SONNBLICK
Observatory above the clouds

Scientific research activities 2011

ZAMG

125 years Sonnblick

GLACIOLOGY

(Photo: Webcam www.sonnblick.net)

Core area since the late 1890s.
Immediately surrounded by four glaciers. Climate monitoring, hydrological cycles and glacial dynamics, supplemented by selected permafrost projects.

RADIATION AND ATMOSPHERIC PHYSICS *(Cover, Photo: H. Scheer)*

Main focus from the very start. The spectrum ranges from atmospheric optics to radioactivity all the way to high-tech radiation measurement.

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Preface

Climate and environmental research have gained enormously in significance over the last few decades. This new thrust and heightened status are evident not only around the globe, but also inside Austria. There are good reasons for this: climate change has a disproportionate, nearly doubled impact on the Alps, compared to low lying regions. Continually adjusting outer limits of weather extremes, repercussions on tourism and marked alterations in flora and fauna are compounding adjuncts to this.

Precise and thoroughgoing research into the phenomena which occur and have an amplified effect in the Alps necessitates well established scientific foundations and a well-oiled accompanying framework. The questions being posed are highly complex and require tried-and-tested cooperation of a wide range of professional expertise. In the process of this interaction, impetus towards new fields of interdisciplinary research areas is ignited which, in turn, launches and furthers constructive dialogue among a variety of disciplines.

At the Sonnblick Observatory, Europe's highest altitude interdisciplinary research facility, more than 40 different research projects are currently being pursued - simultaneously - in highly confined spaces. The ongoing cooperation between diverse institutions is emblematic of "lived interdisciplinary work" in the best sense of the word. The exchange of data via an online network facility in the observatory, coordination of research projects and joint use of the infrastructure at close quarters have been successfully implemented and practiced for years.

National scientific and research policies which promise success entail preparing the answers today to the questions of tomorrow. Only through a detailed understanding of causes can specific and effective countermeasures be taken on an international stage. The key scientific foundations enabling Austria to make its contribution to fulfilling the international climate agreement are located right here.

The success story of this exposed, high altitude observatory in the heart of the Hohe Tauern range is also the history of brilliant personalities, of visionary scientists who look far beyond the horizon, of observers dedicated to the mountains and of a high degree of acceptance and solidarity by the populations of the surrounding valleys. Nearly inconceivable - but true: this work station of the extremes has been unattended only four days over the last 125 years.

The ZAMG as supervising operator of this facility and the Sonnblick Association as proprietor of the observatory have together mastered countless challenges through a collaboration sustained for more than a hundred years. The cooperation between the national and state governments for the geological restoration of the summit facilities in 2007 was exemplary. Its joint financing, which included contributions from individual sponsors, is living proof that the Sonnblick is a embraced as a "national" treasure in every sense of the word.

I extend a vote of thanks to all employees and staff members and convey to them my very best wishes for the successful pursuit of all future projects.

Dr. Karlheinz Töchterle
National Minister for Science and Research

A future-oriented, high alpine research centre celebrates its 125th birthday

The Sonnblick is celebrating a major birthday this year. In our fast-moving age, it is difficult to imagine that in the harsh, sometimes forbidding high alpine regions of the Main Alpine Ridge an outpost of research has existed and been in constant operation for one hundred twenty-five years. As if that weren't enough, housed in a spiked building perched atop a mountain summit, balanced above a steeply plummeting north face and an arduous ascent.

The scientific laurels for this grandiose anniversary will take place at the Convention on "Climate Change in High Mountain Regions" in Salzburg at the end of August, which is being organised through the efforts of the ZAMG weather service and the Sonnblick Association. It will be followed by celebrations in Rauris and at the Sonnblick in a series of scientifically-oriented events for the general public. A week later, the big Sonnblick parade will take place in the town of Rauris.

The sweeping views from the age-old stone tower which dates back to 1886 and the measurement devices which were installed directly adjacent to it demonstrate how tradition and modernity can interweave fruitfully. Without such longstanding tradition, there would never have been such a wide diversity of projects revolving around the theme of atmospheric physics and environmental chemistry; and without the highly modern infrastructure, the measurements of extremely rare trace elements would not be possible.

The history of the observatory is marked by a pioneering spirit at the cutting edge of technical possibilities. As gold mining became ever more difficult, due to the advancing glacier in the nineteenth century, it enabled mine owner Ignaz Rojacher to build and launch operations in the observatory in the year 1886. The challenges at that historical juncture are comparable to the adventurous spirit of an expedition to an 8,000-meter peak in the twentieth century.

The main objective from the outset was to obtain information from higher levels of the atmosphere. At the time, measurements from high altitudes simply didn't exist, and were thus of enormous value to science. The costs and organisational burdens ever since the earliest decades have been borne by the Sonnblick Association as a private sponsor, and by the Central Institute for Meteorology and Geodynamics as a national institution.

The selfsame pioneer spirit which prevailed back then is equally necessary today if new measurement processes in the often harsh conditions at 3,100 meters altitude are to be tested and evaluated. Ice masses weighing many tons often lie atop the instruments, buffeted by winds of over 180 km/h, whereas at lower altitudes a few centimeters of lightweight snow is the only burden the instruments have to cope with.

Measurements which serve as a basis for global climate models can only be reliably conducted in places which are far removed from locally-specific pollution. The Sonnblick is highly suited to fulfil such pre-requisites, since industrial emissions are not to be found in the vicinity, nor does local tourism affect the measurements. The volcanic eruption on Iceland in 2010 and the nuclear catastrophe in Japan amply demonstrate the significance of the Sonnbluck as an emission-free, i.e. interference-free and influence-free, high alpine station with regard to long-distance transport of substances for thousands of kilometers.

The observatory has gone through an enormous upward surge. It is hoped that this little brochure will provide an overview of the diverse activities going on and show the reader just how complex the questions and methods have become.

Univ. Prof. Dr. Franz Schausberger
Former Governor
Chairman of Sonnblick Association

Prof. Dr. Michael Staudinger
Director of Central Institute for
Meteorology and Geodynamics

Mag. Bernhard Niedermoser
Director of Sonnblick
Observatory

"The continuous evolution of meteorology as a science has made research into the activity of the uppermost layers of air an absolute necessity."

With the above statement, the first President of the Sonnblick Association, Albert von Obermayer, begins his description of the construction of the meteorological observation station on the Sonnblick in the first annual report of the Sonnblick Association. Julius Hann, Director of the Royal and Imperial Central Institute for Meteorology and Earth Magnetism, was one of the pioneers of this research facility and an initiator of the observatory's construction.

However, without the boundless energy and zest for action of mine owner Ignaz Rojacher of Rauris, the scientific ideas would never have been turned to reality. It was also Rojacher, together with his miners, who safeguarded the ongoing operations of the observatory during these years.

The responsibility for the ongoing maintenance of the observatory was assumed by the Austrian Meteorology Society in the early phase.

Following the sudden passing of Rojacher in 1891, however, the continuous maintenance was endangered through financial difficulties. In order to place the future of the observatory on a more sound financial footing, the Sonnblick Association was established in 1892.
The Austrian Meteorological Society was supported and assisted in the maintenance of the Sonnblick during that era, then at a later date the Sonnblick Association assumed general responsibility entirely, while at the same time sponsoring the scientific research activities in high alpine regions in the special areas of expertise Meteorology and Geophysics.

Many scientists from a variety of disciplines took advantage of the unique features which distinguish this observatory. As a representative example for many participants, Viktor Franz Hess, Nobel prize winner and discoverer of cosmic radiation, is cited here.

The maintenance of the observatory was often at risk during difficult times; only through the efforts of dedicated individuals could the observatory be saved and its operations ensured.

Photo: M. Staudinger

Subsequently, at the beginning of the 1980s, the observatory was transformed into a modern facility. Energy was drawn exclusively from electricity, the cablecar was modernised and the rooms for observers and scientists were enlarged. Thus, the cornerstone for a modern, high alpine environmental station without parallel in Europe, without any local sources of disturbance in the surroundings, was laid; and could thenceforth be utilised by a wide range of international groups engaged in scientific research. The financing for the ongoing operations of the observatory is borne by the National Ministry for Science, Education and Culture, the Austrian Academy of Sciences, the Central Institute for Meteorology and Geodynamics, the state governments of Salzburg and Carinthia, and from Sonnblick Association donations and dues.

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A new Sonnblick book

On the occasion of its 125th anniversary, three people long active in Sonnblick-related research have written a book on the history of Austria's traditional mountain observatory. Following the restart in a new building during the 1980s, recent decades have seen a complete transformation from weather station to modern environmental observatory. For that reason, the book focuses on the most recent decades, but does not neglect to compare new developments with what went on during the previous 100 years. To date, the book is only in German, but its rich graphical material may well interest readers unfamiliar with the language.

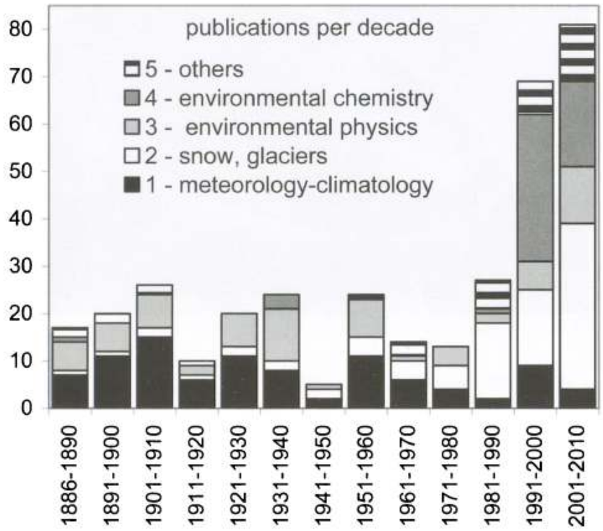
Objectives: The starting point for the new book was to produce a reissue of the Sonnblick history written in 1986 on the occasion of its 100th anniversary. But we quickly realized that it had to be more radically revised than expected – the history of the environmental observatory over the last few decades had to be described for the first time, but parts concerning the first 100 years also had to be re-addressed in various ways.

Contents: For the public science part of the book, we wrote two new chapters on environmental physics and environmental chemistry – two of the focal points of research at the new "laboratory in the clouds". In addition to that, three heavily revised and expanded chapters deal with high alpine climate, climate change, glacier research and monitoring. A "glimpse beyond our horizon" places the Sonnblick in context with other mountain observatories from Hochobir and Jungfraujoch to Pic du Midi, Ben Nevis, Mount Washington and others.

For the historical part of the book, new evidence for the first 100 years of Sonnblick has come to light. This was integrated into the already known history and then extended by a new chapter about the most recent decades. In this respect, the authors relied on their own experience in the field of climate and glaciological research as well as on their personal contacts to other people responsible for the research and the routine work at Sonnblick. Thus, the history is rounded out by stories, is interwoven with science, making the science more clear and comprehensible.

The evaluation of Sonnblick-related research projects in accordance with the basics of modern research control is part of a chapter we called "projects – projects – projects".

The following diagram illustrates that Sonnblick research has been a success in that respect as well and that it has developed impressively over recent decades.



Development of 125 years of Sonnblick-related research depicted through no. of publications per decade

Acknowledgements: The scientific expertise of the team of authors was supported by others in the helpful and friendly way which is typical for the Sonnblick community. This has bestowed upon the book a touch of peer reviewing. Above all, we would like to thank Stana Simic, Dietmar Wagenbach and Anne Kasper-Giebl for their major input. The illustrations benefit substantially from high quality historic and modern photos. We thank first and foremost Gernot Weyss, Bernhard Hynek and Ludwig Rasser for supplying them.
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Meteorology on the Sonnblick: between solid mechanics and digital sensors

Ever since 1886 - for 125 years - weather watchers on the Sonnblick have kept meteorological records. The unremittingly harsh background conditions of nature have remained a constant throughout these years, whereas the technology to measure it has radically changed. Yet not everything at this altitude is made easier by electronics.

illus. 1: Cloud camera (Photo: G. Weyss)

From mechanical...to digital

Well into the 1980s, wind directions and velocities were measured and recorded mechanically via a drum. Subsequently, measuring technology advanced to electronic measurement accompanied by corresponding digital sensors, while still retaining the mechanical registration as a back-up.

illus. 2: Precipitation measurement instruments on the south flank (Photo: W. Schöner)

Several annexes have been added to the observatory, but it is still fundamentally mapped out according to the same blueprint as originally conceived by pioneer Ignaz Rojacher.

Affixed to the northern side of the tower is the "Window Hut", where temperature and humidity are recorded along the same lines that were established more than 120 years ago. Precipitation from snow and rain are recorded by automated scale systems on the northern and southern sides of the summit. (illus. 2)

Hours of sunshine and Global radiation

Since the 1980s, the platform on the southern side of the new building has housed the facilities measuring hours of sunshine and global radiation. These data are measured automatically and simultaneously, then recorded and transmitted to Vienna and Salzburg.

illus. 3: New wind tower with sonographic wind measurement (Photo: G. Weyss)

New measuring tower ensures undisturbed windstream

The buildings on the summit of the Sonnblick themselves cause aerodynamic turbulences at ground level. For that reason, a 20-meter tall tower was erected in 1995. Ever since then, wind measurements have been made from this perch, since at a height of 20 meters, the windstream is unimpeded. Wind velocity and direction can thus be measured and recorded without any ground level interference.

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Meteorological Records

The Sonnblick, Austria's highest altitude observatory, itself experiences some of the most extreme weather conditions the country has to offer. This is not always evident from the recorded data, since a combination of several "normal" factors (e.g. typical autumn temperature of -10°C added to an autumnal wind of 70 km/h) results in a chill factor equivalent to approximately -30°C. Whoever stays outdoors for more than 15 minutes in such conditions without adequate equipment risks grave frostbite.

Europe's Oldest Mountain Observatory:

built in 1886
Highest continually operated workplace in Austria
4 weather watchers
Schedule: 15 days on duty, 10 days off (mind. 2 staff members on duty simultaneously)

Meteorological Records on the Sonnblick

Temperature :
Absolute maximum +15.0 °C (27.07.1983)
Absolute minimum -37.4 °C (02.01.1905)

Average monthly temperature :
Maximum +5.7 °C (08/2003)
Minimum -21.1 °C (02/1956)

Average annual temperature :
Maximum -4.2 °C (2002)
Minimum -7.8 °C (1909)

Precipitation:
Maximum monthly accumulation 490 mm (05/1962)

Snowpack :
Overall depth maximum 1190 cm (05/1944)

Wind :
Gusts 201.6 km/h (20.12.1993)
Daily average
123.1 km/h (34.2 m/s) (17.01.1920)
117.4 km/h (32.6 m/s) (26.04.1948, 16.04.1970)

Air pressure:
Maximum 717.1 hPa (17.09.1975)
Mimimum 654.4 hPa (26.02.1989)

Sahara dust: appx. 2 - 4 times annually

Photo: L. Rasser

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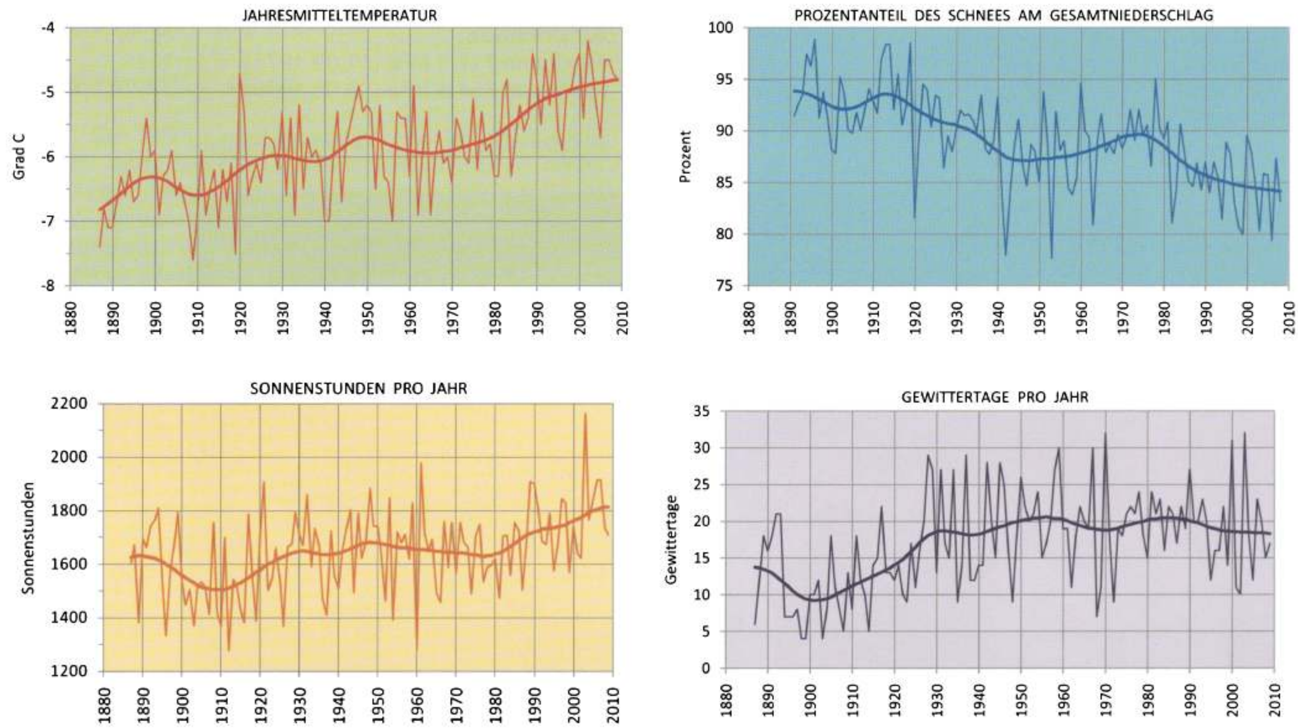
Sonnblick: world record holder in measurements

Worldwide there exists no other research station on a mountain summit at an altitude above 3,000 meters which has measured and documented the climate for such a long time. Since 1886, the observatory on the Sonnblick has served the interests of climate science. That is a unique world record, with no other station coming even close; furthermore, the site at an altitude of 3,100 meters is far removed from cities, roads and factories, where measurements in the (as yet) relatively undisturbed high alpine air are particularly reliable.

Just like everywhere else on earth, it has also become "warmer" on the Sonnblick: from about -6.5°C during a typical year of the 19th century to currently -4.8°C. This warming has been accompanied (and to some extent caused) by ever increasing amounts of sunshine: 1,500 hours of sunshine were recorded in the years around 1910; nowadays, the average is 1,800 sunshine hours. The year 2003 broke every record since 1887, bringing 2,164 hours of sunshine. For mountain climbers, this is a highly pleasant "by-product" of the climate change. But it comes at a price: it is "paid for" by double the number of perilous high alpine thunderstorms. This rise in temperature combined with increasing hours of sunshine brings about an ongoing decrease of the percentage of snowfall in the overall precipitation, which at altitudes of approximately 3,000 meters has declined from 95% to below 85%. This is no cause for alarm among backcountry ski tourers up at these heights, but it is a development which has significant impact on more low lying ski areas. In the recent past, in 2006, this trend towards decline reached the third lowest percentual amount of snowfall since weather recordings began, namely, 79%. This drastic decrease in solid precipitation can be attributed to the lack of snowfall during the month of July. Weather sequences useful for climate analyses, recorded at the Sonnblick and other stations in the Alps and its surroundings, can be downloaded at http://www.zamg.ac.at/histalp.



Illus.1. Homogenized climatic sequences, individual measurements and 30-year mean at the Sonnblick

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A Tale of Two Valleys

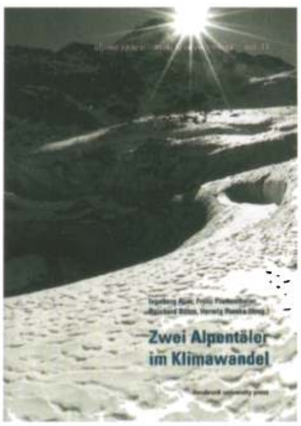
The history of climate change in the Mölltal and Rauris valleys are the subject of a book entitled "Two Alpine Valleys Amidst Climate Change". Both the scientific and sociological foundations resulted from a project known as "A Tale of Two Valleys" which was conducted as part of the "proVISION: Planning Ahead for Nature and Society" research programme.

