



White Paper

Research at Jungfrauoch – Vision and Mission Statement 2015-2050

Strategy for the development of the unique,
internationally renowned High Altitude Research Station Jungfrauoch

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HFSJG
High Altitude Research Stations
Jungfrauoch & Gornergrat

Cover picture: The Sphinx at Jungfraujoch, photographed from the North with view to the Aletsch Glacier. The building houses the observatory with the large astronomical dome and the majority of the scientific equipment of the Research Station. The vantage hall (the glass-enclosed pavilion on the right) and the large terrace on the left are accessible for tourists. The smaller terrace on top of the vantage hall is used for solar radiation observations and long-term meteorological measurements as well as for short-term experiments in various scientific disciplines. The premises are accessible by two express lifts with a capacity of up to 1200 persons per hour. The main building of the Research Station is located about 120 meters below on the southern side of the so-called Sphinx rock (Credit: Jungfrau Railway).

Research at Jungfrauoch – Vision and Mission Statement 2015-2050

Strategy for further developing the capabilities
and infrastructure of the unique, internationally
renowned High Altitude Research Station Jungfrauoch
and for maintaining its clean environment

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Preamble

Jungfrauoch is an extraordinary place: well known worldwide as an exciting tourist destination and at the same time one of the most comprehensive high altitude research sites with great significance on a global scale.

The worldwide recognition of Jungfrauoch rests upon the vision of Adolf Guyer-Zeller. He undertook building a railway to the Jungfrau more than a hundred years ago, at a time when constructing an electrically driven rack-and-pinion railway in a 7.5-km long tunnel up to an altitude of 3454 m above sea level was a daring feat. When granting the operating license, the Swiss Parliament took an exceptional step as well: it committed the Jungfrau Railway to annual financial contributions in support of scientific research at Jungfrauoch.

Based on this commitment, the International Foundation ‘High Altitude Research Station Jungfrauoch’ (now ‘High Altitude Research Stations Jungfrauoch and Gornergrat’, HFSJG) was founded in 1930 under the auspices of the Schweizerische Naturforschende Gesellschaft (now the Swiss Academy of Sciences, SCNAT). The Foundation’s international framework meant that not only the Jungfrau Railway and the Swiss Academy of Sciences could be members of the Foundation, but research organisations from abroad could become members as well. In fact, the interest in high altitude research was such that Austria, Belgium, France, Germany and the United Kingdom became involved, too. This international atmosphere contributed to many discoveries made on Jungfrauoch over the years; two of them were awarded Nobel prizes in physics.

Extensions of the infrastructure for both tourists and scientists have made Jungfrauoch a key station in a competitive international setting. Only six years after the opening of the Research Station in 1931, a second building for science sitting on the Sphinx rock at an altitude of 3570 m, could be inaugurated. Today, the Sphinx Observatory is the Jungfrauoch landmark. Later additions made by the Jungfrau Railway – the high-speed elevators to the Sphinx and new terraces for tourists and for meteorological equipment – have been further significant infrastructure improvements.

In parallel, the focus of science conducted on Jungfrauoch has changed with time. Initial fields of study comprised cosmic-ray research, astronomy, meteorology and glaciology as well as health studies. Later on the detailed investigation of the Sun’s radiation was added. The first accurate value of the solar constant (*i.e.* the total solar irradiance received at Earth) was obtained on Jungfrauoch – by taking advantage of its clear and dry atmosphere. The solar spectrum was studied with two purposes: to better understand the physics of the Sun itself and to trace harmful substances in the Earth’s atmosphere. The concentration of these substances can be measured, because they leave clear imprints on the solar spectrum as the sunlight passes through the layers of air above us.

Following advances in analysis techniques, studies of the chemistry and physics of the atmosphere became of central interest during the last decades. Today such studies are key to the scientific effort: they are a basic input for climate and environmental science. And as continuous data sets obtained on Jungfrauoch go back as far as 1950, covering more than sixty years, they are an invaluable and unique archive for reconstruction of the modifications of our atmosphere over time and their impact on the environment. All measurements made at Jungfrauoch, and so also the powerful direct sampling of the air, which provides highly sensitive analyses of its particulate, chemical and isotopic composition, are conducted at the highest possible level of scientific performance. The exceptional location and infrastructure of Jungfrauoch together with this emphasis on quality attracted invitations to join and support international collaborations. As a result, Jungfrauoch is involved today in more than thirty national and international networks for atmospheric research. Currently the most important ones among them are the World Meteorological Organization’s (WMO) Global Atmosphere Watch Programme (GAW) and the worldwide Network for the Detection of Atmospheric Composition Change (NDACC). Jungfrauoch has taken on the role of a prime site in both these networks.

Such success, however, also brings obligations: there are costs and demands for personnel and for continually improving the infrastructure. Upcoming projects such as the Integrated Carbon Observation System (ICOS) — an undertaking whose initial Swiss contribution has been approved by the Swiss Parliament and which shall last for 20 to 30 years — call for extending the science infrastructure for long-term activities. The mid-century horizon of this White Paper is defined in response to the industrialised countries' 2050 target year for climate goals.

The dynamically developing tourism in the Jungfrau region helps science by making the Research Station better accessible, but it also generates challenges related to local contamination. All concerned must try to minimise such drawbacks by maintaining the excellent, quasi-pristine environmental conditions on Jungfrauoch that have brought the Research Station — as well as the tourist site — the worldwide esteem they enjoy today.

The vision of SCNAT and HFSJG is that the Research Station Jungfrauoch remains, and continues to develop as one of the leading high altitude infrastructures worldwide for investigating alpine surroundings, particularly in environmental and climate research.

The mission is to maintain, improve and extend, as required, the infrastructure of the Research Station Jungfrauoch and to protect its clean environment in close collaboration with the stakeholders engaged in the touristic exploitation of Jungfrauoch, so that the station can continue to serve as one of the best-equipped high altitude research stations worldwide, with the ability to support cutting-edge research, including environmental monitoring and campaigns in various additional scientific fields.

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Executive Summary

The High Altitude Research Station on Jungfrauoch responds to the standing requirement of science for high altitude research facilities in a national and international context. Today's main emphasis on atmospheric research addresses one of the largest problems faced by humanity, namely climate change.¹

These investigations require a locally unpolluted atmosphere in order to characterise sources and sinks of trace species from afar. Thanks to its location above the planetary boundary layer, the Research Station on Jungfrauoch is a key station in the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) as well as in numerous other national and international networks. As such it provides unique reference data on the state and evolution of the chemical composition and aerosol content of the Earth's atmosphere. Today the quality of the operations of the research site is under threat.

The increased demand of space for the various automatic observations and the requirement for modern infrastructures are challenges that Switzerland needs to face now by committing to a long-term perspective on our surveillance for a sustainable world. At the same time, there is a legitimate interest of the Jungfrau Railway to develop and exploit the touristic potential of this unique site.

Thus, Jungfrauoch faces two major challenges, namely

1. the need to extend the floor space available to users of the Research Station at suitable locations.²
2. the need to reconcile the interests of the Jungfrau Railway, whose aim is to welcome an increasing number of tourists to Jungfrauoch, with those of the Research Station, which needs a natural, locally unpolluted atmosphere on Jungfrauoch.

The co-location of tourism and research has been a success story in the past, and must remain one also in future. We note that the Research Station is located not only at an increasingly popular tourist site, but is also adjacent to the UNESCO Natural World Heritage 'Swiss Alps Jungfrau-Aletsch'. A firm commitment by all parties concerned and considerate decisions are thus needed that permit, on the one hand, a constant development of a tourist site of worldwide renown and, on the other hand, research engagements of highest quality and natural preservation.

In order to sustain and strengthen the key role of the unique, internationally renowned alpine Research Station Jungfrauoch we are proposing the strategy and actions summarised in this White Paper. As part of a continuous management process, we further propose to regularly assess this White Paper in a five-year cycle.

Following a general overview, a brief description of the history, the past achievements and an in-depth assessment of the present status of the Research Station, we present our vision and mission:

¹ We refer to the 2013 Headline Statement for Policy-makers by the Intergovernmental Panel on Climate Change (IPCC): "Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system." (www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf)

² Particularly urgent is the accommodation for additional instruments addressing the Integrated Carbon Observation System (ICOS). The Swiss Parliament has approved the funding for the first four operational years of this undertaking that is also advocated by the European Strategy Forum on Research Infrastructures (ESFRI).

The vision of SCNAT and HFSJG is that the Research Station Jungfraujoch remains, and continues to develop as one of the leading high altitude infrastructures worldwide for investigating alpine surroundings, particularly in environmental and climate research.

The mission is to maintain, improve and extend, as required, the infrastructure of the Research Station Jungfraujoch and to protect its clean environment in close collaboration with the stakeholders engaged in the touristic exploitation of Jungfraujoch, so that the station can continue to serve as one of the best-equipped high altitude research stations worldwide, with the ability to support cutting-edge research, including environmental monitoring and campaigns in various additional scientific fields.

The implementation of this vision shall rest on three main pillars:

1. **A clean natural environment at the Jungfraujoch for the next decades:** maintain the cleanliness of the environment for the benefit of both research and tourism.
2. **A world-class research facility for the next generation of scientists:** consolidate the Research Station Jungfraujoch as a world-leading research infrastructure by maintaining and extending its facilities to host upcoming international research initiatives and campaigns and to continue to support various disciplines, including environmental and climate science, glaciology and permafrost studies, materials science and technology, as well as physiological and medical research.
3. **Outreach to policy makers and the public:** raise the awareness of stakeholders, and of the public at large, of the important scientific mission of the Research Station, which delivers the basis for critical policy decisions on climate change that are needed for a sustainable socio-economic development.

1. Introduction

For more than a hundred years, Jungfrauoch, easily accessible by railway, has been one of the most spectacular places to visit on Earth. In parallel, it has become one of the most important high altitude research sites worldwide. The attractiveness of Jungfrauoch is unbroken and the number of visitors is steadily increasing. Thus, further touristic infrastructure adaptations will be required. However, these tend to interfere – particularly during construction phases – with practically all the scientific long-term measurements currently being made at Jungfrauoch. In order to maintain Jungfrauoch both as an outstanding site for tourists and as a key station for science, the issues raised in this document must be discussed openly – and resolved. And appropriate action must be taken.

Moreover, the globally increasing need for additional measurements of the changing chemical and physical properties of gases and particulates of the Earth's atmosphere require additional space for research equipment. This calls for support from beyond the research funding organisations, which assure the maintenance of the Foundation's infrastructure.

In the following we describe the International Foundation for the Research Station, its reference in the concession for the operation of the Jungfrau Railway, as well as the need for collaboration between the Research Station and the Jungfrau Railway. The history and some of the remarkable past scientific achievements at the Research Station are briefly summarised in Chapter 2. Chapter 3 then presents an in-depth analysis that is based on our users' comments on the current status of the Research Station and of the research activities that have established its pre-eminent role in worldwide climate research. Chapter 4 presents our vision for the future of the Research Station – projected out to the current target for the climate goals of the industrialised nations, 2050. Chapter 5 puts forward the challenges and states the actions needed to accomplish the vision's aims, and in Chapter 6 we summarise our conclusions.

1.1. The International Foundation Hochalpine Forschungsstationen Jungfrauoch und Gornergrat (HFSJG) and its Research Stations

The International Foundation High Altitude Research Stations Jungfrauoch and Gornergrat (HFSJG, as per the German abbreviation of the name) dates back to 1930. It is a foundation according to articles 80ff. of the Swiss code of civil law and is under the auspices of the Swiss Federal Government. As shown in the organisation chart (Fig. 1), the Foundation has at present nine members, four of them from abroad and five from Switzerland itself. The Swiss Academy of Sciences (SCNAT) is charged with looking after the interests of the Swiss research community within the Foundation, and has delegated this task to its Commission for the High Altitude Research Station Jungfrauoch.

