Strategy

Virtual Alpine Observatory

Status as of 19th June, 2017

Content

1 Executive Summary

The alpine region with its eight neighbouring countries and about 14 million inhabitants represents a significant economic region within Europe. From an ecological point of view the Alps belong to the most complex parts of the "System Earth" and are particularly affected by environmental change processes.

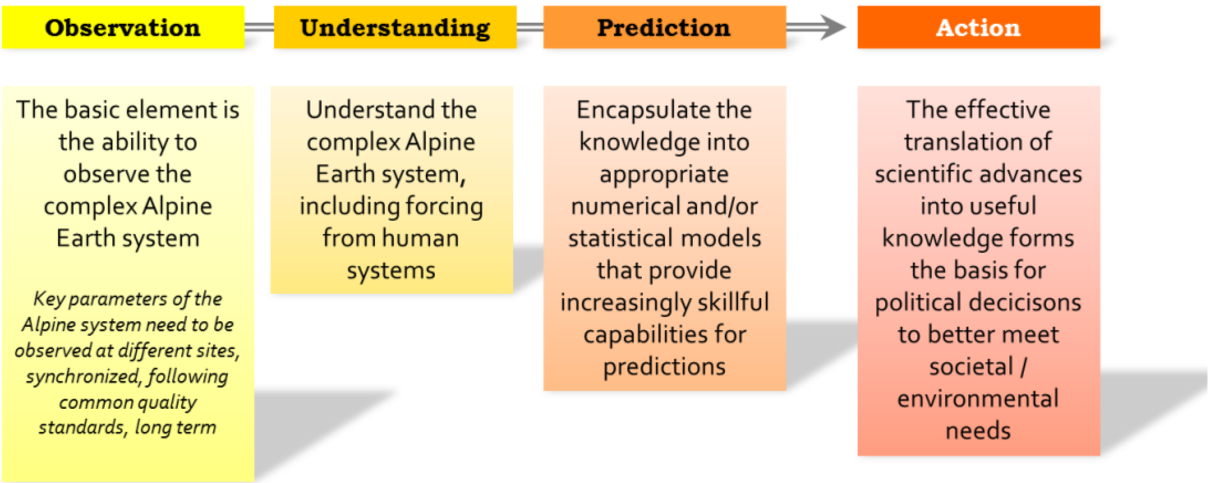
Especially, climate change more and more leaves its mark on this system. Consequences are manifold being among the greatest threats to the ecosystem of the Alps and having far-reaching impacts for the economy, the traffic and the environment including health related issues of human beings. In order to monitor and to understand these complex processes a transnational and interdisciplinary approach is needed. Therefore, conducting joint efforts in order to observe understand and predict the impact of climate change on the alpine region with respect to the environment including health related issues of human beings, economy, and traffic is the foremost objective of the Virtual Alpine Observatory, VAO.

VAO serves to give coherence – where appropriate - to the various research efforts and programs undertaken by the VAO partner organisations or within their infrastructures to try to create the maximum possible scientific profits. As an example, VAO gives the scientific community the flexibility to conduct highly specialised field measurements each in very diverse scientific areas through coordinated simultaneous campaigns at different sites and also promotes an interdisciplinary approach in order to help better addressing demanding specific scientific questions. VAO supports such activities further through granting access to additional resources (additional data and information, computing power, numerical models, analysis tools etc.). Consequently, VAO helps improving understanding the environment and thus contributes to the development of a consolidated fundamental knowledge which also supports decision makers best balancing economic, social and environmental interests in a sustainable way (see figure below). In fact, VAO is already part of the European Alpine Convention as well as of the Alpine Strategy of the EU[1].

VAO brings together already existing infrastructures (observatories, data centres, and high-performance computing centres), scientists, engineers, medical experts and technicians from various disciplines and facilities (universities, large research institutions, and public authorities). Synergism is thus created - even at an interdisciplinary level - which allows achieving results and new knowledge within ever shorter time intervals and with comparatively less resources. Obviously, cross-linking these capacities yields a higher outcome than just the sum of its individual parts. The motto is: ***"Joining forces instead of duplicating efforts"***.

[1] https://www.alpine-region.eu/

The abovementioned cross-link to well-established WMO/ICSU World Data Centres and other data repositories (e.g., other data archives, the COPERNICUS Atmospheric Service CAMS[2]) allows the scientific communities a standardized (based on state-of-the-art Information Technology) access to additional data, information and services such as from satellite-based measurements (e.g. EU-COPERNICUS, other ESA-satellites) or from other ground-based observational networks (e.g. Long-Term Ecosystem Research network, LTER). The cross-link to supercomputing centres not only facilitates the scientific communities to use complex numerical models and advanced data analysis tools but also allows optimization of computational applications (e.g. parallelization of numerical codes, better using big data concepts through support from IT experts). Scientists are thus empowered to even better assess their own results and therefore to enhance their scientific knowledge and to turn this new knowledge into innovative services tailored to the user's needs (for example: new concepts for near real time (NRT) satellite validation in order to improve NRT-services such as better forecast-



VAO's vision from data to understanding to action

ing mesoscale phenomena or implementing health services more focussing on individual persons, etc.).

As a result, this concept strengthens the international competitiveness of European research and development in the long term.

Where appropriate, cooperation with European industrial sectors could be advantageous for both parties, for example, if it comes to technology development (e.g., improving the performance of instrumentation or adapting technologies to other fields of application). It is equally conceivable that parties may cooperate in the development of services tailored to user's needs (so-called 'downstream services' such as the provision of information products).

[2] https://atmosphere.copernicus.eu/

From what has been said above, it follows that the vision of VAO is characterized at least within five dimensions:

(1) it sets new standards in terms of commonly developing new instrumentation *(“**open hardware**”)* often in cooperation with industries,
(2) providing information products and data analysis tools tailored to the scientists needs *(“**computing-on-demand**”)*,
(3) scheduling measurement procedures harmonised between various measurement sites and customised to a specific application *(“**operating-on-demand**”)*,
(4) archiving and delivering data (and meta-data) as well as value added information adjusted to specific requirements *(“**data-on-demand”)***, and
(5) delivering services addressing especially – but not exclusively - public needs *(“**service-on-demand**”)*.

The VAO is already established and constantly increases its attractiveness and visibility. Therefore, it became clear during the first VAO-Board-Meeting, held on the 8th of September 2016 at the Bavarian State Ministry for the Environment and Consumer Protection in Munich that a strategy is required for the upcoming decade assisting to further develop VAO in a target-oriented way. This document describes the VAO strategy. Our mission statement is based on broad discussions within the scientific communities and reads:

The overarching objective of the VAO is to bring together already existing infrastructures (observatories, data centres, and high-performance computing centres), scientists, engineers, medical experts and technicians from various disciplines and facilities (universities, large research institutes, and public authorities) to perform environment, climate and climate change research in the Alps. Cross-linking all these capacities therefore means a lot more than just the sum of it. The motto is: “Joining forces instead of duplicating efforts”. This permits an investigation of environment-relevant topics from different perspectives as it is required due to the complexity of the manifold underlying processes; it creates synergies and opens up a more comprehensive approach in formulating solutions than would otherwise be possible.

The implementation of the VAO strategy rests on four pillars:

Pillar I: advancing the research infrastructures in the Alps, especially at high altitudes,

Pillar II: enhancing the scientific and technological portfolio,

Pillar III: advancing the services, and

Pillar IV: strengthening public outreach.

Understanding alpine processes means - to a certain extent - understanding similar sensitive regions of the Earth. This is why VAO is already being contacted or even joined by associated partners in other parts of Europe and beyond.

The structure of the strategy paper is as follows: chapter two "**Objectives of VAO**" introduces the mission statement. The substantial benefits of VAO are highlighted. Chapter three "**Status**" gives a description of the current status of the observatories / facilities (including facilities such as the Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities (LRZ), and the World Data Center for Remote Sensing of the Atmosphere (WMO/ICSU). The chapter four "**Perspective"** outlines the chances of the collaboration including aspects such as addressing more complex scientific questions, enhancing competitiveness, establishing services for science, society and others, dissemination of information, and addressing technological questions. The last chapter five describes the "**Governance"** of VAO. Compilations of the current VAO partners as well as the identified VAO-challenges round off this paper.

2 Objectives

Mission

The Alpine region is one of the Earth's areas that are particularly affected by climate change. It is to be expected that the strong warming in the Alpine region of about +2° C since the year 1900 (being nearly twice as much as the global warming trend) already has and will have clear impacts on different parts of the Alpine environmental system, namely the atmosphere, biosphere, hydrosphere and the cryosphere. As the environment represents a complex system, all these parts are coupled to each other and shall not be regarded isolated. Especially, how these coupling mechanisms work is still an open question. It belongs to the most demanding questions and is therefore a key topic of current research. Consequently, in order to fully understand the complex Alpine environmental system an interdisciplinary and cross-border research approach is required.

VAO:	Network of European Alpine and associated Observatories, research facilities, data archives and supercomputing centres with cross-linked infrastructure and joint research topics
Motto:	Scientific cooperation – joining forces and resources to avoid duplicate work
Goal:	Conducting joint efforts in order to observe understand and predict the impact of (climate) change on the alpine (mountainous) region with respect to the environment including health related issues of human beings, economy, and traffic.
Countries participating:	Austria, France, Germany, Italy, Slovenia, Switzerland
Countries associated:	Georgia, Norway
Elements of innovation:	+ Data-on-Demand + Computing-on-Demand + Operating-on-Demand + Service-on-Demand + Open Hardware

VAO in a nutshell

As already outlined above, it is therefore an overarching objective of the VAO to bring together already existing infrastructures (observatories, data centres, and high-performance computing centres), scientists, engineers, medical experts and technicians from various disciplines and facilities (universities, large research establishments, and public authorities). Cross-linking all these capacities therefore means a lot more than just the sum of it. The motto is: "Joining forces instead of duplicating efforts". This permits an investigation of environment-relevant topics from different perspectives as it is required due to the complexity of the manifold underlying processes; it creates synergies and opens up a more comprehensive approach in formulating solutions than would otherwise be possible.

Challenges and unique features

The particular vulnerability of the Alpine region to climate change represents both, a challenge and an opportunity. Providing sustainable measurements of key geophysical variables of the Alpine environmental system poses the first considerable challenge. Such measurements have often to be carried out at different sites in the Alpine region in a highly specialised, campaign based fashion. Although such measurements are often rather unique (as is common when working at the forefront of science) it should be tried to conduct these measurements using comparable standards, synchronized to other instruments where appropriate, and with adequate precision and accuracy. There is a broad agreement that reliable and quality-assured observations are paramount for a sound scientific basis. A comparison of such observations with our current understanding of the Alpine environmental system will reveal inconsistencies and deficiencies, and this in turn will lead to additional insights and help improving our knowledge and understanding of the alpine environment.