Objectives

- Interdisciplinary analyses of climate change in Rauris (town in National Park, with Sonnblick Observatory) and Flattach (village at foot of Mölltal Glacier) and its potential impact,
- In-depth information from population and stakeholders on results from climate research,
- Developing scenarios linked to political policymaking and populations of the two towns
- Survey of attitudes on climate change among Flattach and Rauris inhabitants
- Involving youth in the project in the context of Research/ Education Cooperation of Ministry of Economy and Finance

Individual working stages of the project:

- Gathering and assessing all available data from the region in the areas of climatology, glaciology, ecology, sociology and economics
- Obtaining new data through on-the-spot investigation and surveys, evaluation of satellite data
- Regional climate analysis and qualitative/quantitative findings of weather extremes
- Analysis of glacier and runoff behaviour
- Analysis of correlations between climate and tourism
- Analysis of natural dangers, changes in landscape and land usage
- A summary presentation of results in book form

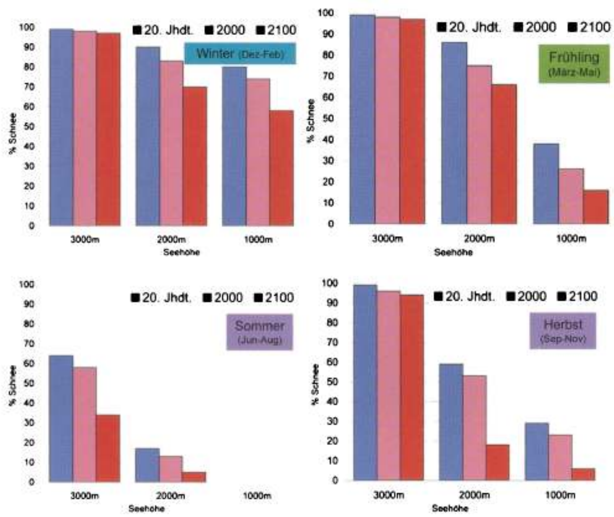


Illus.1: The book *Two Alpine Valleys Amidst Climate Change* was published as volume 11 of the series "alpine space – man & environment" by the innsbruck university press.

Method

Assessing selected key data of climatology, natural dangers and risks, employment and income, demography, tourism, gender aspects, education, mobility and land usage and deploying it as input for a model depicting overall impact to construct future regional scenarios for the two towns.

Illus. 2: View of market town of Rauris from Rainberg looking westwards to Kreuzboden, Reissrachkopf and Hirschkopf 1930 (left) und 2007 (right). Photo credit (H. Proske).



Illus.3: Percentage of snow to overall precipitation: amounts at three different altitudes in the Hohe Tauern region, mid-20th century (blue), around the year 2000 and projected for the year 2100 (computation based on regional temperature scenario A1B and models of links between snowfall and average monthly temperature).

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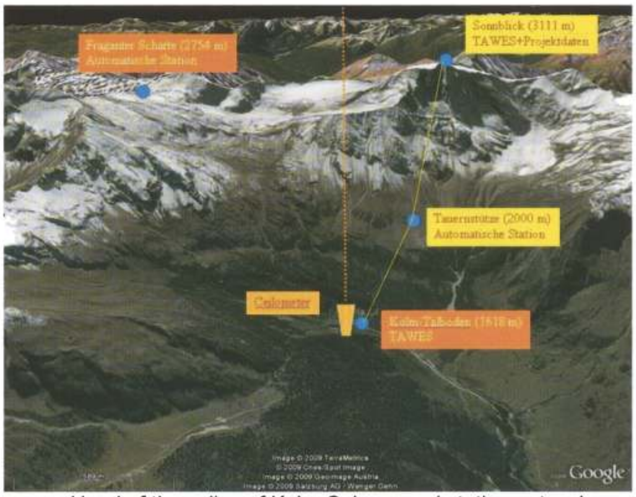
WAVES

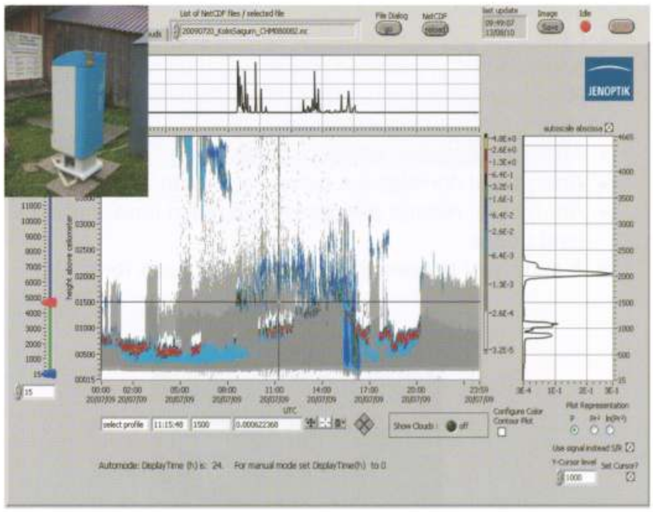
The objectives of WAVES (Wind, Exchange and Vertical Layers Science in the Kolm Saigurn / Hoher Sonnblick region) are analyses of the interactions of strong high altitude winds with valley winds, in particular when southerly foehn winds are blowing; and analysis of the dependence of air component measurements taken on the Sonnblick on vertical intermixture of the valley atmosphere. In summer 2009, a laser ceilometer was used for the measuring campaign, made temporarily available by the ZAMG on loan from the DWD in the context of a "Memorandum of Understanding" on scientific collaboration. This offered a unique opportunity to study in detail the time schedule of intermixed layer altitudes at the head of the valley.

Inneralpine Synoptics: The analysis of the interaction between strong high-altitude winds and valley floor winds, particularly when southerly foehn wind conditions prevail, is a major goal of WAVES. Of equal interest, however, is the flat overflow, e.g. across the Fraganter Scharte, which can come from the north or from the south. From the analysis of all the collected data, it is hoped that parameters can be developed which make it easier for meteorologists on duty to forecast breakouts of foehn wind, in both time and intensity and, whenever necessary, to issue warnings. These questions are of enormous significance both for safe cablecar operations on the Sonnblick and, to a far greater extent, for the issuance of precise storm warnings along the Salzach River and in the lateral valleys in the vicinity of the Tauern Range.



Head of the valley of Kolm-Saigurn and station network

Altitudes of intermixed layers: An additional focal point of WAVES treats the exchange of air additivies and toxic substances between the head of the valley at Kolm Saigurn and the ridge and summit areas. What is decisive for an understanding of the background measurement stations such as the Sonnblick Observatory, far removed from local and regional sources of air additives and pollutants from emissions, is knowledge of the origins of such contaminants and additives, as well as the mechanisms which lead to higher or lower atmospheric loading. Apart from the long-distance transport, the loading of toxic substances in the atmosphere in the mountains is also affected by vertical intermixture in the atmosphere. The WAVES project endeavors to elucidate and explain the interaction between long-distance transport of toxic substances and coupling into local sources of pollutants from the valley floor atmosphere. By means of ceilometer measurements, it is now possible to study in detail the effects of vertical intermixture on the contamination and air additives on the Sonnblick and to develop a method, based on the measurements, to better see the effects of the vertical structure of the atmosphere.



Ceilometer (Jenoptik/DWD) at valley station, with measurements

Ceilometer measurement: Over a period extending from July to September 2009 the DWD ceilometer pictured above was in operation at the foot of the Sonnblick in Kolm Saigurn. It measures the backscattering of aerosols and droplets in accordance with the LIDAR principle, i.e. via laser. From the measurement data, aerosol profiles, cloud layers, borderline layers and intermixed layer altitudes, together with vertical visibility or cloud cover, can be derived. Up to 15,000 meters above ground level, several cloud layers can be detected.

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VALIM

This project aims at the exchange of information and expertise beyond national borders. It devotes itself to the spread of pollutants in the Belluno region; long-distance transport of toxic substances Belluno-to-Sonnblick; and air exchange between the atmosphere in the valley and on the Sonnblick. The geographical area of the project comprises the region from Belluno to the Main Alpine Ridge of the Hohen Tauern. VALIM has been co-sponsored by the European Fund for Regional Development.

In order to study with greater precision the air exchange between valley and mountain summit, the existing measuring network on the Sonnblick was expanded by two additional stations. The newly obtained data are available online, are correlated to already existing measurements and great synergies are thereby achieved.

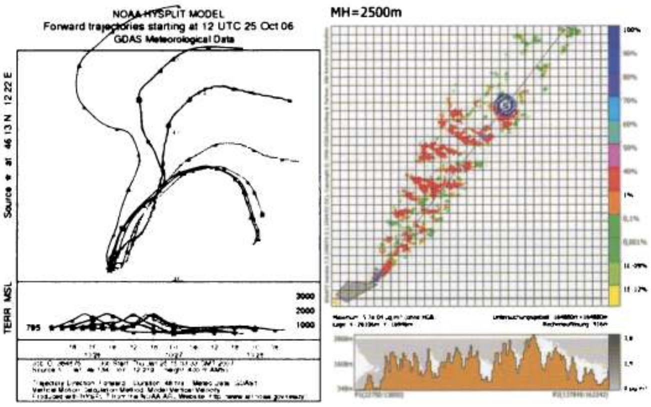
Illus.1: Installation on Fraganter Scharte, 2750 m

For this project, which was conducted from 2005 to 2007, immision measurements were taken in the state of Salzburg. Based on these measurements and the new VALIM stations, the question of long-distance transport between Belluno and Sonnblick could be analysed, while at the same time small-area conditions of toxic substance exchange were examined in greater Belluno and at the head of the valley of Rauris.

Three of the most important results:

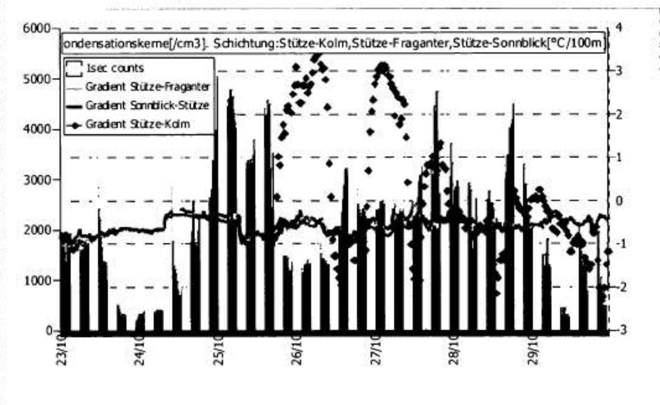
a) On three days during the period of immissions in autumn 2006, the trajectories from greater Belluno reached the Sonnblick region. Due to foehn wind activity, these air masses were mixed into the atmosphere as far as Kolm Saigurn.

b) Based on possible long-distance transport between the starting zone of Belluno and the Sonnblick, accompanied by simultaneous foehn winds in Rauris valley, it is being analysed whether a coupling up with the valley atmosphere in the Piave valley near Belluno was at all possible at this time. It became evident in these cases that the valley atmosphere had detached itself due to the distinct weather inversions. For that reason, a long-distance transport of toxic substances from the valley atmosphere of Belluno on the southwesterly, high altitude air current in the direction of the Sonnblick is improbable.



Illus.2: Forward trajectories NOAA HYSPLIT (left); Lagrange model (right) – starting in Belluno in each case

c) A distinct mechanism operative in the amounts of condensation nuclei on the Sonnblick summit could be identified. When two warm fronts arrive in a region at the same moment, a significant maximum of condensation nuclei is registered for a short time. Overall, these are the highest measurements during a six-week measurement phase. The most likely explanation is that in the frontal zone of the warm front, sources near the ground are "tapped into" which then provide record-breaking immission values on the Sonnblick. This "absorption" into the frontal zone probably occurs 12 to 24 hours before the warm front reaches the Sonnblick. Based on the direction of the warm front air flow, starting zones in Germany, and even in France, are possible.



Illus.3: Vertical temperature gradients in three layers and condensation nuclei on the Sonnblick (3106 m)

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International weather warning system MeteoAlarm

Weather warnings are not only of immense importance to scientists active in research on the Sonnblick summit; the data from the meteorological weather station and from the nearby vicinity are also used directly for public warnings. The ZAMG Weather Service Salzburg operates the international warning programme known as MeteoAlarm, which digests and summarises the warnings of more than 30 partners throughout Europe.

Extreme weather occurrences in the mountains can turn out to be extremely dramatic. After all, mountain climbers perforce expose themselves to weather risks and any error in assessing weather conditions can be fatal. The same risk applies to project participants and researchers actively at work outside the observatory. Thunderstorms, heavy snowfall, storm winds and avalanches in open terrain are objective perils which often render research in open terrain impossible.

Illus.1: www.meteoalarm.eu European measurements

Local and time-specific warnings are thus of major importance for this user group. In the programme MeteoAlarm, the warnings of 30 European weather services from their respective countries are harmonised and depicted on the www.meteoalarm.eu website.

Illus.2: Road closure due to avalanche danger

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At the same time, important measurements are conducted in the immediate vicinity of the Sonnblick which are indispensable for Nowcasting, i.e. the short-term weather forecast:

Wind speeds, precipitation rate, direct observations of weather components by observers are available only at a few locations in high alpine regions. These measurements attain an even greater significance through the fact that ongoing, direct control of the sensors by expert technicians enables them to correct potential errors in sensor measurement immediately.

Illus.3: Wind measurement tower and global radiation unit following a night of white frost (Photo: H. Lindler)

GNSS-MET

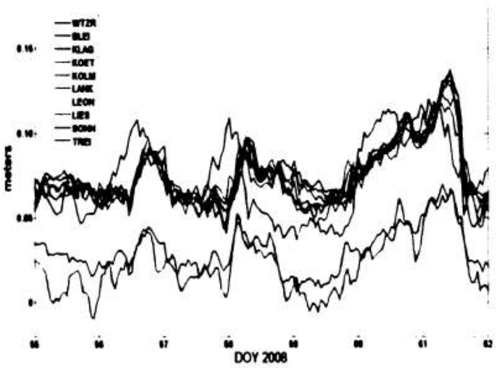
For the project known as GNSSMET (terminated in Feb. 2008) and the follow-up project GNSSMET-Austria which ran until October 2010, the question of whether and in what ways observations made by the GNSS (Global Navigation Satellite Systems) can use deflected atmospheric column water content as a useful source of data in an operational nowcasting system or forecast system was investigated. GNSSMET focused on the development of suitable algorhythms and data processing chains for the quick computation of the delayed moisture percentage from GNSS data within a geographically limited, yet high alpine region in the state of Carinthia; GNSSMET-Austria then expanded the working zone to cover all of Austria. GNSSMET-Austria is carried out by these partners: Institute for Geodesy and Geophysics (TU Vienna), the Department of Synoptical Meteorology (ZAMG), the operating organisations of the EPOSA-GNSS network (ÖBB, WienEnergie, BEWAG) and KELAG, the Carinthian utility company. Both projects were sponsored by the FFG in the context of the ASAP programme, whose assistance is gratefully acknowledged.

Method

GNSSMET was launched in autumn 2006 and formally terminated in spring 2008. The project zone in Carinthia was covered by 8 permanently installed GPS/GLONASS reference stations of KELAG (see illus. 1), of which the Sonnblick Observatory was the highest altitude national station.

Illus.1: GNSS station network incl. Kolm-Saigurn

The GNSS observational data is ongoingly transmitted to the Technical University of Vienna and fed through an hourly network solution for evaluation. The integral, vertical, tropospheric signal delay is used as a parameter, apart from the station coordinates. With the help of measurements from nearby TAWES stations, the moisture delay percentage can be distinguished from the hydrostatic percentage.



Illus.2: Moist, vertical signal delay from all network stations (24.2.-1.3.2008)

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The method developed in GNSSMET is currently being applied for the efficient data processing of approximately 40 GNSS stations scattered throughout Austria.

For GNSSMET, the following was achieved:

- Determining the moisture percentage of the signal zenith delay for 8 Carinthian stations in alpine terrain and for surrounding data points with a temporal resolution of one hour and a spatial resolution of approximately 50 km.
- The hydrostatic reduction was automatically reflected with the help of measurement statistics of the meteorological network TAWES.
- The computation of parameters transformed to precipitable water (PW) with a precision of +/- 1mm-1.5mm.
- The assimilation into the Nowcast System INCA of PW parameters estimated by the ZAMG for testing purposes by means of a distance-related weighting function developed specifically for this project.
- A high degree of correlation of the GNSS-corrected moisture profiles with the results of radio probe measurements was demonstrated and verified.
- It was shown that the improvements in the INCA moisture profile through GNSS corrections could be observed, sampled in summertime in general due to higher moisture content of the troposphere (which validated the conditions of GNSS parameters) and at other times when weather fronts were traversing the region.
- It was shown that traversing weather fronts can be better analysed with GNSS data, since such data included moisture changes in the free atmosphere, whereas ground level station data under certain circumstances reacts to changing air masses only with delay. Heavy precipitation could thereby be forecast with assurance and geographically delineated to a far greater extent.

Calibration of the isotope thermometer via precipitation at Sonnblick

Dedicated samplings of fresh snow for analysis of their stable isotope signature are performed in order to establish an experimental link between this isotope signal and the local air temperature. This relationship is needed for a proper interpretation of isotope information gained from paleo-precipitation, e.g. in preserved ice cores, of the Alpine realm in terms of past temperature changes.

Background

For physical reasons, there is a basic link between the properties of stable water isotopes in precipitation and the temperature under which the precipitation has been formed. In effect, this phenomenon allows for inferring past temperature changes from well preserved water samples, as is widely used in polar ice core studies. However, application of this tool is ultimately much more complex when dealing with Alpine ice cores because they cover only our current Holocene, a climate period marked by a relatively subdued temperature variability. For that reason, a faithful calibration of the isotope thermometer merits a systematic study which covers the entire range of high alpine precipitation occurrences.

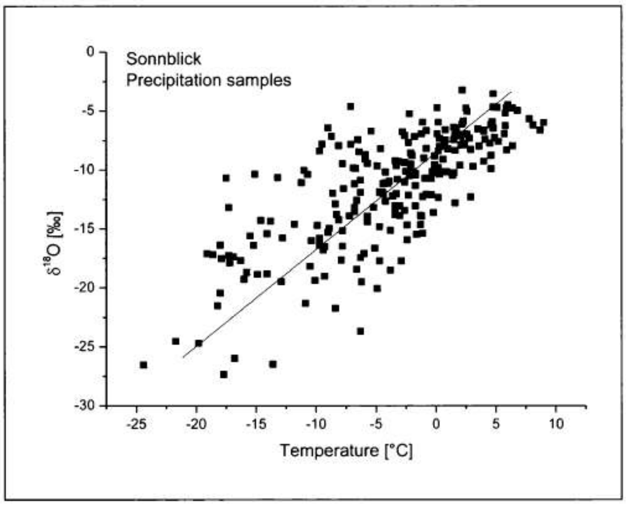

Fig.1: Air temperature vs. relative isotope content in single fresh snow samples

Methods and objectives

Fresh snow is regularly sampled at Sonnblick; subsequently it is classified, and analysed at the Institute für Environmental Physics for stable oxygen and hydrogen isotopes. As regards the individual weather situation, the varying sensitivity of the isotope changes to the condensation temperature can be studied so as to be applied for temperature reconstruction of alpine paleo-precipitation (see isotope records from cold, alpine glaciers within the, ZAMG co-ordinated, EU-Project ALP-IMP). Fig.1 and Fig.12 illustrate the empirical relationships between air temperature and the $^{18}O/^{16}O$ ratio obtained from individual fresh snow occurrences and monthly averaged data, respectively. In this context, considerable progress is expected from water vapour records obtained by quasi-continuous sampling; or even by in situ analyses of the vapour isotope content via a novel laser spectrometry method.

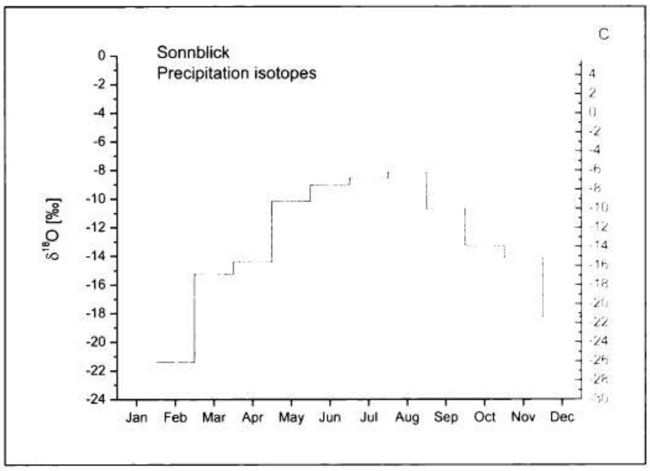

Fig.2: Seasonal air temperature pattern (red line in °C) vs. relative isotope content of monthly precipitation samples

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ARAD – Measuring changes in the radiation balance in the Alps

The sun is and remains the engine of change in the earth's climate. Over the course of many time scales of the earth's history, highly varied attributes of the sun and of the earth have made their effects felt. In the time scale which is relevant for earth's human population, anthropogenic influence on the radiation balance of the earth's atmosphere is of greater interest than natural changes. The project known as ARAD measures with extreme precision the varied components of the radiation balance in order to better understand human influence on the earth's climate; and in order to record the time spans of the changes in the radiation balance.