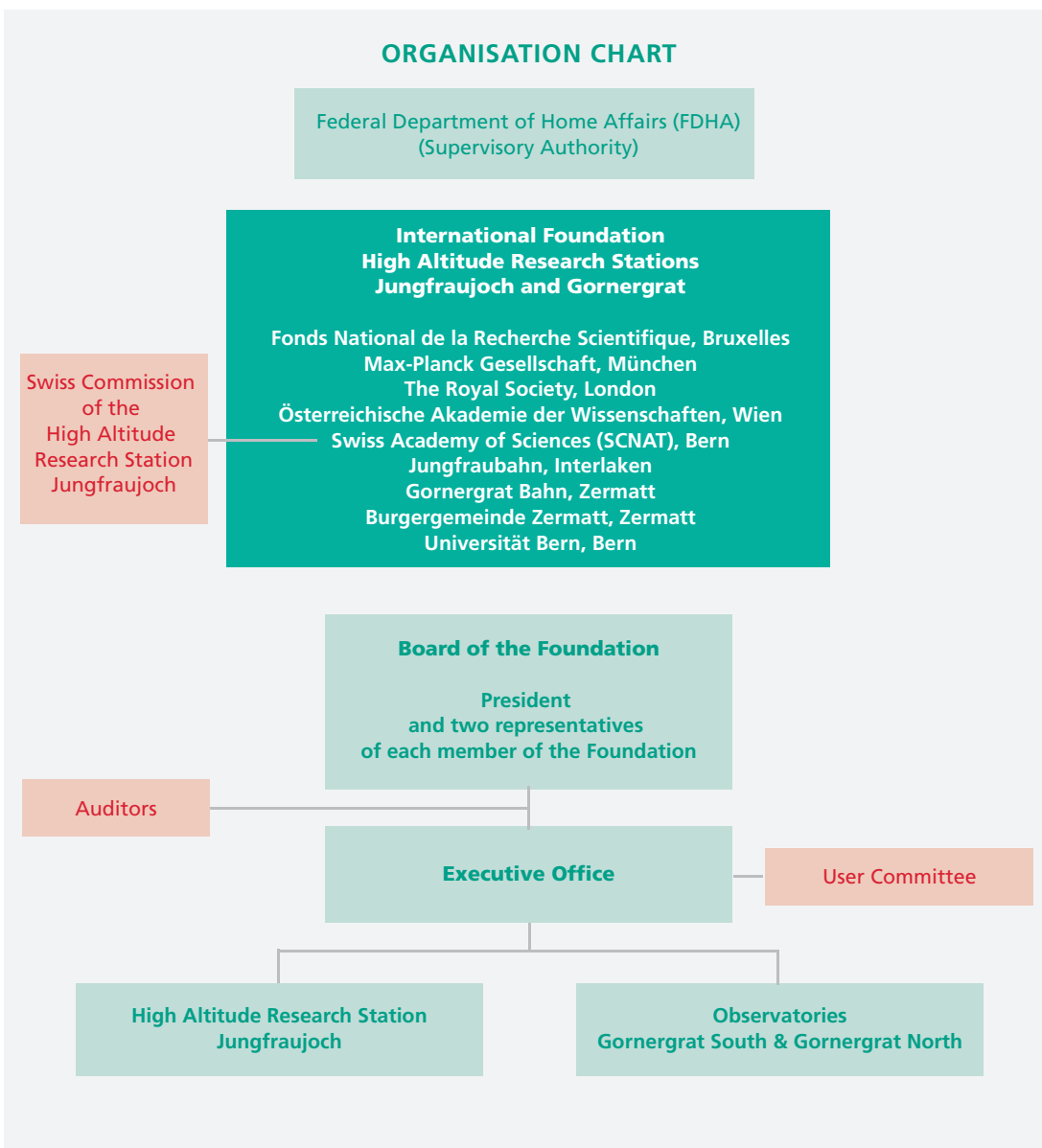


Figure 1: Organisation Chart of the International Foundation High Altitude Research Stations Jungfrauoch and Gornergrat (HFSJG).



Figure 2: Weather conditions with clear and cloudy sky offer access to a wide spectrum of atmospheric research on Jungfraujoch (Credit: Julie Cozic, Paul Scherrer Institute).

The HFSJG's founders established an organisation that allows researchers easy access to the alpine environment. The Foundation provides the infrastructure for the research projects carried out by organisations located in countries represented by its scientific members, namely

- the Fonds National de la Recherche Scientifique, Bruxelles (Belgium),
- the Max-Planck Gesellschaft, München (Germany),
- the Österreichische Akademie der Wissenschaften, Wien (Austria),
- the Swiss Academy of Sciences (Switzerland),
- the Royal Society (United Kingdom) and
- the University of Bern (Switzerland).

The Foundation also promotes the use of its facilities for other international and national research projects. Access is provided and supported by the Jungfrau Railway, the Gornergrat Bahn and the Burgergemeinde Zermatt. Internet communication is secured by SWITCH, the networking of Swiss academia, in collaboration with the University of Bern.

The funding of the Foundation comes from annual fees paid by the member countries and their institutions, from researchers and from voluntary contributions. The Swiss National Science Foundation (SNF) has provided the substantial Swiss contribution for the operation and the maintenance of the research stations since 1965, yet it is not a member of the Foundation, because Swiss law does not allow that a Swiss foundation is a member of another Swiss foundation.

The HFSJG Foundation provides the infrastructure and support for scientific research of international significance that must be carried out at an altitude of 3000 m to 3600 m above sea level or for which an alpine environment is necessary. The Foundation runs research facilities both at Jungfraujoch and at Gornergrat. In the following, however, we will concentrate on the Jungfraujoch location. We note that the Foundation provides an infrastructure, and thus facilitates research, but does normally not carry out research itself.

1.2. The Research Station Jungfraujoch

Jungfraujoch, with the Sphinx Observatory at 3570 m above sea level, is the highest research station in Europe that is accessible year-round by public transportation. It offers an excellent, permanently inhabited infrastructure for environmental research, for solar and atmospheric physics, for meteorology, glaciology, and research in materials sciences, technological tests and high altitude physiology. The meteorological conditions are characterised by air pressure at the Sphinx Observatory between 619 mbar and 675 mbar with an average of 653 mbar and air temperatures between -37°C and $+12.8^{\circ}\text{C}$ with an average of -7.5°C for the period January 1961 to December 2012. The weather conditions (*cf.* Fig 2.) with clear sky (65%) and cloudy sky (35%) offer access to a wide spectrum of research.

The Research Station in the south slope about 120 m below the Sphinx rock remains the base of operations for all scientific work. Today this building provides four laboratories, houses a cosmic-ray detector, a mechanical workshop, a library, a kitchen, a living room, ten bedrooms, two bathrooms, and the living quarters of the custodians. A machine producing liquid nitrogen is available, too. The infrastructure has continually been adapted to the needs of the users. This applies to facilities such as electricity, water, telephone and fax, high-speed Internet access as well as to the chemical laboratories and those for physiology and medicine.

The Sphinx Observatory is located at $7^{\circ} 59' 2''$ E, $46^{\circ} 32' 53''$ N longitude and latitude, at an altitude of 3570 m above sea level. The space available for science comprises two large laboratories, a weather observation station, a workshop, two terraces for scientific experiments, and two domes — one for astronomy and one for meteorology. Thanks to an extension of the Sphinx facility in the mid-1990s by the Jungfrau Railway, more space has become available that offers the possibility to perform short-term experiments outdoors. The laboratory space inside the Sphinx Observatory on the other hand is occupied to its limits.

Two custodian couples share the year-round presence at the Research Station in alternating shifts. They maintain the infrastructure, including the guestrooms, and act as hosts of the researchers. Moreover, the custodians are also responsible for the daily weather reports to MeteoSwiss (the Federal Office of Meteorology and Climatology). In addition, they monitor a number of automatically recording scientific experiments.

Most of the time, Jungfrauoch is located above the planetary boundary layer (*cf.* Fig. 4). This precludes frequent rapid variations in the chemical and particulate composition measured there, and thus provides useful values of background air, *i.e.* of the long-term average composition of the atmosphere, representing an extended source region.

Accordingly, the Research Station Jungfrauoch is a unique location for ground-based observations of the free troposphere, and that's why atmospheric physicists and chemists, and environmental researchers from all over the world access it for their work. It is not surprising then that research related to the Montreal- and Kyoto-Protocols and the aerosol programme at Jungfrauoch are among the most comprehensive in the world.



Figure 3: The custodian couples Fischer (r.) and Otz (l.) at the time of a handover. They share a year-round presence in alternating shifts at the Research Station, where they are responsible for the proper local operation of the infrastructure. As their main duties they daily provide several weather reports, act as hosts for resident researchers, monitor experiments and clean away snow and ice after storms (Credit: Bruno Petroni).

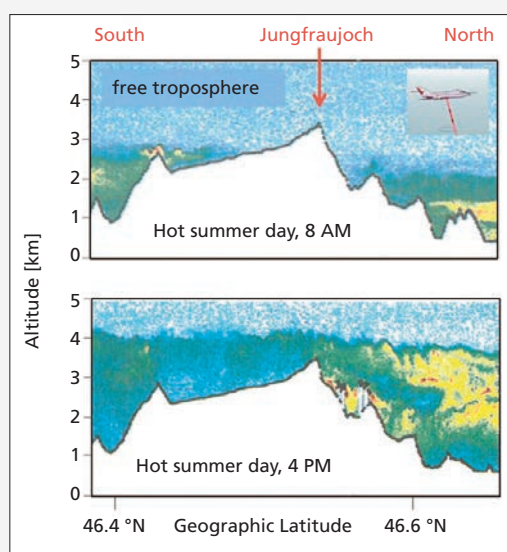


Figure 4: The interface between planetary boundary layer and free troposphere in the morning (top) and afternoon (bottom) of a hot summer day derived from lidar profiles obtained by an airplane flying in the South-North direction over Jungfrauoch (Credit: Stephan Nyeki, Paul Scherrer Institute).



Figure 5: The Jungfrau Railway provides access to Jungfraujoeh throughout the year (Credit: Jungfrau Railway).

1.3. The HFSJG and its collaboration with the Jungfrau Railway

A well-functioning, hand-in-hand collaboration between HFSJG and the Jungfrau Railway has been a success story in the past. We wish that this will continue in today's rapidly changing environment of both tourism and science. Indeed, collaboration becomes increasingly important: often rather rapid adaptations to new conditions must take place. This calls for an even closer collaboration between HFSJG and the Jungfrau Railway in the future.

2. A Brief History of the Research Station on Jungfrauoch

After the early death of the prime instigator and planner of the Research Station, the meteorologist and polar explorer Alfred de Quervain, the physiologist (and later Nobel Laureate) Walter Rudolf Hess implemented the plans for a scientific laboratory at Jungfrauoch. Under his leadership the International Foundation High Altitude Research Station Jungfrauoch (now the International Foundation High Altitude Research Stations Jungfrauoch and Gornergrat) was established in 1930. The Research Station was inaugurated one year later already. Research which, to some extent, had started before, could now be performed extensively and conveniently from a solid home base. Initially investigations focused on cosmic rays, astronomy, glaciology, meteorology and physiology. The Sphinx Observatory, located about 120 m above the initial building of the Research Station was completed in 1937. A first astronomical dome was installed on the roof of the Sphinx building in 1950. This has become a symbol of scientific activity at Jungfrauoch for millions of tourists. Due to an increased demand for observing time and given the limited floor area on Jungfrauoch, the Foundation initiated the construction of two astronomical domes on Gornergrat in the late 1960s.

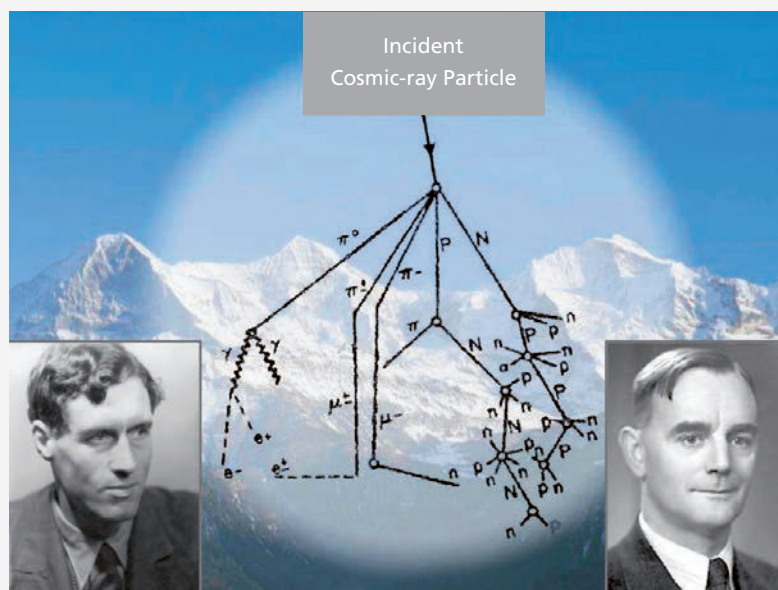
2.1. Scientific achievements

Research work at Jungfrauoch has brought many outstanding results. The following milestones may be mentioned here:

- Research on cosmic rays by Blackett and Powell provided basic results whose importance was recognised by two Nobel prizes in physics (Blackett, 1948; Powell, 1950). The large Wilson cloud chamber that had been installed by Blackett in 1951 at the Sphinx Observatory was later moved to CERN, where it ushered in the era of modern accelerator-based high-energy particle physics.
- Glaciological investigations were among the prioritised science projects performed at Jungfrauoch during the early phases. In 1939, only a couple of years after the inauguration of the station, Hughes, Perutz and Seligman published their results in *Nature*: “Glaciological results of the Jungfrauoch research party.”

