and Climate Science (IAC) of the ETH Zurich. Before being integrated into the archive, the data undergo a variety of quality control procedures. As well as radiation data, other surface and upper air observations (varying from station to station) are stored in the database. At present, users can access data from 38 stations, with more than 3400 monthly data files available (as of the end of 2006).

In addition, a number of sites not currently participating in the BSRN are candidates for future inclusion.

Responsibility

The BSRN is a project of the World Climate Research Programme (WCRP) aimed at detecting global changes in the Earth's radiation field. The WCRP is sponsored by the World Meteorological Organization (WMO), UNESCO and the International Council for Science (ICSU). The BSRN is part of the WCRP subprogramme Global Energy and Water Cycle Experiment (GEWEX). The GEWEX programme is run by a Scientific Steering Group, which is responsible for research planning and thus significantly influences the development of the BSRN. The Institute for Atmospheric and Climate Science (IAC) at the ETH Zurich is responsible for archiving of the global BSRN data.

Resources required

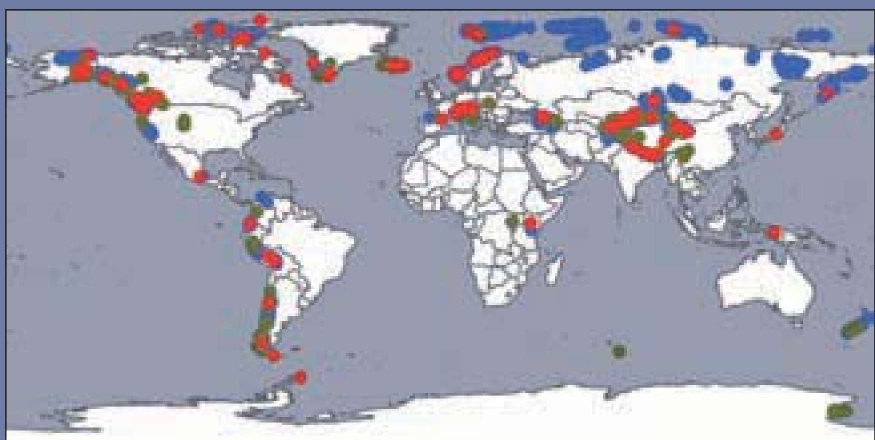
From 2008, continued operation of the BSRN archive at the Institute for Atmospheric and Climate Science (IAC) at the ETH Zurich is no longer assured. Funding to ensure the continuity of this GCOS reference archive should be provided as far as possible through the Swiss GCOS Office.

http://bsrn.ethz.ch

4.3 WGMS

The activities of the World Glacier Monitoring Service (WGMS) are of crucial importance for climate observation. As well as being among the most sensitive climate indicators, glaciers play a key role in the regional water balance and contribute to rising global sea levels associated with climate change.

Global measurements



Observations collected by the World Glacier Monitoring Service (WGMS). Red: monitoring of mass balance; green: monitoring of changes in glacier length; blue: glacier inventory data. Data from the WGMS.

The WGMS manages an extremely comprehensive collection of data on glaciers, their characteristics and fluctuations over time. These regularly updated data are made available to scientists and the public. The database currently holds more than 34,000 length change

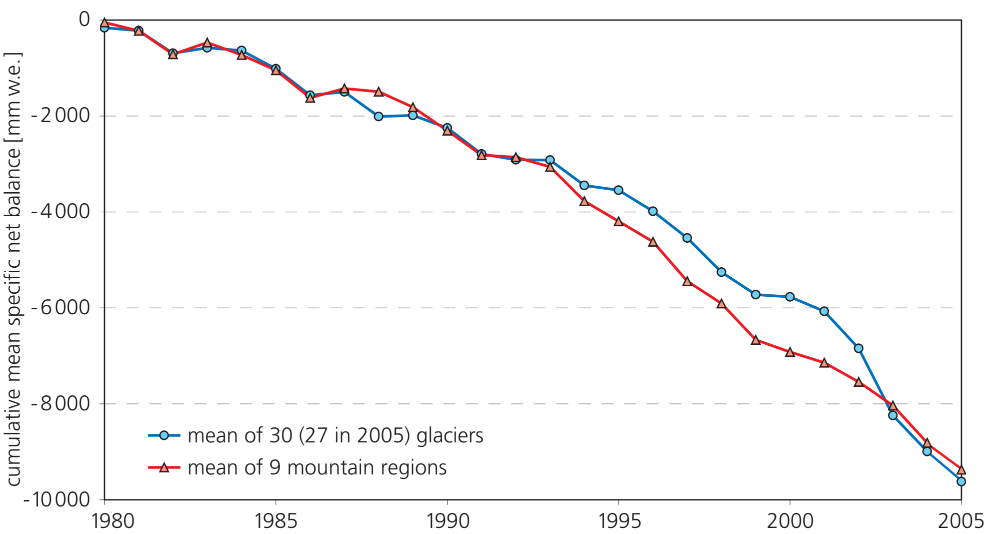
Importance for GCOS

The collection of data on glacier variation worldwide was initiated in 1894 with the establishment of the International Glacier Commission at the 6th International Geological Congress in Zurich. Since 1986, the Zurich-based WGMS has coordinated the international collection and publication of glacier data, and it is responsible for the Global Terrestrial Network for Glaciers (GTN-G) within GCOS/GTOS. The WGMS database currently includes 120 length change series and eight mass balance series for Swiss glaciers.