Measurements

On the Sonnblick, all components of the radiation balance of the atmosphere have been measured since 2010. These components include the following:

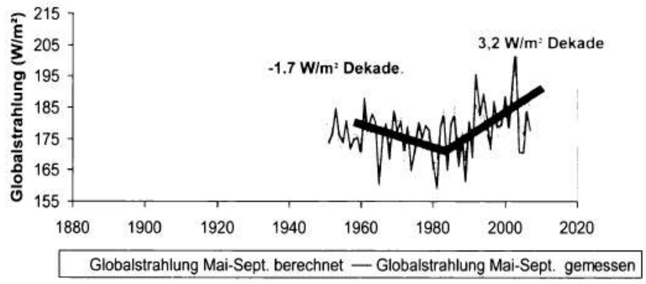
- direct radiation of the sun
- diffuse sky radiation (stray light)
- radiation reflected from the earth's surface
- the longwave heat radiation stemming from inside the earth
- the longwave heat radiation reaching the earth from the atmosphere

For radiation measurements, high precision sensors are used in accordance with international guidelines (Baseline Surface Radiation Network BSRN). Through such measurements, the so-called greenhouse effect is also measured, although there is no direct distinction which can be made between the greenhouse effect caused by people and that which occurs naturally. Only after the model calculations and other atmospheric measurements on the Sonnblick are drawn into the compilation can clues be pinpointed.

Illus. 1: Measuring instrument for recording percentages of direct and scattered, i.e. diffuse, solar radiation (Photo: Niedermoser)

Background and Objectives

Whereas other projects on the Sonnblick measure the natural and anthropogenic influences (aerosols, gases) on the radiation balance, ARAD measures the effects of these influences on the radiation balance. The Sonnblick can look back on a long and internationally highly respected tradition with regard to the specialized area of radiation research. Inge Dirmhirn and Franz Sauberer have carried out outstanding work projects on the radiation climate in high alpine regions. This tradition was subsequently followed up only to a certain extent. ARAD would like to tie into this long tradition and at the same time make a major contribution towards deepening our understanding of the earth's climate system and the influences humankind exercises on the climate.



Illus. 2: Time scale of global radiation (= direct + scattered solar radiation) in Vienna at Hohe Warte. The blue line depicts the effect of global dimming, the red line of global brightening.

Global Dimming and Global Brightening

Apart from the effects of greenhouse gases on long-term heat radiation, the influence of aerosols on solar radiation is also an aspect of particular interest. Due to a variety of human activities, particularly the percentage of sulphate in the atmosphere rose drastically until the 1980s. Acid rain and the dying out of forests were a consequence of this high sulphate concentration. This subsequently led, throughout the course of the 1980s, to extremely effective measures being taken to purify and maintain air quality, which radically diminished the percentage of sulphate (see also Snow Chemistry project). It was not until later that it was recognized that these changes in air quality also caused - and continue to cause - significant changes in the radiation balance of the atmosphere. Due to the high percentage of sulphate aerosols and the reduction in solar radiation which was a direct result of it, the climate "cooled off" somewhat during the 1970s. However, after 1980, due to the air purification measures, this effect disappeared and the "warming" was that much more pronounced. Thus, the aerosol effect covered up the greenhouse effect, which functions utterly independently of it, during this time. This decreasing (global dimming) and increasing (global brightening) trend of solar radiation energy (global radiation) has been superbly recorded through the global radiation measurements at the Hohe Warte Observatory in Vienna (see illustration).

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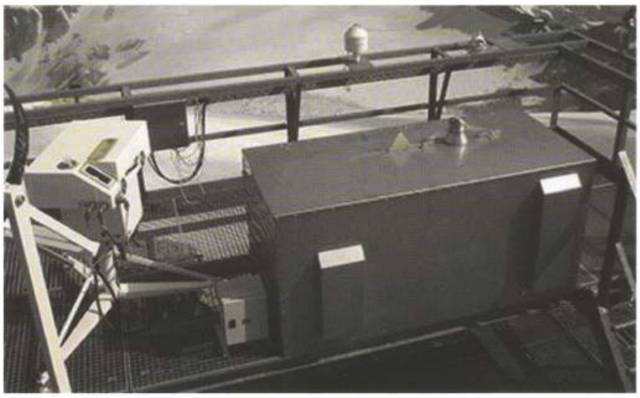
Long-term measurements of total ozone and high-resolution spectral UV radiation at Hoher Sonnblick and Gross-Enzersdorf

Beginning in the 1990s, ongoing measurements of spectral UV radiation and total ozone column have been carried out at the observatory at Hoher Sonnblick. They are a prerequisite for the assessment and understanding of effects of UV radiation on human health and ecosystems, as well as interactions with atmospheric parameters, such as ozone, clouds and ground reflectivity.

Target Objectives: UV radiation reaching the earth's surface is mainly influenced by total ozone, cloudiness, albedo and aerosols. Additionally, the complex topography of the observatory's surroundings are significantly complicating the radiation transfer. The data series exhibit notable variations due to the temporal variations of the influencing factors. The monitoring, aided by model calculations, aims at quantification of the interrelations between UV radiation and its influencing parameters, the long-term evolution of surface UV levels and the potential effects on ecosystems and human health in Austria.

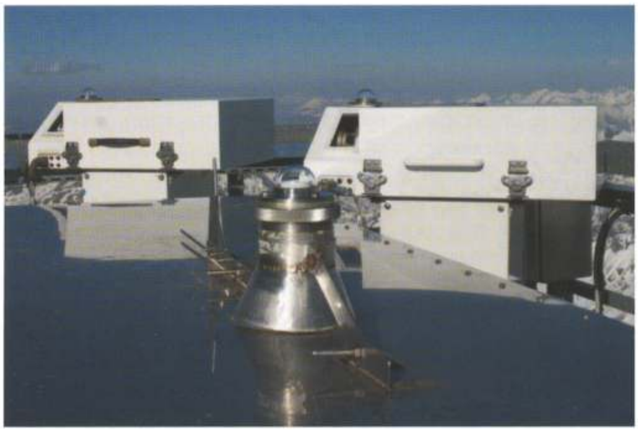


Instruments to measure spectral UV radiation and total ozone column at Hoher Sonnblick

Method: Since 1993 a Brewer spectrophotometer has been deployed at Hoher Sonnblick to measure total ozone and spectral UV irradiance. Thus, the data record is among the longest available in Europe. A Bentham spectroradiometer was installed in 1997, extending the measured UV range and the temporal resolution alike. An additional UV-Biometer has contributed near-real time broadband measurements of UV radiation to the Austrian UV-B Network since 1998.

High levels of data-quality and data-availability are cornerstones of continuous long-term measurements of UV. The measurements presented herein have been conducted to comply with the strict quality requirements of the "Network for the Detection of Atmospheric Composition Change" (NDACC). Due to its spectral characteristics, measuring UV radiation is technically demanding, requiring systems that attain high accuracy and excellent long-term stability. The high quality of the measurements is assured through regular calibrations and international intercomparison campaigns.

Quality control and assurance are prerequisites for the establishment of a data basis to cover the needs for investigating issues in different fields like climatology, environmental meteorology and medicine.



Instrument comparison campaign for quality control and assurance at Sonnblick Observatory, May 2011

The Project: The activities at Hoher Sonnblick are carried out within the framework of the project ***"Long-term measurements of total ozone and high-resolution spectral UV radiation at Hoher Sonnblick and Gross-Enzersdorf*"**, funded by the Austrian Federal Ministry for Agriculture and Forestry, Environment and Water Management. The instruments for the ongoing measurement of spectral UV and total ozone established within this project are vital resources for the precise capture of long-term and short-term variations as a consequence of the changing composition of the earth's atmosphere. The data acquired make possible the investigation of the processes involved in radiation transfer, and form the basis for an improved understanding of UV radiation reaching the earth's surface.

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Operations at Hoher Sonnblick station of Austrian UV-B Monitoring Network

The depletion of stratospheric ozone which began in the 1970s has led to increasing exposure to biologically relevant UV radiation on the earth's surface. Supplying up-to-date information to the general public and monitoring the evolution of UV radiation are vital for evaluating and reducing the risks of skin cancer and other threats to human health.

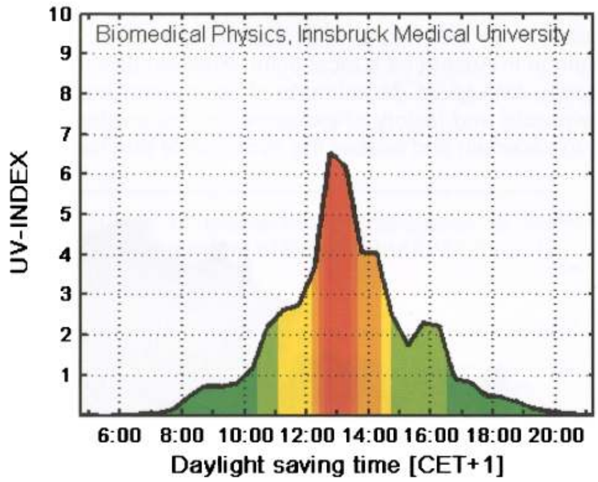
Target Objectives: Ever since the discovery of the ozone hole, scientists from the fields of medicine, climate and environment have been working ardently at investigating potentially harmful effects of UV-radiation. Delivering up-to-date, high quality information on current surface-UV levels to the general public is essential to assess and minimize the risks to human health from UV radiation, e.g. sunburn and skin cancer. To achieve this aim, the Austrian UV-B Monitoring Network was established in 1996. Public information, as well as studies of biological and medical impact and other detrimental effects on human health of erythemally effective UV radiation can only be based on spatially and temporally highly resolved observations. The observatory at Hoher Sonnblick, part of the network since 1998, provides undisturbed conditions for the measurements of surface UV radiation levels.

UV-Biometer at Hoher Sonnblick station, used to measure erythemally effective UV radiation

Method: The UV-Biometer at Sonnblick was installed in 1998 and has since then been part of the Austrian UV-B Monitoring Network. Twelve stations distributed throughout the country, all equipped with UV-Biometers, deliver data ongoingly to the network, together with four additional stations located in Switzerland and Germany. Thus, the biologically relevant UV radiation in Austria is being captured and characterised extensively. The instrument itself measures the erythemally weighted UV-B part of the solar spectrum. Its wavelength sensitivity closely resembles that of human skin.

To meet the high standards set for quality control and assurance, each instrument of the network is individually annually calibrated and compared with reference instruments.

The most recent of the continuously measured values are made openly accessible on a public website (http://www.uv-index.at) in intervals of 10 minutes.



Exemplary course of UV index values throughout one day at Hoher Sonnblick (www.uv-index.at)

The Project: Measurements of erythemally effective UV radiation are conducted at Hoher Sonnblick, among other locations in Austria, on behalf of the National Ministry of Agriculture, Forests, Environment and Water Management. The Austrian UV-B Monitoring Network has been operated by the Division for Biomedical Physics of the Innsbruck Medical University since 1996.
The Institute of Meteorology at the University of Natural Resources and Life Sciences Vienna operates and maintains two of the network's stations, Hoher Sonnblick and Gross-Enzersdorf.

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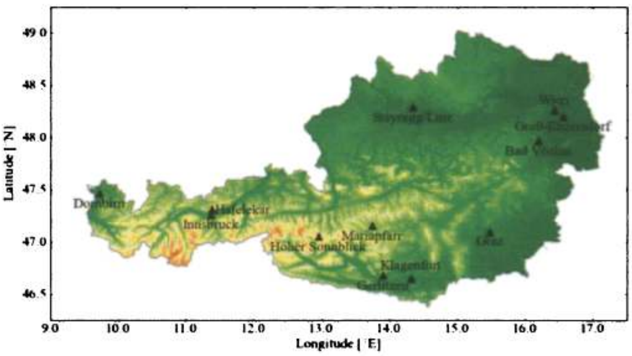
UVSkinRisk - Human health threatened by UV-induced skin cancer in a changing climate

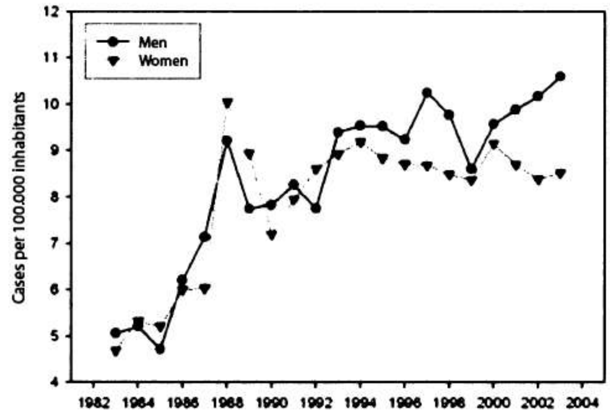
Our understanding of long-term changes in biologically pertinent UV radiation and its effects on human health needs to be improved. This study involves, apart from the Sonnblick Observatory, ten Austrian stations in representative locations extending throughout the nation. Its goal is to provide insight into the impact of climate change on long-term progression of UV radiation as well as on human health, past, present, and future.

Target objectives: To understand long-term relations between changes in biologically relevant UV radiation and deducible health risks, e.g. the sharp increase in skin cancer incidence since the 1980s, comprehensive knowledge of the spatial and temporal distribution of UV radiation and its influencing parameters is essential. Thus, a better understanding of UV radiation in the past is imperative, as well as of the prospective evolution of UV radiation in the future, with various scenarios of climate change in Austria as a focal point. After establishing a high-quality data basis, an estimate of risk perception, individual behaviour and history of exposure can be posited. The aim is to ascertain and assess the evolution of skin cancer risk.



Geographical distribution of the 11 stations in Austria, where past and future calculations of modelled scenarios are conducted; the station at Hoher Sonnblick provides major data foundations.

Method: The period in which direct measurements of UV radiation in Austria are available is too short for valid long-term assessments and must therefore be extended by reconstructing time-extension series of periods before measurements became available. The reconstruction of past time-series as well as the modeling of future scenarios is based on measurements of erythemally effective UV radiation at the locations of the Austrian UV-B Monitoring Network established in 1996 and operated by the Division for Biomedical Physics of the Innsbruck Medical University. Together with standard meteorological observations, past surface UV levels are calculated using radiation transfer models. Future trends are estimated by means of climate models on a regional scale which includes long-term cloud cover and other influential parameters in climate change scenarios.
For a detailed estimate of individual exposure and the development of skin cancer risk, a three-dimensional model of the human body is deployed to calculate the actual level of exposure in representative conditions.



Number of new melanoma skin cancer cases in Austria per 100,000 inhabitants (source: StartClim 2007.B)

For a targeted approach to specific risk or peer groups, a telephone survey is also conducted permitting a special focus on public perception of UV-related health risks and individual risk and exposure behaviour. These gathered results, together with the model calculations, will be used to better understand and evaluate the evolution of skin cancer risk in Austria.

The Project: The research project UVSkinRisk is funded by the "Austrian Climate Research Programme" (ACRP) of the "Climate and Energy Funds" (KLI.EN) and is scheduled for the period from 2011 to 2013.
It is managed by the Institute of Meteorology of the University of Natural Resources and Life Sciences, Vienna, supported and co-conducted by the Institute of Meteorology and Climatology of the Leibniz University Hanover and the Institute for Environmental Hygiene of the Medical University of Vienna.

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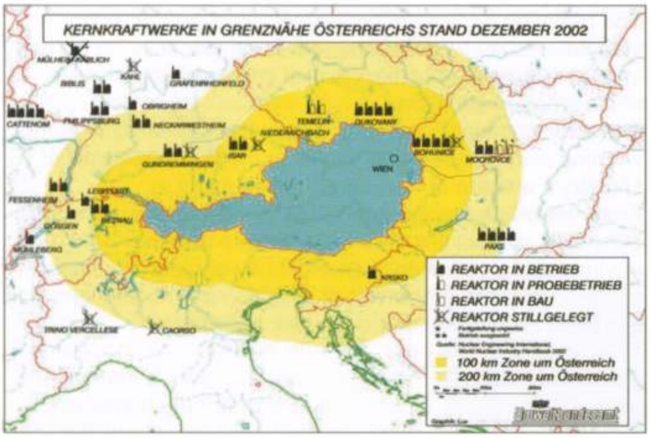
“Souvenirs” in the air as a result of nuclear accidents

In the aftermath of accidents in nuclear plants, radioactive material can be released into the atmosphere. Such substances can be transported over very long distances and deposited across the earth’s surface. At the Sonnblick Observatory aerosol-bound radionuclides are measured routinely by experts of the Austrian Agency for Health and Food Safety (AGES). In case of an accident at a nuclear power plant, the analysis of the radioactive cloud provides essential information about health effects for the population.

Rapid implementation of precautionary measures

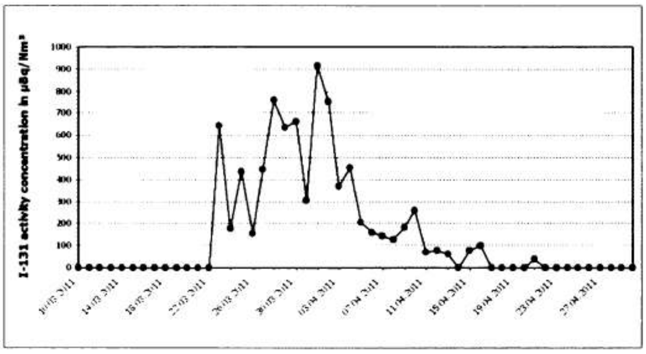
At the Sonnblick Observatory a high-performance system for collecting aerosols on glass fiber filters is installed. Following aerosol-sampling, the filters are analyzed for their radioactivity at the AGES Competence Centre for Radioecology and Radon in Linz. This work is carried out on behalf of the Austrian Ministry of Environment. If radioactive particles of man-made origin are transported to Austria by air, these measurements make it possible to estimate the dose and health hazards to the population.
This information helps the responsible authorities to take the necessary precautionary measures.



Illus. 1:Nuclear power plants in the vicinity of Austria

High-resolution gamma-spectrometry example of FUKUSHIMA

With the high-resolution gamma-spectrometers of the Competence Centre for Radioecology and Radon, the exact concentration of radioactive particles in the air is determined. Due to the high sensitivity of the measurement system, it is possible to detect concentrations of a few radioactive aerosols per cubic meter of air.
Drawing on the example of the accident at the nuclear power plant of Fukushima, Japan in March 2011, the timeline of transportation of radioactive aerosols to Austria could be narrowly defined.



Illus. 2: Timeline of Iodine-131 concentration at Sonnblick after the accident of FUKUSHIMA (11.03.2011)

The measured concentrations were very low (approximately a tenth of the concentration of the natural radionuclide Beryllium-7). There was no health risk to the population.

To determine the exact concentration, the temperature- and pressure-corrected flow-rate through the filter is calculated automatically at the end of the sampling period. Filters are changed automatically as well; moreover, the sampling period is freely programmable so it can easily be adapted to the specific situation.

Myriad Additional Benefits

Beside evidence of radiant particles in the air, the measurements also provide information about a wide range of processes in the atmosphere – for example when using Beryllium-7 as a tracer for investigations on ozone-transportation.

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Austria's Early Warning System for Radiation

Since the end of the 1970s, an automated radiation measurement network - an early warning system - has been in operation in Austria, including more than 300 measurement instruments for local limits, together with air monitors which ongoingly monitor and measure the radioactive contents in the air. The system is supervised by the National Ministry for Agriculture, Forests, Environment and Water Supply.

Blanket coverage warning system

The measurement stations of the radiation early warning system are distributed throughout Austria and supply measurements on levels of radiation in the environment and any possible radioactive contamination which might affect Austria, e.g. following disorders at nuclear power plants near Austrian borders. Supplementing the measurements of local limits, the monitors ongoingly measure and relay the contents of radioactive aerosols and gases in the air.