Figure 6: Before the advent of large accelerators, nuclear and particle physics was performed to a large extent at high altitude. The Physics Nobel Laureates of 1948 and 1950, in particular, had performed important parts of their cosmic-ray research on Jungfrauoch. P.M.S. Blackett (left) was

awarded the Nobel Prize in 1948 “for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation” and C.F. Powell (right) won the Prize in 1950 “for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method” (Credit: Picture of Eiger, Mönch, Jungfrau and cosmic ray cascade: Erwin O. Flückiger, HFSJG; pictures of Nobel prize winners Blackett and Powell: www.nobelprize.org).



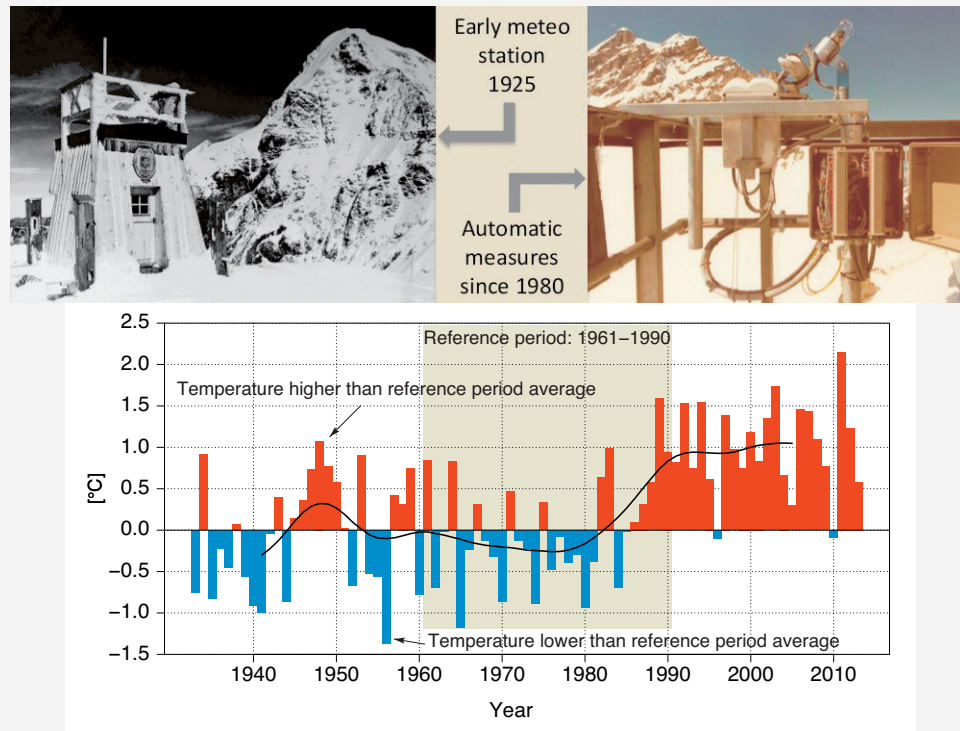


Figure 7: Residual temperature showing that the temperature on Jungfrauoch has increased by $\approx 1.4\text{ }^{\circ}\text{C}$ since 1937. As the number of days, where the temperature remained above $0\text{ }^{\circ}\text{C}$ during 24 h has increased by 60 % since 1961, problems with permafrost have become more frequent (Credit: M. Begert, C. Appenzeller & L. Vuilleumier, MeteoSwiss).

- Continuous meteorological recordings started in 1925 at Jungfrauoch. From 1937 onwards, these measurements are taken on the Sphinx Observatory and are today part of the SwissMetNet run by MeteoSwiss. A temperature increase of $1.4\text{ }^{\circ}\text{C}$ was found for the period between 1937 and 2005 (*cf.* Fig. 7), while no trend was observed for the first decade of the current century.
- In 1950 the Université de Liège (Belgium) began to investigate the spectrum of the sunlight in great detail (*cf.* Fig 8). One of the first results obtained on Jungfrauoch concerned however the Earth's atmosphere: Migeotte established that CH_4 and CO are permanent constituents of the terrestrial atmosphere. A first atlas of the solar spectrum between $2.8\text{ }\mu\text{m}$ and $23.7\text{ }\mu\text{m}$ was then published by Migeotte, Neven and Swensson in 1956. Thanks to support from the International Geophysical Year, the Liège group could install a large vacuum prism-grating spectrometer in 1958, with which an atlas covering the wavelength range 750 nm to $1.2\text{ }\mu\text{m}$ was then

recorded by Delbouille and Roland, and published in 1963. After a digital computer was installed in 1966 to control the evacuated spectrometer — now with a double-pass on the grating — a digital solar atlas was recorded by Delbouille, Neven and Roland. This atlas, which covers the wavelengths from the atmospheric cut-off at 300 nm to the near infrared at $1.016\text{ }\mu\text{m}$ was published between 1973 and 1983. These data are still used today as a reference solar spectrum and thus remain a fundamental resource for solar physics and astronomy in general, and at the same time for studying the evolution of constituents of the Earth's atmosphere.



- In 1962, the German physicists Labs and Neckel took advantage of the excellent transparency of the atmosphere above Jungfraujoch to obtain the first absolute measurement of the solar constant, *i.e.* the total solar irradiance at Earth.
- In 1967, initiated by the French astronomer Chalonge and with financial support from Belgium, France, Switzerland and the United Kingdom, a new dome and a 76 cm telescope were installed on the upper terrace of the Sphinx.
- The Geneva astronomer Golay developed a seven-colour photometry system for the classification of stars. Under his leadership astronomers from Geneva Observatory took observations from the Jungfraujoch, which formed the basis of a unique catalogue including over 40 000 stars.
- In 1973, Empa started continuous *in-situ* measurements of reactive gases as part of an early engagement of Switzerland in a programme of the Organisation for Economic Co-operation and Development (OECD). Designed to investigate changes in the local atmospheric composition, this programme aimed at collecting data to ensure a sustainable development in the OECD member states, and implicitly in the entire world.



Figure 9: In 1973 Empa, the Swiss Federal Laboratories for Materials Science and Technology, started measuring the concentration of reactive gases on Jungfrauoch *in situ* and continuously. With advances in technology and algorithms, and based on today's detailed meteo information, it has become possible to quantify and locate the geographical origin of harmful substances, which violate international agreements (Credit: Empa).

- In the mid-1970s the Liège group had observed a spectral line of hydrofluoric acid (HF) during a balloon flight, which they subsequently confirmed by high-resolution spectroscopy on Jungfrauoch. This supported the hypothesis of Molina-Rowland-Cicerone and Stolanski about the destruction of stratospheric ozone by Freons released into the atmosphere by spray cans, and then led to the Montreal Protocol of 1987 (cf. Fig. 10).
- In the 1980s the Université de Liège initiated column-integrated spectroscopic measurements of gases related to the Montreal and Kyoto Protocols. These measurements, which are based on Fourier-transform spectroscopy in the infrared spectral domain, show the evolution of the concentration of these substances in the terrestrial atmosphere (cf. Fig. 14).
- After the solar flare on June 3, 1982, the cosmic-ray detector of the Physics Institute of the University of Bern recorded for the first time high-energy solar neutrons, and thus was able to prove their impact on the Earth's atmosphere.

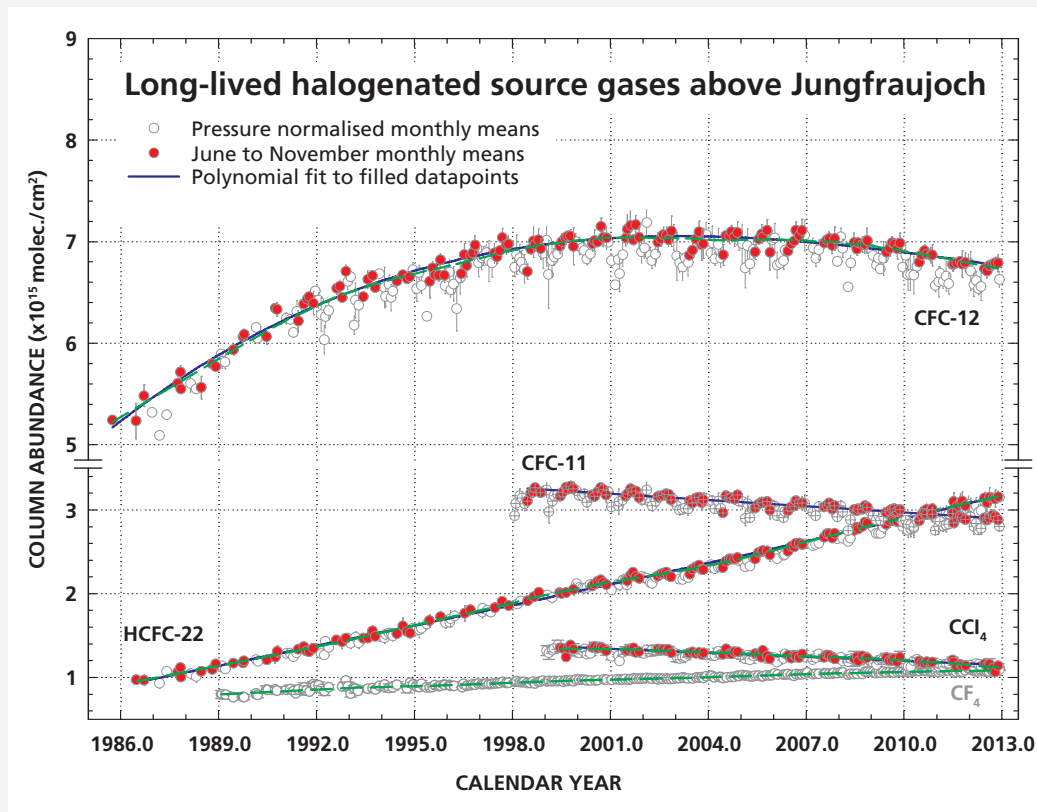


Figure 10: Fourier-transform spectrometry with very high spectral resolution enables the Liège group to accurately monitor the changing concentration of ozone-destroying fluorohydrocarbons (Freons) in the atmosphere, and thus to follow the effects of the Montreal Protocol. This protocol, put in force in 1989, has led to a slowing down of the increase and now finally to a slow decrease of the concentration of the Freon CFC-12. On the other hand, the concentration of Freon HCFC-22 is still increasing, but a phase-out plan has been set in place targeting a complete reduction by 2030 (Credit: Institut d'Astrophysique et de la Géophysique, Université de Liège).

In 1988 the Paul Scherrer Institute started continuous aerosol measurements with their newly developed epiphaniometer on Jungfraujoch (and in parallel on Colle Gnifetti, Monte Rosa). Urs Baltensperger and colleagues were able to show for the first time that vertical transport results in high aerosol concentrations even at alpine altitudes. This was in drastic contrast to earlier conclusions that had been based exclusively on ozone measurements.

- In 1990 the Austrian researchers Blumthaler and Ambach gained worldwide attention for the first direct measurements of an increase in the UV-intensity in Europe due to stratospheric ozone loss.

- In 1995 MeteoSwiss, in collaboration with several partners, initiated the Swiss participation in the Global Atmosphere Watch (GAW) programme. This started continuous measurements of a large variety of atmospheric substances. Today, Jungfraujoch is one of the most comprehensive GAW stations worldwide. The uninterrupted, high-quality data obtained on Jungfraujoch have led to a number of trend analyses that are of great relevance for understanding climate change.



Figure 11: Even with automatic weather observations human intervention is often needed on Jungfraujoch. The year-round presence of custodians helps to overcome these difficult conditions. MeteoSwiss gets help from the Jungfraujoch custodians in cases like this severe rimming event, where the MeteoSwiss ventilation and heating system could not prevent frost on one of the sensor-covering caps (Credit: L. Vuilleumier & C. Félix, MeteoSwiss).

- At the same time the ‘Physikalisch-Meteorologisches Observatorium Davos’ (PMOD) initiated comprehensive electromagnetic radiation measurements in order to investigate the Earth’s radiation balance.
- From 2000 onwards Empa has successfully used long-term datasets based on *in-situ* gas analysis to quantify European emissions of ozone-depleting substances and greenhouse gases for the verification of the Montreal and Kyoto Protocols. Based on comprehensive large-area meteorological information one can locate the geographic origin of forbidden substances. Based on these measurements, Jungfraujoch became a member of the prestigious AGAGE network (Advanced Global Atmospheric Gases Experiment).
- In February 2005, Jungfraujoch achieved further distinction, as it was certified as the twenty-third global site in the network of the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO).