This is where a further challenge appears: A state-of-the-art IT infrastructure, the so-called Alpine Environmental Data Analysis Centre (AlpEnDAC) ensures that the measurements taken at the various sites are easily and conveniently accessible and exchangeable within the VAO according to international standards, irrespective of where the scientists or engineers are located („*data-on-demand*"), and according to a data policy which is accepted by all partners. Furthermore, it will be possible to access data available elsewhere (e.g. satellite-based measurements, ground-based data, etc.). The core of the AlpEnDAC is formed by high-performance computing centres such as the Leibniz Supercomputing Centre in Garching and networked data centres like the WMO/ICSU World Data Centre for Remote Sensing of the Atmosphere in Oberpfaffenhofen. These partnerships also allow supporting further initiatives, such as the optimisation of numerical computer codes (e.g. parallelisation) or to handle large data volumes (e.g. big data). It is expected that such opportunities can also contribute to further supporting, enhancing and speeding up scientific progress in general.

AlpEnDAC is also a platform to turn appropriate tools developed by scientists and engineers to support data interpretation (e.g., special statistics) into easy-to-access services which may be used or adapted by other scientists for their individual purposes. Besides enabling data visualisation and the combination of different datasets, this "toolbox" of the AlpEnDAC also allows access to more complex numerical computer models (e.g. 3D-trajectory and air quality models, meteorological models etc.) that can be assembled and used by the scientists in accordance with their individual requirements („*computing-on-demand*"). These functions of the AlpEnDAC provide "*services"* for the scientific community itself and are meant to support scientists in their research activities.

It is also a goal of the VAO to develop and operate services that are directed to the outside world (public society, other stakeholders) where they can help to face up to major challenges confronting society today (so-called *societal benefit areas*). This is a further challenge and is described in greater detail below.

Benefits of the VAO and added value

VAO supports the development of measuring equipment and sensor technology in order to allow researchers to stay at the forefront of scientific research. Regarding the remarkable success of the "open-software-concept" in the world of information technology it shall be tried to adapt this concept to the development of instrumentation *("open hardware").* This would help to avoid duplicate work, to shorten development cycles, and to achieve the best possible technological solution. Where appropriate (e.g., in the design of instrumentation to be used within international measurement networks), experts from different facilities – but working on similar technological developments - are encouraged to contribute their skills, knowledge, and competences and therefore guarantee an optimal achievement of the envisioned target.

The scientific and technical expertise gathered under the umbrella of the VAO can also be turned into valuable contributions towards meeting the major challenges of our times *(so-called "Societal Benefit Areas")*. One example for this is to help creating a better understanding of the interaction between individual human health and the environment ("health sentinel"). This knowledge may then be used to help further developing kinds of bioclimatological information services (BioClIS) in the foreseeable future for the public *("service-on-demand")*.

Another example illustrating the potential value that VAO can add to applications beyond the pure scientific world is to use the VAO also to contribute to a permanent quality assurance (in particular in near-real-time) of satellite-based measurements in the tomographic complex alpine region. This aspect of assuring quality should be of interest in the context of the European COPERNICUS program, which is essentially dedicated to further improve the competitiveness of European industry in the field of technologies and services using satellite-based remote sensing data of the Earth. On the other hand, establishing closer contact to ESA means a promising approach in order to get access to satellite-based data which are of special value for the alpine region and which can be used to better reach VAO's goals (see also chapter four).

It is further noteworthy that specific VAO activities are linked to the European GALILEO program. As an example, VAO may also work on concepts to use swarms of unmanned aerial vehicles (UAV) in order to better answer dedicated scientific questions or to invent a new stage of satellite validation quality. Commanding not only the flight route of such a swarm but also the distance between individual UAV's (variable mesh width) does not only require innovative solutions for sensor miniaturisation but also a very efficient navigation, which can be based on GALILEO.

Finally, VAO may initiate developments which allow the operation of specific instruments at the different sites on demand. As an example, instruments may be switched on or triggered remotely on a specific request (e.g., tracking a satellite's overpass, measuring the approaching plume of a Sahara dust outbreak or forest fires, triggering probes of air if a contaminated air mass is expected to arrive) *("operating-on-demand")*.

Political and societal integration

The VAO is part of the Alpine Convention[3], in which the Contracting Parties have agreed to promote and harmonise research and systematic observations in close cooperation that will serve a better understanding of the interaction between region, economy, and environment in the Alps and help to forecast future developments. In this context, the platforms „ABIS/SOIA"(System for Observation and Information on the Alps of the Alpine Convention) and the AlpEnDAC of the VAO shall be cross-linked where appropriate and technically feasible.

The VAO is, moreover, one of the tools to be used for implementing the Alpine Strategy of the EU[4]. This strategy is aimed to cover the political topics of economic growth, innovation, mobility and environment as well as energy. The main goal of the strategy is to ensure that this region remains one of Europe's most attractive spaces, leveraging on its benefits and initiating a sustainable, innovative development in a European context. One of the tasks in this respect is to manage climate change and its consequences. The VAO delivers a scientific basis for addressing this task.

[3] http://www.alpconv.org
[4] http://www.alpine-region.eu

3 Status

Participating observatories and institutions

Since 2013 the "Virtual Alpine Observatory" (VAO) has been operating as a network of European High Altitude Research Stations based in the Alps and with associated partners in similar mountainous regions, and now includes eight countries: With the already well established institutions in the Alpine and foothill regions, such as the observatories Sonnblick (Austria), Jungfraujoch/Gornergrat (Switzerland), Schneefernerhaus (Germany), Otlica (Slovenia), EURAC Research (Italy) and OSUG (France) and its associated facilities, outstanding research infrastructures have joined to form the VAO. Other institutions such as ALOMAR (Norway) and Abastumani (Georgia) are associated with the VAO.

The above mentioned observatories and institutions are assisted by the Leibniz Supercomputing Centre in Garching (Germany) and the WMO/ICSU World Data Centre for Remote Sensing of the Atmosphere in Oberpfaffenhofen (Germany). Furthermore, the VAO is always open to new partners, conducting research in alpine or foothill regions in Europe and beyond, and is set for continuous expansion in the coming years.

The following two chapters (3.1 VAO-Partners and 3.2 Associated VAO-Partners) give a short description of the current status of the participating observatories and facilities as well as a description of the scientific foci of each observatory and institution.

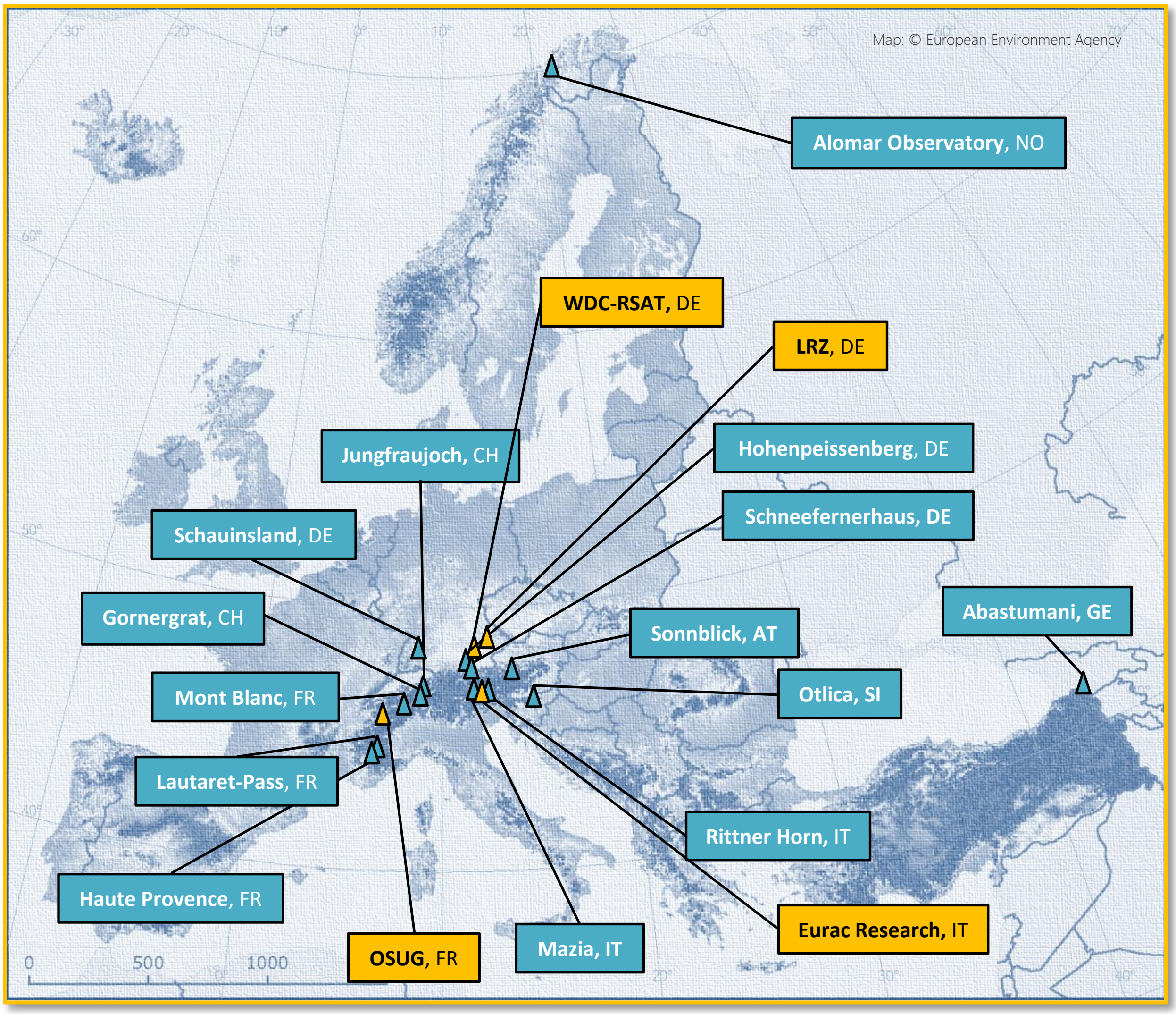
A) VAO-Partners:

Research stations / institutions in the VAO:	Country:	Altitude:
Environmental Research Station Schneefernerhaus (UFS)	Germany	2.650m
Schauinsland Observatory	Germany	1.284m
Hohenpeißenberg Observatory	Germany	975m
Observatoire de Haute-Provence	France	650m
Station Alpine Joseph Fourier, Lautaret-Pass	France	2.058m
Vallot Observatory, Mont Blanc	France	4.362m
Sentinel Alpine Observatory, Ritten	Italy	2.260m
Eurac-LT(S)ER site Macia/Matsch	Italy	2.700m
Sonnblick Observatory	Austria	3.106m
High Altitude Research Station Jungfraujoch (HFSJG)	Switzerland	3.580m
High Altitude Research Station Gornergrat (HFSJG)	Switzerland	3.135m
Otlica Observatory	Slovenia	945m
Supporting research infrastructures:		
Leibniz Supercomputing Centre (LRZ), Garching	Germany	
World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT), Oberpfaffenhofen	Germany	
Observatoire des Sciences de l'Univers de Grenoble (OSUG)	France	
European Academy of Bolzano (EURAC)	Italy	

B) List of associated VAO-Partner:

Research stations / institutions in the VAO:	Country:	Altitude:
Abastumani Astrophysical Observatory	Georgia	1.700m
Alomar Observatory	Norway	380m
Supporting research infrastructures:		
-	-	

VAO participating and associated observatories, status as of June 2017



3.1 VAO-Partners

3.1.1 Austria – Sonnblick Observatory

Homepage: http://www.sonnblick.net

Location/Altitude:

Geographical coordinates:	473'15''N, 012°57'28''E
Altitude of station:	3106 m a.s.l
Minimum altitude within study area:	1600 m a.s.l
Maximum altitude within study area:	3254 m a.s.l

Zittelhaus and Sonnblick Observatory in winter

Sonnblick Observatory at mountain "Hoher Sonnblick" in early summer

The Sonnblick Observatory is owned by the association Sonnblick Verein and managed by the Austrian Central Institute for Meteorology and Geodynamics (in German: ZAMG: Zentralanstalt für Meteorologie und Geodynamik), Regional Office Salzburg, in cooperation with the Sonnblick Verein.