Satellite data are increasingly being used in the maintenance of the World Glacier Inventory. Remote sensing methods were developed in the Global Land Ice Measurements from Space (GLIMS) project and are now also being used in new initiatives such as the ESA Data User Element (DUE) GlobGlacier project or the International Polar Year (IPY) 2007/2008.

Mass balance for 30 glaciers worldwide 1980 – 2005

Cumulative mean annual net balance in mm water equivalent



Cumulative mean annual net balance for 30 reference glaciers (27 in 2005) and nine mountain ranges where mass balance has been monitored continuously since 1980. The glaciers are in North America (4), South America (1), Europe (19) and Central Asia (6). This internationally recognized index (cf. Haeberli, 2004; 2005) includes data on the Swiss glaciers Silvretta and Gries. The average annual thickness reduction of 0.6 m w.e. over the period 2000–2005 brings the average cumulative ice loss since 1980 to about 9.6 m w.e., confirming that climate forcing has continued (Zemp et al., 2007). Data from the WGMS.

measurements from 1725 glaciers and 3000 mass balance observations from 200 glaciers worldwide, extending back to the mid-19th and mid-20th century, respectively. Three products are published by the WGMS: firstly, the "Fluctuations of Glaciers" (FoG) series, presenting standardized data on changes in glaciers throughout the world, published at 5-yearly intervals; secondly, the "Glacier Mass Balance Bulletin" (GMBB), which reports mass balance measurements from selected glaciers worldwide every 2 years; and thirdly, the "World Glacier Inventory" (WGI), which contains information on more than 72,000 glaciers throughout the world. The parameters include geographical location, area, length, orientation, elevation and classification of morphological type and moraines.

Responsibility

The WGMS is a service of the International Association of Cryospheric Sciences (IACS) of the International Union of Geodesy and Geophysics (IUGG), and of the Federation of Astronomical and Geophysical Data Analysis Services of the International Council for Science (FAGS/ICSU). Internationally coordinated glacier observations began in 1894 and have been pursued since 1986 by the WGMS, now based at the University of Zurich. The WGMS maintains contacts with local researchers and national correspondents in all countries involved in glacier monitoring.

The WGMS makes an important contribution to the Global Terrestrial Observing System (GTOS) within the global climate observation programmes of major international organizations (UNEP, WMO, UNESCO and ICSU).