Based on their pioneering work and their professional experience gained by work on Jungfraujoch, Swiss researchers from MeteoSwiss, Empa, PMOD and PSI have been asked to take on leading roles in several Scientific Advisory Groups of the GAW programme, and thus are contributing to quality assurance and capacity building in many different places around the world.

3. Current Activities at the Research Station on Jungfrauoch

Here we introduce two of the leading long-term atmospheric monitoring and research programmes, namely the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) and the Network for the Detection of Atmospheric Composition Change (NDACC). We explain in some depth Jungfrauoch's role as a global station in GAW and as a primary site in NDACC. Subsequently we will look at additional long-term measurements, address research campaigns, and also discuss research in fields other than, but often still related to atmospheric and climate research at high altitude, such as glaciology and permafrost. Technological research, as well as studies in physiology and medicine will be covered, too.

Quality assurance, *i.e.* assuring the proper calibration of the measurements through frequent comparisons with standards is part of any research, but it turns into a central issue with the ambition to perform high-accuracy long-term monitoring of decisive atmospheric components. Therefore, in the past and at present quality assurance has been given highest priority by both the HFSJG Foundation and its infrastructure users. It is indispensable to continue this in future.

3.1. Long-term monitoring of atmospheric composition

3.1.1. Global Atmosphere Watch (GAW)

The demand for information about status and evolution of the atmosphere has increased significantly over the last decades and, accordingly, has led to an increasing number of projects performed on Jungfrauoch that are related to climate issues. Global Atmosphere Watch (GAW), established in 1989, and coordinated by the World Meteorological Organization's (WMO) Atmospheric Research and Environment Branch (ARE), is one of the WMO's most important contributions to the study of environmental issues. The programme focuses upon the role of atmospheric chemistry in global change, and builds upon a partnership of managers, scientists, and technical experts from 80 countries — all coordinated by the WMO Secretariat in Geneva.³

³ GAW is the atmospheric chemistry section of the Global Climate Observing System (GCOS), which in turn is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) as well as the International Council for Science (ICSU).

GAW contributes also to the Global Climate Observing System (GCOS) under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). The GCOS implementation plan of August 2010 (GCOS-138) calls for sustained observations of the Essential Climate Variables (ECVs), because progress in generating global climate products and derived information crucially depends on such observations. The plan also recommends enhanced support for research, modelling, analysis, and capacity-building activities for all parties of the UNFCCC and underlines the need for observational records to improve seasonal-to-interannual climate predictions.

The backbone of the GAW programme is its network of measuring locations. It consists of global and regional measurement stations, as well as contributing stations that provide additional information. All GAW stations are operated by their host countries, either by their national meteorological services or by other national scientific organisations. More than 80 countries currently host GAW stations. In total the GAW can rely on data from 30 global stations (*cf.* Fig. 12), more than 400 regional stations, and around 100 contributing stations (see GAWSIS).

The High Altitude Research Station Jungfrauoch has been certified as a Global GAW Station in February 2005 in recognition of the high quality of its comprehensive long-term measurement programmes that cover all Essential Climate Variables (ECVs) for atmospheric surface sites.

The Swiss GAW programme (GAW-CH) was launched in 1994 as national contribution to the international GAW programme. It is coordinated by MeteoSwiss. Within GAW-CH, federal offices and national research institutions have organised a strong collaboration in atmospheric observations and analyses. Thus, the Swiss GAW programme includes the monitoring of various physical and chemical atmospheric variables, research activities and advanced services. The programme is regularly reviewed: the 5th GAW-CH conference discussed the results of the period 2006 to 2009 and decided on projects for the period 2010 to 2013. In 2014, another series of research projects started, with a significant involvement of Jungfrauoch.

The GAW Strategic Plan 2008-2015 lists the following goals:

“Global Atmosphere Watch seeks to understand and control the increasing influence of human activity on the global atmosphere. Currently the greatest challenges are

- the stratospheric ozone depletion and the associated increase of ultraviolet (UV) radiation reaching the Earth’s surface,
- the changes in the weather and climate related to human influence on atmospheric composition, particularly, greenhouse gases, ozone and aerosols,
- the reduction of the detrimental influence of air pollution on human health and issues involving long-range transport and deposition of air pollution.”

Many of these remits have socio-economic consequences: modifications of the atmosphere affect weather, climate, human and ecosystem health, water supply and quality, and agricultural production.

GAW follows the strategy of the Integrated Global Atmospheric Chemistry Observations (IGACO), and thus aims to

- reduce environmental risks to society and meet the requirements of environmental conventions,
- strengthen capabilities to predict climate, weather and air quality, and

▪ contribute to scientific assessments in support of environmental policy, through

- maintaining and applying global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere,
- emphasizing quality assurance and quality control, and
- delivering integrated products and services of relevance to users.

3.1.2. Network for the Detection of Atmospheric Composition Change (NDACC)

Jungfraujoch is also deeply involved in the Network for the Detection of Atmospheric Composition Change (NDACC) – another major contributor to the worldwide atmospheric research effort. In this programme a set of globally distributed research stations provide standardised and inter-calibrated long-term measurements of atmospheric trace gases and particles, of the spectrum of UV radiation reaching the Earth’s surface, as well as of physical parameters from the wide range of observations that are schematically illustrated in Fig. 13.

NDACC has the following priorities:

- detecting changes and trends in atmospheric composition and understanding their impact on the stratosphere and troposphere,



Figure 12: The ‘Global Stations’ of the Global Atmosphere Watch (GAW) (Credit: www.wmo.int).

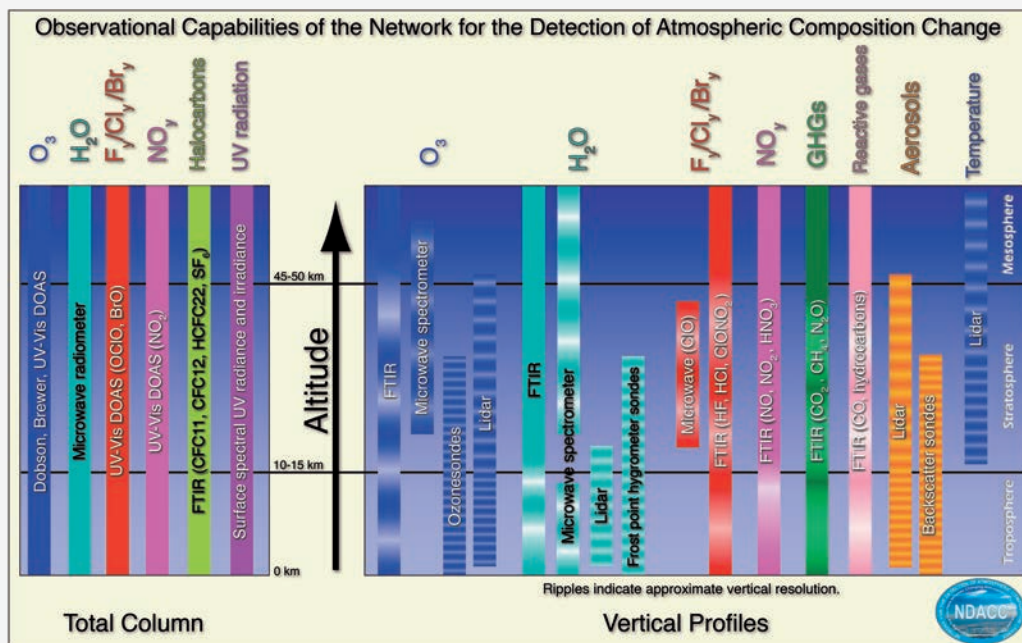


Figure 13: The column-integrated parameters and vertical profiles observed by the different measurement techniques within the Network for the Detection of Atmospheric Composition Change (NDACC) (Credit: www.ndsc.ncep.noaa.gov/).

- establishing scientific links and feedbacks between climate change and atmospheric composition,
- testing and validating (by ‘ground truth’) atmospheric measurements from satellites,
- supporting process-focused scientific field campaigns, and
- testing and improving theoretical models of the atmosphere.

Since its inception in the early 1990s, NDACC (formerly NDSC) is a major contributor to the Global Atmosphere Watch (GAW) presented in the preceding section⁴ as well as to many other internationally and nationally coordinated research networks and programmes such as NORS.⁵

⁴ Being a major component of the international atmospheric research effort, NDACC has been endorsed by national and international scientific agencies, including the United Nations Environment Programme (UNEP) and the International Ozone Commission of the International Association of Meteorology and Atmospheric Sciences.

⁵ NORS – the Demonstration Network Of ground-based Remote Sensing Observations in support of the Copernicus Atmospheric Service – aims at demonstrating the value of ground-based remote-sensing data from NDACC for quality assessment and improvement of the Copernicus Atmospheric Service products. The COPERNICUS programme, previously known as GMES (Global Monitoring for Environment and Security), is coordinated and managed by the European Commission. The observation infrastructure is developed by ESA for the space component and by the European Environment Agency and the EC Member States for the *in-situ* component.

3.1.3. Studies of atmospheric chemistry and physics

For the investigation of the chemistry and physics of the Earth’s atmosphere about 25 long-term projects with automated measurements are in operation on Jungfraujoch. In addition there is a number of short-term measuring campaigns. Advanced investigation methods and techniques, such as multi-axis differential optical absorption spectroscopy (MAXDOAS) and instruments based on a quantum cascade laser (QCL) provide high-precision isotope measurements on carbon dioxide and NO_x.

Long-term comparability of multi-decadal time series for the detection of change in the atmospheric composition, such as those obtained by the Université de Liège, requires not only environmental conditions with minimal local perturbations but also frequent comparisons of methods and instruments. Jungfraujoch is a key site for this kind of quality assurance (QA) activities. Jungfraujoch participates in the dedicated QA-Programme of GAW and also within several other international monitoring programmes, including some that belong to European Framework Programmes.

3.1.4. NABEL, EMEP and AGAGE – Monitoring pollution and greenhouse gases

Empa started continuous *in-situ* observations of atmospheric constituents at Jungfraujoch in 1973. Since 1978, these are part of the Swiss National Air Pollution Monitoring Programme

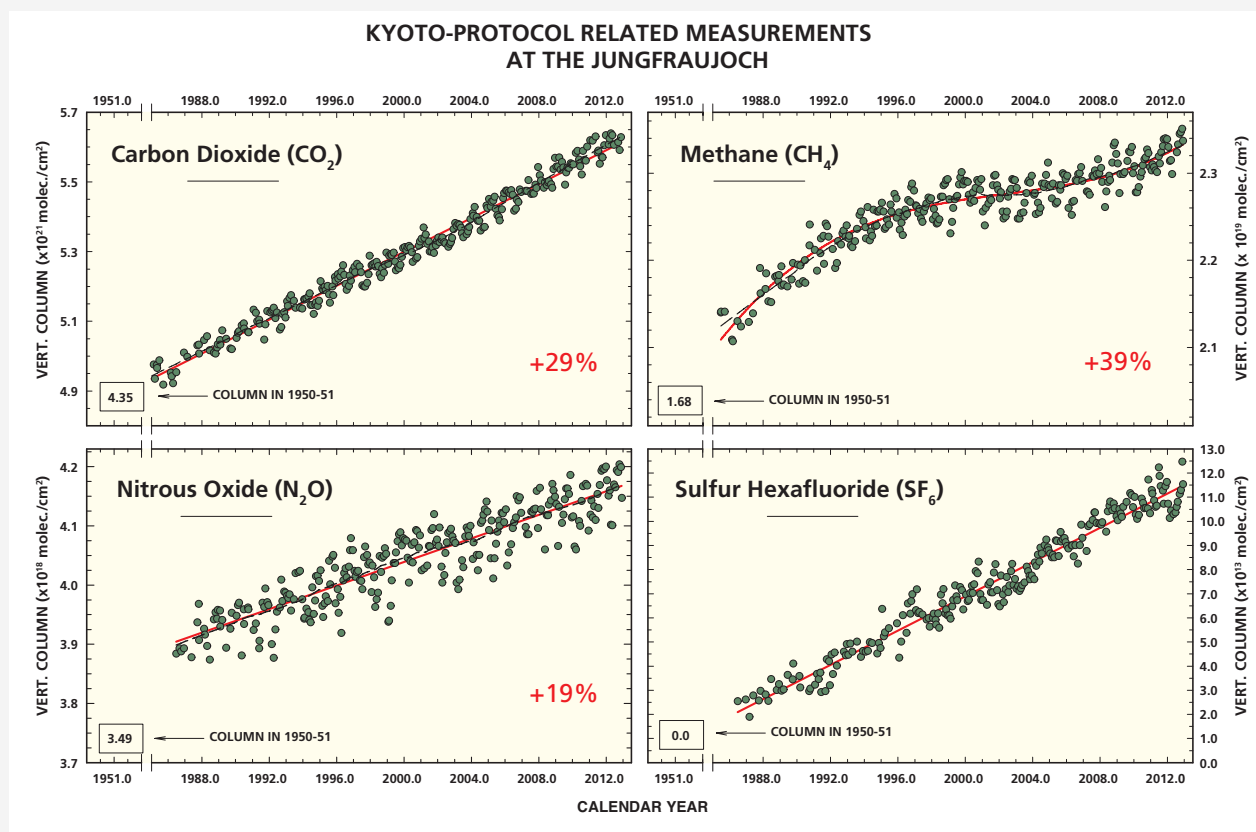


Figure 14: Trends observed by the Liège group at Jungfraujoch of the atmospheric concentration of gases covered by the Kyoto Protocol. The Kyoto Protocol sets binding targets for the emission of greenhouse gases. The EU nations, in particular, had pledged to reduce their emissions between 2008 and 2012 by 5.2 % on the average. A particularly striking case is sulphur hexafluoride (SF_6), a quenching gas used in switches which is expected to remain in the atmosphere for 3000 years or longer. Fortunately, a major producer of running shoes has stopped its use for filling the soles of such shoes in 2006 (Credit: Institut d'Astrophysique et de la Géophysique, Université de Liège).