Fully automated measurement and transfer

All the systems measure continually and fully automatically. The measurements are then fed online to the radioactivity protection division of the BMLRUW Ministry in Vienna, where they are consolidated with other measured data and information which form the basis for assessing the situation in the interests of making recommendations for protection measures in case a breakdown makes them necessary. From that central command center, they are also accessible by warning centres and government agencies of the nine Austrian states.

One of these measurement stations is located at the Sonnblick Observatory. As Austria's highest altitude measurement station, it plays an important role with regard to early warning in case air masses contaminated with radioactivity traverse the land.

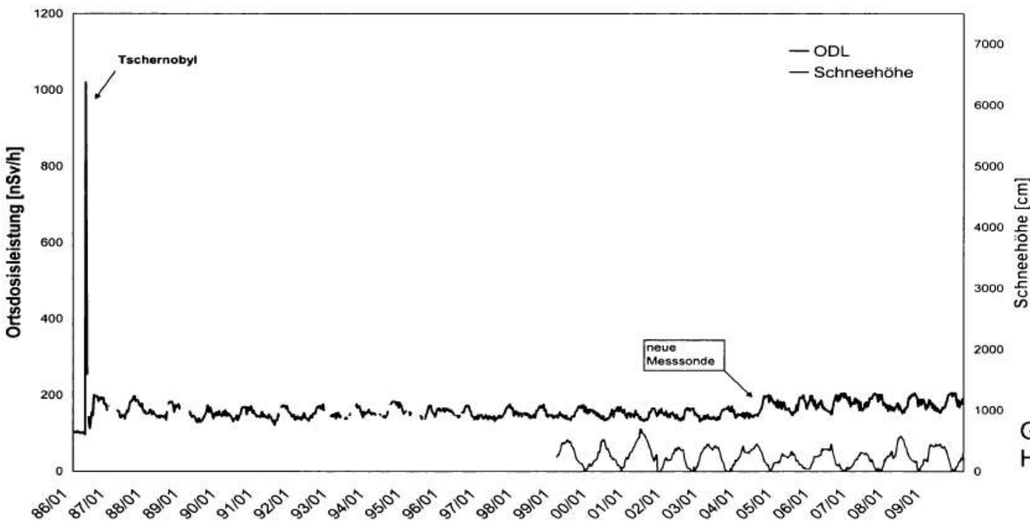
Method

For purposes of measuring the gamma radiation, a proportional counting pipe is used which is installed on the highest altitude outdoor terrace at the observatory (see photo, covered in white frost). The instrument can be used for extremely wide-band measurements, beginning with a level of natural background radiation all the way up to 9 different magnitudes. The data supplied by this device are evaluated in the measurement center of the observatory, stored and then relayed.

The radiation early warning system supplied, for example, valuable results following the reactor accident in Tschernobyl in April 1986 and kept Austria well informed of the contamination situation.

The current measurement data from the radioactivity early warning system are made public on the Environmental Ministry's website at www.strahlenschutz.gv.at.

From the graph below containing the measurements of the Sonnblick station, it is also recognizable that the environmental radiation level ordinarily correlates with the snow depths: the proportion of radiation from below ground is correspondingly shielded by a thick snowpack.



Graph of local limits measured at Hoher Sonnblick 1986 - 2009

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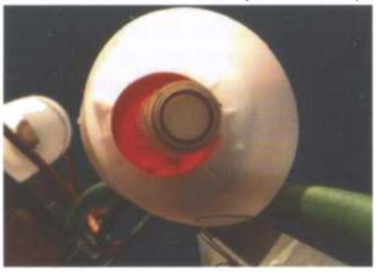
Background measurements at Sonnblick – respirable dust and trace gases

Aerosol particles influence the radiation balance of the earth in two ways: they have cooling traits, although they can lead to a further warming of the planet. And, since they are condensation nuclei for steam, they also provide the basis for cloud formation and, ultimately, precipitation. Beyond that, aerosol particles - also known as respirable or fine dust - are something of health-relevant magnitude. The measurements for the project group "Background Measurements at Sonnblick" supply solid foundations for all these thematic areas.

It is now almost 20 years ago that a two-year series of measurements was launched to record atmospheric trace gases, e.g. sulphur dioxide, nitric acid and ammonia; and water-soluble elements of respirable dust, e.g. nitrate, sulphate, ammonium as well as chloride, sodium, potassium, calcium and magnesium.
Probes were taken daily with filter packs in order to obtain simultaneous readings of particle-formed and gas-formed air contents.



Illus. 1: Filter bag measurements

In the following years, this successful project enjoyed two phases of continuation and expansion in the context of GAW (Global Atmosphere Watch), entailing activities on the Sonnblick which led to a set of data comprising many years now being available.

Over the last few years, the measurements have concentrated on taking samples of respirable dust. In the process of this, sample-taking was changed from filter packs to a Hi-Volume collector with PM10 separation. Due to this change, the simultaneous determination of trace gases was no longer possible, but as an additional reward, besides ionic aerosol components also total carbon and soot, as well as organic tracer elements could also be determined.

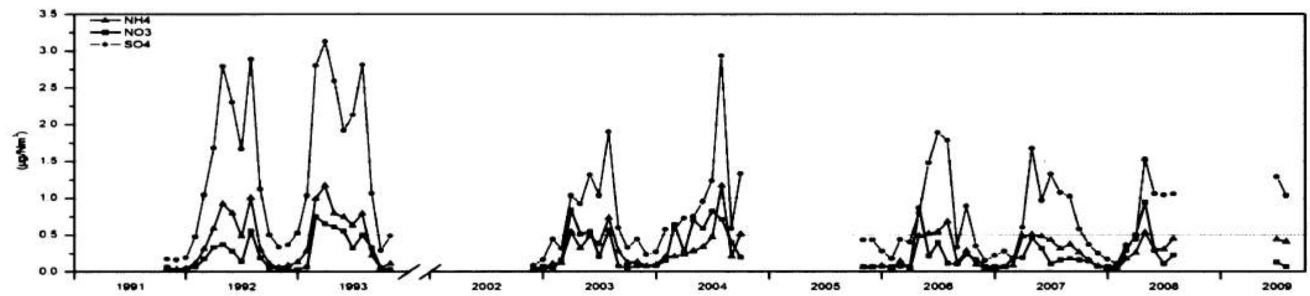
Illus. 2: High-volume collector

Complementary measurements and models

Determining background contamination by air contents in particle-form and gas-form provides a basic foundation for generating and verifying climate models or deposit models. Whereas there is a relative abundance of information on air quality in cities, suburban settlements and near industrial zones, there is very little information for higher layers of the atmosphere. This is particularly the case for 'non-conventional' air-polluting elements which for reasons of impractibility are rarely reflected in the immission measurement networks. Models calculate the horizontal and vertical distribution of concentration values of aerosols (airbourne particles) and gases based on emission data and meteorological parameters. These statistics have to be verified at least pointwise through measured data. The Sonnblick is such a measurement station, located at 3 kilometers altitude. Whereas flight measurements can only provide snapshots, the Sonnblick is in operation all year round. Such comparable measurements are also necessary for developing the parameterisation of physical-chemical processes in the atmosphere which is used in models.

Respirable dust and human health

Over the last few years, the term 'fine dust' has become a household word due to its direct effects on human health. Exceeding permissible concentrations of respirable dust as set out in the immission laws guarding air quality is something which is impossible on the Sonnblick. Maximum contamination values are determined for urban areas. However, respirable dust has a medium retention time in the atmosphere of 3 to 5 days and can be transported several hundred kilometers in that time. Thus, background contamination far removed from metropolitan areas is something which must not be neglected. Determining aerosol composition at the Sonnblick supplies important information towards a deeper comprehension of background air contamination and long-distance transport.



Illus. 3: Time scale of aerosol concentration at Sonnblick

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Chemical-physical characteristics of older aerosol particles ($PM_{2.5}$)

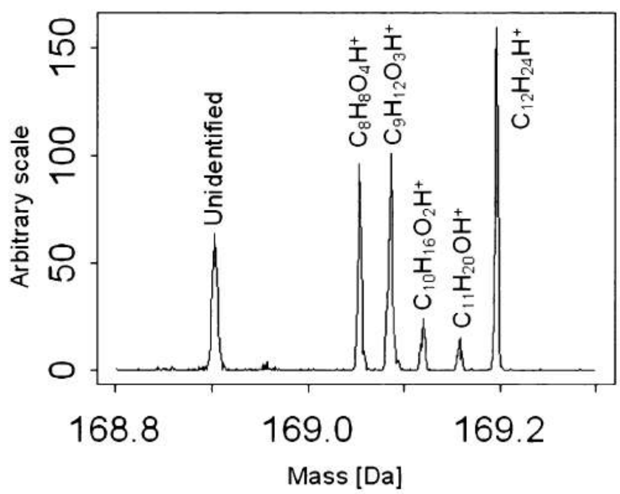
$PM_{2.5}$ is the designation for small particles up to two-and-a-half thousandths of a millimeter in diameter floating in the air. This class of particles consists by and large of organic compounds, sulphate, nitrate, with inorganic components. The organic components of PM2.5 are of particular interest, for they play a key role in the understanding of human-caused earth warming; and because many of these compounds pose a threat to human health.

Climate effects of aerosol particles: The backcoupling effects of aerosols on the climate are highly variegated and difficult to quantify. Aerosol particles serve as cloud condensation nuclei and thus define the characteristics and development of a given cloud being formed. In regions with high loads of atmospheric aerosol, clouds form with droplets of smaller size but higher density. Such clouds have a higher reflectance and a longer life than clouds which form in regions which are not contaminated. One of the most important questions in climate research is the extent to which hydrocarbon and nitric oxides emissions, as well as heightened ozone concentrations at ground level, influence the formation of organic aerosols. New types of measuring instruments are being developed all around the world in order to analyse the chemical composition of aerosols in detail. Such instruments endeavor to obtain new insights into the chemical and physical processes in which organic compounds make a significant contribution to existing aerosol loads.

Input system above the measurement terrace

Measuring method: A new type of device for analysing organic aerosol has been developed at the University of Utrecht. The aerosol particles are collected on an impactor, then thermically extracted. The chemical analysis ensues with a proton-transfer reaction mass spectrometer (PTR-MS) developed by the Ionicon Co. in Innsbruck. The PTR-MS dector is equipped with a modern flight-time mass spectrometer whose high dissolution capability makes it possible to determine the sum formula of a detected signal. In such ways, the elementary composition of various aerosol components can be measured. Through the thermic extraction method, furthermore, parameters of the fugitive qualities of aerosol components can also be measured.

The Project: An initial series of measurements was carried out at the **Sonnblick Observatory** in July/August 2009. The local conditions make it possible to measure aged aerosol particles in the free troposphere. Valley winds with fresh, local emissions were occasionally superimposed on these basic background conditions. Initial results show that older aerosol evidences a higher grade of oxidation, with a higher percentage of non-fugitive compounds.



A small excerpt from the spectrum of the flight-time mass spectrometer. Its high capacity to dissolve mass enables scientists to make chemical specification of the detected signal

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Monitoring mountain air with high altitude instruments

Since 1998, the Environment Agency Austria has been monitoring a variety of atmospheric gases at the Sonnblick site. These gases include ozone, carbon monoxide, carbon dioxide and reactive nitrogen oxides (including nitrogen monoxide and nitrogen dioxide).

For these measurements ambient air is sampled via a central sampling manifold on the northern part of the roof of the meteorological station and from there distributed to the monitors. Because of the altitude and prevailing weather conditions, all parts of the central sampling manifold must be heated electrically throughout the year.

Ozone (O_3)

The reactive gas ozone is formed due to the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Ozone measurements are performed with a monitor specifically modified for the altitude. The principle of measurement is based on the absorption of ultraviolet light with a wavelength of 254 mm by ozone molecules. Since there are hardly any other gases that absorb light of this wavelength, the decrease in light intensity is proportional to the ozone concentration. With an ozone calibrator, which can produce both ozone-free air and defined ozone concentrations, the correct operation of the monitor is checked automatically every 23 hours. The ozone monitor is calibrated with an independent calibration system 4 times a year to ensure traceability and comparability of the measurement results at international level.

Carbon monoxide (CO)

The measurement principle is based on the ability of carbon monoxide to absorb infrared light with a wavelength of 4.7 µm. Since there are a large number of other gases that are also able to do that (notably, water vapour and carbon dioxide) a catalyst is used to remove carbon monoxide from part of the ambient air. The difference between the two signals is used as a measure for the carbon monoxide concentration. The detector is a thin metal membrane that expands, depending on the intensity of the infrared light received. The correct operation of the monitor is checked automatically every 23 hours. Carbon monoxide measurements are calibrated with an independent system 4 times a year to ensure traceability and comparability of the measurement results at international level.

Carbon dioxide (CO_2)

Measurements of carbon dioxide have up to now been performed with a measuring instrument specifically modified for the altitude on the basis of the absorption of infrared light. In the course of 2011 a new instrument will be installed which is based on laser spectroscopy. It is expected that with this Cavity Ring Down Spectrometer a higher level of data quality and reliability will be achieved. The instrument can also detect methane (CH_4) and therefore a measurement series for methane will be started by exchanging the old instrument for the new one. Since carbon dioxide-free ambient air does not exist and observed concentration fluctuations are very low, this instrument is calibrated for a very small range of measurements by using carbon dioxide gas mixtures with known concentrations. The gas mixtures needed for this purpose are specifically certified for measurements under the "Global Atmosphere Watch" programme so as to ensure comparability of carbon dioxide measurements worldwide

Nitrogen oxides

Nitrogen oxides – of which nitrogen monoxide (NO) and nitrogen dioxide (NO_2), together referred to as NO_x, are most widely known - have both natural and anthropogenic sources and play an important part in the formation of ozone, as well as eutrophication and particle formation. Apart from NO and NO_2, higher nitrogen oxides (N_2O_5) and nitrous and nitric acid, together with organic nitrate compounds, are referred to as reactive nitrogen oxides (NO_y). The different compounds are quickly transformed into one another and are difficult to determine. Determination of nitrogen oxides is based on the principle of the chemiluminescence of NO. Apart from measuring NO directly it is necessary to convert all nitrogen oxides present in ambient air fully to NO because it is only NO that can react with surplus ozone in the measurement chamber of the monitor and, by conversion back to NO_2, a emits light in the infrared region. This amount of light is used to measure NO (without conversion) and/or the sum of the nitrogen oxides (with NO_x and/or NO_y conversion). In addition to measuring NO_y through conversion with a molybdenum converter, an NO_x monitor with a photolytic converter has been in use for measuring NO and NO_2 since January 2010. All measured values are immediately transferred to the Air Quality database at the Environment Agency Austria in Vienna. The Umweltbundesamt web site for up-to-date air quality information provides direct access: (http://www.umweltbundesamt.at/umweltsituation/luft/luftguete_aktuell/)

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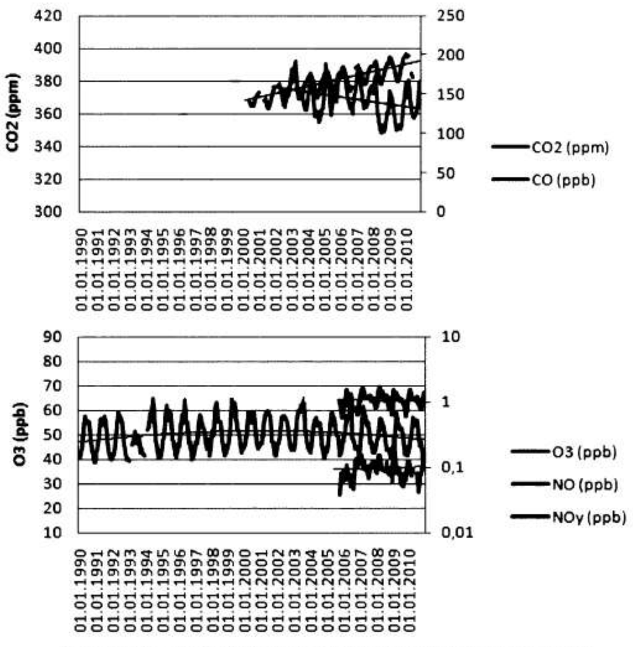
International cooperation to protect the atmosphere

The Sonnblick Observatory contributes to the Global Atmosphere Watch Programm (GAW) of the World Meteorological Organization, which forms a global network to research the large scale chemical composition of the atmosphere. The measuring sites need to be be far distant from local or regional pollutant sources. Together with the German GAW sites Hohenpeißenberg/Zugspitze and the Swiss Jungfraujoch Observatory, the three countries constitute the so called „GAW-DACH-co-operation".

Extensive measurements: The measurements at the Sonnblick Observatory are organized as follows: Meteorological parameters are carried out by ZAMG; the Austrian Environmental Protection Agency carries out measurements of ozone, carbon monoxide and –dioxide and nitrogen oxides, the Institute for Meteorology of the University of Natural Resources and Life Sciences conducts total ozone and UV-B and the Federal Chancellery of the Republic of Austria measures beryllium-7. The Institute for Chemical Technologies and Analytics of the Technical University Vienna, together with the provincial government of Salzburg, analyses the chemical composition of precipitation.

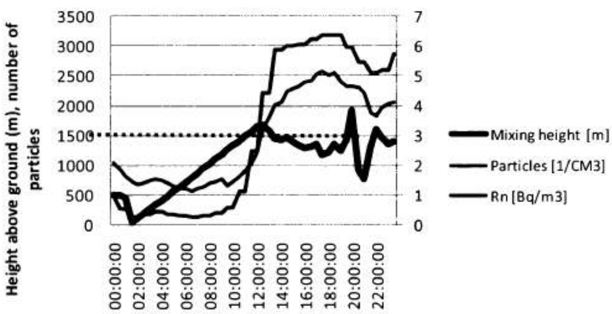
Early detection of trace gas trends: Because of its unique location far removed from emission sources, Sonnblick is highly suited for the early detection of trace gas trends. In addition, European emission sources and intercontinental air pollutant transport can be detected and analysed.



Monthly means of trace gas concentrations at Sonnblick
1. 1. 1990 - 31. 12. 2010.
Top: CO2 (ppm, left scale) and CO (ppb, right scale).
Bottom : O3 (ppb, left scale), NOy and NO (ppb, right scale).

Carbon dioxide (CO_2 (ppm), violet curve, top figure) has increased continuously since the beginning of the measurements (1 ppm is one single part within one million parts of air). Ozone (O_3 (ppb), blue curve, bottom figure) reached its maximum in 2003 and decreased thereafter (1 ppb is one part within one billion parts of air). Carbon monoxide (CO, green curve, top figure) and nitrogen oxides (NOy, black curve, bottom figure) show a small decrease, whereas nitrogen monoxide (NO, red curve, bottom figure) remains nearly constant. The trace gas trends at Sonnblick are consistent with the trends observed at the partner stations Jungfraujoch, Zugspitze and Hohenpeissenberg. Analyses of the reasons for the trends are in progress.

Air has no marker – research can help: A high degree of emphasis is placed on the analysis of the origin of the air masses arriving at the Sonnblick: Near ground air masses show an enhanced content of anthropogenic pollutants. Large scale air pollutant transport has been studied intensely with trajectory statistics. During the summer in 2009 the effects of vertical pollutant transport on the trace gas concentrations at the Sonnblick caused by thermal mixing were studied using a laser-ceilometer (see also project WAVES).



Height of the mixing layer (black), number of condensation particles (red) and 222-Rn-activity (blue), 27.7.2009.

The ceilometer emits a vertical laser beam which is reflected by cloud droplets or aerosols. The backscatter signal can be used to determine the height of the mixing layer, the layer with near ground air pollutants is vertically mixed over a time period of approximately one hour. The figure shows an example of the increase of the mixing laxer height (black curve) up to the height of Sonnblick (dashed line) on 27.7.2009, combined with an increase of the number of condensation particles (data from Technical University Vienna) and of the 222-radon activity (data from University Heidelberg). 222-Rn is a radioactive gas emitted from the ground and thus, an excellent indicator for trace gas transport from the valley.

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MONARPOP – Persistent Organic Pollutants: Sonnblick part of global monitoring plan

The locality-specific air measurements which were carried out for the first time in high alpine regions in the context of the international project MONARPOP are now being continued in the framework of the Global Monitoring Plan to evaluate the Stockholm Convention. Persistent organic pollutants (POP) such as dioxine, PCB, chlorpesticide, etc. are measured both in their deposits and in the surrounding air, separated according to origin in accordance with pre-defined areas of origin.