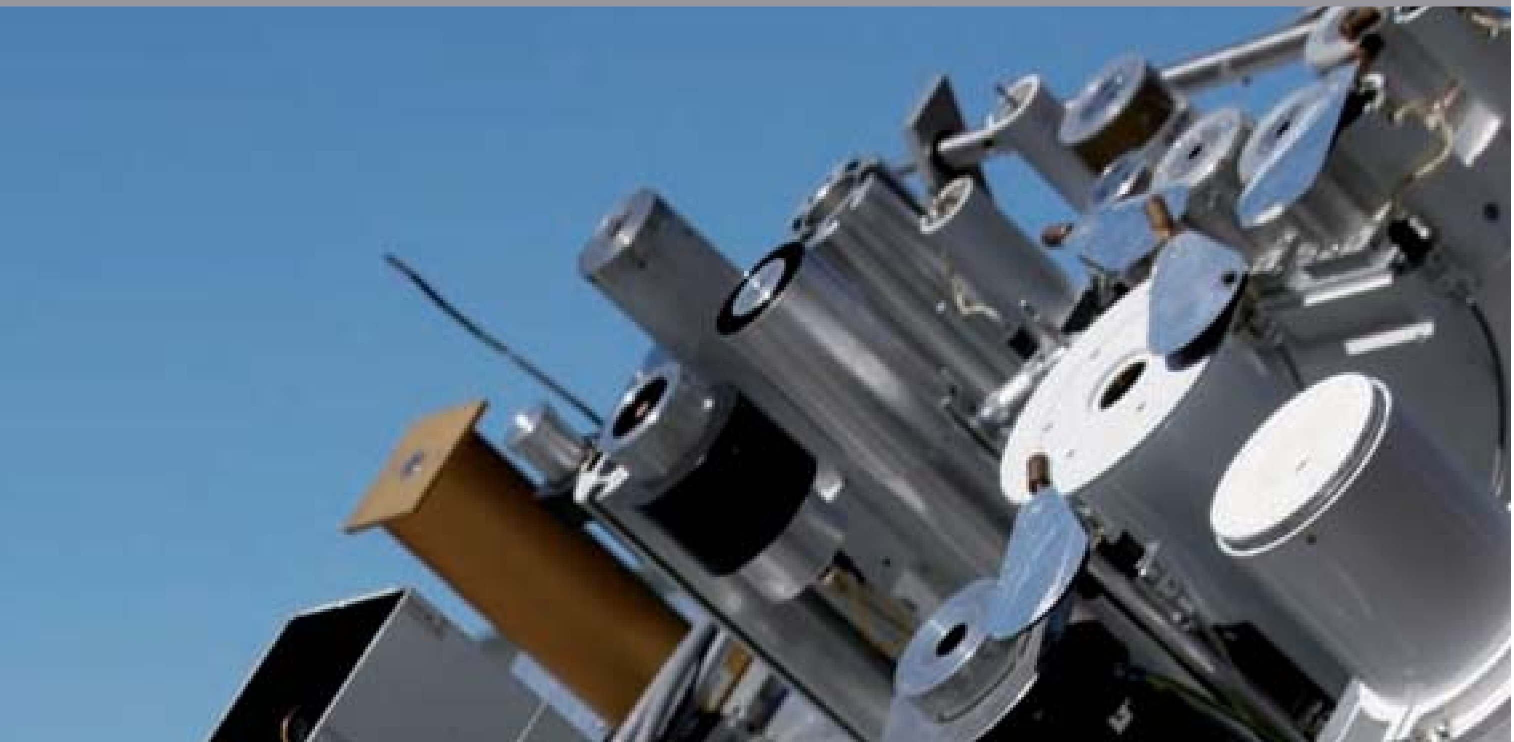
Resources required

Basic funding for WGMS is assured until March 2009 through the Swiss National Science Foundation and the University of Zurich. Thereafter, continuation of the already 110-year-old Swiss responsibility for worldwide glacier monitoring at the University of Zurich will require long-term funding through the Swiss GCOS Office. The justification for funding is based on the major importance of glaciers for national and international climate observation.

http://www.wgms.ch

4.4 Other centres

To determine state and variability of the climate system, measurements need to be globally standardized and meet the highest quality standards. With their reference instruments and regular calibration activities, international calibration centres make a vital contribution to the quality of global observation programmes.



World Radiation Center (PMOD / WRC)

The Physical Meteorological Observatory (PMOD) was founded at Davos in 1907 to carry out research in the field of solar radiometry and to study the effects of climate and weather conditions on humans, animals and plants. In 1971, the World Radiation Center (WRC) was established at the PMOD on the recommendation of the World Meteorological Organization (WMO). In 2006, the WMO Commission for Instruments and Methods of Observation (CIMO) resolved that the WRC should be divided into two sections, with two additional facilities.

Solar Radiometry Section (WRC-SRS)
The main responsibilities of the WRC-SRS Section are (a) to guarantee worldwide homogeneity of meteorological radiation measurements by maintaining the World Standard Group (WSG), which is used to establish the World Radiometric Reference (WRR); (b) to support the calibration of meteorological radiation instruments; (c) to promote research and development in radiometry and methods of observation of atmospheric radiation parameters; and (d) to provide training for radiation specialists.

Infrared Radiometry Section (WRC-IRS)
The Infrared Radiometry Section was originally established at the PMOD in 2004 on the recommendation of the CIMO and has been a Section of the WRC since 2006. The WRC-IRS is establishing an interim WMO Pyrgeometer Infrared Reference using the procedures and instrumentation that make up the World Infrared Standard Group (WISG) of pyrgeometers. The Section holds the global infrared radiation reference and thus defines the longwave infrared scale to which all longwave infrared radiation measurements should be traced. The role of the WRC-IRS is to disseminate this scale to the worldwide community either by individual instrument calibrations at the PMOD/WRC or through the creation of regional calibration centres with standards traceable to the WRC-IRS reference.

Additional facility: World Optical depth Research and Calibration Center (WORCC)
The World Optical depth Research and Calibration Center (WORCC) was established at the PMOD/WRC in 1996. Its tasks include: (a) development of a radiometric reference for spectral radiometry to determine atmospheric optical depth (AOD); (b) development of procedures to ensure worldwide homogeneity of AOD observations; (c) development and testing of new instrumentation and methods for AOD; (d) implementation of a pilot network at

http://www.pmodwrc.ch

World Calibration Centre WCC-Empa

The World Calibration Centre (WCC) for Surface Ozone, Carbon Monoxide and Methane (WCC-Empa) was established at Empa in 1996 at the request of the WMO. The goal of the WCC is to ensure that measurements carried out at different GAW stations are fully traceable to the designated reference. This is achieved by means of (a) close cooperation and regular intercomparisons with the central calibration laboratories and (b) regular system and performance audits at global GAW stations. In addition, the WCC offers assistance in the event of technical problems and provides on-site training. To date, the WCC has completed 44 audits at 18 stations worldwide. As well as improving data quality and increasing operators' technical know-how, these activities ensure the long-term evaluability of the data series for GCOS.

Quality Assurance/Scientific Activity Centre Switzerland

The GAW Quality Assurance/Scientific Activity Centre (QA/SAC Switzerland) was established at Empa in 2000 and is one of four such facilities worldwide. Although it focuses on surface ozone, carbon monoxide and methane, the scope of its activities covers additional measurements as well. The main tasks of QA/SAC Switzerland are (a) to support and audit the quality control system at global GAW sites, (b) to assist GAW sites with data quality issues and questions of data submission, (c) to promote the use of GAW data, and (d) to support capacity building in developing countries through training, workshops and scientific partnerships (twinning).

One major ongoing activity is the development and operation of the GAW Station Information System (GAWSIS), an interactive database application for integrating information on the GAW measurement programme. This includes station characteristics, metadata on available measurement data and contact information.

GAW global observatories to test measurement of AOD with precision filter radiometers; (e) development of quality control of data, in cooperation with the GAW Quality Assurance/Science Activity Centres (QA/SAC); and (f) training operators to use precision filter radiometers.