The Sonnblick Observatory is located in the Austrian Central Alps at elevation of 3106 m a.s.l.. It is situated at the alpine main divide, which is a natural climatological border. It lies in the core zone of the national conservation park "Nationalpark Hohe Tauern" which covers 1856 km² of the Austrian Alps at the border between the provinces of Salzburg, Carinthia and Tyrol. Nearest villages are Heiligenblut to the South (10 km away) and Rauris to the North (20km away). Access to Sonnblick Observatory is possible throughout the year either by cable car from the North or by hiking from Rauris or Heiligenblut. As Sonnblick is situated within the "Nationalpark Hohe Tauern" the use of helicopter is restricted. However, scientific activities usually will get permission for required flights. Sonnblick Observatory is built together with an alpine hut "Zittelhaus" which offers additional accommodation and space.

The Sonnblick Observatory was built in 1886 at the summit of the mountain “Hoher Sonnblick”, motivated from the need for information on meteorology in higher altitudes of the atmosphere. Very soon other scientific disciplines became interested in the extreme location of the observatory, e.g. Nobel-prize winner V.F. Hess for his measurement of cosmic rays. In 1986, the observatory was rebuilt to a modern observatory with cable car access, electricity, and a large research platform. From that time onwards investigations on atmospheric chemistry became a new research field at Sonnblick. Today, Sonnblick is a station of interdisciplinary research covering the atmosphere, the cryosphere, the biosphere, the lithosphere, and the hydrosphere

Sonnblick Observatory covers an area under roof of about 200 m² with 20 m² used for scientific laboratories and 80 m² are used for logistics. In collaboration with the management of the hut “Zittelhaus” the area of scientific laboratories will increase within the next years. Within the observatories there are 4 bed rooms and additional 50 beds in the hut “Zittelhaus”. The power supply comes from a cable (230V 50Hz) and can be used 24 hours per day. WLAN is offered as well as workshop facilities for metal, wood, plexiglas and other material is available to assist with constructions every day. The station operates round the clock having always two people stationed who also take care of running projects at the station. Communication facilities are a fixed telephone (mobile phone works too), VHF, internet, computer, printer, scanner and Fax. Data can be stored at Sonnblick Observatory.

The Sonnblick Observatory supports technological development regarding analyses of ageing processes of different materials and security equipment. It is also in contact with various companies to improve scientific instruments.

Beside national networks the Sonnblick Observatory is part within NDACC, WMO-GAW, WMO-GCW, BSRN, WGMS, GTN-P, LTER, INTERACT, MONET, GTS, VAO. Soon, Sonnblick Observatory will participate in ACTRIS and ICOS.

Sonnblick is outstanding with respect to its long-term climate observations and studies on glacier changes. Thus, the impact of Climate Change on the cryosphere is a major research topic at Sonnblick. Since 1886, Sonnblick was also involved in many international projects on atmospheric chemistry and atmospheric physics. Sonnblick Observatory cooperates with several Austrian and international universities/research institutions.

The main disciplines the Sonnblick Observatory is involved are astrophysics, atmospheric chemistry and physics, isotopic chemistry, climatology, climate change, environmental sciences and pollution, geodesy, geology and sedimentology, geophysics, glaciology, geocryology and geomorphology, soil science, human biology and high altitude medicine, mapping, GIS, hydrology, terrestrial biology and ecology, paleolimnology, paleoecology and limnology. The features within the study area include ice cap or glacier, permanent snowpatches, mountain and valley.

Research at Sonnblick Observatory is currently formulated in the research program ENVISON (ENVironmental Research and Monitoring SONblick). The program covers three main topics (atmosphere, cryosphere, biosphere) in an extensive monitoring program (ATMON, CRYMON, BIMON) and with many research projects:

ATMON: “The monitoring of the Atmosphere covers the acquisition of meteorological parameters as well as the determination of atmospheric trace gases, particulate matter and radiation by in-situ and remote sensing techniques. Regarding air constituents the Sonnblick Observatory allows a determination of the background boundary layer as well as free tropospheric air masses. While a limited set of parameters, e.g. defined by the demands of GAW (Global Atmosphere Watch), is determined on a routine basis, research projects introduce additional components, novel techniques and additional short term programs. The continuous monitoring of the above mentioned parameters allows the evaluation of satellite data, model calculations and the interpretation of short term programs (e.g. measuring campaigns, vertical profile data obtained by airplane measurements) in the scope of long term observations.” (ENVISON 2016-2020)

CRYMON: “The general aim of CRYMON is to monitor the status and the changes of the Cryosphere in the spatiotemporal domain at high elevation sites of the Alps as well as its linkages to the atmosphere and the biosphere. This includes the measurements of glaciers, perennial snow and permafrost. In order to capture all these aspects of the monitoring spatially distributed observations at glaciers, test fields of permafrost distribution and the snow cover are established. The spatial variability of atmospheric conditions in the region demands for meteorological observations not only at the summit of Sonnblick but also at various sites covering local variability. CRYMON contributes to various international monitoring programmes as e.g. WGMS (World Glacier Monitoring Service) GTN-P (Global Terrestrial Network for Permafrost) and WMO GCW (Global Cryosphere Watch).” (ENVISON 2016-2020)

BIMON: “BIMON establishes a regular monitoring of vegetation changes and of changes of stream-flow ecology. Thus it will be possible to explore high added value from linking atmospheric changes to changes in the cryosphere and finally to the consequences for the biosphere, not observed elsewhere in the Alps. Several ecological observations are currently performed as part of research projects. The cooperation with NP Hohe Tauern is part of BIMON. “(ENVISON 2016-2020)

3.1.2 Switzerland – High Altitude Research Stations Jungfraujoch/Gornergrat (HFSJG)

Homepage: http://www.hfsjg.ch

Location/Altitude:

Research station Jungfraujoch:	3450 meters a.s.l.
Sphinx observatory at Jungfraujoch:	3580 meters a.s.l.
Jungfrau East ridge:	3700 meters a.s.l.
Gornergrat:	3135 meters a.s.l.

Sphinx Observatory at Jungfraujoch

Research station Jungfraujoch: besides the hosting facilities for scientists - including a library, a dining and recreation room, a kitchen, ten bedrooms and two bathrooms – the station comprises five laboratories, a mechanical workshop with a small equipment room and a compressor for liquid air production. Two custodian couples guarantee a 365 day presence to look after these facilities, the running projects and to host the scientists.

Sphinx observatory: It has an astronomical dome, two large and two small laboratories, a workshop, two terraces for scientific experiments, and a weather observation station run by MeteoSwiss.

Jungfrau East ridge: Since 2014 additional laboratory space is available in the former Swisscom relay station at the Jungfrau East Ridge. There is a room available on the second floor as well as one in the attic. A heated inlet system is installed on the roof of the house.

Gornergrat: In the southern part of the Swiss Alps, near Zermatt, the sister station Gornergrat hosts a public outreach project in astronomy named *Stellarium Gornergrat* (https://stellarium-gornergrat.ch/).

Online data: most of the measurements made at Jungfraujoch are publicly available via the respective databases, many of them in real or near real-time: http://www.hfsjg.ch/en/jungfraujoch/online-data/

Services and regulations: Several services are provided by our homepage which includes a description of past and current research projects, details about project application, regulations for stays in the research facilities at Jungfraujoch, information about local emissions etc. see e.g. under:www.hfsjg.ch/en/jungfraujoch/regulations

IT capabilities: All working places at in the labs are equipped with a phone and wired broad-band internet connection. Wireless connection is available in the library, the recreation room, and the bedrooms in the research station.

History of the Foundation: After the early death of the prime father 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 Jungfraujoch. Under his leadership the International Foundation High Altitude Research Station Jungfraujoch (now the International Foundation High Altitude Research Stations Jungfraujoch 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 Jungfraujoch for millions of tourists.

Former Research Highlights: Research work at Jungfraujoch has brought many outstanding results, documented by close to 1000 peer-reviewed publications originating from studies either conducted at the research infrastructures or related to work being done there. Research on cosmic rays by Blackett and Powell provided basic results whose importance were recognised by two Nobel prizes in physics (Blackett, 1948; Powell, 1950). In 1951 a large Wilson cloud chamber was installed by Blackett in 1951 at the Sphinx Observatory. Many additional and exceptional results have been obtained since then.

Actual Research: Besides this multi-facetted research on atmospheric chemistry and physics, extended investigations in meteorology, glaciology, monitoring of permafrost, radionuclides and cosmic rays are being conducted and make Jungfraujoch a lively research site. Furthermore, internationally coordinated campaigns on cloud-aerosol interaction research, i.e. CLoud and Aerosol Characterization Experiment (CLACE) were started in 2000 by the Paul Scherrer Institute. 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 Jungfraujoch. Common during the early times of research at the Jungfraujoch, medical campaigns have ceased during a certain period, but are lately going through a revival. Current medical experiments on Jungfraujoch are focusing on themes, such as “Human adaptation to high altitude” or on the “Effect of high altitude exposure on hemodynamic response to exercise in patients with mild congenital heart disease”.

The Research Station Jungfraujoch 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 materials and even textiles for outdoor activities can easily be tested to many extremes at Jungfraujoch – namely very cold temperatures, heavy snowfall, high 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.

Quality assurance and quality control (QA/QC): QA/QC, i.e. ensuring known and adequate quality and traceability of the measurements e.g. 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. 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. 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.