POPs: Long-distance, long-lasting environmental pollution

POP (persistent organic pollutants) are organic toxic substances not easily degradable, such as polychlorinated dibenzodioxine or DDT. Due to their long persistence in the environment, they are transported through the air for hundreds of kilometers into the most isolated regions. Their preferred chemical bond to fatty or organic substances is responsible for the enrichment in humus, plant parts, animal tissue and in the nutritional chain. This is a worrisome process, since POP even in very tiny concentrations release a series of toxic effects.

MONARPOP: an exemplary European pioneer project

MONARPOP (Monitoring in the Alpine Region for POP) uncovered the POP contamination in the Alps in a three-dimensional resolution during the years 2004 - 2007. To this end, 40 locations scattered throughout the Alps, plus seven altitude profiles, three high alpine air measurement stations (Sonnblick, Weissfluhjoch, Zugspitze), five different types of samples (air, deposits, passive collectors, spruce needles, ground) and more than 70 analysis parameters were deployed. For the very first time, a method of air sampling was used which made it possible to collate the measured concentrations to pre-defined areas of origin. The sample takers were directed via Internet, based on the trajectory forecasts of ZAMG in Salzburg.

The costs for the implementation of this large scale project were borne by funds from the EU programme "Interreg III B Alpine Space" and by the national government. Under the aegis of the BMLFUW and the project management for the National Environmental Ministry, the research facilities and public agencies in five alpine countries measured the degree of contamination in common cause.

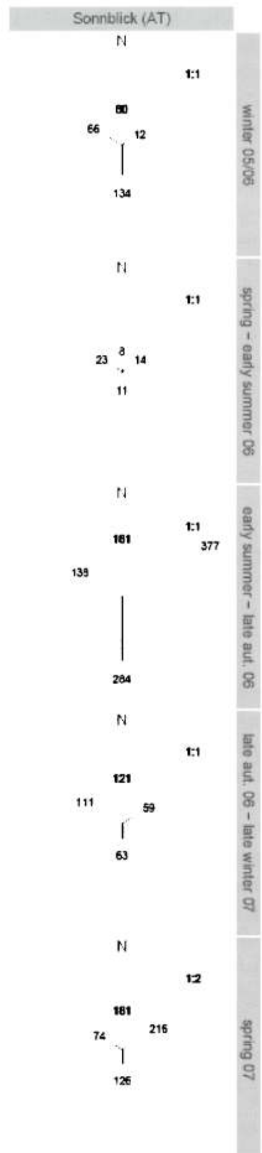
The Alps: a catch-all for toxic substances?

In the course of this project it became clear that spruce needles and humus samples from isolated areas possessed relatively high concentrations - with locations at high altitude having even higher concentrations - of certain POP, some of which have been prohibited for a long time. In spite of the absence of local sources of pollutants, these locations clearly suffered a significant enrichment of toxic substances, namely through contaminated air masses. Low temperatures, high deposit rates and wind impact are conditions which enhance an enrichment of such substances and which are highly typical of the Alpine region. At the three air measurement stations as well, both in the air of the nearby vicinity and in deposits, pollutant concentrations of the same magnitude were found, as they also were in farming areas in the flatland countryside.

Global Monitoring Plan

This was sufficient cause for the UN to take on the project MONARPOP with the three air measurement stations including the Sonnblick in the "Global Monitoring Plan" to "effectively evaluate" the UN's "Stockholm Convention to prohibit or reduce persistent organic pollutants (POP). Through these measurements, the success of the regulations issued by the Stockholm Convention can be assessed. If the measures which were undertaken have a positive effect, the concentrations measured can be expected to diminish in coming years or decades. For that reason, air measurements will be continued at the three stations through the project MONARPOP, with newly adapted, origin-specific sample-taking to be financed by the respective national governments.

Illus. 1:
Σ PCDD/F air concentration in [fg / Nm^3] over five 3-month periods of measurement, allocated to area of origin. The vectors depict concentration and origin of the toxic substances in air masses from three pre-defined areas of origin, the ring depicts the measured concentrations in non-traceable air masses.



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What is the role of air mass transport in atmospheric trace constituent variability at Sonnblick?

Understanding the variable air mass advection to Sonnblick Observatory is important for the interpretation of all atmospheric chemistry records obtained at this site. Is there a direct uplift of valley air and how long has an air mass been in contact with the relatively polluted ground level air of the European continent? Continuous monitoring of the atmospheric Radon activity at Sonnblick provides an excellent tool to deal with these questions.

Background

The natural, radioactive noble gas Radon (^{222}Rn) is produced exclusively from soil radium and steadily diffuses into the atmosphere. Here its live time with respect to radioactive decay is 5.5 days, which is comparable to the typical residence time of atmospheric dust or the characteristic time scale of atmospheric circulation changes. Since, unlike for all other trace constituents, the source and sinks of Radon are definitely known, this constitutes a reliable tool in elucidating the influence of air mass transport on the variability of other chemical species. Especially at mountain sites, continuous Radon monitoring allows for identifying the intermixture of polluted ground level air with the free troposphere, as well as for estimating the degree of maritime and continental signature of air masses under investigation.

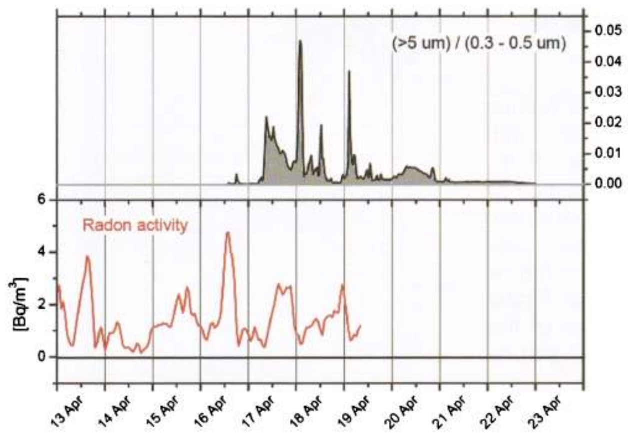

Fig.1: Arrival of Eyjafjallajökull ash particles at Sonnblick in 2010 indicated by the strongly enhanced ratio of large to small particles observed by an optical particle sensor (upper panel). The Radon record (lower panel) clearly shows that the particle signal is not driven by ground level air. This provides clear evidence that the large particle plume reached the site from above and, indeed, was associated with the volcanic eruption event.

Continuation of Radon monitoring

Even after the end of the EU-CARBOSOL project (examining European wide distribution of organic aerosol species), associated Radon observations were maintained at Sonnblick (see previous Annual Report). This effort is mainly aimed at backing up observations of other atmospheric species on the diurnal, synoptic, seasonal and inter-annual time scale. Fig.1 shows the Radon-supported identification of a volcanic ash plume at Sonnblick, whereas Fig.2 illustrates the typical patterns of the ground level air fraction (as indicated by the Radon level) over the last 8 and 7 years, respectively. For analytical reasons, we basically refer here to the ^{214}Po decay product which is closely linked to the ^{222}Rn activity.

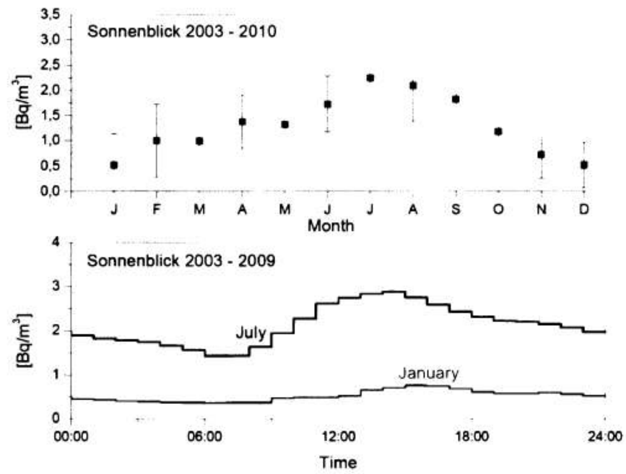

Fig.2: Mean seasonal cycle of average monthly Radon activity (upper panel) and the respective diurnal pattern of hourly means for mid-summer and mid-winter, respectively (lower panel). Note the clear summer maximum (driven by the more intensive vertical mixing in that season) as well as the relatively low level and essentially flat diurnal Radon cycle during January.

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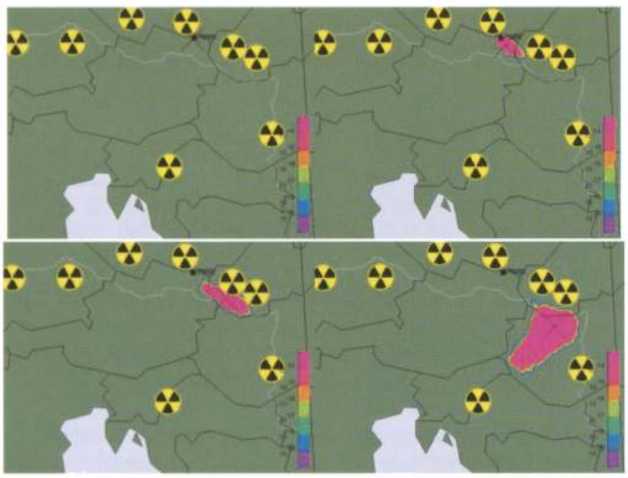
Calculation of source receptor matrices for mountain observatories: Project QRS-Sonnblick

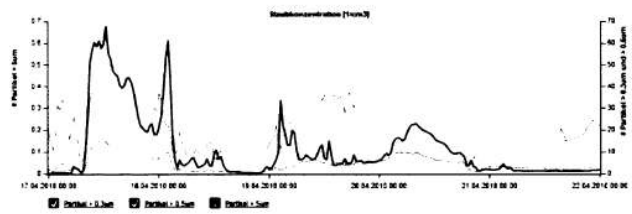
On the Sonnblick and at other high alpine observatories (Jungfraujoch, Zugspitze und Hohenpeissenberg), concentrations of atmospheric trace gases and aerosols have been monitored for many years, and the trends of these air components determined. By means of trajectory statistics, possible regional origins of the measured substances can be estimated. As part of the project QRS-Sonnblick, source receptor sensitivity fields are computed with backward runs of a Lagrangian particle diffusion model (LPDM). Using these new data sets, the analysis of possible regional origins and of the trends of various sources can be considerably improved.

Objective: At the Sonnblick (3106 m), apart from ongoing meteorological observations, there is continuous monitoring of air chemistry (O_3, CO, CO_2, NO_y), aerosols (particle concentrations, size distributions) or radioactivity (effective dose rates, radioactive aerosols). As one of the European background stations, the observatory is a crucial contributor to the Global Atmosphere Watch (GAW) Programme of WMO. For many years, source regions of air constituents have been determined by means of air trajectory statistics, and trends are determined and discussed. For a further improvement of transport calculations and data analysis, source receptor sensitivity (SRS) fields will be computed for measurements taken at the Sonnblick. Similar calculations will be performed at the observatories at Jungfraujoch, Zugspitze and Hohenpeissenberg. The project team expects to achieve a significant improvement in the future determination of source regions of air pollutants.



Display of a source receptor sensitivity field calculated for a measurement taken at a station of the Austrian radiation monitoring system.

Methods: To investigate the origin and trends of measured trace gases and air components, the application of adjoint models has been recommended for many years. The simplest method to estimate sources of measured substances is the calculation of backward trajectories. Such trajectories can be utilized in single case studies as well as in statistical evaluations. Backward trajectories, however, represent a significant simplification of the description of atmospheric transport and diffusion. Therefore, full-fledged adjoint tracer transport models have been used increasingly for source analyses over the last years. As part of this project, source receptor sensitivity (SRS) fields will be computed. The calculations are performed with the Lagrangian particle diffusion model FLEXPART in backward mode. As input data, meteorological analyses from the European Centre for Medium-Range Weather Forecasts are used. Regarding the source location post-processing, several different methods are applied, including the statistical evaluation of SRS fields (SRS statistics) and the source correlation technique. Results are compared with the results obtained by applying traditional methods.



Measurement of the number of large, medium-sized and small particles at the Sonnblick in April 2010 during the passage of the volcanic ash plume of Eyjafjallajökull

The project: The project QRS Sonnblick is a so-called "internal project" of ZAMG. ZAMG's internal projects are supported by a specifically allocated fund of the Austrian National Ministry for Science and Research. The project was launched in February 2011

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Snow Chemistry on the Sonnblick

For the purposes of this research project, the wintery blankets of snow serve as natural archives for environmental disturbances over the last 20 years. At the Sonnblick and the nearby Schareck, annual changes are ascertained by measuring the ion composition of all the snow layers in each winter half-year. The ion concentrations in the snow on the Sonnblick are the result of large-scale transporting through the atmosphere. A particularly impressive aspect of these measurements is the declining sulphate content in the snow, documenting the success of the environmental measures undertaken in Europe.

Objectives

In 1983, this project was launched by the Central Institute for Meteorology and Geodynamics and the Institute of Chemical Technologies and Analytics of the Vienna Technical University. At the time, the so-called "acid rain" was a much discussed scientific problem, and, as an upshot of it, the dying out of European forests. The cause of the high amounts of toxic substances lay in antiquated heat generating power plants in which low quality, sulphur-rich coal was burned, most of them located in Eastern Europe. Measurements of toxic imbalances in the snowpack were initiated on the Wurtenkees (Schareck) in 1983. Since 1987, such measurements are also conducted on the Sonnblick. The following objectives are pursued:

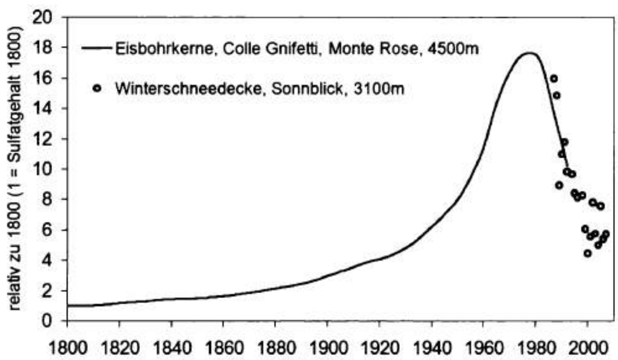
- Long term monitoring of ion composition, i.e. toxic substance load, of the snowpack
- Correlation of individual snow probes to precipitation events and meteorological description of precipitation sequences
- Quantifying long-distance transport of toxic substances in Europe
- Improving overall understanding of the process of events and links between inclusion and deposit of toxic substances in precipitation in the Alps

Illus.1: Taking a snow probe on the Sonnblick

The measurements have been optimized and internationally standardized in the course of a research project being conducted throughout the Alps, making comparison of measurements from a variety of locations efficient and reliable.

Method

The measurements are carried out annually at the end of April. At that juncture of the season, it is improbable that the snowpack at 3,000 meters altitude is being influenced by melting. Snowmelt, after all, "washes out" the ions from the snowpack. Snow galleries are dug down to the summer borderline of the previous year, then probes are removed layer by layer. The snow profiles are kept deep-frozen until they reach the laboratory in Vienna, where they are analysed.



Illus.2: Development of sulphate concentrations in the snowpack in the Sonnblick region since 1987 (blue dots) compared to measurements from ice probes in Switzerland (data source: D. Wagenbach)

In addition to the snow probes, profiles of snow layers are also precisely analysed and recorded. The analysis comprises size and form of snow grains, hardness, water content, temperature and density of individual snow layers. From these physical snow masses and meteorological measurements on the Sonnblick, the individual snow layers can be correlated with precipitation events. As an extension of this, snow layers with lower or higher ion concentrations can be more precisely characterised through the meteorological conditions. A point of special interest are the waves of dust from the Sahara desert, which establish a significant buffer zone against the acid components, e.g. sulphate, in the snowpack.

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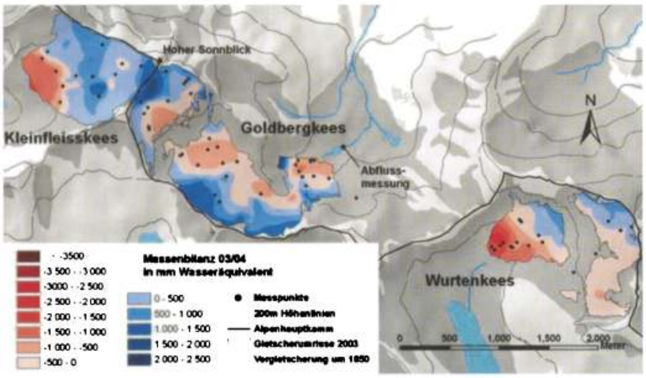
Glacier monitoring on the Sonnblick

In the context of the project known as HIGHmon (High-alpine Glacier Hydrometerological Monitoring Sonnblick) and WURTEN, changes in glacial mass of the three major glaciers of the Goldberg range - Goldbergkees, Kleinfleisskees and Wurtenkees - are measured twice annually on-the-spot at various locations. In addition to actual measurements, historical data of glacial development of the Goldberg range is assembled, digitalised and evaluated. Both the historical glacier data and the annual measurements, in combination with the dense station network in the area of the Hoher Sonnblick, provide an incomparable data basis for glaciological and hydrological model studies in the Sonnblick region.

Each year at the beginning of May, approximately the time when snow depths reach their maximum, snow density and snowpack depth are measured in a series of snow profiles. At other times of year, in a far greater number of places, the snow depth is probed and/or measured via ground-penetrating radar, then the increase in mass during the half-year of winter, i.e. the winter mass balance, is calculated.

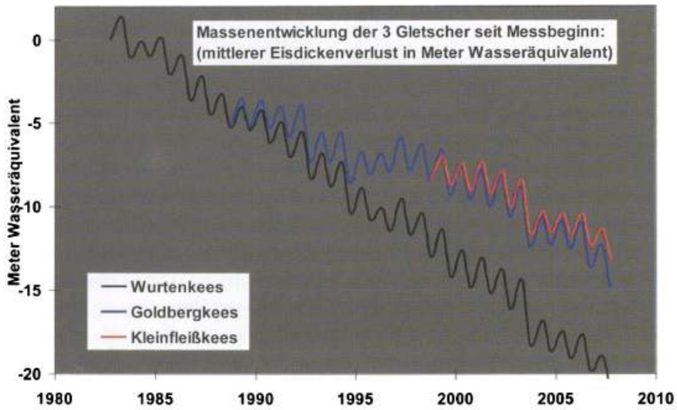
Approximately on the 1st of October, the time of maximum snowmelt, snow profiles are taken annually in the upper part of the glacier in the nearby vicinity to measure the increase of mass and the so-called "ablation gauge", i.e. reduction of glacial mass, in the melting regions. The gauges are drilled into the ice with a steam drill, where they freeze hard and fast; subsequently, as the ice melts, the degree to which the gauge stands out from the ice can be directly measured. From such point-measurements, the annual balance of glacial mass can be computated.



Illus. 1: Balance of glacier mass in Sonnblick region 03/04

The Goldbergkees is currently losing an average of a half-meter of ice thickness annually. In the relatively cold winter of 03/04, the glacier barely reduced its mass at all; in the extremely warm season 02/03, the reduction of ice on the Goldbergkees reached an average of 2 meters! Thus, for an average ice thickness of approximately 34 meters, the Goldbergkees thus lost about 6% of its glacial mass in one single year (2003). The measured changes serve as a basis for glaciological and hydrological models and are submitted to the Glacier Monitoring Service in Zurich, Switzerland.

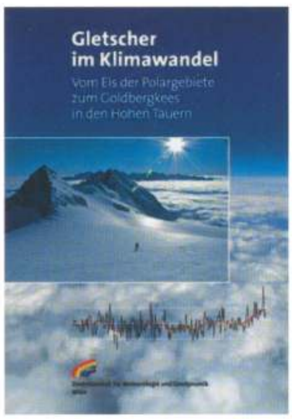
It is quite possible for glaciers located quite near each other to develop differently. Due to less precipitation and southern exposition, the Wurtenkees, located on the southern flank of the Main Alpine Ridge, melts "faster" than the more northerly Goldbergkees.



Illus. 2: Changes over time of the 3 measured glaciers

In addition to the current measurements, historical data of the size and depth of the Goldberg range glaciers are digitalised and assessed. To this end, for example, the glacial mass of the entire Goldberg range in the years 1850, 1931, 1992 and 1998 was reconstructed. From historical maps, modern digital altitude models are computated in order to calculate differences in glacial volume.

The results of many glacier examinations in the region of the Hoher Sonnblick are described in great detail on the 15 demonstration panels erected in 2007 along the glacier trail on the Goldbergkees as well as in the book "Glaciers in a Changing Climate", where the alterations are easy to grasp for everyone. These permit profound insights into the interactions between climate fluctuations and glacier changes.