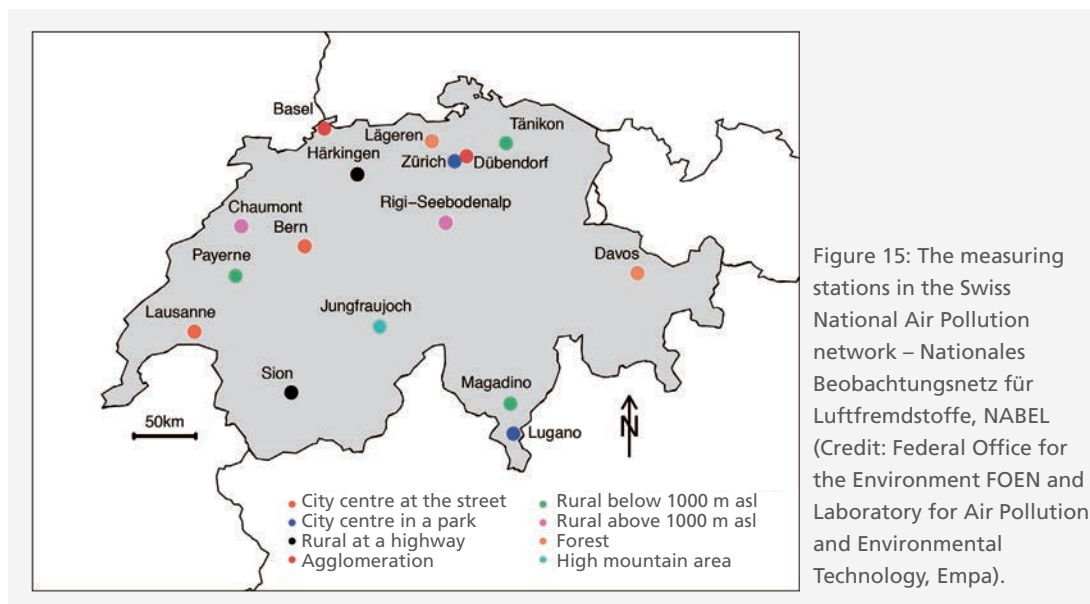
(NABEL), a programme run jointly by Empa and the Federal Office for the Environment (FOEN). Today, Jungfraujoch is one of 16 NABEL monitoring sites. These stations cover the entire range of air pollution levels — from curb side to the free tropospheric background.

The NABEL site at Jungfraujoch provides background measurements for the lower free troposphere in central Europe and also contributes to the European Monitoring and Evaluation Programme (EMEP).

The Swiss Global GAW Station on Jungfraujoch measures more than 70 gaseous species of reactive and greenhouse gases including some of their isotopes. This is made possible through a joint commitment of Empa and FOEN that is part of an on-going long-term international co-

operation within the international Advanced Global Atmospheric Gases Experiment (AGAGE) network and the U.S. National Oceanic and Atmospheric Administration (NOAA). Today the greenhouse gas measurements on Jungfraujoch are fully integrated into the global activities of this renowned worldwide measurement network.

An additional, noteworthy aspect of these measurements is that they are often used as 'ground truth' for satellite observations.



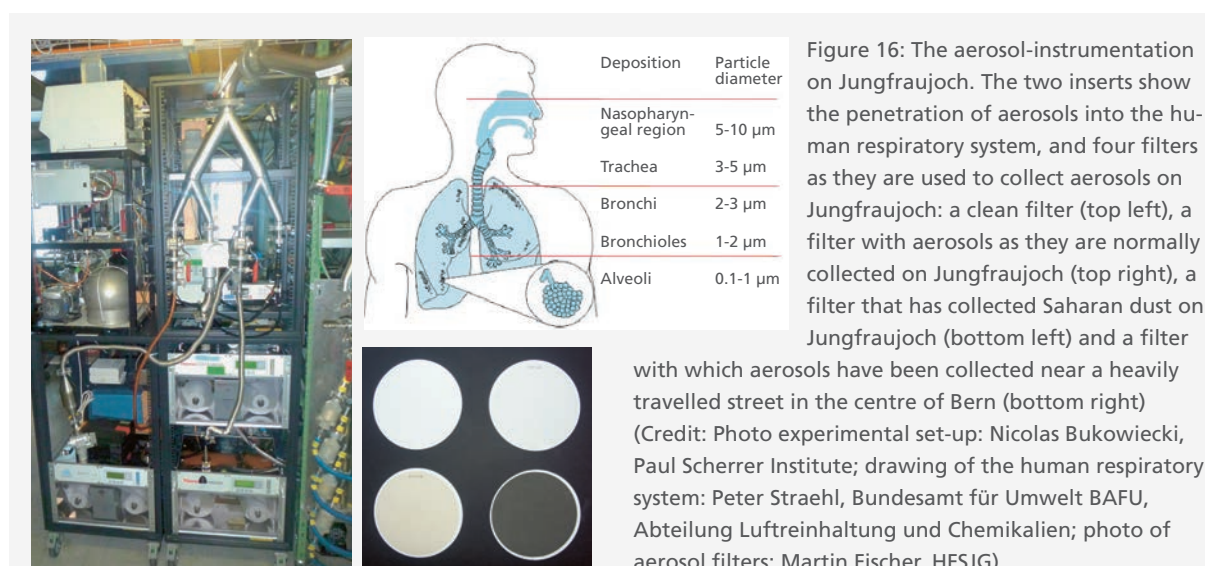
3.1.5. Aerosol research

The aerosol programme of the Paul Scherrer Institute (PSI) was started in 1988 and has continuously been expanded by adding a variety of long-term measurements of physical, optical, and chemical properties of aerosols. These measurements aim at quantifying the influence of aerosols on climate.

Jungfraujoch is an ideal site for studying an aged aerosol above a continental area with an anthropogenic influence. The measurements are embedded into the Swiss GAW programme (GAW-CH) under the auspices of MeteoSwiss since 1995. Today, Jungfraujoch has one of the most comprehensive aerosol programmes

worldwide, and is among the few stations providing aerosol datasets that are long enough for trend analyses (see www.psi.ch/lac/gaw-monitoring). The Jungfraujoch aerosol programme is linked to numerous past and current EU infrastructure projects and other large integrated projects, such as EUSAAR, EUCAARI, GEOMON, ACTRIS, and BACCHUS.

All aerosol measurements as well as the previously mentioned *in-situ* trace-gas measurements taken on Jungfraujoch are in full compliance with the Essential Climate Variables (ECVs) requirements at an atmospheric surface site of the Global Climate Observing System (GCOS).



3.1.6. Meteorological monitoring including radiation

Meteorologists have observed the weather on Jungfraujoch for nearly a century. Today Jungfraujoch is the highest SwissMetNet station (*cf.* Fig. 17). The automatic recordings are augmented by five daily visual observations of clouds and visibility range.

Since 1996 MeteoSwiss also performs high-accuracy downward-radiation flux measurements as part of the Swiss Alpine Climate Radiation Monitoring programme (SACRaM); the infrared, visible and ultraviolet radiation is monitored following the guidelines set up by the Baseline Surface Radiation Network (BSRN). Moreover, the optical depth caused by aerosols is deduced based on measurements of the direct solar irradiance in several narrow spectral bands.

3.1.7. Monitoring of radionuclides

Starting in 1993, the Swiss Federal Office of Public Health (BAG) has been monitoring aerosol radioactivity at Jungfraujoch as part of the RADAIR network (Réseau Automatique de Détection dans l'Air d'Immissions Radioactives). RADAIR includes an automated alpha and beta surveillance with alarm function as well as radioisotope analysis using gamma spectrometry.

Since 1986 without interruption until today the University of Heidelberg has performed atmospheric radiocarbon measurements ($^{14}\text{CO}_2$) on Jungfraujoch. These measurements provide the clean-air background that permits to assess the regional fossil fuel CO_2 component at other observational sites in Europe. These measurements are also used as a reference for carbon cycle studies and bomb radiocarbon dating of young organic material. In general, the radio-

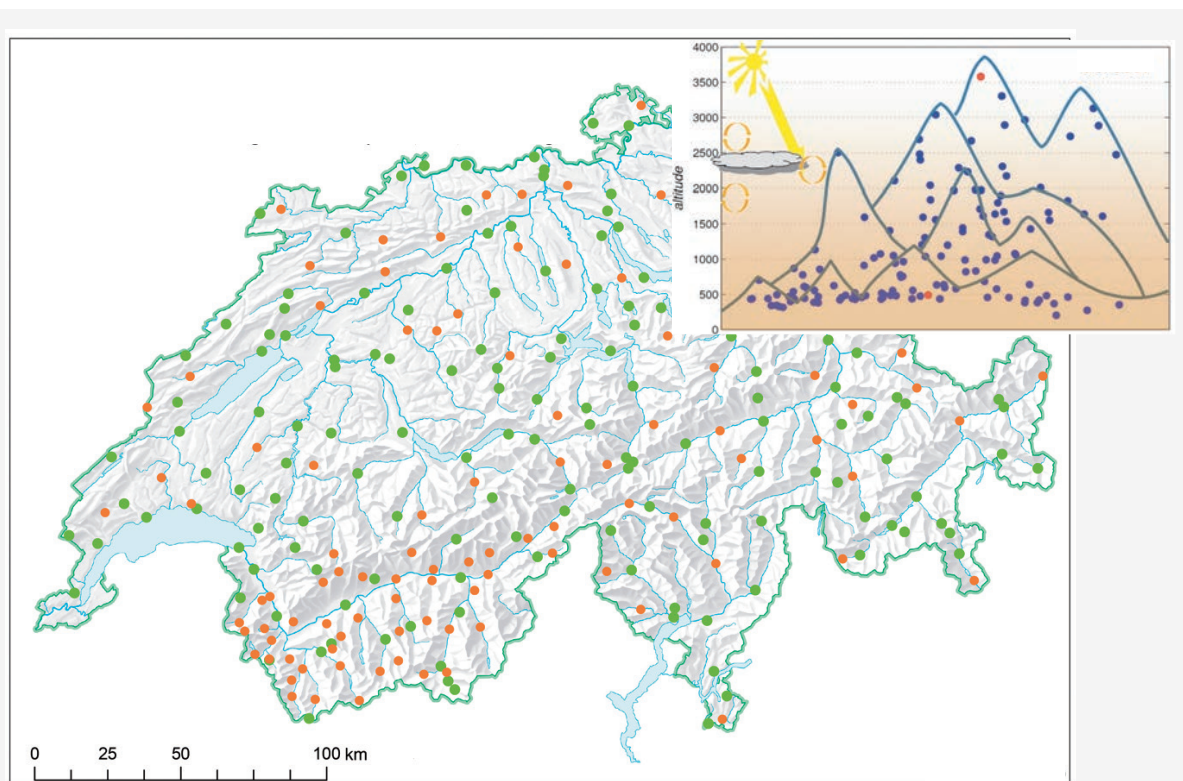


Figure 17: The location of the automated stations belonging to the Swiss Meteorological Network and, in the insert, their distribution in altitude. The measurements taken at the stations provide information on precipitation only (orange circles) and additional information on clouds, radiation, convection and on aerosols – with the latter derived from transparency measurements (green circles). Jungfraujoch, the highest station in the network, measures in very specific conditions, since it is frequently above the so-called Planetary Boundary Layer, also known as the lower turbulent troposphere. By combining these observations with the rest of the MeteoSwiss data one obtains a complete picture of conditions in Switzerland (Credit: L. Vuilleumier, C. Félix & M. Collaud Coen, MeteoSwiss).

carbon data from Jungfraujoch are slightly higher than those from the Schauinsland site in the Black Forest, particularly in winter, demonstrating how Schauinsland, compared to Jungfraujoch, is directly influenced by regional European fossil fuel CO₂ emissions.