List of major nationally and internationally coordinated networks and/or research programs where Jungfraujoch is a key station:

NDACC: Network for the Detection of Atmospheric Composition Change Primary Site

GAW, GAW-CH: Global Atmosphere Watch, Global GAW Station

GAW-PFR: GAW Aerosol Optical Depth (AOD) Network

GCOS: Global Climate Observing System

GCOS-CH: Swiss GCOS office

AGAGE: Advanced Global Atmospheric Gases Experiment Collaborative Sampling Station

NADIR/NILU: NILU's Atmospheric Database for Interactive Retrieval

EUMETNET: Network of European Meteorological Services

SwissMetNet: Automatic Measuring Network of MeteoSwiss

RADAIR: Swiss Automatic Network for Air Radioactivity Monitoring

ICOS: Integrated Carbon Observation System

NADAM: Netz für automatische Dosis-Alarmierung und Meldung

NABEL: Nationales Beobachtungsnetz für Luftfremdstoffe - National Air Pollution Monitoring Network

AGNES: Automated GPS Network for Switzerland

PERMASENSE: Wireless Sensing in High Alpine Environments

PERMOS: Permafrost Monitoring Switzerland

NMDB: Real-Time Database for High Resolution Neutron Monitor Measurements

E-GVAP I + II: EUMETNET GPS Water Vapour Programme

ACTRIS: ACTRIS: European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases

Swiss Glacier: Federal Office for the Environment (BAFU) Monitoring Network

EARLINET-ASOS: European Aerosol Research Lidar Network – Advanced Sustainable Observation System
InGOS: Integrated non-CO2 Greenhouse Gas Observing System
NORS: Network of Remote Sensing (http://nors.aeronomie.be)

AGACC-II: Advanced exploitation of Ground based measurements, Atmospheric Chemistry and Climate applications
EMEP: European Monitoring and Evaluation Programme

GAIA-CLIM: Gap Analysis for Integrated Atmospheric ECV Climate Monitoring
QA4ECV: Quality Assurance for Essential Climate Variables

Most of the measurements made at Jungfraujoch are publicly available via the respective databases, many of them in real or near real-time. Further information can be found at www.hfsjg.ch.

Network examples: 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).

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 Jungfraujoch. The next call for the period 2017 to 2019 will be placed soon.

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 (NABEL), a programme runs 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.

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/gawmonitoring). 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).

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 standardized 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. Since its inception in the early 1990s, NDACC (formerly NDSC) is a major contributor to the Global Atmosphere Watch (GAW) as well as to many other internationally and nationally coordinated research networks and programmes such as NORS (NORS – the Demonstration Network Of ground-based Remote Sensing Observations in support of the Copernicus Atmospheric Service).

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.

For the investigation of the chemistry and physics of the Earth's atmosphere about 25 longterm projects with automated measurements are in operation on Jungfraujoch. In addition there are 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 NOx.

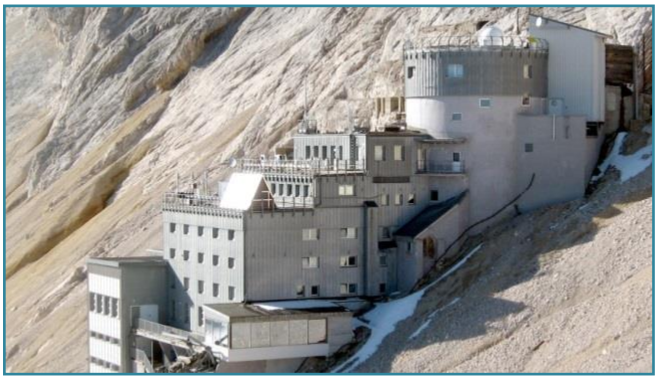
3.1.3 Germany – Umweltforschungsstation Schneefernerhaus (UFS)

Homepage: http://www.schneefernerhaus.de/en/home.html

Location/Altitude:

Umwelt Forschungsstation Schneefernerhaus

Research station Schneefernerhaus:	2650 meters a.s.l.
Summit of Zugspitze:	2962 meters a.s.l.



Umweltforschungsstation Schneefernerhaus (UFS), Zugspitze

The Environmental Research Station Schneefernerhaus is located at 2650 m above sea level near the summit of the mountain Zugspitze – Germany's highest mountain. The Schneefernerhaus is an internationally linked center of competence for high altitude, climate, and environmental research with focus on development, demonstration, and operation of innovative technologies in the context of atmospheric and climate research, satellite validation, model verification, quality assurance for value added products, analyses for the understanding of climate system and hydrology processes, environmental and high altitude medicine, early detection of natural hazards, cosmic radiation and radioactivity. The UFS has the status of a global station within the Global Atmosphere Watch Programme (GAW) of the World Meteorological Organization (WMO). It is in addition part of the NDACC program and linked with the ICSU/WMO World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT). Linked to UFS are various climate and environmental monitoring stations on the Zugspitzplatt and in the surrounding Werdenfelser Land (subalpine to mountain forests) including a unique botanical garden at the Schachen.

The Schneefernerhaus is organized as a Virtual Institute for altitude and climate research under the auspices of the Bavarian State Ministry of the Environment and Consumer Protection. Ten leading German research institutes are currently members of the Virtual institute:

German Aerospace Center | Deutscher Wetterdienst | Helmholtz Zentrum München | Karlsruhe Institute of Technology | LMU Munich | Max-Planck Society | Technische Universität München | Federal Environment Agency | University of Augsburg | State of Bavaria

Partners are the Free State of Bavaria, the German Aerospace Center (DLR), the Karlsruhe Institute of Technology (KIT), the German Research Center for Environmental Health (HMGU), the Technical University of Munich (TUM), the Ludwig-Maximilians-University München (LMU), the University of Augsburg as well as the Federal Republic of Germany represented by the German Meteorological Service (DWD), and the Federal Environment Agency (UBA).

This consortium has a contractual agreement over the use of the infrastructure of the UFS whereby each of the partners has a long-term rental arrangement for the laboratory space and the outdoor platforms for their respective research activities. It is also responsible for defining the future scientific strategy. Each partner of the consortium has a representative in the so-called UFS-Science Team which is responsible for the organization and coordination of the different research interests and the definition of common R&D-projects.

Currently there are eight research topics:

- Satellite-based observations and early detection
- Regional Climate and Atmosphere
- Cosmic radiation and radioactivity
- Hydrology
- Environmental and high-altitude medicine
- GAW (Global Atmosphere Watch)
- Biosphere and Geosphere
- Cloud dynamics

The UFS is one of the most modern high-altitude research stations in the world and offers a unique research environment:

- Year round access and year round transportation of heavy loads independent of weather conditions
- High-Speed internet connection to the Munich Scientific Network (operated by LRZ), connecting all scientific institutions in the Munich metropolitan area
- 750 m^2 laboratory and office space
- 480 m^2 outdoor experiment platforms
- “Room Prof. Siegfried Specht” large conference room (144 m^2) for 80-90 persons
- “Gletscherstube” panorama room (56 m^2) for up to 25 persons
- Lobby (60 m^2) for presentations
- South facing patio (82 m^2) with direct access from the conference area
- Overnight facilities for 51 persons
- Emission-free concept
- Ultra-pure water and liquid nitrogen available

The UFS fosters the cooperation with other institutions in order to develop new technologies. The most recent are:

- An electric, battery-powered snow-blower developed in cooperation with the Technical University of Munich
- A pilot study about the use of UAVs (Unmanned Aerial Vehicle).
- **WMO** World Meteorological Organization
- **GAW** Global Atmosphere Watch
- **GAWTEC** Global Atmosphere Watch Training & Education Centre
- **NDMC** Network for the Detection of Mesospheric Change
- **SPARC** Scholarly Publishing and Academic Resources Coalition
- **ICOS** Integrated Carbon Observation System
- **ENVRI+** Environmental and Earth System Research Infrastructures

3.1.4 Germany – Deutscher Wetterdienst /Hohenpeissenberg Meteorological Observatory (DWD)

Homepage: http://www.dwd.de

Location/Altitude:

Hohenpeissenberg Meteorological Observatory: 975 meters a.s.l.

Hohenpeissenberg Meteorological Observatory

The Hohenpeissenberg Observatory (HPB, www.dwd.de/mohp) is one of two meteorological observatories run by the German Meteorological Service DWD (Deutscher Wetterdienst). It is located in Southern Germany, 985 m a.s.l., on a foothill of the Alps. It is situated in a rural area, which is typical for central and Western Europe. In 1994 HPB became, together with its sister station Zugspitze/Schneefernerhaus, a Global Station in WMO's Global Atmosphere Watch program (GAW) and an EMEP supersite. Since 2007 HPB is a regular (founder) member of the UFS Schneefernerhaus consortium (http://www.schneefernerhaus.de/). In 2009 HPB became an associated partner of EUSAAR, since 2011 the observatory is partner in follow-on projects ACTRIS and ACTRIS-2. HPB is further actively involved in EUMETNET/E-Profile, ICOS, AERONET and EARLINET. Since 2005 HPB is part of the GEMS/MACC I-III development team and responsible for the validation of modelled aerosol and trace gas distributions using GAW data. In 2016 HPB became a member of the COPERNICUS Atmospheric Monitoring Service (CAMS) consortium and is responsible for validating the spatio-temporal distribution of aerosols.

Hohenpeissenberg is well-known for routine ozone monitoring, which started in 1967 with balloon-soundings and total ozone measurements. Monitoring of surface ozone started back in 1971. Since 1987 a differential absorption UV-LIDAR is profiling ozone and temperature between 15 and 50 km altitude. A more powerful Lidar has been installed from 2013-2015 and is currently extensively tested in parallel to the existing device. All data are routinely submitted to the international NDACC, WMO and NILU data centers. Since 1994, when HPB became a GAW Global Station and an EMEP supersite, continuous measurements of the trace gases O3, NO, NO2, NOX, NOY, NH3, PAN, SO2, and CO, the greenhouse gases CO2 and CH4, as well as non-methane hydrocarbons (NMHC, C2 to C14, up to 100 different species) and selected OVOC have been started. Continuous measurements of OH radicals and gaseous H2SO4 have been run since 1998. Aerosol parameters, including total suspended matter (TSP), PM_{10}, optical parameters (scattering by nephelometer) and absorption ('equivalent' black carbon by aethalometer, MAAP and PSAP), condensation nuclei number concentrations (3 and 11 nm cut-off) and size distributions (SMPS and optical) are monitored, complemented by routine analyses of the chemical composition of precipitation and (size resolved) aerosols by a 4-stage Berner impactor and an aerosol chemical speciation monitor (ACSM). The full set of standard meteorological parameters is routinely recorded, as well as the shortwave global radiation (global and diffuse), the longwave atmospheric radiation and the NO2 and O1D photolysis frequencies. More details of the state-of-the-art monitoring program at HPB are summarized at www.dwd.de/mohp , in the metadata of the GAW world data centers, and the GAW Station Information System (GAWSIS, see https://gawsis.meteoswiss.ch/).