Additional facility: European Ultraviolet Radiometer Calibration Center (EUVC)

The European Ultraviolet Radiometer Calibration Center (EUVC) has been based at the PMOD/WRC since July 2005. It took over responsibility for this activity from the European Reference Centre for Ultraviolet Radiation Measurements (ECUV) at the European Commission Joint Research Centre (JRC) in Ispra (Italy). This handover also involved the transfer from the JRC of the transportable reference spectroradiometer QASUME. This unit was subsequently used as a UV reference in the first Brewer comparison, hosted by the GAW Regional Brewer Calibration Centre Europe in September 2005. In the COST-726 project (Long-term changes and climatology of UV radiation over Europe), the "Quality Control" Working Group is led by the EUVC. The goal of this Working Group is to homogenize UV measurements in Europe by defining common quality assurance and quality control procedures for the participating national and regional UV monitoring networks.

Euro-Climhist

Euro-Climhist is a database developed at the Institute of History at the University of Bern, including records of early instrumental measurements, weather reports and data on river freezing, snow cover, phenology and the impacts of natural disasters, as well as reports on perceptions of weather. The database is a valuable resource for analysis of the climate history of Switzerland and Europe, focusing on the 14th and 15th century. Altogether the database currently holds more than 1.2 million records, of which 620,000 are available in digital form. In addition, around 35,000 individual observations from pre-1500 Europe were processed in the EU Millennium project. The continuation of EuroClimhist is assured until 2009 through funding from the Swiss National Science Foundation, the National Centre of Competence in Research on Climate (NCCR Climate) and the University of Bern.

WCC, QA/SAC: http://www.empa.ch/gaw
Euro-Climhist: http://www.euroclimhist.com

5.0 Observations outside Switzerland

Introduction

In order to ensure an appropriate spatial distribution of climate-related observations, long-term, continuous time series are also required in developing countries. In these countries, the continuation of observations is more threatened than in Switzerland as a result of the often limited technical and financial resources available.

The observations in foreign countries described below are made possible by technical and/or financial support from Swiss institutions. A number of examples are given, but the list is by no means exhaustive. In future, support for national and regional programmes involving the observation of essential climate variables in developing countries should be expanded as far as possible.

Ozone (Kenya)

At the aerological station of the Kenyan Meteorological Department (KMD) in Nairobi, ozone soundings have been carried out under the direction of the WMO, the UN Development Programme (UNDP) and the UN Environment Programme (UNEP) since 1 May 1996. This site is part of the Southern Hemisphere ADditional OZonesondes (SHADOZ) network. SHADOZ, which is coordinated by the NASA Goddard Space Flight Center, is designed to produce consistent balloon-borne ozonesonde data on tropical tropospheric ozone. At the KMD station in Nairobi, weekly ozone soundings have been carried out continuously according to predefined standards since the project began. These observations are financially supported by the Federal Office of Meteorology and Climatology (MeteoSwiss) under the WMO Global Atmosphere Watch (GAW) programme.

Why is there a need for a denser ozone measurement network in the tropics? Firstly, while atmospheric ozone concentrations in these regions are influenced by numerous natural and human factors, the current spatial coverage of tropical ozone profiles is not sufficient to determine ozone trends. Ozone profiles are of fundamental importance in determining the chemical and dynamic processes influencing ozone concentrations. In addition, ozone profiles in the tropics play a key role in the validation of satellite data. A case in point is the validation of the new Total Ozone Mapping Spectrometer (TOMS) data in the summer of 2004. Here, the KMD Nairobi station supported by MeteoSwiss was the primary source of ozone profile data in Central Africa.

The local KMD team in Nairobi received and continues to receive training on ozonesonde operation from MeteoSwiss. A first level quality control and processing is performed at the KMD, a second level is carried out by MeteoSwiss in Payerne before the measurements are submitted to the international SHADOZ data centre at the NASA Goddard Space Flight Center. These data are an essential resource for the calibration and validation of satellite observations.

In addition, since May 2005, parallel measurements have been performed in Nairobi with the refurbished Dobson #18 spectrophotometer. The ozone column measured by the Dobson instrument and vertical ozone distribution measured by radiosonde are important complementary measurements. Each year, two MeteoSwiss staff members visit the station to provide training and to assure the quality of the various operational ozone measurement systems on site. According to the latest assessment of the data, the KMD ozone station now offers a continuous and reliable series going back more than 10 years, i.e. to May 1996, when observations began.

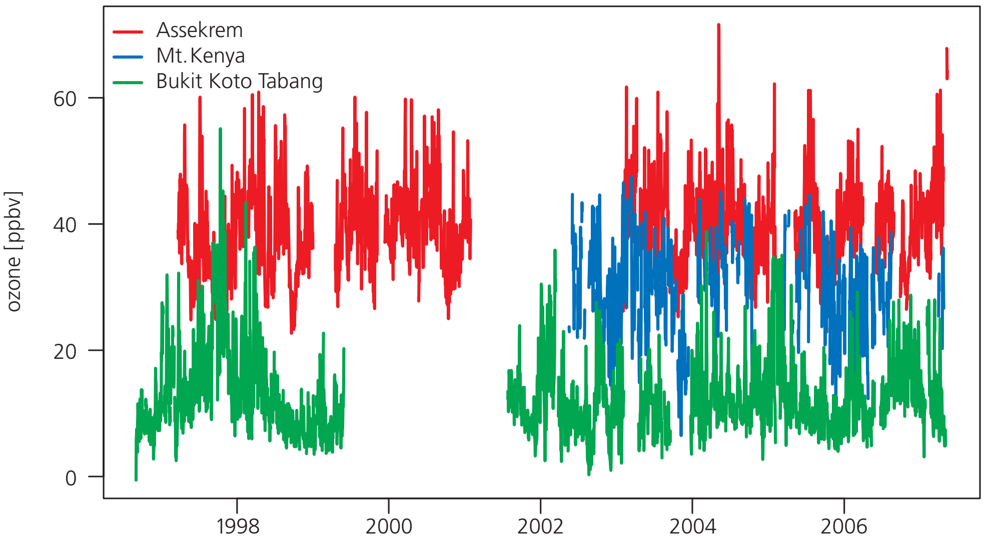
http://croc.gsfc.nasa.gov/shadoz/Nairobi.html