3.1.8. Cosmic-ray monitoring – as part of a worldwide network, and its role in space weather research

Since the International Geophysical Year (IGY) 1957/58 the University of Bern has conducted continuous cosmic-ray measurements. Neutron monitors provide key information about the interactions of the galactic cosmic radiation (GCR) with the plasma and with the magnetic fields in the heliosphere.⁶ They also provide information about the production of energetic cosmic rays at or near the Sun, the so-called solar cosmic rays (SCR); as well as about geomagnetic, atmospheric, and environmental effects. Two standardised neutron monitors are in operation on Jungfraujoch: an 18-IGY NM model since 1958, and since 1986 a neutron monitor of type 3-NM64.

Ground-based neutron monitors ideally complement space observations. The neutron monitors of the University of Bern are part of a worldwide network of standardised cosmic-ray detectors. By using the Earth's magnetic field as a giant spectrometer, this network is able to determine the energy dependence of intensity variations of primary cosmic rays in the GeV range that impinge on the Earth's atmosphere. Furthermore, the high altitude of Jungfraujoch offers good response to the sporadic impact of solar protons with energies above 3.6 GeV and of solar neutrons with energies as low as ≈ 250 MeV. Neutron monitors, and especially their real-time data, also play an essential role in space weather research. As our civilisation relies more and more on a space-based electronic infrastructure, space weather research has become a scientific discipline of growing importance.

Jungfraujoch is also an ideal site for investigating a possible causal relationship between

changes in the cosmic-ray intensity and changes in the global cloud cover. The hypothesis that cosmic rays may affect the climate on Earth via ionisation effects in the atmosphere is currently a subject of controversial dispute in the scientific community. While possible pertinent interaction mechanisms are being studied under well-defined laboratory conditions in the CLOUD⁷ experiment at CERN, this subject of high societal impact is addressed on Jungfraujoch by benefitting from the synergy of three types of investigations: the extensive aerosol measuring programme of PSI, the studies of aerosol-cloud interactions in the CLACE⁸ campaigns and the permanent cosmic-ray monitoring by the University of Bern.

3.1.9. Glaciology at Jungfraujoch

Long-term glacier observations have documented variations of the Great Aletsch Glacier since the mid-nineteenth century. Despite a pronounced retreat and loss of ice volume, this glacier with a surface area of 78 km² and an ice volume of 13 km³ (as of 2009) is still the largest in the Alps.

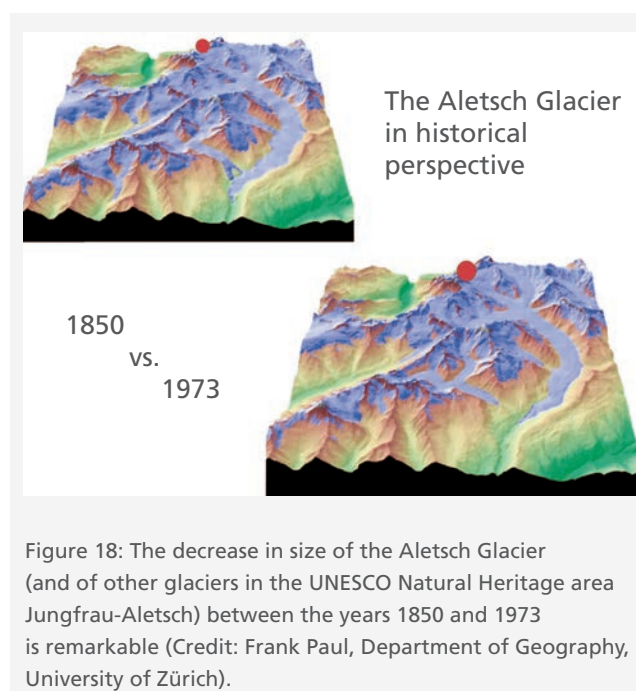


Figure 18: The decrease in size of the Aletsch Glacier (and of other glaciers in the UNESCO Natural Heritage area Jungfrau-Aletsch) between the years 1850 and 1973 is remarkable (Credit: Frank Paul, Department of Geography, University of Zürich).

⁶ The heliosphere is the space around the Sun, where solar wind and magnetic field carried away from the Sun dominate. This bubble-like region reaches beyond the orbit of Pluto and also far above and below the poles of the Sun. The boundary of the heliosphere marks the onset of interstellar space.

⁷ This experiment, named 'Cosmics Leaving Outdoor Droplets' (CLOUD) aims to study the influence of galactic cosmic rays on the Earth's climate through the media of aerosols and clouds (<http://cloud.web.cern.ch/cloud/>).

⁸ CLACE (Cloud and Aerosol Characterization Experiment) campaigns take place on Jungfraujoch at regular intervals. In these campaigns coordinated comprehensive aerosol-cloud interaction studies are conducted within national and international collaborations.



Figure 19: Permafrost studies rely on automatic measuring devices. These must however first be mounted in exposed locations (Credit: Project PermaSense, Jan Beutel, ETHZ).

The entire glacier area was mapped between 1846 and 1851 and the first detailed map of the surface topography with modern accuracy stems from 1880. Two high-precision topographic maps covering the whole catchment area of the branched glacier system document the glacier's state of 1927 and of 1957. These maps have later been complemented by periodic photogrammetric analyses of aerial photographs in 1980, 1999 and 2009. Volume changes were then determined by comparing two consecutive surveys of the surface topography. Detailed volume and thickness changes for five multi-decadal periods could thus be deduced. Based on these results, the mass balance of the glacier has been reconstructed with seasonal resolution since 1865.

Starting in 1918, point-based accumulation and mass-balance measurements have been performed on the Jungfraufirn and the Silvretta Glacier. Together with measurements that started already in 1914 at the Claridenfirn these collected time series, covering almost 100 years, are by far the longest *in-situ* measurements of mass-balance components worldwide and make it possible to assess how climate change has affected alpine glaciers in the past century.

The changes recorded at the Great Aletsch Glacier so far allow clear statements about the impact of climate fluctuations on glaciers, and as such represent a central element of the GLacier MONitoring Programme in Switzerland (GLAMOS).

3.1.10. Permafrost monitoring in high altitude rock walls at Jungfraujoch

Thanks to its high elevation, topographical setting and easy accessibility, the Jungfraujoch has become a key site for both long-term monitoring and process studies in high altitude bedrock permafrost. These investigations involve ETH Zürich, the Institute for Snow and Avalanche Research (SLF) Davos, and the University of Zürich. This research and the associated monitoring activities are part of the Swiss Permafrost Monitoring Network (PERMOS).

The thermal condition of perennially frozen mountain flanks determines slope stability. Climate change thus influences the so-called down-slope hazards, *i.e.* rock slides. In intact near-vertical bedrock slopes these hazards are coupled to temperature changes of the atmosphere. Rock surface temperatures have now been measured within the scope of PERMOS at a number of such locations for nearly ten years. In additional investigations, permafrost temperatures are monitored in two 20 m long boreholes in the Jungfrau East Ridge. Moreover, PERMOS is concentrating on extending rock temperature measurements for fractured or non-vertical rock where snow can accumulate, as well as on small-scale variability, because information on such situations is still sparse.

Ultra-low-power wireless sensor networks suitable for autonomous operation in the open air at high altitudes have been developed within the multidisciplinary PERMASENSE consortium. Sensors that have been installed in 2006



Figure 20: Scientists working on Jungfraujoch during a campaign for the Cloud and Aerosol Characterization Experiment (CLACE) (Credit: Paul Scherrer Institute).

on the Sphinx north and south face measure the temperature dynamics of rock masses and ice faces (*cf.* Fig. 19). Additional *in-situ* investigations of the snow cover on both sides of the Sphinx within a new SNF-DACH project of SLF in collaboration with the Universities of Bonn, Fribourg, and Zürich will contribute to a better understanding of the role of snow on the heat regime in the rock.

In addition, the forming of ice within rock has been investigated since 2010. Such ice is an important cause of rock damage within a few meters from the surface. *In-situ* measurements of acoustic emissions are part of the PERMASENSE project. Two continuous measurement systems that have been installed on a rock wall close to the Jungfraujoch Research Station test the sensitivity of the frost cracking activity under different environmental conditions.

Results on the above phenomena, obtained at Jungfraujoch and in rocks on the Jungfrau East Ridge, have yielded knowledge that must be applied when building on rocky, ice-bearing permafrost substrates. Practical guidelines 'Bauen im Permafrost', derived from these results, have been published by SLF in collaboration with various engineering companies.

3.2. Research campaigns

3.2.1. Cloud and Aerosol Characterization Experiment (CLACE)

In 2000 Cloud and Aerosol Characterization Experiments (CLACE Campaigns) were started by the Paul Scherrer Institute. These campaigns

have been held in regular intervals and resulted in seminal data on the interaction between aerosols and clouds. The investigations take advantage of the Jungfraujoch being engulfed in clouds part of the time — and in wintertime sometimes even in ice clouds, where crystals of ice induce different chemical and physical processes. Currently, microphysical properties of the prevailing liquid clouds are investigated. These comprehensive aerosol-cloud interaction studies are conducted within national and broad international collaborations (*cf.* Fig. 20).



Figure 21: A medical test on a patient with mild congenital heart disease. Here the hemodynamic response to exercise at high altitude was investigated (project by Dr. S. Kriemler, Exercise Physiology, ETH and University of Zürich).

terials and even textiles for outdoor activities can easily be tested to many extremes at Jungfrauoch – namely very cold temperatures, heavy snowfall, wind velocities up to, and beyond 200 km/h, and significantly reduced atmospheric pressure. The results of such tests lead to rugged and robust instrumentation. Improvements in building design and of outdoor wear have emerged, too.

3.3. The scientific output

Owing to its unique location and excellent infrastructure the Jungfrauoch Research Station – being the highest in Europe and among the highest in the world that are accessible year round by public transportation – has taken on key importance. Top-grade science is currently being carried out by a large international community: about 50 projects belonging to many disciplines of science measure some 100 physical and chemical variables.

3.2.2. Health studies

Studies investigating the effect of high altitude exposure on healthy persons or on patients with cardiovascular disease are important for both visitors and workers at the Jungfrauoch. Common during the early times of research at the Jungfrauoch, medical campaigns have ceased during a certain period, but are lately going through a revival. Current medical experiments on Jungfrauoch are focusing on themes, such as “Human adaptation to high altitude” (Team of the University of Zürich) or on the “Effect of high altitude exposure on hemodynamic response to exercise in patients with mild congenital heart disease” (Team of the University of Bern).

3.2.3. Testing of new materials and technologies

The Research Station Jungfrauoch has been, and still is frequently used as a testing platform for new technologies. Electronic devices (i.e. computers, controlling units, storage disks etc.), detector units (for cosmic rays, for gas concentrations, for meteorology, etc.), photovoltaic cells, medical equipment, building ma-

Table 1 provides an overview of the scientific output. The references to the publications of all groups performing research on Jungfrauoch are made available in annual activity reports of the HFSJG. Around 40 articles that describe results obtained at Jungfrauoch appear each year in peer-reviewed scientific journals. Further, each year, a significant number of PhD and master theses, as well as books, are based on measurements originating fully or at least in part from Jungfrauoch. In addition, we annually count about 65 conference contributions. A complete list of peer-reviewed publications that resulted from scientific investigations in connection with Jungfrauoch is contained in the electronically accessible Appendix II (www.hfsjg.ch/publications).

Table 1: Scientific publications

year/publications	2010	2011	2012	2012	2014
peer-reviewed publications	57	42	32	35	53
conference contributions	77	77	48	61	79
data reports	9	11	8	8	7
PhD and master theses	9	12	2	4	4
books and book contributions	3	4	5	1	0

Various parameters measured on Jungfrauoch, as well as webcam pictures are available as real-time data. Such data stem from projects carried out by MeteoSwiss, PSI, Empa, SWITCH, Jungfrau Railway and the University of Bern.