Illus. 4: Book cover "Glaciers in a Changing Climate"
ISBN: 978-3-200-01013-0

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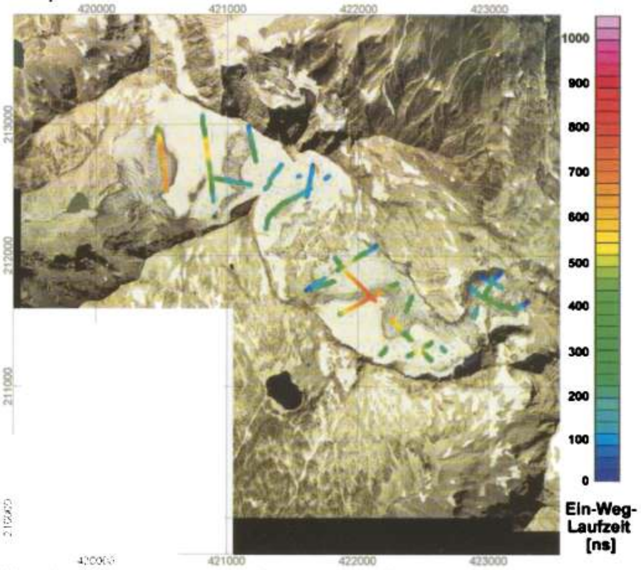
Measuring Ice Thickness in the Sonnblick Region

One of the most obvious consequences of the present climate change is the rapid decline of many glaciers. Quantitative glacier observations are essential to the running climate discussion in order to comprend the degenerative backcoupling effects between climate change and glaciers. Apart from the balance of glacial mass, determining the overall volume and its distribution also play an important role in glacier models. Interactions between climate change and glacier dynamics can be understood and reconstructed when based on physical glacier models. Only on the basis of such current models can scientifically reliable forecasts for the future of glaciers be made. Economic and logistical constraints on ice thickness measurements on glaciers which are not easily accessible, however, often result in irregular and sparse data compilation. On the basis of such data, standard interpolation methods frequently supply unsatisfactory results.

Measuring

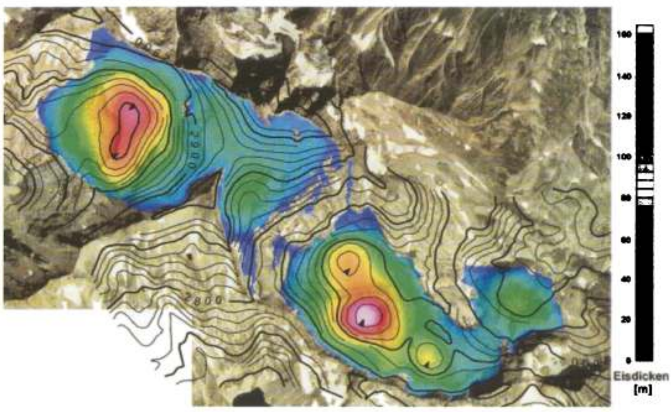
Between 2002 and 2004, four ground penetrating radar (GPR) measurement campaigns were carried out in order to compile glacial bed and ice thickness maps for the Goldbergkees and Kleinfleisskees for the first time. As measuring frequency, 20 MHz was chosen, with which maximum exploratory depths of more than 100 meters were attained. The quality of the data obtained varied. Reflections of the glacier bed cannot be clearly determined in each mapping entry. The data tables which were obtained of glacier bed reflections have a too irregular and scanty data distribution to achieve satisfactory results through standard interpolation methods.



Illus.1: Measurement data (coloured lines) obtained in GPR examinations. The colour denotes the single-direction running time of the radar signal. The glacier rims of Kleinfleisskees and Goldbergkees are drawn from the aerial photos taken in 2003.

Evaluation

The objective of the evaluation was to construct plausible glacial bed geometry and ice thickness distribution in objective fashion which could be replicated. Ultimately, the Kriging interpolation technique and a mechanical glacier constant were used. The interpolated data were subjected to a 3D migration. The expansion speed of the GPR signal inside the glacial ice was set at 0.16 m/ns. A morphological interpolation approach ensured a realistically smooth transition between calculated and known terrain data. The maximum depths of the Kleinfleisskees and Goldbergkees which were compiled in this way are 150-165 meters.



Illus.2: The iso-lines depict the calculated glacial bed, the colour-graded depiction is the ice thickness. Whereas the Kleinfleisskees has a classical glacial bed, the Goldbergkees evidences a far more complex subterranean structure.

Conclusion

Many global forecasts, e.g. future rise in sea level, are based on estimates of worldwide ice volume and on glacier models. Surface volume comparisons of glaciers similar in size to the two cited glaciers supply no satisfactory results. For numerous alpine glaciers there are ice thickness measurements with similar or worse density of data than for the two cited glaciers. The interpolation strategy developed for this project supplies plausible results for such sets of data in objective ways which can also be replicated.

Since the Sonnblick Observatory lies adjacent to this site and to the running glacier monitoring which has been conducted since 1983, the two examined glaciers are highly suitable for a model of the relationship between climate and glaciers. The results of the ice thickness measurements supply important surrounding conditions for the development of such models.

Based on the data obtained in this work, more precise water balance models and forecasts of future runoff masses of the glaciers are possible. Such subsequent results are, in turn, highly interesting for the operators of reservoirs and hydraulic power plants. It would be desirable for the future if a direct examination of the data via ice drilling and sets of ice thickness data of other glaciers were available for purposes of testing the developed interpolation strategy.

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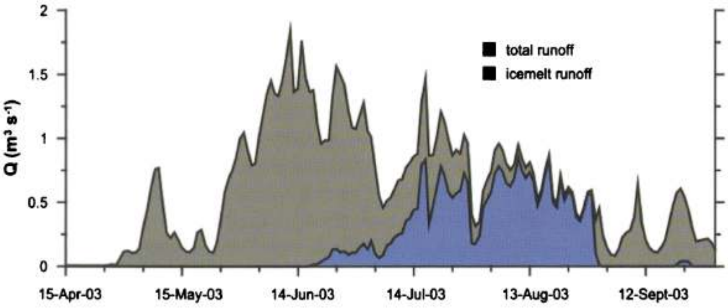
U_GLACIER

For the research project known as SNOWTRANS (2004-2007), climate data was utilised to simulate the effluent from glaciated runoff basins. To date, however, this has been done only for individually selected past years. For the research project U_glacier (Uncertainties in modelling hydrological scenarios in glaciated runoff basins) which was launched in December 2009, the future development of glaciers and the effluent over the course of the 21st century is being calculated on the basis of various climate scenarios. The glacial-hydrological model is validated through comprehensive data from climate and glacier monitoring in the area of the Rauris Sonnblick.

Objectives

Since the glacial areas in the Alps are diminishing more and more, the contribution of icemelt in the overall runoff will become less and less over time. This can reduce the water level of rivers in dry summers in particular (see illus. 1). The objective of this project is to simulate the future decline of glacial surfaces as perfectly as possible; and then to computate future runoff scenarios in varying, heavily glaciated sectors, based on a series of posited climate scenarios. The hydrology model which is used is optimised and tested by means of wide ranging meteorological and glacial-hydrological measurements in the Sonnblick region.



Illus. 1: Simulated moving runoff line of Goldberg brook in the hot summer of 2003, including contribution of ice melt (blue). Source: Koboltschnig (2007).

Method

A hydrological model is operated with meteorological and topographical data to simulate the runoff in the glacial drainage basin, and includes glacier melting as well. The results of such a simulation model are verified with runoff measurements, glacier mass balance measurements, two automated weather stations on the glaciers of the Goldbergkees and Kleinfleisskees, measurements of snow-water equivalents and remote exploratory data (automated terrestrial photography and satellite data) of the snow cover. In order to make the runoff model useful over long-ranging periods of future time, the calculated changes in glacial mass perforce lead to a change in glacier topography and in the glacial surfaces using simple approaches to glacial flow dynamics. Here is where such simple approaches and parameter definitions are tested, i.e. dependable glacier models developed. The assembly of models is checked and verified through measurements of volume, surface area and changes in length of the glaciers surrounding the Rauris Sonnblick over the last 150 years, using all the available historical data.

If the model which is developed can describe both runoff and glacial mass balance as well as the change of glacier volume and surface area throughout the past, the model will then be run through a variety of scenarios based on regional climate models and future scenarios for potential changes of runoff; and development of glaciers in the areas under observation will be computated. By using a variety of regional climate transformation schedules and varying model parameters, a definitive statement about the uncertainties of models and hydrological predictibility will be able to be made with a high reliability quotient.

The model will be examined in the runoff areas of the Goldberg brook (2.1km²) and the Kleinfleiss brook (1.5km²) in the Goldberg range of the Hohe Tauern, glaciated by the Goldbergkees glacier (1.5 km²) and Kleinfleisskees (0.8 km²). On both glaciers, detailed measurements of wintertime and annual mass balance have been carried out. There exist widely spaced measurements of ice thickness (2003) and repeated measurements of glacier surface area, volume and annual changes in glacier length, as well as continual runoff measurments in both runoff basins. Apart from that, the close vicinity of the Sonnblick Observatory provides outstanding meteorological data going back to 1896. To test the transferability of the model, the model which was optimised in small-scale runoff areas will be applied to runoff areas of medium size (Mittersill, Salzach, appx. (600 km²), where for verification purposes runoff data and daily remote exploratory data of the snow cover are available.

Illus. 2: Runoff basin of Goldberg brook, with Goldbergkees and Hoher Sonnblick. Source: Koboltschnig (2007).

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Measuring and Making Models of melt runoff of Goldbergkees

During the summer seasons of 2002 and 2003, the Institute for Water Economy and Hydrological Construction of the University of Natural Resources and Life Sciences in Vienna conducted measurements of glacial runoff from the Goldbergkees. In the course of conducting these measurements, a fully automated measuring instrument with integrated data recording and remote transmission came into use for the first time. From these measurements, new insights of the runoff causes on the glacier and the melting process within a daily cycle, as well as its dependence on hydro-meteorologica

Background and Motivation

Ever since September 2002, runoff measurements have been conducted on the Goldbergkees by the IWHW. To this end, a self-registering gauge system was installed. The measurements are designed to support in ongoing fashion the balances of snow cover and glacier volume measured by the ZAMG. Furthermore, the following possibilities and additional benefits accrue, due to the existing runoff area characteristics and data assembly for snow-hydrological hypotheses:

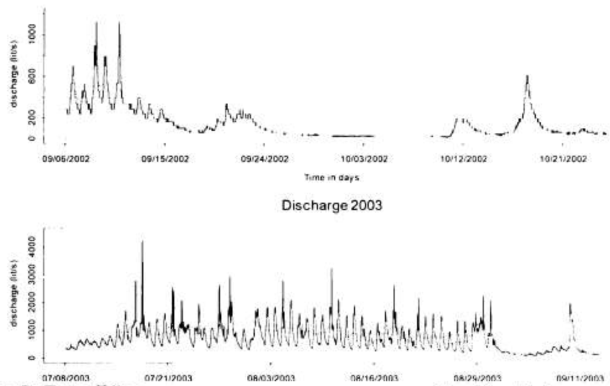
- Access to a comprehensive hydro-meteorological measurement network as a basis
- Marked identifiability of melting process through lack of basic earth or ground water drainage
- Review of existing snowmelt and snow accumulation programmes of the IWHW,
- Adaptation of programmes for glacial snowmelt
- Testing measuring devices in high-alpine conditions
- Examination of hydraulic runoff conditions on the glacier.

Illus.1: Installing a runoff gauge Seitz

Completed Projects

The gauge station (see illus. 1) is located at the outlet of the glacier lake at the foot of the Lower Goldbergkees. The measurement of the water level is effected by recording the hydrostatic pressure in the stream bed channel of the glacier brook. The station is equipped with a modem, enabling a remote scan via telephone. Due to the exposed, avalanche-endangered site, the data log unit is dismantled every autumn, the water "bubble pot" on the stream bed remains in place. During the summer, the measuring device ongoingly supplies water level measurements every ten minutes. In the course of periodic field measurements, the runoff measurements were also carried out by means of flow speed measurements. This makes possible a conversion of the water levels (mm) into runoff values (l/sec). In August 2003, salt tracer trials were launched in the lower and intermediate Goldbergkees areas, and continued in Semptember 2003. These trials made an allocation of the runoff percentages from various areas of the glacier possible, as well as an estimate of the flow times.

The observed runoff is a result of direct precipitation, snowmelt and glacier movement. In illustration 2 the time-measured dynamics of the runoff amounts in liters-per-second for summer in 2002 and 2003 are depicted. The daytime cycle is noticeable, i.e. maximum and minimum values often differ by 100%. The depicted step lines (red) show the mean daytime runoff.



Illus.2: Runoff line Graphics: Holzmann

In the course of two doctoral studies, the observed data are prepared and (1) snowmelt calculations are computated, together with (2) an examination of the runoff dynamics.

Prospects

Based on work projects which have been carried out thus far, new insights into snowmelt modelling and the transferrability of such models to regional precipitation-runoff models is anticipated. Thereby, inquiries into the reservoir economy, and the forecast of snowmelt in high alpine regions or the runoff effectiveness of precipitation distributed over various altitudes can be dealt with. The work to date is currently being carried out as individual research of the IWHW.

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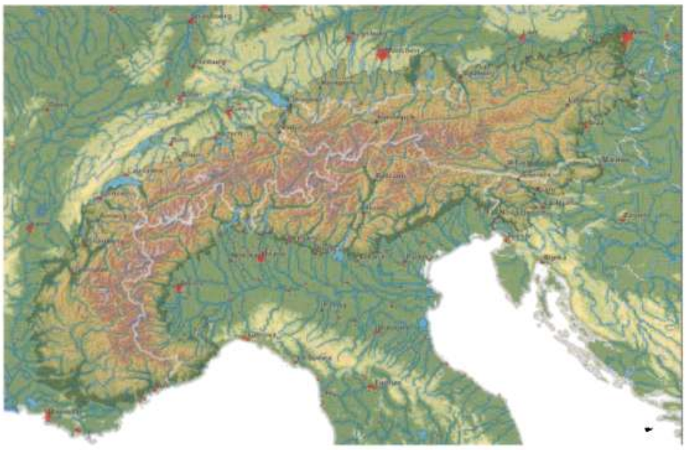
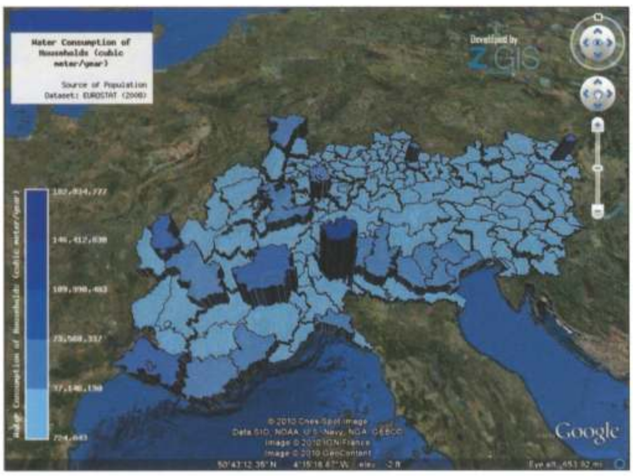
AlpWaterScarce - Management strategies towards indexing water shortage in the Alps

Not only the lands of the south, but also the Alpine region can potentially be struck by water scarcity. In a consortium comprising 17 partners from the five alpine countries, experts from the fields of water management, agricultural science, geography and geo-informatics, engineering, ecology, biology, tourism and economics worked out realistic solutions and concepts in interdisciplinary fashion to approach the issue of forecasting water shortage in the Alps.

Problem definition: Over the last few decades, experts from Austria and Slovenia have established a seasonally-based decline in the amounts of precipitation. Furthermore, the demonstrable rise in temperatures has led to heightened evaporation and thus, to lowered regeneration rates of groundwater in parts of the Alps.



These water shortages have natural topographical and climatic disparities as their cause and thus, will not affect the entire alpine region to the same extent. Some regions, however, particularly in the Southern Alps, will suffer intensified reductions in water availability.



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Enquiries in a Styrian-Carinthian pilot project show a decline in the rate of groundwater regeneration of 20 percent over the last 100 years. Research and analysis from drainage measurements in Slovenia have revealed a similar decline.

Objectives: One objective is the development of a local early-warning system for water scarcity in the Alps and the establishment of realistically implementable concepts and solutions for the multi-functional use and re-use of water. This will include an analysis of the availability of water and water consumption in 23 pilot regions of the Alps as a special focus. Whereas water as a natural resource is often consumed in great amounts in some regions during the winter, particularly in winter resort towns, the energy-intensive production of artificial snow and the ever-increasing numbers of tourists further reduce the available quantity of water to a high degree. The temporally and regionally heavily fluctuating but in some regions immense water consumption has, in addition to the reduced amounts of precipitation, an enormous influence on the available water resources. Due to the global climate change, combined with the human pressure towards consumption, it can be assumed that the Southern Alps in particular, as well as certain individual inneralpine valleys, will suffer from increasing dryness in future years, accompanied by corresponding effects on flora, fauna and human life in these regions. The foremost goal of the project is a detailed problem recognition in the 23 test areas and the summary of the obtained knowledge in an informative atlas of water scarcity in the Alps.

A great role is this interdisciplinary project is played by the active evolution of attitudes and awareness in the population and the major actors from the involved sectors of the economy, industry and tourism. The networking of individual players on transalpine levels, at national levels and even at regional levels is the declared goal. Following the analysis of problem zones, concrete steps to counteract inordinately high water consumption and, linked to that, to counteract water shortage, will be taken. The Z_BIS is the responsible authority of this project for data from the entire alpine region in the areas of data management, data preparation, web services and visualisation of results, with the aid of virtual globes.

Protecting drinking water between Croatia and Sonnblick

Protecting drinking water is a preeminent problem throughout the world. Croatia suffers unusual obstacles to solving this problem due to its geological ground structure. For that reason, water protection numbers among the highest national priorities. To meet the difficulties, physical and chemical analytical methods are utilised.

The Karst problem: About half of Croatia is covered by Karst, that is, soil structures which are formed largely of weathered limestone through which crevices and fissures permit water to seep away quickly. On the earth's surface, emergency water shortage often prevails. This form of dehydration takes place in a complex network of subterranean channels, even caves can be formed. For a research project at the University of Rijeka, together with the Ruđer Bošković Institute in Zagreb and the University of Varaždin, geologists, chemists and physicists are collaborating to analyse those networks, and are also providing assistance to local users in planning water supply and reservoirs.

Isotope as "marker" for hydrological analyses: The isotope composition of a system can be constructively used as a marker without interfering with the system itself. However, for that very reason, it must be extremely precise if one wishes to record even the slightest disparities in its behaviour. This is possible with magnetic mass spectrometry, for which a stream of fast-moving, charged atoms or molecules of varying mass is diverted in a magnetic field and then measured. For example, water (H_2O) contains not only the major isotope ^{1}H (mass 1) and ^{16}O (mass 16), but also miniscule amounts of ^{2}H (Deuterium, mass 2), as well as ^{17}O and ^{18}O. Every disparity from the "natural" values, brought about by so-called fractionation and measured in "delta-value", reveals something about the operative processes in the system. Evaporation, for example, influences the isotope ratio: light isotopes are more mobile than heavy ones, thus evaporate more easily. Steam above a water surface, e.g. the sea, is thus enriched in the light isotopes ^{1}H und ^{16}O. When condensation and rainfall occurs, the heavy isotopes tend to drop out, but due to the isotopically light steam, rainfall and snow are still somewhat "lighter" than seawater, namely, to that degree to which it is colder and further distant from the sea. The same rule applies, incidentally, to H and for O; thus, there is a simple, linear correlation between the two, the "meteoric waterline", thus named because these are meteorological, i.e. weather processes. Thus, the delta-value says something about the origin and history of water.

The project: The University of Rijeka focuses on measuring the stable isotopes of H, C, N, O; the Ruđer Bošković Institute sets its sights on the radioactive isotopes ^{3}H (Tritium) and ^{14}C; and the University of Varaždin on the chemical composition of water and the interpretation of the results. The **Sonnblick Observatory** provides samples for the so-called water reference standards, since the mass spectrometrical measurements have to be carried out against reference standards in order to achieve the requisite degree of precision. Snow from very high alpine sites is a highly rated reference standard because it is, isotopically speaking, particularly "light", enabling it to record a wide spectrum of delta-values, together with isotopically "normal" seawater.