Trace gases (Kenya, Indonesia, Algeria)

The establishment of the global GAW stations Mount Kenya-Nairobi (Kenya), Bukit Koto Tabang (Sumatra, Indonesia) and Tamanrasset Assekrem (southern Sahara, Algeria) was initiated in the early 1990s by the WMO with support from the Global Environment Facility (UNDP, UNEP, World Bank) to fill evident gaps in the global surface observation network. These gaps were and are still located mainly in countries south of the equator, which are particularly vulnerable to the effects of climate change as a result of political, economic and social structures. At most of these stations, infrastructure and instrumentation were completed in the mid-1990s. After providing initial training for the station operators and operational support, the countries involved in setting up these stations rapidly withdrew following the early successes.

Surface ozone at three global GAW stations 1997 – 2007

Concentration expressed as ozone volume mixing ratio in parts per billion by volume (ppbv)



Surface ozone measured at three southern Saharan (Assekrem, Algeria, red) or equatorial global GAW stations (Mt. Kenya, Kenya, blue; Bukit Koto Tabang, Indonesia, green). On account of their elevation, Assekrem (2770 m a.s.l.) and Mt. Kenya (3678 m a.s.l.) show higher ozone concentrations than Bukit Koto Tabang (964 m a.s.l.). The varying mean concentrations reflect the complex interactions between ozone formation and destruction. Data: WDCGG, QA/SAC Switzerland.

Since the beginning of the 21st century, Empa has been responsible for two GAW functions co-financed by MeteoSwiss – the Quality Assurance/Scientific Activity Centre (QA/SAC Switzerland) and the World Calibration Centre for Surface Ozone, Carbon Monoxide and Methane (WCC-Empa) (→ 4.4 Other centres). In their efforts to ensure the continuation of these observations, the institutions focus in particular on quality assurance, training of station operators, replacement of instruments and scientific support.

The surface ozone and carbon monoxide measurements from these stations are the only continuous series available for the southern Sahara, equatorial Africa and equatorial Asia and are thus particularly valuable and worthy of protection. They are ideally complemented by the NOAA flask sampling programme. Nonetheless, there is an urgent need to supplement and independently validate weekly sampling with continuous measurements of the greenhouse gases methane and nitrous oxide, and of hydrogen.

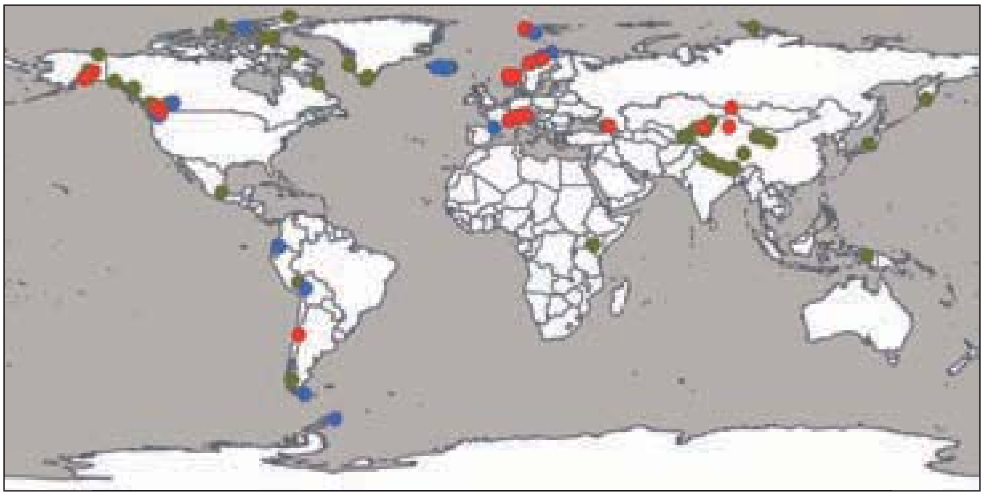
The importance of these stations for GCOS lies primarily in their geographical location and relatively sound infrastructure. They permit unique continuous atmospheric measurements – also allowing the determination of trends in these regions – which would hardly be possible with satellite-based observations alone.

Glaciers

Glacier mass balance is the direct and undelayed reaction to the prevailing atmospheric conditions in a year and is thus one of the most important indicators used in international climate monitoring programmes. Worldwide, as well as 30 long-term continuous mass balance series and 50 shorter series, around 120 interrupted series are available, covering periods of various lengths. The World Glacier Monitoring Service (WGMS) at the University of Zurich supports and actively promotes the continuation of the 30 long-term reference series and the resumption of a number of particularly valuable series, most of which were discontinued for political and/or financial reasons. In addition, new observations are being initiated in glaciated mountain ranges in the tropics and the southern hemisphere, as these two regions are currently underrepresented in the glacier monitoring network.