In recent years several conferences and workshops related to research at Jungfrauoch have been held, listed in Table 2:

Table 2: Conferences and workshops

conference/workshop	year	location
Jungfrauoch 75 th Anniversary Conference	2006	Interlaken
Spawning the Atmosphere Measurements of Jungfrauoch	2008	Bern
Symposium on Atmospheric Chemistry and Physics at Mountain Sites	2010	Interlaken
192 nd SCNAT Annual Congress, «Höher und kälter – Forschung am geographischen Limit»	2012	Interlaken
Spawning the Atmosphere Measurements of Jungfrauoch, Schneefernerhaus and Sonnblick	2014	Bern

In addition, numerous groups of scientists, who are interested in the research projects performed on Jungfrauoch visit our facilities every year.

3.4. Outreach to the public at large

During their visit, Jungfrauoch tourists encounter a popular science exhibition, which consists of a number of panels that illustrate the varied scientific activities of the High Altitude Research Station. On each panel a one- to two-minute video clip conveys an idea of the scientific endeavours undertaken on Jungfrauoch and some historic pictures remind the visitors of the 80-year heritage of the Research Station.

We also strive to make selected research results from Jungfrauoch accessible to a wider public. We do this through local, regional, national and also international media. As shown in Table 3, there has been a significant number of news releases in printed media, on radio and television, as well as through the Internet. Updated information is always available on our webpage (www.hfsjg.ch).

Table 3: News releases

year/publications	2010	2011	2012	2013	2014
print media	59	48	40	19	29
Radio	6	2	2	3	6
Television	4	3	6	7	6
Internet	9	4	1	1	5

4. The Future of the Jungfrauoch Research Station – our Vision

Over many decades the HFSJG Foundation and its members, together with a large interested research community and significant financial support by the Swiss National Science Foundation, have established the Research Station Jungfrauoch as one of the leading scientific high altitude infrastructures worldwide. Success in the past and today, however, does not guarantee success in the future. Therefore, a continuous open and critical review of present-day conditions at the Research Station is mandatory. We perform this review and shape the strategy for achieving our goals based on **our vision and mission**:

The vision of SCNAT and HFSJG is that the Research Station Jungfrauoch remains, and continues to develop as one of the leading high altitude infrastructures worldwide for investigating alpine surroundings, particularly in environmental and climate research.

The mission is to maintain, improve and extend, as required, the infrastructure of the Research Station Jungfrauoch and to protect its clean environment in close collaboration with the stakeholders engaged in the touristic exploitation of Jungfrauoch, so that the station can continue to serve as one of the best-equipped high altitude research stations worldwide, with the ability to support cutting-edge research, including environmental monitoring, and campaigns in various additional scientific fields.

In the remainder of this document we identify the challenges being faced, and the associated actions to be taken by the HFSJG Foundation, its members and research partners. The success of these measures will depend on a close collaboration with the Swiss Academy of Sciences (SCNAT) and the Swiss National Science Foundation (SNF) on the one hand. On the other hand, we need to seek the support of major public agencies, such as the Department of the Environment, Transport, Energy and Communications – and in particular with the Federal Office for the Environment (FOEN) –, with the Federal Department of Economic Affairs, Education and Research – and there with the State Secretariat for Education, Research and Innovation (SERI) –, and with the Federal Department of Defence, Civil Protection and Sport (DDPS). The Federal Office of Meteorology

and Climatology MeteoSwiss (as one of the authors of the White Paper) will be a key contributor in this effort to foster the involvement of the public administration in Switzerland.

How to implement the vision

Our approach builds upon three main pillars:

1. **A clean natural environment at the Jungfrauoch for the next decades:** maintain the cleanliness of the environment for the benefit of both research and tourism.
2. **A world-class research facility for the next generation of scientists:** consolidate the standing of the Research Station Jungfrauoch as a worldwide leading research infrastructure by maintaining and extending its facilities to host upcoming international research initiatives and campaigns and to continue to support various disciplines, including environmental and climate science, glaciology and permafrost studies, materials science and technology, as well as physiological and medical research.
3. **Outreach to policy makers and the public:** raise the awareness of stakeholders and of the public at large of the important scientific mission of the Research Station, which delivers the basis for critical policy decisions on climate change that are needed for a sustainable socio-economic development.

Implementing these three pillars shall be the responsibility of the Director of HFSJG in consultation with both the Swiss Commission of the High Altitude Research Station Jungfrauoch and the Board of the Foundation.

4.1. Maintain the quasi-pristine environment on Jungfrauoch

To maintain an unpolluted, natural atmospheric environment at Jungfrauoch is a *conditio sine qua non* for the Research Station. This obviously benefits tourism as well, as it provides the visitors with the experience of a quasi-pristine alpine environment. We must take into account that touristic exploitation and scientific research often have inherently conflicting objectives. Good mutual communication with close and steady contact between the HFSJG Foundation and the Jungfrau Railway, both at strategic and operational levels, is and will remain crucial. The number of tourists grows and the demand for authentic environmental



Figure 22: For tourists of the entire world a visit to Jungfrauoch offers a once in a lifetime experience. However, tourists do also bring pollution to the local atmosphere – think, for example, of smokers on the Sphinx terrace below the laboratories. Furthermore, serious disturbances may be caused by construction projects and therefore need careful advance preparations. The Jungfrau Railway is already pursuing a policy of designating non-smoking areas and wherever possible using electrified, rather than combustion driven machines for snow removal and similar tasks (Credit: HFSJG).

data, which rely on a clean site, becomes even more compelling. Easy access to high-level decision makers should be facilitated in cases of urgent need. As seen from the science side, regular contacts on policy level would contribute to, and enhance a more comprehensive appreciation of mutual interests and of our international commitments.

4.2. Consolidate Jungfrauoch as a European key infrastructure of worldwide significance

In order to maintain the status of Jungfrauoch as an internationally renowned research station we must actively promote the Research Station in European and Global networks.⁹ The International Carbon Observation System (ICOS) has been positively evaluated by the Swiss parliament in autumn of 2012, its financial support is spoken for the first four years. ICOS is a European research infrastructure that aims to run for the next 20 to 30 years. Switzerland with Jungfrauoch in the centre of the Alps and its undisputed scientific track record is in the ideal position to consolidate this facility for the next generation of environmental and climate scientists. Its response to the political mandate enables a commitment on a

multi-decade climate change perspective. We will work hard to obtain national funding for the whole time period.

An active promotion of the research facilities at Jungfrauoch by its users and by the HFSJG Foundation itself will attract existing and emerging scientific networks to join the research community working in our exceptional alpine environment. In turn this will further strengthen Jungfrauoch's key position. Such promotion and outreach resulted in 2011 in a letter of intent for an intensified collaboration, including the organisation of combined meetings regarding infrastructural and science issues, between the HFSJG and the 'Virtuelles Institut Umweltforschungsstation Schneefernerhaus' (UFS, Bavaria/Germany).¹⁰

Specifically the options and necessary measures to be pursued are:

4.2.1. Existing infrastructure: maintenance¹¹ and extension

Today the quality of operations of the research site is under threat: the increased demand of space for the various automatic observations and the requirement for modern infrastructures

⁹ Examples of such networks are (i) the Integrated Carbon Observation System (ICOS), (ii) the Aerosols and Clouds, and Trace gases Research InfraStructure network (ACTRIS) and (iii) the Integrated non-CO₂ Greenhouse Gas Observing System (InGOS). All these projects are on the list for EU support for the development of pan-European research infrastructures.

¹⁰ A first such meeting has taken place in Bern, including not only German, but also Austrian researchers, in January 2014.

¹¹ Infrastructural investments are routinely taken care of. They are based on a maintenance plan with a rolling ten-year outlook, including a periodically updated risk analysis.



Figure 23: The East Ridge (at the location of the former Swisscom Station) is a potential area for extended facilities of the Research Station Jungfrauoch (Credit: HFSJG).

are challenges that Switzerland needs to face now, by committing to a long-term perspective on our surveillance for a sustainable world. Today the enclosed space at disposal is ca. 100 m² and consideration to double this area shall be given in order to secure this site for long term trend studies on a time scale up to 2050.

a) **Extend the Sphinx infrastructure on the meteo terrace¹²**

An extension of the Sphinx meteo terrace would offer a close-to-ideal airflow for the two main wind directions. Such an extension would however change the visual aspect of Jungfrauoch with today's eye-catching cupola. If even possible, any modification involving building construction would require a close coordination between the Jungfrau Railway and the HFSJG Foundation.

b) **Extend the original Research Station**

An extension of the original Research Station in the south slope would increase the capacity to host more technicians and scientists than currently possible. This would facilitate implementing state-of-the-art environmental technologies as well as

research campaigns aimed at investigating the chemistry and physics of the atmosphere, and would benefit medical and physiological research campaigns.

4.2.2. New infrastructure on the Jungfrau East Ridge

An extension of the HFSJG facilities by using the Jungfrau East Ridge is a serious option for the Research Station. Currently, the old Swisscom Station there (cf. Fig. 23) is being instrumented with a few standard air quality measurements to investigate its suitability for atmospheric measurements. This building and its existing infrastructure may represent the ideal solution, although less preferable alternative locations exist in this area. The status of plans of the Jungfrau Railway for a VIP lounge at this location will be re-considered in a few years, in the context of the envisaged realisation of the V-cableway.¹³

4.2.3. New running costs

An extension of the HFSJG facilities requires an increase of funding support and staff. The current resources at disposal for HFSJG are covering the running costs for the present infrastructure with a mid-term perspective of about five years. A political mandate that enables and supports the Foundation HFSJG to realise the vision described in this White Paper would entail both the investment and the operational costs accordingly.

¹² An agreement between the HFSJG and Jungfrau Railway has already been reached to build an additional radiation bench on the Sphinx meteo terrace.

¹³ The Grindelwald-Männlichen Gondola Cableway and Jungfrau Railway are planning to build a V-cableway that will provide access to both the nearby Männlichen and to Eiger Glacier. At Eiger Glacier passengers will transfer to the railway line taking them to Jungfrauoch. Railway access from Interlaken to the V-cableway will go through the new Rothenegg station to a common terminal in Grindelwald Grund. A tricable gondola cableway will connect Grindelwald Grund with Eiger Glacier.

5. Actions to turn Vision into Reality

Under the headings below, the most important characteristics, which actually comprise the stringent requirements that affect our qualification as Global Site for the GAW¹⁴ are discussed in view of current and upcoming challenges for scientific activities on Jungfrauoch:

1. Protect the pristine environment of the site as a pre-requisite for its sustained value for research, while supporting an environmentally conscious development of its touristic activities.
2. Meet the evolving requirements of researchers in terms of availability and quality of the infrastructure.
3. Unleash the full potential of institutional collaboration of all stakeholders (Jungfrau Railway, Sphinx AG, HFSJG, SCNAT, SNF, Swiss Government) in support of the above.

Moreover, quality assurance is a key issue for the HFSJG. It impacts all aspects of our operations and of the scientific observations. From the operations side this includes (i) training of Jungfrau Railway technical personnel and HFSJG staff and users, (ii) continuously surveying and assessing the suitability of the infrastructure and the quality and calibration of observations at the site, (iii) continuously documenting the activities at the Research Station as it is done in the annual HFSJG activity reports and (iv) submitting documented data to the World Data Centres (WDCs).

The actions that will help meet these issues and challenges are the following:

5.1. Action 1: Improve the infrastructure currently available for research

This action summarises activities to make the most of the existing laboratory space and supporting infrastructures. Imminent improvements deemed necessary include

1. Reallocation of laboratory space, including the use of the Sphinx cupola and the terrace, based on user requirements.
2. Installation of an improved climate control in the laboratories on the 2nd floor of the Sphinx Observatory.
3. Reassessment of the current location of air inlets to avoid local emissions in an optimum way.

The above activities fall mostly under the remit of the HFSJG and its director and have a horizon of not more than three years.

5.2. Action 2: Extend the infrastructure available for research

This action summarises activities in response to essential Earth system and climate science needs in the Alps. It is clearly necessary to significantly expand the suitable floor space at Jungfrauoch. This implies:

1. Exploring the possibility for expansion of facilities in the Sphinx building, particularly on the meteo terrace.
2. Exploring the option of extending the Research Station to the Jungfrau East Ridge and developing a project.

These activities need to involve to various degrees all the stakeholders identified above (Jungfrau Railway, Sphinx AG, HFSJG, SCNAT, SNF) as well as the Swiss Government, and have a horizon of five to ten years.

5.3. Action 3: Raise awareness of the mutual benefit for all stakeholders to protect the pristine environment at Jungfrauoch

This action summarises activities¹⁵ needed to protect the pristine environment of Jungfrauoch and to identify how this can support the interests of both, science and commercial activities:

1. Mutually share the respective strategies and identify synergies for both science and commercial activities. Negotiate the areas where contaminating emissions are to be limited.
2. Actively promote outreach activities and develop Jungfrauoch into a 'Public Science Awareness Centre at the Top of Europe' in close collaboration with the Jungfrau Railway.
3. Continue the formal interaction between stakeholders and periodical reporting at board meetings.