Aerosol profile network: As the decided German 'Volcanic Ash Advisory Center' the HPB observatory is scientifically responsible for DWD's ceilometer network of currently ~100 stations (~70 more to follow until end of 2018) of Lufft (former JENOPTIK) CHM15k ceilometers in Germany, which are continuously operated (24/7). Information about cloud layers, the height of the mixing layer and aerosol vertical profile measurements are routinely retrieved and performed, interpreted and evaluated. The parallel operation of CIMEL/AERONET and PFR AOD instruments complements the set of aerosol parameters and supports calibrating the ceilometer profiles. DWD is further involved in the EUMETNET project E-Profile within a community algorithm for rigorous ceilometer profile analysis and absolute calibration is developed until the end of 2017. A mobile multi-wavelength-depol-Raman Lidar ($POLLY^{XT}$ of TROPOS, Leipzig, Germany) is operated at HPB since September 2015. It is part of ACTRIS/EARLINET but operations are performed continuously provided the meteorological conditions are in favour of aerosol profiling (no precipitation, no fog).

Access to further measurements: A MAXDOAS instrument is operated for NO2 and SO2 profiles in the lower troposphere. HPB is also involved in the installation and the operations of finally eight German ICOS tall towers for height-resolved measurement of CO2, CH4 and meteorology in the lowest (<300m a.g.) surface layer. Once the network is established HPB will also be involved in the routine data evaluation.

3.1.5 Italy – EURAC Research

Homepage: http://www.eurac.edu/

Location/Altitude:

Earth Observation centre:	2260 m a.s.l
Summit of Ritten:	2260 m a.s.l
Minimum altitude within study area in Mazia:	990 m a.s.l.
Maximum altitude within study area in Mazia:	2700 m a.s.l.

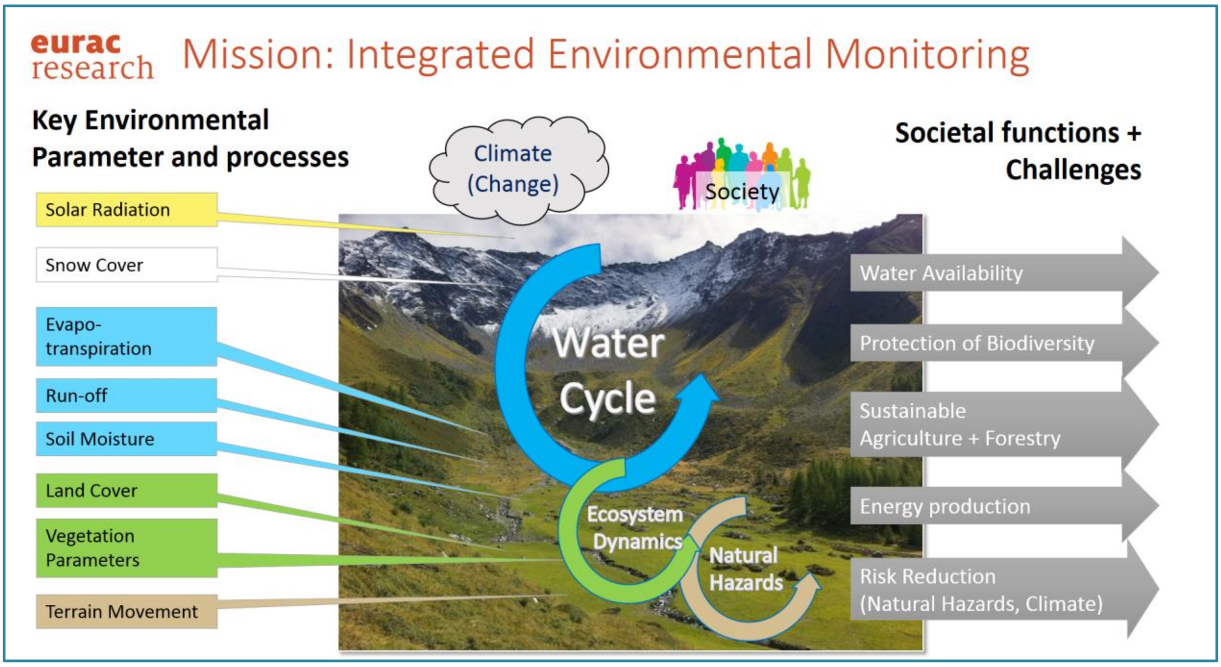
Satellite receiving station on top of Mt. Ritten/ Bolzano

Eurac Research is an interdisciplinary research centre located in Bozen/Bolzano, Italy. Eurac Research has a strong focus on mountain research and climate change including natural science as well as interdisciplinary approaches. Our research addresses the greatest challenges facing us in the future: people need health, energy, well-functioning political and social systems and an intact environment. These are complex questions, and we are seeking the answers in the interaction between many different disciplines. In so doing, our research work embraces three major themes: regions fit for living in, diversity as a life-enhancing feature, a healthy society.

Eurac Research is contributing to VAO with three mountain observatories:

- An Earth Observation centre with an own receiving facility located at 2260 m and state-of-the-art ground facilities for processing and archiving satellite data.
- A Sentinel Alpine Observatory (SAO), which focuses on the application of the latest ESA Sentinel satellites and other satellite data for research and operational monitoring of key environmental parameters such as snow cover, vegetation or soil moisture over the Alps.
- A LT(S)ER site for long term (socio-)ecological monitoring, managed by Eurac-Institute for Alpine Environment, located in Matsch/Mazia with 19 microclimatic stations from 990 to 2700m measuring standard microclimatic parameters, soil moisture and temperature, rain/snow, (Net) radiation, vegetation phenology a. o.

The combination of Earth Observation, ground stations and fieldwork allows studying the relation between climate, environment and human impacts in an integrated manner across spatial and temporal scales. One clear focus of Eurac Research is to better understand the impact on climate variability and climate change on the complex alpine environment. Focus Topics are (1) Water and Cryosphere, (2) Vegetation, agriculture and Forestry, (3) Climate and Disaster Risk.



Eurac Research is closely related to national space agencies in Italy, Austria and Germany and part of EODC (Earth Observation Data Centre), an initiative for shared processing and dissemination of Sentinel satellite products. Eurac Research has close collaboration with institutes from other mountain regions such as ICIMOD in Himalaya.

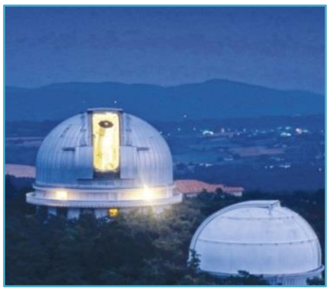
The main contributing Eurac institutes to VAO are the Institute for Earth Observation and the Institute for Alpine Environment. Further links exist to the Institute for Alpine Emergency Medicine, the Institute for Renewable Energies and the Institute for Regional Development.

3.1.6 France – Observatoire des Sciences de l'Univers de Grenoble (OSUG)

Homepage: http://www.osug.fr

Location/Altitude:

OSUG headquarter in Grenoble:	220 m a.s.l.
Observatoire de Haute-Provence:	650 m a.s.l.
Station Alpine Joseph Fourier, Lautaret-Pass:	2.058 m a.s.l.
Vallot Observatory, Mont Blanc:	4.362 m a.s.l.


Observatoire des Sciences de l'Univers de Grenoble, OSUG research activities

The Observatoire de Sciences de l'Univers de Grenoble (with its headquarters located 220 m a.s.l.) is one of 24 French Observatories of Earth Sciences and Astronomy (OSU, in French), which are public scientific institutions dedicated to observation, research, education, and public outreach. OSUG is engaged in scientific studies related to all aspects of the Universe and the Earth systems, in particular in astrophysics, planetary science, geophysics, geology, climatology, hydrology, glaciology, ecology, and environmental sciences. Linked to multiple institutions of research and higher education (Université Grenoble Alps, IRD, CNRS, Irstea, Météo France), OSUG includes overall about 1150 members in six research institutes, five associated research teams, and two service units. All institutes and groups are equipped with modern, high technology analytical facilities, laboratories, and instrumentation. OSUG and its institutes also include advanced IT facilities operated by highly skilled personnel to provide access to computing and storage capacities. Intensive calculations are carried out on the high-performance computing clusters and servers of the Université Grenoble Alps and in national computing centres. The OSUG members maintain numerous field sites in the French Alps equipped with both conventional and cutting-edge field instrumentation. They also develop, maintain, and apply a large number of numerical computer codes following international standards in all thematic fields developed within OSUG. Satellite data are widely used at OSUG, as such for research purposes, but also for the methodological development of new algorithms to process remote sensing data and to introduce novel applications.

At OSUG, alpine research activities are conducted in almost all research components, namely in the Institute for Geosciences and Environmental Research (IGE), Institute of Earth Sciences (ISTerre), Grenoble Centre of the National Institute for Environmental Science and Research (Irstea), Laboratory of Geophysical and Industrial Flows (LEGI), Laboratory of Alpine Ecology (LECA), French Snow Research Centre (CEN) of Météo France, Signal Images Physics (SIGMAPHY) research team of the Grenoble Images Speech Signal and Control laboratory (GIPSA-lab), and Environments research group of the Social Science Research Centre (PACTE). The SAJF service unit operates the Joseph Fourier Alpine Station at the Lautaret Pass (2058 m asl). IGE is in charge of the Vallot observatory (4362 m asl) on the Mont Blanc. Although dealing only with the outer space, the research activities performed within the Institute of Planetology and Astrophysics of Grenoble (IPAG) partly rely on a world-class facility located 100 km south of Grenoble, the NOEMA interferometer, which is operated by the French-German-Spanish IRAM research institute for radio astronomy.

The research performed in the Alps by the OSUG members heavily relies on monitoring activities and dedicated field sites. OSUG plays a leading role for running CNRS-approved observation services at national and international levels. OSUG is contributing to 18 observation services and is directly in charge of 11 of them at the national level. Roughly 120 scientists (50 full-time persons) are involved in the various observation systems. This strong investment in long-term observation systems notably concerns the evolution of the mass balance of glaciers, the characterization of snow and permafrost properties, the monitoring of seismic activity, land- and rockslides, and the detailed analysis of biodiversity. These observation activities are performed at numerous locations in the French Alps. Specific field investigations on snow, on hydrological and erosion processes, and in ecology are carried out at the Col de Porte, the Col du Lac Blanc, the Col du Lautaret, and in the Draix-Bléone basin observation sites. The OSUG Data Centre contributes to the storage, processing and dissemination of the collected data with an open-access data policy. With the current construction of the European Research Infrastructures (ESFRI), most of our observation services are progressively included in this European framework via the national application of research infrastructures in terms of data and service web portals.