Mass balance observations worldwide

Long-term (red), recent (blue) and interrupted (green) data series



Glacier mass balance observations worldwide. Continuous series from 1980 onwards are available for 30 glaciers (red) in 9 mountain ranges. In addition, yearly mass balance measurements are available for about 80 glaciers (blue) for the period 2000–2005. Discontinued series of various lengths exist for around 120 glaciers (green). From a climatological and hydrological perspective, it is important that a number of these interrupted observation programmes should be reactivated as rapidly as possible in underrepresented regions.

The WGMS also offers technical support for glacier observations, particularly in developing countries, including assurance of compliance with international methods and standards, data quality control and training for glaciologists in the field. With support from the WGMS, new observations were recently initiated in Columbia and New Zealand. In addition, efforts are being made to secure the continuation of reference series in Alaska, which are at risk for reasons of financial policy. Foremost among the valuable series to be reactivated are measurements in Russia, the former Soviet republics, China, Kenya and the Himalayas.

Resources required

Funding of the ozone soundings in Nairobi (Kenya) is assured through the international component of the Swiss GAW programme.

The measurements of trace gases (surface ozone, carbon monoxide) in Kenya, Indonesia and Algeria are only partly assured through cooperation between MeteoSwiss and Empa. In the medium term (from 2010), additional funding will be required to maintain the series (instrumentation, capacity building). Expansion of the measurement programme, as is desired, to cover other substances of relevance for GCOS (methane, nitrous oxide, sodium hexafluoride, hydrogen) would also call for additional financial resources.

Additional funding is required to ensure the continuation of mass balance measurements at the 30 reference glaciers, the resumption of a number of discontinued long-term series and the initiation of new mass balance observations in underrepresented regions by the WGMS.

http://www.wgms.ch

6.0 Conclusions and outlook

Conclusions

This report gives an account of the current state of systematic observations of all the essential climate variables measured in Switzerland. In particular, it identifies cases where time series are at risk or the legal basis is inadequate. The long-term data series presented here provide a comprehensive picture of climate monitoring in Switzerland today. The report thus informs efforts to secure the future operation of the national climate observing system (GCOS Switzerland).

GCOS Switzerland is an important component of the Global Climate Observing System (GCOS), which is covering the systematic observations required by the Climate Convention. According to the GCOS Implementation Plan (WMO, 2004), the development of the global system is crucially dependent on strong national efforts. In Resolution 3.2.3/1 adopted at the Fifteenth WMO Congress (WMO, 2007), member states are urged:

«[...]
1. To strengthen their national atmospheric, hydrological and related oceanic and terrestrial climate observing networks and systems within the framework of GCOS and in support of user needs;

2. To assist developing country Members to strengthen their observing networks, to improve their capacity to acquire climate-relevant data, and to enhance their provision of climate services by implementing projects in the ten GCOS Regional Action Plans, and by contributing to the implementation of the ClimDev Africa Programme and to similar initiatives in other regions;
[...]»

For the implementation of GCOS at the national level, distinctive regional features are also to be taken into account. In Switzerland, particular attention is to be paid to key climate variables in the Alps (e.g. glacier monitoring). In this report – in addition to the essential climate variables –, pollen, isotopes and phenology were defined as important climate variables for Switzerland. These should also be considered as essential climate variables within the global GCOS framework.

Assessments of future climate change remain subject to numerous uncertainties. Relevant research activities require a high-quality climate data base, and it is therefore essential that existing long-term data series for the most important variables be continued. For each of the essential climate variables, this report describes the type of observations carried out in Switzerland and indicates to what extent significant time series are at risk. An account is also given of the legal basis, the importance of long-term series for GCOS and international significance and context of these time series. The scientific results illustrate the insights already obtained from long-term, continuous, high-quality data series. Finally, the prospects fo future operations of the time series are assessed and possible risks are identified. All the results underline the major importance of systematic observations for scientific studies such as the recently published Fourth IPCC Assessment Report. The results of the analysis are summarized in Table 3, with at-risk series highlighted in red.

In the case of long Swiss time series (Chapters 2 and 3), a legal basis exists for many of the variables. However, this legal basis is often unrelated to the relevance of the observations for climate monitoring. A legal basis is almost entirely lacking for cryosphere observations (snow, glaciers, permafrost). For certain variables – carbon dioxide, lakes, snow cover, glaciers, permafrost and phenology – funding is not ensured. For these six variables, plans for the future of these monitoring networks should be elaborated to accompany requests for funding. At the same time, an appropriate legal basis should be established.