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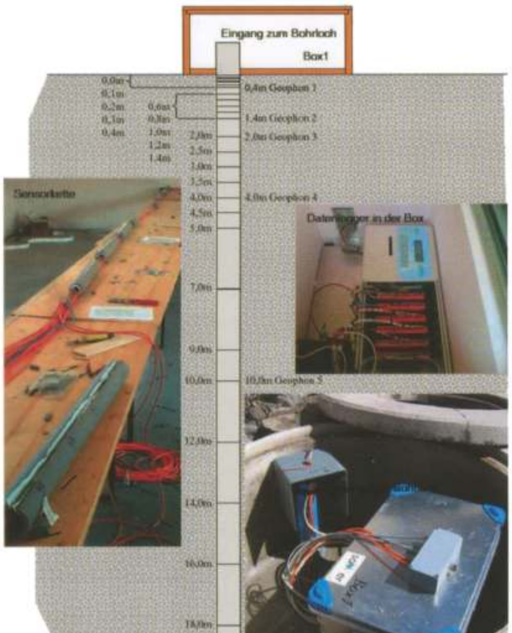
Permafrost measurements

In high alpine regions, nothing is as certain or as clear as it initially appears. If you look at the immense scree dumps below the steep cliff walls, it is easy to see what masses of rock materials have been relocated over the course of time and how this process has accelerated in recent years. That is also the way it looks all around the summit of the Sonnblick; here, too, the climate change has accelerated geological alterations and decomposition due to weathering. Such effects are now being examined and modelled.

Objectives

Since August 2007, the distribution of permafrost on the summit is being measured and modelled in precise fashion for a project of the Austrian Academy of Applied Sciences. The objectives of the project are

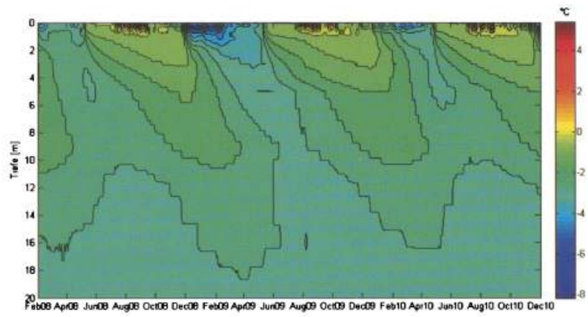
- Precise knowledge of annual distribution of permafrost on the summit
- Influence of the building on the distribution of permafrost in the rock
- Modelling of permafrost relationships on a small-scale
- Measurement of permafrost conditions at the rim of the swiftly declining glacier
- Effects of permafrost changes on the stability of the rock



Illus.1: Mapping out a drilling hole

Measuring System

The three, 20-meter deep drilled holes are each equipped with geophones and appx. 20 temperature sensors. The middle sensor has, in addition, an extension meter which records even miniscule movements in the rock structure. Through the changing frost conditions during the course of the year, the ground lifts and sinks several millimeters.



Illus.2: Temperature changes inside the rock

In addition to measurements inside the rock, surface sensors are installed at 50 locations above the earth's surface which give information about the snow cover in the various parts of the Sonnblick summit area. A precise laser scan picture of the summit building is used for modelling and documentation of the rock movements.

Prospects

The modelling will make the highly detailed structure of the permafrost distribution on one summit of the Austrian Alps transferrable to other geomorphological locations. From that, conclusions can be drawn as to which parts of the rock structure typically become instable through changes in permafrost. Z_TIS calculates the vulnerabilities for typical alpine hiking trails from this data.

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PermaNet

Damages from permafrost have become a problem in the last few years not only in the Austrian Alps. Large scale damage in high alpine regions have has also become evident in Switzerland, France and Italy. For this project, which is supported by the EU (European Fund for Regional Development - EFRE), permafrost scientists in the Alps endeavor to establish a network for purposes of developing models which can be deployed throughout the Alps to depict the distribution of permafrost on an alpine-wide map and to standardise the measurements which are necessary for the validation of these models.

Objectives

PermaNet was launched in July 2008. It draws together the knowledge and experience of 14 partners in the Alpine countries who are explorational leaders in the research of permafrost. The project is being led by the Office of Geology and Building Materials Testing of the Autonomous Province of Bozen in South Tirol.

Individual steps of the project:

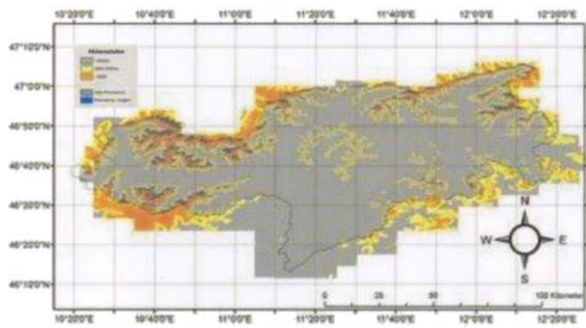
- Standardisation of measurement systems for sensors in drilled holes and on the surface
- Carrying out measurements in accordance with the standards in various parts of the Alps
- Modelling permafrost conditions on a scale with the Alps, in a standardised method
- Validation of modelling in the various partner regions
- Small-scale modelling of permafrost at individual locations with special inquiries
- Determining slope movements via laser scanning
- Effects of permafrost changes on the water regime

Illus.1: Placing sensors on the north flank of the Sonnblick summit

The wide ranging objectives of this project are intended to provide the basis for future planning and policymaking decisions in high alpine regions. Risks due to changes in permafrost have an impact in architecture, the safety of alpine trails, high altitude tourist projects and the placement of lifts in snow-guaranteed regions.

Method

In certain countries, maps already exist which depict the probabilities of permafrost occurrence through approximation processes, based on mean annual temperatures, north-south exposition and snow cover.



Illus.2: Permafrost map of South Tirol

These models are further refined through additional laser-scanned data for potential radiation, geological characteristics, plant cover and other micro-meteorologically local attributes. Utilising standardised measuring techniques, the newly developed model versions can be validated and further adapted to specific conditions.

Located on the Sonnblick is Austria's only measuring network with deep-bore drilling, which focuses its attention on long-term fluctuations from year to year. In addition, local knowledge with regard to permafrost distribution is drawn into the small-scale modelling on an exact meter scale.

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Permafrost in the Hohen Tauern

In the Alps, a rise in temperature of two to three times the global average is forecast (Intergovernmental Panel on Climate Change, 4. Bericht, 2007). One of the many consequences is the thawing of permafrost which occurs in the Alps inside rock or scree above approximately 2500 meters altitude. A pre-study (doctoral thesis of B. Ebohon, 2007) demonstrated that in all of Austria, one can calculate a permafrost surface of approximately 1600 km² (corresponding to about 2% of the overall land surface). For Austria, therefore, as a core country of the Alps, it is urgently necessary to come to terms with this thematic complex, since interrelations in these processes and future developments are still veiled in uncertainties, making precise scientific analyses imperative.

Permafrost detection – Why? Permafrost is the soil, sediment or rock of differing thickness and depth beneath the earth's surface in which temperatures below freezing have been measured uninterruptedly for at least two years. A rise in its temperature would thereby bring about a destabilisation of mountain slopes and steep, rocky flanks in many locations. In those regions, increased rockfall, slope failure, mud flow will be triggered and cause untold damage to transportation routes, cablecars, electrical lines and buildings. Scheduled building projects in the mountains depend on detailed information on the spread of permafrost as well as its prognosticated development. And last but not least, this change also has major implications for mountain sports, since many classic trails and routes have already become inaccessible, or can be used only at heightened risk.

Illus.1: Test regions which were subjected to analysis permalp.at

Methods: The area under investigation is the Hohen Tauern range, comprising a surface area of 2477 km². Of this, approximately 170 km² (according to CORINE 2000) are covered by glaciers and thereby excluded from permafrost, by and large. If one sticks to the 'rule of thumb' that permafrost generally is found above 2500 m above sea level, a surface area of about 800 km² has to be closely examined. To derive a so-called topoclimatic key with regard to the occurrence and spread of permafrost, several local test areas (see illus. 1) were selected which have disparate topographical and climatic situations. In these test areas, basic data of temperature, terrain and subterranean structures were obtained by applying a series of geomorphological-geophysical methods in order to record the current permafrost spread. This analysis had a high degree of resolution and precision. The actual modelling of the permafrost spread is then carried out reflecting local topographical and climatic conditions. From the ratio of the parameters of altitude, slope gradient and exposition, the permafrost distribution is simulated.

Illus.2: BTS measurement on Kreuzkogel at appx. 2680 m altitude (23.03.2010)

The question of which additional parameters, such as surface covering, solar radiation, etc. ought to be taken into consideration for the modelling of permafrost distribution will also be weighed. The calculations will be implemented based on a digital terrain model with a resolution of 10 meters in order to depict the finely differentiated terrain in high alpine regions as precisely as possible.
An indexable result of permafrost spread will replace the sharp minimum borders of possible and probable permafrost which have been used to date. Due to the fluid transitions and the statistics of probable permafrost spread expressed in percentages, the quality of the map can be radically improved.

The project: The objective of the planned permafrost modelling for the Hohen Tauern does not entail developing a fundamentally new model, but rather, adapting existing approaches to a topoclimatic key which have been tried and tested (see PERMAKART) to local conditions of the subterranean geological layers, also taking into consideration the project results for Austria which are already available. The generation of a key for permafrost spread in the Hohen Tauern, in the sense of rules of thumb and lower borders, is the focal point of the examination. With this key, the simulation of permafrost spread in the Hohen Tauern will be made possible, utilising a variety of models. The **Sonnblick Observatory** will provide climate data and information permafrost-relevant analyses for the validation of models, thereby making possible a better adaptation of the modelling to the analysed region.

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Archival storage and supervision of the permafrost zone and its effects on Sonnblick terrain - PERMAFROST DEPTHS ON THE SONNBLICK

As a result of the climate change, the depths of permafrost and its distribution throughout the Alps are being subjected to especially drastic change. It has been proven that the permafrost is continually diminishing, and is manifesting unusual temporal variations. This causes increased erosion and rockslides in cliff walls, which in turn massively increases geo-technical problems and dangers. Through geophysical measurements and 3D laser scanning, the actual current state of permafrost and the natural surfaces will be documented; moreover, its evolution and impact on surrounding nature will be determined.

Permafrost on the Sonnblick: For many years, permafrost on the Sonnblick has been analysed by utilising a variety of methods, e.g. meteorological, geophysical, hydrological, geodatic. The measured physical parameters correlate with the changes observed in the permafrost which have marked effects on the terrain on the Sonnblick.

Spezifikation LMS-Z420i

Messentfernung	max 800 m (Reflektivität 0.8), max 200 m (Reflektivität 0.2)
Messgenauigkeit	± 10 mm
Strahldivergenz	0.25 mrad
Messrate	8000 Messungen / Sekunde
Winkelbereich	0 – 80°vertikal 0 – 360°horizontal
Winkelauflösung	0.01°

Kameraspezifikation

Modell	Nikon D100
Objektiv	Nikkor 14 mm / 2.8
Auflösung	3008 x 2000 Pixel
Winkelbereich	80°x 58°

Illus. 1: 3D laser scanner RIEGEL LMS Z420i im in use on the Sonnblick and its specifications.

3D Laser scanner messungen in 2009: For the measurements, a 3D laser scanner RIEGL LMS-Z420i combined with a calibrated NIKON D100 digital camera was used (illus. 1). For recording the Sonnblick terrain, 8 different scanner positions were used. A total of about 14 million measurement points were captured, for which the site, the distance and the reflection intensity were stored. For each scan, photos overlapping by 10% were made. Immediately following this collection of data, the scanned and photographic data were consolidated on the spot. The initial result of the combined evaluation of scans and digital photos resulted in a colour 3D point-cloud. The coloured points of the individual scans can be combined with each other and then fed together to form an overall point cloud. This overall point cloud depicts a three-dimensional model of the conditions on the Sonnblick at the time the photos were taken. Through a selection of individual areas, the overall point cloud can subsequently be dismantled into individual partial clouds (illus. 2).

Illus. 2: Screenshot by RiSCAN PRO of individual scans registered and coloured through digital photos

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Enhancing geophysical monitoring at Hohen Sonnblick to determine permafrost change

The Department of Geophysics at the National Geological Institute began to pursue and develop geoelectric monitoring a few years ago. One of the instruments was specially adapted for measuring permafrost on the Sonnblick.

For geoelectric measurements, the resistance structure of subterranean layers is analysed. These below-ground parameters are contingent on water content, water conductivity and temperature of the surrounding site, among other things, for which the dynamic interplay of freezing and thawing, as well as the depth of the permafrost horizon can be measured geoelectrically.

Geoelectric monitoring profile at Hoher Sonnblick

In the Department of Geophysics at the National Geological Institute, a measuring instrument was specially developed for geoelectric measurements known as GEOMON^{4D}. The innovations of this device are:

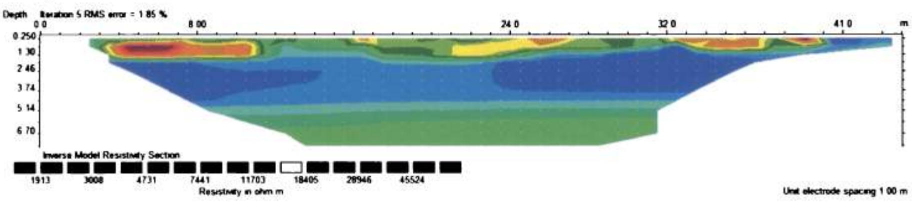
- 3000 data measurements in 45 minutes
- all individual samples are recorded, not merely the average values of individual samples; this enables researchers to make subsequent quality checks of the measured data with regard to noise content and signal strength
- remote maintenance through GPRS

GEOMON^{4D} can be deployed as a monitoring station, since it can be remotely maintained by GPRS.

For the special demands of permafrost monitoring it was neccessary to develop lightning-protection modules as well as a special electricity supply.

The development of a constant source of electric power was essential, since due to the anticipated, extremely high electrical resistance levels of permafrost and the analysis of the geoelectrical measurements carried out, a great many of the measured potential differences enter the saturation zones (i.e. at ±10V) of the measuring apparatus. That can only be prevented if the electric power supply can be appropriately regulated in order to keep the electrical power desirably low and thereby, the potential differences will remain below the saturation zone (of resolution precision) of the measurement device (normalerweise ±10V).

Initial measurements have shown that the measurement results with the new electric power supply are quite promising. Test profiles were carried at Sonnblick Observatory and on the Mölltal Glacier along which the permafrost depth can be clearly delineated. It is planned to begin permanent monitoring operations in autumn 2010.



Test profile results on the Mölltal Glacier

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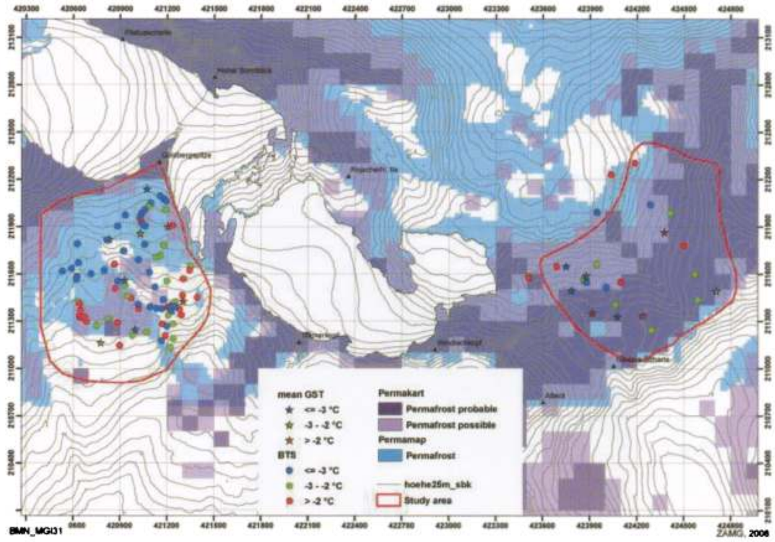
PERSON Permafrost monitoring on the Sonnblick

The project known as PERSON addresses a still young field of research in the Austrian Alps, namely, permafrost. Due to the climate change and the risks in the Alps associated with it, it is imperative to expand our knowledge of the permanently frozen ground in high alpine regions. In the Austrian Alps, permafrost layers generally occur, depending on exposition, above 2500 m, in some places of southern exposition only above 3000 m altitude. The difficulty in researching permafrost is that the uppermost surface is generally not visible and its lower layers can take on widely disparate forms, which might consist of easily detected ice lenses, or very difficult-to-detect frozen rock. The PERSON project, which runs for eight years, analyses both spatial distribution and temporal changes of permafrost in selected test areas of varying expositions.

Defining the problem and the objectives

Rockfall, fissures in cliffs, unstable foundations of cablecar pylons or mountain refuges: high alpine infrastructure and touristic construction in particular make it imperative to learn more about permafrost in the mountains.

In the course of the PERSON project, as a special assignment of the Ministry of the Environment, the Central Institute for Meteorology and Geodynamics has operated a permafrost monitoring network in the Sonnblick area since 2006. The objective of this monitoring program is to observe changes in the permafrost and determine what factors are relevant to permafrost spread, e.g. snowpack influence, effects of shade and exposition. The PERSON project will gather necessary basic data to better understand and model the relations between climate change and permafrost spread.



Illus.1: Temperature measurements (BTS and GST) and the models Permamap and Permakart in the Sonnblick area

Measurements and models

To provide a contained, yet also measurable framework, several areas of examination on the Sonnblick were selected. In the zones Goldbergspitze and Wintergasse, temperature (BTS) and measurements of the earth surface temperature at the snowpack base (GST) have been carried out since 2005. Further, measurements are taken regularly in the reservoir lake on the northern flank of the Sonnblick which was formed by moraine materials of the Pilatuskees glacier. Since June 2008, the daily melting of snow and snow distribution in the Wintergasse area of investigation have been under observation through a permanently installed camera.

The measurement of basic snowpack temperature is an effective and inexpensive method to obtain information on the permafrost spread. To this end, the electrical resistance at the base of the snowpack is measured with a special probe. In 1975, Haeberli developed empirical limits of BTS (through a large number of measurements) through which the spread of permafrost can be derived. According to these guidelines, a base temperature below -3°C probably indicates permafrost below ground. The uncertainty zone lies between -3°C and -2°C, and for temperatures above -2°C, permafrost can in all probability be ruled out .

Building upon these empirical rules, models to estimate permafrost spread have been developed at different locations. In the areas of investigation selected here, the models Permakart and Permamap by the University of Zurich were used for the initial estimate (see illus. 1). The measurement of earth surface temperature as carried out through temperature data loggers. Since autumn 2006, 20 data loggers have recorded the surface temperature hourly in two areas of investigation. In 2010, the measurement network was expanded in density. In addition, since 2008, changes in the snowpack have been recorded by means of an automatic camera.

Prospects

The results of both BTS and GST measurements point to a heterogenous and small-scale permafrost spread whose spatial variations depend heavily on the topography. The calculated models Permamap and Permakart have too rough a resolution to be able to depict this small-scale heterogenity (see illus.1). To be able to make statistically assured statements about the distribution and changes in permafrost in the Sonnblick region, a long-term measurement series is necessary. PERSON completes this point-for-point monitoring of the Sonnblick Observatory through its surface-wide approach.

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Avalanche Reporting Station Sonnblick

Avalanches rarely pay any heed to rules laid down by people. They are triggered sporadically in the most variegated and widespread areas of the Alps. Models can help to predict them, but the ultimate information of choice is the outcome of a dense network of informational stations which must include all ranges of altitude in the state of Salzburg. The Sonnblick is Salzburg's highest altitude station.

Data flow

The Salzburg Avalanche Warning Service draws its information from a network comprising more than 40 stations, some of which are operated by the Avalanche Warning Service, others in cooperation with other institutions, e.g. the Sonnblick Observatory. The daily observations gather and record all avalanche-relevant data with regard to the snowpack, extending well beyond measurements of its depth, i.e. sink-in depth of a norm weight into the snowpack, type of surface snow covering, snow temperature, snow transport through the terrain and precise observations and descriptions of avalanches which have been unleashed are reported at the Avalanche Warning Centre from the Sonnblick in the early morning hours of each day in order to complete the picture of the invariably highly diverse snowpack in the Salzburg province.

Methods of designating dangers

The Sonnblick is the highest altitude avalanche reporting station in the state of Salzburg. Only through observation points at this altitude can the disparities in the variety of snowpack components between intermediate altitudes at approximately 2000 m and at high alpine regions above 3000 m be analysed with precision. Every 14 days, measurements of even greater precision are undertaken: a "snow profile" in the vicinity of the observatory reveals the hidden truth about the deeper layers inside the snowpack. The bonding of individual layers to each other can change radically over time. Due to influences of wind, cold, temperature fluctuations or springtime warmth, the bonding of layers to each other is weakened or strengthened. The consolidation of merely two layers inside the snowpack can change by a factor of 1000. Observers simultaneously estimate the extent of local avalanche peril in accordance with a 5-level danger scale.