The Institute for Geosciences and Environmental Research (IGE) conducts research in the fields of climate, cryospheric, and environmental sciences and hydrology aiming to better understand the processes that govern the various geophysical compartments (ocean, atmosphere physics and chemistry, cryosphere, watersheds, critical zone), their interactions, their responses to human activities, and the adaptation and resilience of societies. The main topics investigated at IGE related to alpine research are the past and present evolution of the composition of the atmosphere and the feedback between the chemistry of the atmosphere and climate; the study of glaciers and alpine hydro-glacio-meteorological processes; the processes and the vulnerability of the critical zone for a better management and the protection of the resources and the environment; and the intensification of the hydrological cycle and its interactions with societies. To carry out these studies, the IGE approach is based on a combination of observations and monitoring (field observations, national monitoring services, space missions) with instrumental developments and data modelling.

The research performed at the Institute of Earth Sciences (ISTerre) addresses three major scientific priorities: understanding earthquakes, landslides, volcanic eruptions and the Earth's magnetic field;

studying processes shaping the Earth; and investigating the changes of rocks as a function of natural and human constraints. These priorities are reflected in research activities in the Alps, notably via long-term observations and analyses of solid Earth processes based on experimental, numerical and field data including their interpretation. For example, monitoring of the seismic activity in the Alps has been very useful to detect damaging active faults, image deep structures by tomography techniques, and study amplication effects of the ground motion in alpine valleys and on rough topography. If mountain topography is the expression of geodynamics due to fault activities, it is also related to processes involving erosion and sediment deposition. These processes can be investigated by means of GPS and geochemical measurements. The former technique has been found to be also very effective to assess the precipitable water vapor in the atmosphere and to monitor the flow of glaciers. Mineralogical and geochemical proxies are used by ISTerre scientists to better quantify and model time and space variations of rock evolution and soil transformation under natural conditions (pressure, temperature, deformation, fluid migration) and/or anthropogenic influences (pollution, mineral/ oil and gas extraction).

The Grenoble Centre of Irstea (National Institute for Environmental Science and Research), composed of three research units, conducts research in the Alps and develops expertise to improve the knowledge and management of mountain ecosystems, territories and natural hazards. The Mountain Ecosystems unit works on analyzing mountain system dynamics at various scales and examining their vulnerability in a time of global change. The aim is to improve the knowledge about ecological processes and to produce operational methods and tools supporting the management of mountain ecosystems and ecological engineering. The Mountain Territories Development unit aims at characterizing and encouraging the integration of environmental considerations into development plans for rural and mountain territories as part of the overall pursuit of sustainable development. For various themes, the researchers use territories as subjects of their studies and analyze the operators, practices and public policies that influence or derive from their development. The research is carried out with the aim to support decision-making and development policies. The Torrent erosion, snow and avalanches unit aims to develop tools for engineering preventing natural hazards in mountains related to avalanches, wind-driven snow movements, floods, debris flows, rock-falls, and glaciers. It performs basic exploration into the origin, the rheology, and the dynamic of flows.

The Laboratory of Geophysical and Industrial Flows (LEGI) conducts research activities in fluid mechanics and transfer by combining modelling, testing, high performance numerical simulations, and development of innovative measuring instruments. These activities have many applications for solving environmental and industrial issues. The research activities in the Alps are mainly dealing with the dynamics of turbulent flows (hydrodynamics, mixing, transfer of heat and mass ...) and geophysical fluid dynamics concerning processes in and simulations of natural systems like the atmosphere or rivers. Major objectives are a better understanding of climate change and the development of forecasting tools.

The Laboratory of Alpine Ecology (LECA) addresses present and crucial environmental issues like global change, loss of biodiversity, and low-level chronic pollution with activities centered on ecology, environmental and evolution sciences. The study scales range from (populations of) genes to ecosystems and landscapes, including processes at each scale with a specific focus on mountains. The research is organized according to four topics. The first topic is to describe the variation of different aspects of biodiversity (specific, functional and phylogenetic) along environmental gradients and their co-variation across spatial scales and trophic levels, to study the response of species to environmental changes and the assembly mechanisms of biotic communities influenced by micro- and macro-evolutionary mechanisms. The second topic is related to the understanding of the genetic bases of the adaptation of organisms to their environment, through the selection of genotypes that are specialized for a given environment as well as their ability to present different traits according to where they live. The third topic deals with the role of functional traits in biotic interactions between plants, animals, and microorganisms at a range of spatial and temporal scales, including the impacts on major elemental cycling (water, C, N) and ecosystem services. The last topic concerns the understanding of direct and indirect impacts of xenobiotics (pesticides, HAPs, PCBs, heavy metals,…) on ecosystems (ecotoxicology, adaptation, resistance, effects on interspecific relationships, communities, ecosystem functionality).

The Centre d'Études de la Neige (CEN) or French Snow Research Centre is one of eight research units of the research department of Météo France. It is specialized in snow studies and in the forecasting of avalanche hazards. It performs research on different aspects of snow to improve the SAFRAN-Crocus-MEPRA modelling chain and to support operational activities. It is involved in the snow modelling for climate and hydrological applications. To reach its objectives, the CEN uses several tools: dedicated computer models, field observations (on permanent sites or during intensive campaigns), and experiments in cold laboratory.

The activities of the Signal Images Physics (SIGMAPHY) research team of the GIPSA-lab in the alpine region concern the application of active remote sensing. The research for SAR image processing is guided by two theoretical and applicative perspectives. The first axis targets the methodology aspects of the quantitative remote sensing in the context of polarimetric or interferometric SAR images. The second axis studies the technological potential and limits of the SAR imaging for the tracking of complex geophysical objects. The applications target the monitoring of levees, snow, firn, and ice in order to extract snowfall parameters, improve avalanche forecasting, detect snow mass motions, and predict landslides associated with the thaw of permafrost.

Long-term environmental and landscape dynamics are among the topics of the Environment research group of the PACTE Social Science Research Centre. The aim pursued is to approach the landscape in the Alps with a socio-environmental and ecological perspective, integrating both contemporary dynamics and historical depth (paleo landscapes). The studies concern the analysis of the changes of uses, and the trajectories in order to identify the processes at the origin of bifurcations, transformations or inertia landscapes. The landscape is considered as an indicator of socio-environmental strategies in different contexts (periods of crisis or stability, climate change).

The missions of the Joseph Fourier Alpine Station (SAJF) service unit are the development of research platforms, the maintenance of botanical collections, the training of students, and outreach activities for the general public. The SAJF is taking care of the Robert Ruffier-Lanche arboretum on the university campus in Grenoble in addition to managing a unique botanical garden at the Col du Lautaret. It also operates the Chalet-Laboratory and the newly created Galerie de l'Alpe exhibition centre also located at the Col du Lautaret. The Chalet-Laboratory is an alpine biology research laboratory, which is extensively equipped with scientific instruments offering the opportunity to study the biology of alpine plants in their natural environment.

3.1.7 Slovenia - UNG Atmospheric Observatory at Otlica, Center for Atmospheric Research (CRA)

Homepage: http://www.ung.si/en/research/centre-for-atmospheric-research/otlica-observatory/

Location/Altitude:

Otlica: 965 m a.s.l.
Otlica Observatory: 945 m a.s.l.

View from Otlica, (45.93N, 13.91E) towards S (Carst plateau, Bay of Trieste)

The **UNG Atmospheric observatory at Otlica** is a node in the national network for environmental monitoring operated by the Environmental Agency of the Republic of Slovenia (ARSO) and continuously provides a number of meteorological and environmental measurements, which are being used for research and teaching at UNG.

In 2013, the meteorological station at Otlica has been upgraded and serves as a test case for the future monitoring network in Slovenia. It has new wind, precipitation, temperature and solar irradiation sensors and broadband connection, which provides increased sampling frequencies with periodicity of 10 minutes. The new station will in particular be used for Bora wind studies, a phenomenon that frequently gives rise to winds with speeds exceeding 120 km/h in the region. Lidar measurements of aerosol transport as well as other environmental and meteorological measurements are being performed at Otlica observatory site.

Remote sensing of atmospheric properties

Centre for atmospheric research conducts aerosol transport studies using three lidar devices, measuring various types of backscattering of short laser pulses on partices and molecules in the atmosphere. The two stationary systems (Mie and Raman lidar), stationed at the Otlica observatory site have the possibility of vertical scanning, while the mobile elastic/fluorescence lidar provides the capability of 3D scanning and identification of aerosols of biological origin through the fluorescence of the triptophane amino-acid. All the systems are the result of our own R&D; and are being used for the determination of optical properties of the atmosphere such as aerosol back-scattering coefficients, atmospheric optical depth and tracing of aerosols and clouds. They facilitate studies of tropospheric processes above the Vipava Valley, the Carst Plateau and the Bay of Trieste up to altitudes of about 10 km. Measurements with the mobile unit can provide information on aerosol concentrations in the lower atmosphere – which may indicate air pollution from extraordinary events, such as thermal inversion, appearance of Saharan dust, wildfire and exhausts of hazardous substances, as well as studies of the spreading of biological aerosols, such as pollen. Subsequent use of meteorological models for air-mass transport can provide clues about aerosol sources and trajectories. The mobile lidar is used also for teaching purposes at the Schools of Applied and Environmental Sciences.

Bora wind studies

Our most recent research interest lies in the studies of the Bora wind phenomenon, for which we are in the process of design and construction of a fast scanning elastic wind lidar, providing information on wind field speed and direction. This lidar will be used to obtain 2D and 3D wind fields in selected locations, where airmass motion is expected to be most turbulent. We are also planning to deploy a permanent field of high frequency ultra-sound anemometers, which will be used in Bora wind periodicity studies.

Atmospheric impact on the performance of satellite navigation systems

A part of the research activities of the Centre is focused on the study of ionosphere, ionised part of the atmosphere extending from about 60 km to beyond 1000 km above ground. Irregularities in electron plasma density in ionosphere, which move by diffusion and other transport mechanisms, have a strong influence on communications between satellites and ground receivers. A radio wave propagating through drifting irregularities experiences irregular fluctuations in amplitude and phase. Characteristics of these fluctuations, known as scintillations, depend on the wavelength, current magnetic and solar activity, time of day, season of year and magnetic latitude of the observation point. Scintillations are responsible for signal degradation and disruption of satellite navigation services, such as GPS and Galileo. Remote sensing of electron density irregularities is a key to the understanding of fundamental processes behind navigation signal scintillations and will provide important clues for performance improvement of GPS ground receivers. Of particular interest are small-scale irregularities in electron plasma density at high magnetic latitudes.

Atmospheric monitoring

In collaboration with the Environmental Agency of the Republic of Slovenia (EARS) the Otlica Observatory became in 2006 a node in the national network for environmental monitoring. Standard meteorological and environmental measurements are routinely performed and presented online on UNG and EARS web pages.

3.2 Associated VAO-Partners

3.2.1 Norway - Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR)

Homepage: http://andoyaspace.no/

Location/Altitude:

Geographical coordinates: 69 N 16 E
Altitude of station: 350 m a.s.l

Arctic Lidar Observatory for Middle Atmosphere Research ALOMAR

The observatory is part of the Andøya Space Center, the world´s northernmost launch site for sounding rockets, situated at 69° N, 16° E. Universities and institutes from eight countries have installed instruments at ALOMAR and contribute to the operation costs.