Jungfrauoch offers the unique potential to attract tourists and scientists by advertising both its pristine environment and the well-equipped scientific infrastructure. This is at the same time a business and a science opportunity.

Finally, this White Paper shall be reviewed on a five-year cycle.

¹⁴ To become one of the currently 30 Global Sites of the Global Atmosphere Watch (GAW) programme of the WMO, Jungfrauoch had to fulfil 14 criteria (cf. Appendix III and section 3 "Observing systems" of the GAW Strategic Plan 2008-2015). Our qualification for this status is regularly reviewed by international experts.

¹⁵ A protocol exists between Jungfrau Railway and HFSJG which summarises the various communication channels as well as the actions needed to assure a clean site environment.

6. Conclusion

Safeguarding the established and much esteemed position of Jungfrauoch as a key site on the international scientific scene in parallel with the commercial aims of the Jungfrau Railway is our goal.

It is the considered judgement of the members of the International Foundation HFSJG and its research partners, who have been involved in writing this White Paper, that the time has come to take decisions followed by action so that the Research Station modernises and expands its current space and infrastructure. In this way only will we be ready for future needs of general research and in particular environmental and climate science in the Alps – with a perspective to the current target year for the climate goals of the industrialised countries, 2050. The White Paper gives the necessary background and states the issues that now must be discussed and resolved.

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Epilogue

Jungfrauoch and the Roadmap of *Science Europe*

Science Europe has recently released a Roadmap that spells out its vision and priority areas.¹⁶ Our inherently international research activities will be affected by this document.

Specifically, one of the strategic objectives of *Science Europe* is to facilitate ‘borderless science’. From its very beginning over 80 years ago, the International Foundation High Altitude Research Stations Jungfrauoch and Gornegrat has been supporting this objective: it makes the research station on Jungfrauoch available to a multi-national research clientele – based on scientific merit.

Currently, most studies at this high altitude site located in a quasi-pristine alpine environment are devoted to the chemistry and physics of the Earth’s atmosphere, in particular to monitoring changes in the concentration of pollutants, and understanding their influence on the climate. Given the industrialised countries’ long-term climate targets, the unique infrastructure on Jungfrauoch will be needed for a sustained multi-decadal effort. This touches upon the problem of ‘infrastructure policies’ – a high priority action area of the Roadmap.

We also note that the Foundation HFSJG has started a collaboration with other leading alpine research stations with the aim to find ways to exploit the synergy of their observations. This relates to the Roadmap’s strategic objective of ensuring that research results are utilised in the best way possible, *i.e.* with ‘communicating science’.

The HFSJG Foundation and its international research community are therefore looking forward to the implementation of the *Science Europe* Roadmap and the concomitant strengthening of the European Research Area. To support this goal, we will act in concert with the Swiss National Science Foundation and the European National Research Funding Organisations, which support the infrastructure of the High Altitude Research Station and the research carried out on Jungfrauoch.

¹⁶ *Science Europe* is an association of European Research Funding and Research Performing Organisations, founded in 2011, with the aim of promoting the collective interests of members and facilitating collaboration at policy, funding and performing levels. The ultimate mission of *Science Europe* is to facilitate collaboration of its members, in order to contribute to the design and development of a strong and effective European research system. The Roadmap, which has been released in December 2013, can be downloaded via the URL www.scienceeurope.org/policy/policy-2/roadmap.

Abbreviations and acronyms

ACTRIS	Aerosols and Clouds, and Trace gases Research InfraStructure network
AGAGE	Advanced Global Atmospheric Gases Experiment
ARE	Atmospheric Research and Environment branch
BACCHUS	Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding
BAFU	Bundesamt für Umwelt
BAG	Bundesamt für Gesundheit (Swiss Federal Office of Public Health)
BSRN	Baseline Surface Radiation Network
CLACE	CLOUD and Aerosol Characterization Experiments
CLOUD	Cosmics leaving Outdoor Droplets
DACH	Deutschland (D) Österreich (A) Schweiz (CH)
DDPS	Federal Department of Defence, Civil Protection and Sport
EC	European Commission
ECVs	Essential Climate Variables
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructures
ETHZ	Eidgenössische Technische Hochschule Zürich
EU	European Union
EUCAARI	European Integrated Project on Aerosol Cloud Climate and Air Quality Interactions
EUSAAR	European Supersites for Atmospheric Aerosol Research
FDHA	Federal Department of Home Affairs
FOEN	Federal Office for the Environment
GAW	Global Atmosphere Watch Programme
GAW-CH	Swiss Global Atmosphere Watch Programme
GAWSIS	Global Atmosphere Watch Station Information System
GCOS	Global Climate Observing System
GCR	Galactic Cosmic Radiation
GEOMON	Global Earth Observation and Monitoring
GLAMOS	GLacier MONitoring in Switzerland
GMES	Global Monitoring for Environment and Security
HFSJG	High Altitude Research Stations Jungfrauoch and Gornergrat
ICOS	Integrated Carbon Observation System
ICSU	International Council for Science
IGACO	Integrated Global Atmospheric Chemistry Observations
IGY	International Geophysical Year
InGOS	Integrated non-CO ₂ Greenhouse gas Observing System
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
MAXDOAS	Multi-Axis Differential Optical Absorption Spectroscopy
NABEL	Swiss National Air Pollution Monitoring Programme
NDACC	Network for the Detection of Atmospheric Composition Change
NM	Neutron Monitor
NOAA	National Oceanic and Atmospheric Administration
NORS	Demonstration Network Of ground-based Remote Sensing observations
OECD	Organisation for Economic Co-operation and Development
PERMOS	Swiss Permafrost Monitoring Network
PMOD	Physikalisch-Meteorologisches Observatorium Davos

PSI	Paul Scherrer Institute
QA	Quality Assurance
QCL	Quantum Cascade Laser
RADAIIR	Réseau Automatique de Détection dans l’Air d’Immissions Radioactives
SACRaM	Swiss Alpine Climate Radiation Monitoring
SCNAT	Swiss Academy of Sciences
SCR	Solar Cosmic Rays
SERI	State Secretariat for Education, Research and Innovation
SLF	Institut für Schnee- und Lawinenforschung
SNF	Swiss National Science Foundation
SwissMetNet	Swiss Meteorological Network
UFS	Umweltforschungsstation Schneefernerhaus
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UV	Ultraviolet
VIP	Very Important Person
WDC	World Data Centre
WMO	World Meteorological Organization

List of current major nationally and internationally coordinated networks and of research programmes where Jungfrauoch is a key station

NDACC	Network for the Detection of Atmospheric Composition Change Primary Site (www.ndacc.org)
GAW, GAW-CH	Global Atmosphere Watch, Global GAW Station (www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html , and www.meteoschweiz.admin.ch/home/forschung-und-zusammenarbeit/internationale-zusammenarbeit/gaw.html)
GAW-PFR	GAW Aerosol Optical Depth (AOD) Network (www.pmodwrc.ch/worcc/index.html)
GCOS	Global Climate Observing System (www.wmo.int/pages/prog/gcos)
GCOS-CH	Swiss GCOS office (www.meteoschweiz.admin.ch/home/suche.subpage.html/de/data/publications/2013/10/schweizer-gcos-daten-in-internationalen-datenzentren.html)
EARLINET-ASOS	European Aerosol Research Lidar Network – Advanced Sustainable Observation System (www.earlinetasos.org)
AGAGE	Advanced Global Atmospheric Gases Experiment Collaborative Sampling Station (http://agage.eas.gatech.edu)
NADIR/NILU	NILU's Atmospheric Database for Interactive Retrieval (www.nilu.no/nadir)
EUMETNET	Network of European Meteorological Services (www.eumetnet.eu)
SwissMetNet	Automatic Measuring Network of MeteoSwiss (www.meteoschweiz.admin.ch/home/mess-und-prognosesysteme/bodenstationen/automatisches-messnetz.html)
RADAIIR	Swiss Automatic Network for Air Radioactivity Monitoring (www.bag.admin.ch/themen/strahlung/00045/02372/02374/index.html?lang=de)
ICOS	Integrated Carbon Observation System (www.icos-infrastructure.eu)
NADAM	Netz für automatische Dosis-Alarmierung und Meldung (www.naz.ch/de/aktuell/tagesmittelwerte.shtml)
NABEL	Nationales Beobachtungsnetz für Luftfremdstoffe – National Air Pollution Monitoring Network (www.empa.ch/plugin/template/empa/699/*/--/l=1)
AGNES	Automated GPS Network for Switzerland (www.swisstopo.admin.ch/swisstopo/geodesy/pnac/html/en/statjujo.html)
PERMASENSE	Wireless Sensing in High Alpine Environments (www.permasense.ch)
PERMOS	Permafrost Monitoring Switzerland (www.permos.ch)
NMDB	Real-Time Database for High Resolution Neutron Monitor Measurements (www.nmdb.eu)
E-GVAP I + II	The EUMETNET GPS Water Vapour Programme (http://egvap.dmi.dk)
ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network (www.actris.net)
Swiss Glacier Monitoring Network	ETH Zürich / Laboratory of Hydraulics, Hydrology and Glaciology (VAW) (http://glaciology.ethz.ch/messnetz/?locale=en)
InGOS	Integrated non-CO ₂ Greenhouse Gas Observing System (www.ingos-infrastructure.eu)
NORS	Network of Remote Sensing (http://nors.aeronomie.be/)
AGACC-II	Advanced exploitation of Ground based measurements, Atmospheric Chemistry and Climate applications (http://agacc.aeronomie.be/)
EMEP	European Monitoring and Evaluation Programme (www.emep.int)

Most of the measurements made at Jungfrauoch are publicly available via the respective databases, many of them in real or near real-time.

Criteria for GAW sites

Box 9. Essential Characteristics of a GAW *Regional* or *Contributing* Station

1. The station location is chosen such that, for the variables measured, it is regionally representative and is normally free of the influence of significant local pollution sources.
2. There are adequate power, air conditioning, communication and building facilities to sustain long term observations with greater than 90% data capture (*i.e.* <10% missing data).
3. The technical support provided is trained in the operation of the equipment.
4. There is a commitment by the responsible agency to long term observations of at least one of the GAW variables in the GAW focal areas.
5. The GAW observation made is of known quality and linked to the GAW Primary Standard.
6. The data and associated metadata are submitted to one of the GAW World Data Centres no later than one year after the observation is made. Changes of metadata including instrumentation, traceability, observation procedures, are reported to the responsible WDC in a timely manner.
7. If required, data are submitted to a designated data distribution system in near-real-time.
8. Standard meteorological *in-situ* observations, necessary for the accurate determination and interpretation of the GAW variables, are made with known accuracy and precision.
9. The station characteristics and observational programme are updated in the GAW Station Information System (GAWSIS) on a regular basis.
10. A station logbook (*i.e.* record of observations made and activities that may affect observations) is maintained and is used in the data validation process.

Box 10. Essential Characteristics of a GAW Global Station

In addition to the characteristics of Regional or Contributing stations, a GAW Global station should fulfil the following additional requirements, namely

11. Measure variables in at least three of the six GAW focal areas (see item 4 above).
12. Have a strong scientific supporting programme with appropriate data analysis and interpretation within the country and, if possible, the support of more than one agency.
13. Make measurements of other atmospheric variables important to weather and climate including upper air radio sondes at the site or in the region.
14. Provide a facility at which intensive campaign research can augment the long term routine GAW observations and where testing and development of new GAW methods can be undertaken.

Summing up

The vision is:

Jungfrauoch shall remain, and
continue to develop as one of the
leading high-altitude science infrastructures
worldwide – in parallel with its touristic exploitation.

The time has now come
to take decisions followed by action,
because the Research Station needs to modernise
its infrastructure and expand its current space.

In this way only can Jungfrauoch
respond to future needs of research.

Back cover: The three images on the back cover show from top to bottom:

- The outside buildings existing in 1931 on the south slope of Jungfraujoch: the original Research Station can be seen below the undisturbed Sphinx rock; the Hotel Berghaus, shown to the left, was destroyed in a fire in 1972 (Credit: Jungfrau Railway).
- The Sphinx Observatory today (Credit: Jungfrau Railway).
- The former Swisscom Station on the Jungfrau East Ridge, seen from the meteo terrace on the Sphinx Observatory. Future additional laboratory space might be situated there (Credit: HFSJG).

1931



TODAY



FUTURE EXTENSION?