Illus.1: Slab avalanche below the Pilatusscharte

Illus.2: Examining a snow profile

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UV-deterioration of ropes and loops used in mountain sports

Debates have long been conducted on the issue of durability of ropes and loops and their resistance to UV radiation. It is well known that energy-rich ultraviolet radiation has an impact on the synthetic fibres which are used in their manufacture. However, the precise degree of UV-deterioration in alpine regions is not known in ways which are usable.

UV-deterioration of synthetic fibres:

If synthetics are used outdoors, alterations in their material characteristics take place, contingent on their length of use. One of the main causes for this deterioration is UV radiation. Additional weathering influences, for example temperature and moisture, can accelerate the process.

In the sector of mountain sports, the ropes and loops which are permanently installed on rock faces are heavily exposed to UV radiation, e.g. hourglass loops and rapelling stands. Until now no reliable estimates of their longevity could be made.

A polyamid rope rapelling stand, about 20 years old.

Measurement methods to ascertain deterioration: The aging and deterioration through UV radiation is a consequence of changes in the molecular structure of polymer chains and the additional additives. From very small samples, the degree of deterioration can be proven even in early stages, depending on material, using a variety of analytical methods. A locality-specific measurement of material deterioration is thereby possible and the actual penetration depths of UV radiation can be determined with great precision.
Together with measurements of sturdiness recorded from weathered samples, a forecast of expected longevity for the materials used can be made.

The project:

At the Southern Germany Synthetics Centre in Wurzburg, rope and loop samples are weathered in high-speed methods in the lab. This deterioration process is then evaluated through a variety of direct and indirect methods. The sturdiness of the weathered samples is then tested by the German Alpine Club. The **Sonnblick Observatory** makes this analysis possible by providing samples exposed to real high alpine conditions and also by providing measurement data to correlate natural conditions to artificial laboratory deterioration. Additional samples of natural weathering are at the National Radiation Protection Agency in Munich.

Samples on the measurement terrace of Sonnblick Observatory

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Austria's highest altitude LINUX cluster

Since March 2004, Austria's highest altitude server has been in service in the airy heights of 3,106 meters altitude. To be precise, there are two servers which have been connected to a so-called cluster for purposes of raising outage safety. At the website www.sonnblick.net, all the activities on and around the Sonnblick can be "researched".

The concept which was selected and implemented has been confirmed with an availability of 99.89% (48 hours of outage in appx. 42,000 operating hours) despite intensely limited accessibility due to weather conditions, in turn justifying the investment in terms of reliability and availability.

Illus.1: Website www.sonnblick.net

Since individual expenses for data storage and transfer are dispensed with, due to our centrally-operated computer infrastructure, both project operators and project budgets enjoy great benefits. New projects and measurements are integrated immediately into the network, existing projects have been successively connected.

For research groups, access via Internet all the way to their own measuring instruments, collection and transfer of all their measurement data, automated function supervision of measurement instruments, storage of collected data and structural availability of measured data for interdisciplinary collaboration are offered. When desired, even special solutions, e.g. remote control of pumps for filter suction, can be implemented.

The heart of the installation is the high-availability cluster operated by the Linux operative system. All hardware and software components are laid out redundantly. Both servers report to the respective partner via so-called "heartbeat" lines any incorrect operation. In case this "heartbeat" fails, the remaining server adjusts to emergency operation and assumes the work of the outed partner.

The Internet connection, protected by a firewall, is effected via a 2 Mbit directional radio signal route, which corresponds to 30 times that of a normal modem connection. Within the building, an intricately branched fiber optics network serves all the lab rooms and the terrace. The fiber optics also provides a reliable connection and simultaneously protects against the consequences of lightning strikes and other excess voltage occurrences. For supplying measuring instruments outside the building, a WLAN radio network has launched operations. The valley station is also coupled to the observatory via WLAN, which is useful for measurements which utilise the large altitude disparity of 1500 meters.

The web server on the Sonnblick offers all interested parties information on the history and science of the area. Selected measurement data and the latest weather panorama are also presented to the public at www.sonnblick.net.

Illus.2: Server cabinet

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Astronomy Year arrives on the Sonnblick

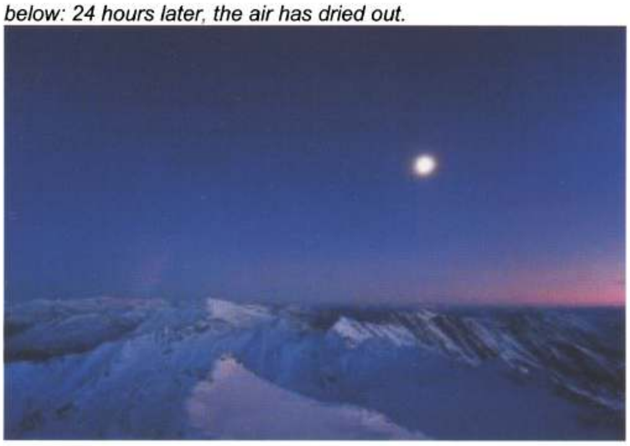
The World at Night (TWAN) is an official project for International Astronomy Year 2009. In a worldwide exhibition programme, the star-studded skies above the facilities of this World Heritage Site and above the most fascinating landscapes on earth will be portrayed. For the realization of this non-profit project, some of the most famous astro-photographers from all around the globe were assigned to make a high-speed film of the starry skies above the peaks of the Alps. For its implementation, Hohe Sonnblick provides ideal pre-requisites. Since the mountain is far removed from any city, the star-filled sky above the Sonnblick is not influenced in any way by artificial sources of light.

At the end of April, the conditions for a spectacular fast-forward recording are especially favourable. In the early part of the night, the moon crescent provides ideal illumination of the landscape. And after midnight, the summertime Milky Way rises majestically over the southeastern horizon. Since the models simulate high air pressure and relative humidity of 50%, Pröschold sets out on his way to the Sonnblick. But the astro-photographer underestimates local conditions. Caught in the prevailing northerly airstream, the clouds along the Main Alpine Ridge congest in a barrier effect and shroud the summits intractably in fog. Disappointed, Pröschold beats a hasty retreat.

Not until the end of October does the opportunity for a renewed try offer itself. The first snowfall has arrived and created a perfect wintery backdrop. With high pressure and a moist layer of air blanketing the ground surface, Pröschold hopes for spectacular shots above the clouds.

above: Low lying clouds are a much sought motif – as long as they don't ice up the lens.

below: 24 hours later, the air has dried out.



High-speed picture: on left, the zodiacal light, on right, the wintery Milky Way including Sirius. Below, stray city lights.

But once again, his plan threatens to fail. On the one hand, the skies are for the most part crystal clear, but repeatedly, plumes of fog form around the summit and ice up the lens of his camera. Thus, he is able to take a few good shots, but a 16-hour fast-speed film is simply not possible. Not yet.

Twenty-four hours later, the low lying clouds have dispersed. In their place, reams of cirrus clouds now race across the sky. But the high altitude clouds don't impede the photographer, since they are illuminated from Innsbruck. In the Hohen Tauern, on the other hand, there is no nearby city and the high altitude clouds stand out against the dark sky," reports Pröschold.

For more than 16 hours, Pröschold's camera fixes the happenings on the firmament above the mountain peaks: from 2:30 pm until 7:00 am next morning. Sunrise, sunset, the meandering moonlight shadows, the wintery Milky Way and even the faint light of the zodiac are all visible in the finished high-speed film. But until it is ready, a lot of work awaits the astro-photographer. Before the many individual photos can be merged into a harmonious high-speed film, a whole series of work processes are necessary.

"Retouching the artificial sources of light on the Mölltal Glacier was especially time-consuming," says Pröschold. The whole night long, ski slope vehicles and snow cannons were in operation in the ski area. It took several days until Pröschold had painstakingly removed their headlights and was finally satisfied with the result. The effort was worth it. The "World at Night" Gallery has been enriched by a brand new, spectacular set of photographs.

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Ice optics on the Sonnblick - the upside-down observatory

"How real is reality?" or Awareness through Picture Reversal

Water and light are the materials young artist Reinhold Aschbacher of Goldegg works with. Out of frozen water he cuts ice blocks and shapes them with adroit craftsmanship into optical lenses. Just as is the case with a classical glass lens, the sculpted ice blocks bundle the light and produce an upside-down image.

Turning pictures on their head, i.e. requiring the beholder to turn upside down, appears to call factual things in question, and recalls the famous book title of Paul Watzlawick, "How real is reality?" to memory. What is reality, really? Can we believe what we see and hear? Is everything around us but a mirage? Something our brains think up? To what extent can we accept anything as correct and true? Isn't everything just a matter of perspective, and thus, of personal belief?

Heinz Kaiser

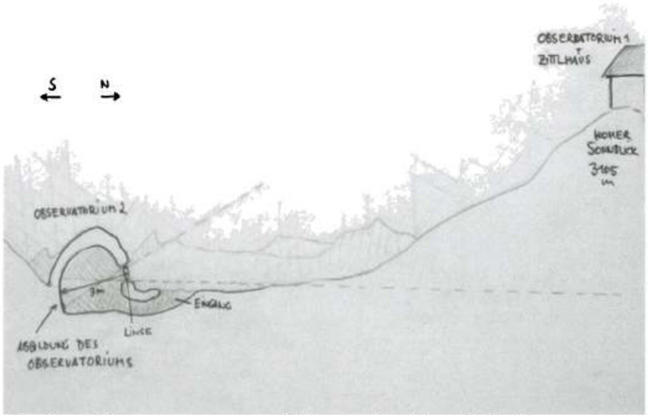
A "snow camera" functions just like a photo camera, except that everything is made of water: the space in which the picture is projected, upside down, is simply built of snow, the optical lens is made of ice.

On New Year's Day 2009, I set up such a snow camera about 70 meters of altitude below the weather observatory on the Sonnblick in order to observe the observatory. In other words, the very weather station whose task it is to collect data for scientific, i.e. objective purposes, and make a forecast, would now itself become the object of observation.

The snow camera, quite unlike a "true" observatory, is a highly inefficient instrument. What's more, in high alpine conditions it is also enormously difficult to handle. The picture it produces is imprecise and exists only for a brief interval. Quite contrary to this, the weather observatory supplies precise data on the most widely varied climatic processes.

above: The observatory building 2, in the background the "true" observatory on the Sonnblick.

below: The projection of the summit and the weather observatory produced in the snow camera. Strong winds and intense cold made the undertaking rather difficult.



Sketch of the snow camera:„ "Observatory Sonnblick 2"

Even the way the Sonnblick Observatory was built is the diametrical opposite of the snow camera, comprising an estimated 1000 liters of water worked by hand, whereas the weather observatory consists of more than 65 tons of steel and is designed for the highest possible endurance and longevity.

The question is, what type of perception and thus, of reality, lies behind the two observatories? My snow camera (Observatory 2) is a parody of the weather observatory and aims to point out the following: both observatories, both ways of perceiving reality, are created by religion, in the sense of God's view of being, and by utopia, i.e. illusion, of a healthy and integrated world. In the end, the question remains of how one can best locate oneself in this complex (me, human being, awareness - you, nature, an object) which distinguishes between respect and subjection.

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Time Scans

"Photography represents in certain ways a measurement of time, for it extracts fragments of instants from the flow of time which cannot be replicated.

This labour-intensive, time-consuming project by Robert Bodnar (Academy of Fine Arts, Vienna) dazzles viewers through its conceptual and technical precision through which the theme of time is portrayed. Out of several hundred individual pictures which were shot over the course of one day, he pieces a mosaic together which condenses the timespan which flowed by."

Galerie Westlicht

Robert Bodnar's Time Scans win enthusiasm and acclaim through their bizarre way of depicting dynamics. Through the collage-like technique of working with linear scans, a mapping of space (picture axis) and time take form atop one another. The basis of the work often comprises several thousand pictures, which together form a fast-motion recording of a certain specific interval of time which covers the same picture. Thus, the Time Scan consists of trace elements of a movement whose depiction remains open to the viewer. The partly surreal, partly starkly abstract-seeming pictures thus generated often call forth uniquely profound responses or alienation which lead to completely different assessments and points of view taking form in the mind of the beholder. They are simulations of a real process whose interpretations lead us to utterly different conclusions and leave behind impressions where nothing is what it seems. If one permits the pictures not only to work upon one's spirit and then actually studies them, one can decode their formation and thereby discover a potent, nearly scientific aid towards reconstruction of an event which actually took place.

Lukas Lederer

Illus.1: Festival - Timescan

Illus.2: Timescan from Sonnblick summit looking south

The Sonnblick: a truly extraordinary spot which is highly suited not only to observing the goings on of the weather. I have tried, in a period of highly technological measurements of weather changes, through a method of feeling my way through time, to re-direct our visual focus towards the peculiarly intense dynamics of celestial phenomena.

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Art project "Weatherwhisk"

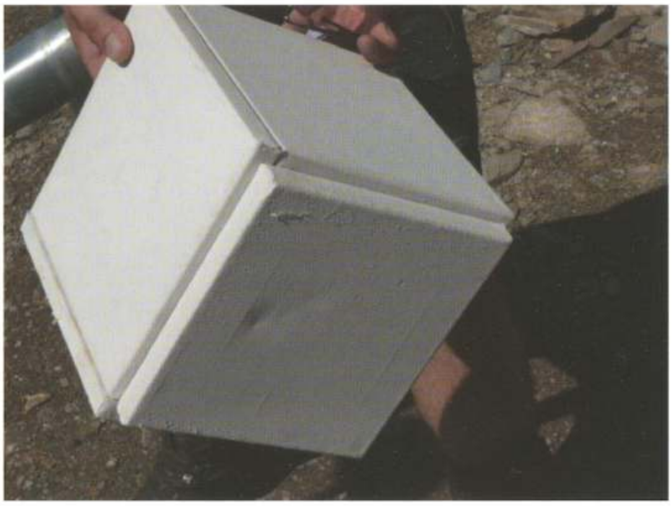
A wide open spirit prevails on the Sonnblick, and not only for natural sciences; art projects also occupy a respected niche. After all, natural science has been a source of inspiration to artists since time immemorial. Giorgione in his "Tempesta" posited a conundrum which is still valid today; William Turner was fascinated by extreme weather occurrences and geology; Georges Seurat was highly stimulated by physical studies; and Wassily Kandinsky was magnetized by new discoveries in nuclear physics. Alois Holzer is a guest at the Sonnblick, with a benefit campaign for the "Celebrity Brush" project.

From July 2007 until July 2008, the opening phase of an art project was launched which revolved around the precise placement of small, white cubes fashioned of linen stretched over wooden frames in various climatic locations from the metropolis of Vienna to the fresh-air resort Mönichkirchen, all the way to the high alpine rummit of Hoher Sonnblick in the Tauern Range in order to demonstrate what the effects of weathering in a year of Austrian climate on such simple objects might be. All the cubes were placed at official weather stations of the Central Institute for Meteorology through the friendly cooperation of the ZAMG weather service, Hohe Warte, for purposes of comparing measured weather data.

Illus. 1: Weather box on the Sonnblick summit terrace

By far the most difficult, logistically speaking, was ensconcing the box at the Meteorological Observatory on the Hoher Sonnblick, at 3106 meters altitude, even though the ORF weather editor himself, Alois M. Holzer, installed the object personally, with the welcome assistance of the weather observers.

Whereas in the lowlands certain patterns of mildew and soil deposits formed over a period of time, initial impressions of the weather cubes on the Sonnblick evidenced mechanical damages (apparently from ice blocks) and UV damage (loosening of the protective covering) - which in turn led to completely different structures on the object itself.



Illus. 2: Effects of hail (Photo: Staudinger)

Ultimately, the objects will be folded up and organised for purposes of viewing and depicting a weather year in Austria. A subsequent series will be auctioned off for charity.

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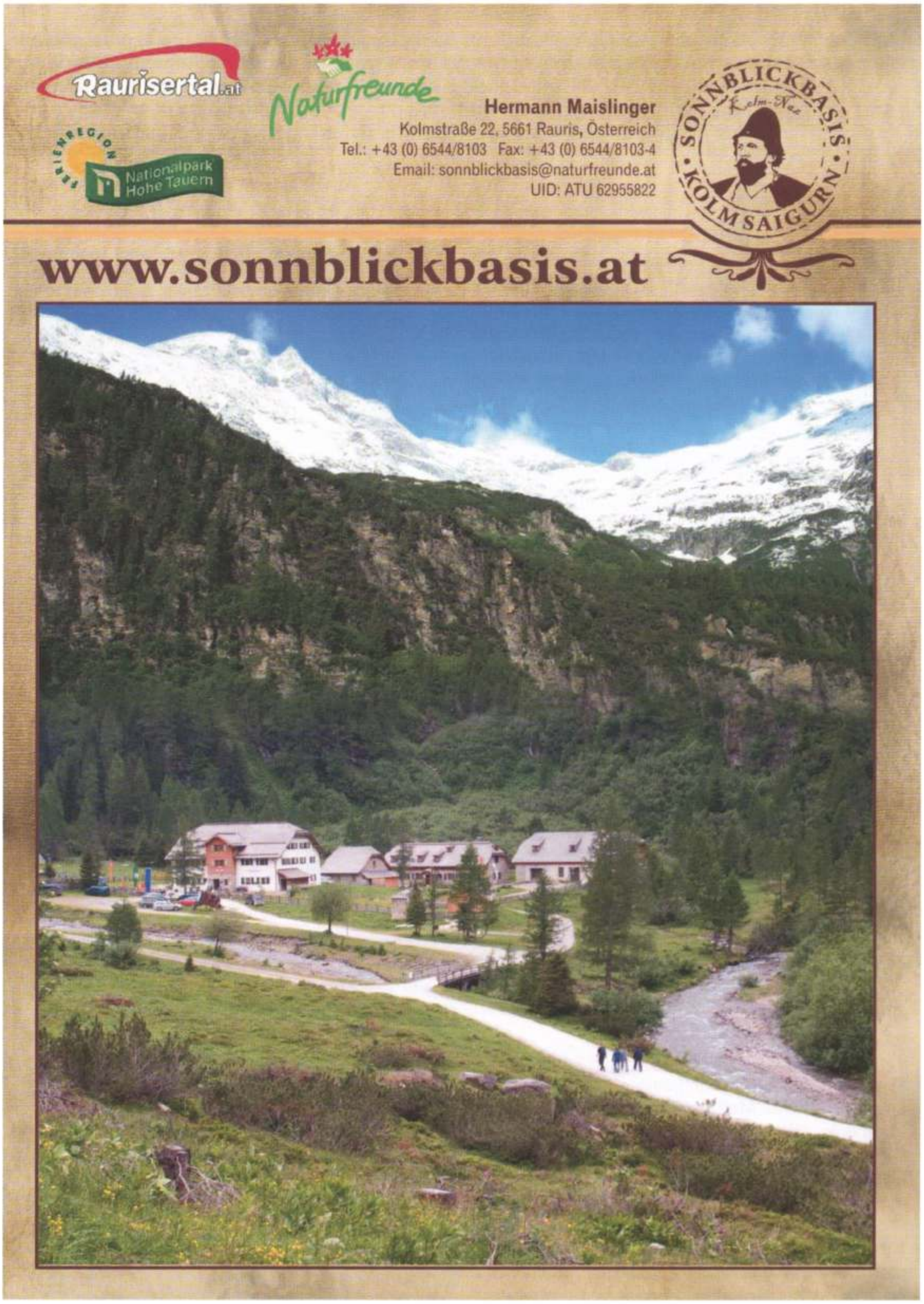
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ALPINE METEOROLOGY

The actual key reason for erecting this facility 125 years ago - meteorology at unknown heights.

Free and unimpeded views from the Northern Alps of Bavaria to the Marmolata in Italy. Meteorological divide. Foehn winds in both directions. Alpine wind system. Coupled with the free atmosphere.

(Foto: G. Schauer)

AIR CHEMISTRY - BACKGROUND MEASUREMENTS - GAW

A major focus since the 1980s.

Extremely exposed location. For all practical purposes, no emissions. Only the two weather watchers are on the summit approximately 100 days each year. Free-standing Main Alpine Ridge summit at 3,100 meters altitude. Ideal for measurements of long-distance transport and background.

(Foto: L. Rasser, H. Thomaseck)