Facility

The well equipped facility, easily accessible by mountain road, includes laser cooling water, power backup (UPS, diesel generators), high speed internet access, mechanical workshop, laboratories, telescope hall and office space. Overnight stay is possible.

Science Opportunities

The observatory includes remote sensing instruments that cover the atmosphere from ground to lower thermosphere. Synergy is gained through co-location of different instruments investigating both in a common height region and across the atmosphere layer.

Scientific Installations

Present instruments at ALOMAR comprise active and passive remote sensing systems. Active remote sensing facilitates the atmospheric return of strong laser pulses or radar signals to probe for various height depended physical properties. Passive remote sensing utilizes the emission or the absorption of radiation in the atmosphere to get various column properties, e.g. trace gases, electron or aerosol content.

Human Resources

Interested scientists need only to coordinate their desired research involvement with the PIs of the ALOMAR instruments they wish to use. Instrumentation, PI contact addresses, and information on the possible cost involved in such endeavors is available.

Advocacy of the scientific users of ALOMAR

In order to maximize the science benefits arising from ALOMAR instrumentation, the community of ALOMAR scientists, the ALOMAR Science Advisory Committee (ASAC) express their joint interest in enhancing participation in collaborative research by guest scientists from other institutions throughout the world.

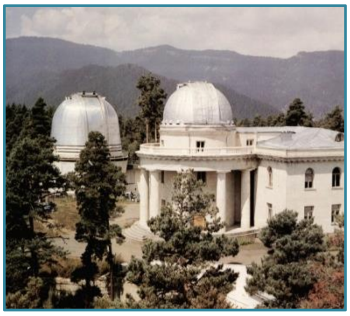
3.2.2 Georgia - Evgeny Kharadze Abastumani National Astrophysical Observatory

ABASTUMANI ASTROPHYSICAL OBSERVATORY

Homepage: http://observatory.iliauni.edu.ge/en/

Location/Altitude:

Altitude of observatory: 1700 m a.s.l



Abastumani Observatory

Abastumani Astrophysical Observatory was founded in 1932 as the first alpine astrophysical observatory on the former Soviet Union territory. It is one of the research institutes belonging to the Ilia State University. It is located on mountain Khanobili, about 240 km away from Tbilisi, and 30 km north-west of Akhaltsikhe, at an altitude of 1700 meters above sea level.

Stellar and extragalactic astronomy: The High-energy Study of Blazars; Observations and Comprehensive Investigation of Stars on Different Evolutionary Stage; Research of galactic open clusters, in order to identify their binarity and multiplicity and some particular problems related to this

The Sun: Magneto seismology of solar atmosphere and the solar weather; Study of the characteristics of solar rotation by mean of coronal holes. Dynamics and classification of coronal holes; Monitoring of Active Physical Processes and Waves in the Upper Layers of the Solar Atmosphere on the Basis of Observational with High Dispersion Spectrograph and Field Observations of the Solar Eclipses

The Solar system: Studying physical characteristics of selected objects in the solar system and their monitoring; Approaching Earth asteroids photometric and astrometer methods of research, fiber range

Atmosphere-ionosphere and near-space Studies: Ground-based and spaceborne monitoring of stratospheric aerosol; Earth's atmosphere and near space research group;

4 Perspective

This chapter outlines the cornerstones of the strategy to further develop VAO within the next decade. In the first subsection the following overarching topic priorities are described:

(i) Identifying and addressing demanding major scientific questions including their relevance for applications, where appropriate

(ii) Improving infrastructure (including technological and technical challenges) and networking;

The second subsection describes what actions are needed to be taken in order to achieve these goals. This incorporates activities towards strengthening both, the cooperation within the different scientific communities (especially promoting interdisciplinarity) as well as between the different infrastructures / facilities.

4.1 Scientific challenges

The overarching scientific challenges that the VAO will address in the upcoming decade are part of the following research fields:

(i) Atmospheric and climatic variability
(ii) Climate impact on Alpine environment, hazards and risks
(iii) Alpine water cycle
(iv) Environment and human health

4.1.1 Atmospheric and climatic variability

The atmosphere is a complex system. It is characterised by a multitude of chemical, dynamic and radiation-related processes. Our knowledge of these processes is still incomplete. Forecasts on climate development are therefore still relatively unreliable. Improved measurement and analysis techniques will help to close this gap.

Challenge 1 *Understanding the coupling mechanisms among atmosphere, clouds and land surface and their changes in view of impact on the greenhouse effect*

Besides CO_2, water vapor and methane belong to the most prominent greenhouse gases in the atmosphere. In fact, H_2O as a natural greenhouse gas has the strongest warming potential while CH_4 is expected to significantly increase its concentration in the atmosphere within the next century. Water vapor, methane, and clouds mutually interact with each other and are all subject to climate feedback. Yet, the scientific understanding of clouds is still incomplete.

Prediction of the future climate still suffers from large uncertainties which makes strategical decisions affecting the politics and society rather difficult. Especially important in this context is the quantitative understanding of the trends and climate feedback mechanism of water vapor, methane, and clouds which are still underexplored. To be addressed is the question: What processes govern the observed increase of atmospheric CH_4? (e. g. warming of wetlands, melting of permafrost soil, burning of fossil fuel, etc.). Furthermore, does the concentration of H_2O change in the upper troposphere / lower stratosphere (strongest warming potential)? If so, how and why? Especially, what is the contribution to such changes due to coupling mechanisms with aerosols and smaller cloud droplets? How does increasing CH_4 impact the H_2O budget due to increasing oxidation of CH_4?

Needed are measurements of H_2O, CO_2 and ideally its isotope compositions, CH_4, and of cloud physical parameters including aerosols at different heights in the atmosphere from the ground up to the middle stratosphere. High-altitude stations are key in improving our understanding as they allow to regularly sample within clouds due to the orographic conditions favoring the exposure of the sampling sites to clouds (with very reasonable costs compared to airborne observations). A smart link of atmospheric measurements to biosphere processes can be done by near and far remote sensing as well as modelling.

Challenge 2 *Understanding the impact of the Alps (mountains) on atmospheric dynamics in the middle atmosphere (10-100km height)*

Atmospheric dynamics at middle latitudes – and thus in the alpine region - is characterized by a complex interaction between large scale zonal jets as they arise from the overall meridional temperature gradient and atmospheric waves on a wide range of spatiotemporal scales (planetary waves, gravity waves and mixed wave forms). Mountains are known as prominent sources for generating atmospheric gravity waves. Due to their comparatively small spatial dimensions, gravity waves are only parameterized in state-of-the-art climate models and can therefore cause significant uncertainties in the forecasts.

To be addressed is the question: What is the structure function (strength of sources, spectrum of wavenumbers generated, rate of group and phase velocities, amplitudes, propagation vectors, etc.) of atmospheric gravity waves generated by the Alps and how does it compare to other mountainous regions in Europe? How does climate change impact the structure function of atmospheric gravity waves? Is the filtering of gravity waves by planetary waves changing? Answering these questions allows insight into the open question: how representative are state-of-the-art parameterizations of gravity waves due to mountainous regions in climate models?

Needed are measurements of atmospheric temperature, wind, and other conservative tracers (e.g., ozone) including imaging measurements from the ground up to the lower thermosphere (ca. 100 km height) to allow even for stereoscopic or tomographic studies at various sites in the Alps and other mountainous regions in Europe. Further needed is the access to large computer capacities in order to run numerical models of gravity wave propagation within a reasonable time period as well as access to satellite-based observations.

Challenge 3 *Understanding the impact of climate change on human exposure to cosmic radiation and environmental radioactivity*

Primary cosmic radiation consists of relativistic particles, mainly protons and alpha particles, in the universe, in the heliosphere, and near Earth. These particles with atoms and molecules in the Earth's atmosphere, and the resulting secondary particles are called "secondary cosmic radiation". The composition of the secondary cosmic radiation depends on the altitude and the energy of the particles. Secondary neutrons are of particular interest because they dominate the radiation dose from cosmic radiation to humans at the surface of the Earth and at flight altitudes.

There is evidence that changing environmental conditions (especially soil moisture and snow) can alter the amount and the energy spectrum of neutrons near the Earth’s surface. These changes also will influence the amount of environmental radionuclides that are deposited on the surface due to precipitation, their transport in snowpack and release to aquatic environments.

The questions to be addressed are the following: Is there any impact of climate change on the energy distribution of secondary neutrons from cosmic radiation at mountain altitudes, close to the interface between atmosphere and lithosphere? If so how and why? Is there any impact of climate change on deposition and distribution of environmental radionuclides? If so, how does their spatiotemporal distribution in mountainous aquatic ecosystems affect water quality and human radiation exposure in the alpine region?

To answer these questions, detailed measurements of the energy and angular distribution of secondary neutrons from cosmic radiation, and ambient parameters measured with innovative techniques, are needed with a sufficient precision, and should be complemented with Monte Carlo simulations. Activity concentrations of the environmental radionuclides in seasonal snowpack and in situ meltwater after initiation of snowmelt should be determined at different locations in the Alps. Validated remote sensing data on soil and snow moisture will be used to extrapolate measured point data to an alpine-wide area.

Challenge 4	*Monitoring and understanding of the contamination of the Alps*

The Alps represent a barrier for atmospheric wind flow. Consequently, condensation and subsequently deposition (“cold trapping”) of pollutants transported with the winds results in an enhanced contamination of the Alpine region with such pollutants. The same process is going on in other cold regions (e.g., polar regions).

The understanding of the contamination of the Alps with persistent pollutants is of high relevance for the Alps as a recreation area, for food production related to transhumance and the health of wild animals. Thereof consequent societal benefits are the production of food of high quality within the Alps, biodiversity and a high recreational value. The question to be addressed is: How strong is the contamination of the Alps with persistent pollutants due to deposition from the atmosphere, are there any trends, and what is the relevance to a clean water supply, to food production, and to biodiversity?

Challenge 5	*Impact of meteorological extremes in the Alps and surrounding regions on natural hazards*

The Alps and the surrounding regions are frequently impacted by extreme events such as storms, heat waves, serious flooding and dry periods. Despite several decades of advances in atmospheric research and modeling, the development of skillful highly resolved weather forecasts stills remains a challenge.

The question to be addressed is: Has the frequency/intensity of severe weather events changed? If so, how and why? Especially of interest is the question to what portion climate change influences such extreme events.

Answering these questions requires investigating processes on different spatio-temporal scales. This includes understanding possible changes in the structure function of the planetary scale wave regime and its coupling with the Jetstream which significantly governs the mesoscale weather phenomena. Directly related to this is the question if there is a possible impact of the abovementioned processes on forming so-called Vb-weather systems which are known to have serious potential for severe weather in the Alps and its surrounding regions.