Switzerland's international data and calibration centres make a vital contribution to the global standardization of observations and to data quality. As shown in Table 3, the continued operation of two data centres (GEBA,

Essential climate variable		Legal basis	Responsible institution(s)	Funding
Swiss time series				
2.1	Air temperature	Yes	MeteoSwiss	Assured
2.2	Precipitation	Yes	MeteoSwiss	Assured
2.3	Air pressure	Yes	MeteoSwiss	Assured
2.4	Sunshine duration	Yes	MeteoSwiss	Assured
2.5	Radiation	Yes	MeteoSwiss	Assured
2.6	Clouds	Yes	MeteoSwiss	Assured
2.7	Water vapour	Yes	MeteoSwiss, University of Bern	Assured
2.8	Ozone	Yes	MeteoSwiss	Assured
2.9	Carbon dioxide	Yes	University of Bern	Not assured
2.10	Greenhouse gases	Yes	Empa, FOEN	Assured
2.11	Air pollutants	Yes	Empa, FOEN	Assured
2.12	Aerosols	Yes	MeteoSwiss	Assured
2.13	Pollen	Yes	MeteoSwiss	Assured
3.1	River discharge	Yes	FOEN	Assured
3.2	Lakes	Yes	FOEN, Eawag, cantons	Not fully assured
3.3	Groundwater	Yes	FOEN, cantons	Assured
3.4	Water use	Yes	FOAG, FOEN	Assured
3.5	Isotopes	Yes	FOEN, University of Bern	Assured
3.6	Snow cover	Partly	MeteoSwiss, WSL/SLF, private companies	Not fully assured
3.7	Glaciers	No	EKK, ETHZ, University of Zurich	Not assured
3.8	Permafrost	No	PERMOS (FOEN, MeteoSwiss, SCNAT)	Not assured (from 2011)
3.9	Land use	Yes	FSO	Assured
3.10	Forest ecosystem	Yes	FOEN, WSL	Assured
3.11	Forest fires	Yes	FOEN, WSL	Assured
3.12	Phenology	Yes	MeteoSwiss	Not fully assured
International centres				
4.1	GEBA	–	ETHZ	Not assured (from 2008)
4.2	BSRN	–	ETHZ	Not assured (from 2008)
4.3	WGMS	–	University of Zurich	Not assured (from 2009)
4.4	Other centres	–	PMOD/WRC, Empa, University of Bern	Assured, except for Euro-Climhist (from 2010)
Observations outside Switzerland				
5.	Observations outside Switzerland	–	MeteoSwiss, Empa, University of Zurich	Assured for ozone, trace gases; not assured for glaciers

Table 3: Overview of essential climate variables, the legal basis and institution(s) responsible for monitoring, and the availability of funding. Time series and data centres whose future is at risk are shown in red.

BSRN) is at risk in the immediate future, and that of one other centre (WGMS) is threatened by insufficient funding in the near future. Since all three centres have a long tradition and are nationally and internationally respected, action required to secure their future operation (including funding) should be initiated as soon as possible. The globally unique climate history database EuroClimhist lacks funding commitment from 2010 on, and should also be preserved.

Technology transfer and local training are important means of enhancing the quality of climate-related observations abroad, especially in developing and emerging countries. As presented in Chapter 5, the observations carried out by Swiss institutions abroad cover the following climate variables: ozone (Kenya), trace gases (Algeria, Kenya, Indonesia) and glaciers (worldwide). In the future, additional financial resources will be required in particular for selected glacier observations abroad.

Outlook

The continuity of the most important Swiss climatological time series should be ensured for the future. The Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss is therefore seeking to protect the long-term series of essential climate variables that are at risk. In addition, to ensure that climate signals or artificial inhomogeneities can be distinguished from systematic biases, continued and careful attention should be paid to the GCOS Climate Monitoring Principles (Table 1). Aspects deserving special attention within the Swiss GCOS Office framework include metadata, quality assurance and data archival.

In the future, improved climatological analyses can be carried out using long-term data series from surface- and satellite-based remote sensing systems. These technologies make it possible to fill gaps in global climate observations arising from a lack of appropriate instruments or measurement methods. Satellite data are particularly suitable for the production of global datasets for a number of essential climate variables that cannot be obtained otherwise (WMO, 2006). However, in the analysis of satellite data, high-quality surface and in situ observations remain of central importance for calibration and validation. In this area, using the observations described in this report, Switzerland can play a leading role. In the future, measurements of many climate variables will increasingly involve the use of integrated systems, i.e. synchronous observations by a combination of systems (surface, in situ, airborne, satellite-based). High priority should be attributed to adequate calibration and validation with existing time series, and also to the continuity of observations.

The set of essential climate variables is not static. In autumn 2008, each Party to the Climate Convention will be required to prepare an updated national report on systematic observations. These national reports, together with the Fourth IPCC Assessment Report, will provide the basis for a review of the adequacy of the essential climate variables. Accordingly, additional variables can be expected to be included in the national climate observing system at a later date.

In addition, assessments of several climate variables (i.e. integrated assessments) will increasingly be promoted by the Swiss GCOS Office. The identification of synergies in the monitoring networks should consequently help to optimize climate observations and to improve our understanding of the climate system as a whole.

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Abbreviations

AERONET	Aerosol Robotic Network
AGNES	Automated GPS Network in Switzerland
AMDAR	Aircraft Meteorological Data Reporting
ANETZ	Automated Monitoring Network
AOD	Aerosol Optical Depth
ASRB	Alpine Surface Radiation Budget
(A)ATSR	(Advanced) Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BSRN	Baseline Surface Radiation Network
CHARM	Swiss Atmospheric Radiation Monitoring
CIMO	Commission for Instruments and Methods of Observation
CM-SAF	Satellite Application Facility for Climate Monitoring
CNRS	Centre National de la Recherche Scientifique
COP	Conference of the Parties
CORINE	Coordinated Information on the Environment
COST	European Cooperation in the field of Scientific and Technical Research
CWINDE	European Windprofiler Network
DDPS	Federal Department of Defense, Civil Protection and Sport
DETEC	Federal Department of the Environment, Transport, Energy and Communications
DLR	German Aerospace Center
DWD	Deutscher Wetterdienst
EAN	European Aeroallergen Network
EARLINET	European Aerosol Research Lidar Network
Eawag	Swiss Federal Institute of Aquatic Science and Technology
ECC	European Cloud Climatology
ECMWF	European Center for Medium-Range Weather Forecasts
EEA	European Environment Agency
EKK	Cryospheric Commission of SCNAT
EMEP	European Monitoring and Evaluation Programme
Empa	Swiss Federal Laboratory for Materials Testing and Research
ENET	Supplementary Network
EPFL	Swiss Federal Institute of Technology Lausanne
EPN	European Phenology Network
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETH	Swiss Federal Institute of Technology Zurich (ETHZ)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUVC	European Ultraviolet Radiometer Calibration Center
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FAO	Food and Agriculture Organization of the United Nations
FOAG	Federal Office for Agriculture
FOEN	Federal Office for the Environment
FoG	Fluctuations of Glaciers
FOPH	Federal Office of Public Health
FSO	Federal Statistical Office
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GEBA	Global Energy Balance Archive
GEWEX	Global Energy and Water Experiment
GFMC	Global Fire Monitoring Center
GLIMS	Global Land Ice Measurements from Space
GLORIA	Global Observation Research Initiative in Alpine Environments
GMBB	Glacier Mass Balance Bulletin
GMES	Global Monitoring for Environment and Security
GNIP	Global Network of Isotopes in Precipitation
GOME	Global Ozone Monitoring Experiment
GPS	Global Positioning System
GRDC	Global Runoff Data Centre
GRUAN	GCOS Reference Upper Air Network
GSN	GCOS Surface Network
GTN	Global Terrestrial Network (-G: Glaciers; -H: Hydrology; -P: Permafrost)
GTOS	Global Terrestrial Observing System
GUAN	GCOS Upper Air Network
HFSJ	High Altitude Research Station Jungfraujoch
HUG	Hydrological Study Areas
IAC	Institute for Atmospheric and Climate Science
IACS	International Association of Cryospheric Sciences
IAEA	International Atomic Energy Agency
IAP	Institute of Applied Physics
ICP	International Co-operative Programme
ICSU	International Council for Science
IDNDR	International Decade for Natural Disaster Reduction
IGRA	Integrated Global Radiosonde Archive
IGRAC	International Groundwater Resources Assessment Centre
IMIS	Intercantonal Measurement and Information System
IPCC	Intergovernmental Panel on Climate Change
IPG	International Phenological Gardens
ISDR	International Strategy for Disaster Reduction
IUGG	International Union of Geodesy and Geophysics
JMA	Japanese Meteorological Agency
JRC	Joint Research Centre, Ispra
KLIMA	Conventional Monitoring Network
LKO	Licht-Klimatisches Observatorium Arosa
LULUCF	Land Use, Land-Use Change and Forestry
LWF	Longterm Forest Ecosystem Research
MERIS	Medium Resolution Imaging Spectrometer Instrument
MeteoSwiss	Federal Office of Meteorology and Climatology
MISR	Multiangle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MVIRI	Meteosat Visible and Infrared Imager
NABEL	National Air Pollution Monitoring Network
NADUF	National River Monitoring and Survey Programme
NAPOL	National Pollen Monitoring Network
NAQUA	National Groundwater Observation Programme
NASA	National Aeronautics and Space Administration
NBCN	National Basic Climatological Network
NCCR	National Center of Competence in Research
NCDC	National Climatic Data Center
NDACC	Network for the Detection of Atmospheric Composition Change
NILU	Norwegian Institute for Air Research
NIME	Precipitation Monitoring Network
NOAA	National Oceanic and Atmospheric Administration
NRP	National Research Programme
NSIDC	National Snow and Ice Data Center
OBS	Visual Observations Network
OcCC	Advisory Body on Climate Change
OECD	Organisation for Economic Cooperation and Development
OMI	Ozone Monitoring Instrument
OPERA	Operational Program for the Exchange of weather RAdar information
PERMOS	Permafrost Monitoring Switzerland
PMOD	Physical Meteorological Observatory Davos
PSI	Paul Scherrer Institute
QA/SAC	Quality Assurance/Scientific Activity Centre
RBCN	Regional Basic Climatological Network
SCNAT	Swiss Academy of Sciences
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SGI	Swiss Glacier Inventory
SLF	Swiss Federal Institute for Snow and Avalanche Research
SOGE	System for Observation of Halogenated Greenhouse Gases in Europe
SR	Systematische Sammlung des Bundesrechts
swisstopo	Federal Office of Topography
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VAW	Laboratory of Hydraulics, Hydrology and Glaciology
WCC	World Calibration Center
WCP	World Climate Programme
WCRP	World Climate Research Programme
WDCA	World Data Centre for Aerosols
WDCGG	World Data Centre for Greenhouse Gases
WGI	World Glacier Inventory
WGMS	World Glacier Monitoring Service
WMO	World Meteorological Organization
WORCC	World Optical depth Research and Calibration Center
WOUDC	World Ozone and Ultraviolet Radiation Data Center
WRC	World Radiation Center
WRC-IRS	World Radiation Center, Infrared Radiometry Section
WRC-SRS	World Radiation Center, Solar Radiometry Section
WRMC	World Radiation Monitoring Center
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research