It is needed to establish innovative measurement system in the Alps looking at different height regimes of the atmosphere in order to improve monitoring and forecasting of such extreme events. Also needed is the access to large data repositories to also make use of satellite-based data and climate simulation data sets. Access to supercomputing facilities is also needed to run numerical meteorological models and sophisticated downstream algorithms.

4.1.2 Climate impact on Alpine environment, hazards and risks

Challenge 6 *Understanding the dynamics of the Alpine vegetation in response to climate (change)*

The alpine vegetation is particularly affected by the pronounced warming in this region. Consequences are manifold.

The questions to be addressed are: How and why does the Alpine vegetation change? What are the consequences for biodiversity, ecosystem services, atmospheric variability, hydrology, alpine hazards, recreation and human health?

A combination of ground and remote sensing observations to answer these questions, the dynamics of the vegetation over a wide range of spatiotemporal scales, including in-situ observations, webcam installations on altitudinal gradients and satellite information need to be quantified. Information on vegetation composition, activity and productivity can be used to determine sensitivity of the biosphere to climate change and its implications for biodiversity, ecosystem services, atmospheric variability, hydrology, alpine hazards, recreation and human health. To facilitate this, meteorological parameters, the biological footprint within isotopic composition of CO_2 and H_2O as well as pollen concentration need to be observed. Additionally, vegetation information can be used to improve and validate remote sensing products (satellite validation).

The results do not only improve our understanding on the impact of vegetation change on the ecosystem in terms of biodiversity, carbon sink capacity, agriculture, tourism, protection from avalanches and erosion etc. but help to mitigate climate change impacts and solve socio economic conflicts in a highly vulnerable environment.

Dissemination and participation in this research can be enhanced via mobile apps and social media.

Challenge 7 Interrelation of the environment with seismic activity

Due to their tremendous hazardous potential and because of their very limited forecast capabilities Earth quakes still represent one of the biggest challenges. Improving the forecasting quality of Earth quakes has been the subject of intensive research for many decades.

There are several hints for Earth quake precursors on the surface as well as in the atmosphere. There is an ongoing discussion whether coordinated observations of surface parameters as well as specific radiation emitted by atmospheric trace gases can help to improve the forecast skill for Earth quakes. Especially the southern part of the Alps and Northern Italy has frequently been affected by Earth quakes in recent years. Thus, research at the VAO facilities can be highly relevant.

4.1.3 Alpine water cycle

The aim of this key topic is to acquire more expertise on the Alpine water balance in order to be able to estimate the future availability of water. Another priority is to study environmental radioactivity in the Alpine region, caused by snow and rainfall.

Challenge 8 Understanding the Alps as a water tower for the pre-Alpine regions under climate change conditions

The Alps collect large amounts of precipitation, are characterized by extensive water storage in snow and ice as well as by above-average run-off and can therefore be regarded as a water tower for the pre-Alpine regions. Climate change induced warming of the Alps results most plausibly in changing precipitation, evapotranspiration, storing behavior and run-off. This will lead to a changing water balance in the Alps and their surrounding regions.

Hydrological investigations will provide quantitative assessments of changes in water availability in alpine and pre-alpine areas under climate change conditions being especially relevant for land-use, energy production and tourism, but also for risk management concerning extreme events like floodings and extended dry periods.

To be addressed are the following questions:

- Does the Alpine storage capacity for water, snow and ice change? If so, how and why and what are the consequences?

- To which amount (including uncertainty ranges) will all other principal components of the water balance (precipitation, evapotranspiration, all sub-types of run-off) probably change in the future (depending on different scenarios for future climate change)?

- Will climate change lead to higher frequencies and/or higher intensities of hydro-meteorological extreme events (floodings and extended dry periods) in the Greater Alpine region?

- How can we reliably distinguish between natural climate variability and robust climate change signals with respect to Alpine water balance and related extreme events?

- What are the hydrological consequences of superimposed impacts from climate change and anthropogenic water use (for land use, energy production and tourism)?

Particular requirements for investigating these questions are

- a quality-controlled hydrological measuring network including a professional gauge station at Partnach-Ursprung and a Double Fence Intercomparison Reference station for solid precipitation as well as extensions of measuring stations between high-alpine and pre-alpine locations.

- Long-term monitoring of hydrological variables including isotopes like HD and ^{18}O.

- Dynamical and statistical downscaling of hydrological variables like percentage of solid precipitation, water storage in snow and ice, seasonal glacier mass balances, run-off from rainfall, snow and ice melting as well as extreme events of both signs (e.g. high and low water levels).

- Improvement and application of hydrological models including both impacts from climate change and anthropogenic water use.

4.1.4 Environment and human health

Persistent hazardous substances, particles or pollen, and also meteorological parameters such as temperature or humidity, can have a negative impact on human health in Alpine regions. They can, for instance, lead to allergies, respiratory diseases or cardiovascular diseases. Long-term studies, analyses, studies and recommendations for appropriate action are therefore of paramount importance.

Challenge 9 Understanding the impact of pollutants, radiation and meteorological stress on human health

Pollutants including biological aerosols (pollen) as well as radiation or meteorological stress (humidity, temperature) are well known to impact the human organism in various ways. For example, cardiovascular problems, diabetes, obstructive pulmonary disease (COPD), asthma, allergies and many more can be caused by such environmental factors. The reaction of the human organism on these factors is very complex and represents the joint effect of various factors.

To be addressed is the question: How does the environment impact human health?

Observations and medical studies at high altitude stations allows, as an example, to study the reaction of the human organism when exposed to comparatively clean air (in terms of pollutants) or to study the reaction on enhanced ultraviolet radiation. Such studies would help to better understand the interaction between the environment and the human organism. Furthermore, studies at higher altitudes also allow some insight into better understanding lung functions.

4.2 Improving the Infrastructure

The basis for competitive research and development is an efficient research infrastructure. The backbones of VAO are observational sites, data archives and computing facilities. As a consequence the focus of VAO is on improving and further developing this infrastructure. Elements of these activities are manifold. They include developing specific technological solutions for operating instrumentation, developing new sensor technologies or measuring platforms (for example UAV's), developing efficient concepts for (meta) data storage, analysis and visualisation, cross-linking different observational sites via information technology etc. Also considered are specific questions concerning the maintenance of buildings/locations located on permafrost.

Challenge 10 Improving the validation of satellite-based measurements through combined in-situ and remote sensing measurements

Several Earth-observing satellites will be launched in the next decade. Especially, Europe is participating to such satellite-based systems through ESA and its COPERNICUS program. It is the intention of ESA and the European Commission to promote the use of satellite-based data especially in the commercial or public sector ("downstream services") also in the Alpine region and its foothills. The acceptance of satellite-based data, however, depends largely on their quality. The validation above the Alps presents a challenge because of the comparatively complex terrain. VAO can contribute to the continuous and even operational validation of such satellite-based instruments.

The challenge therefore is to solve the following scientific and technological questions: The comparison between ground-based and satellite-based measurements needs to take into account the influences of the “miss-distance”, the “miss-time”, and the “observational filter” effects. Solving these problems requires to understand and to know about spatio-temporal variabilities in the atmosphere (trace gases, aerosols, temperature etc.) or on the surface (vegetation, water, ice). Furthermore, it is required to understand and to know about the sensitivities of the instruments that are to be compared against their individual observational geometry.

It is needed to work out the observational filter characteristics of the instruments within VAO to be used for satellite validation and to thoroughly monitor the atmospheric fine structure (e.g. layers of aerosols or plumes of pollutants near their sources).. Numerical modeling (e.g. Chemical-Transport-Models) in its capacity of data assimilation shall be used to reduce the “miss-time” and “miss-distance” problem (therefore, the access to supercomputing performance and also the access to large data centers in order to help handling larger data volumes is crucial). Regions in the atmosphere or on the surface with systematically lower variability shall be mapped and flagged as regions allowing for higher precision for validation. Remote sensing instruments shall be mounted at high altitude positions, where appropriate, allowing for limb-sounding type observations and unmanned aerial vehicles (UAV) equipped with suitable sensors may be operated during satellite overpasses in order to help reducing the “miss-match errors”. Demonstrating the operation of UAVs for satellite validation from a high-altitude station opens new perspectives for international networks (e.g. GAW stations) and also for similar evaluation tasks of atmospheric models.

Additionally, it shall be studied if the measurement of the energy distribution of secondary neutrons in the atmosphere may help to validate satellite-based measurements of soil moisture (see also Challenge 4). Webcams and UAV may provide the necessary link of far remote sensing data to ground observations in the biosphere (see also Challenge 6).

Challenge 11 *Establish a powerful IT-linkage between all observatories, high-performance computing centres and data repositories (further develop AlpEnDAC)*

In the already ongoing effort to link infrastructures that are part of VAO, the Alpine Environmental Data Analysis Centre (AlpEnDAC) has a vital role as a platform for collaboration. It provides an IT-linkage framework between participating infrastructures (observatories, computing and data centres). On this basis the AlpEnDAC sparks initiatives between partners in VAO.

There are many institutions that take part in VAO. This means there are many heterogeneous infrastructures involved in VAO. To foster a deeper collaboration between the participants it is necessary to develop powerful linkages between the respective infrastructures, as is outlined below.

Scientific questions should be addressed using the best and most complete data set. So it is vital to make data available and share it including a set of standardised metadata following an appropriate data policy. The AlpEnDAC provides services for the storage, management and analysis of environmental and research data. The data should be available in a quick, simple and comprehensive manner. To achieve this, modern concepts for capturing, archiving, distributing, referencing and publishing data are in use.

A single entry point to access services and data that may be organized in a non-centralist way (meaning it shouldn't matter where data is stored / services are hosted, as long as they are accessible from the central repository) is provided. This allows easy access to data / services, while every party may keep their contributions under their own control. This means if direct ingestion or mirroring of data into AlpEnDAC is not possible, not efficient or undesired, AlpEnDAC may provide completely transparent access to data stored on remote servers. With an appropriate access-rights management, the scientists' needs in terms of IT security and data protection are addressed.

By now the AlpEnDAC provides an infrastructure that links observatories, HPC Centres and data repositories. Currently, the Leibniz Supercomputing Centre and the ICSU/WMO World Data Center for Remote Sensing of the Atmosphere, WDC-RSAT, hosted by DLR provide large pieces of the IT-backbone of the infrastructure. This way the AlpEnDAC is able to offer large storage capacities, compute power for Services (i.e. operational forecasts) and an easy way to run simulations via a computing on demand model. WDC-RSAT also provides the AlpEnDAC with access to data from satellite observations and other stations and station networks. It is intended to broaden and deepen the AlpEnDAC by including more HPC's and data repositories from partner organisations in order to achieve the highest possible degree of performance.

The AlpEnDAC is not solely an infrastructure or infrastructure provider. It engages in dialogue with the participating scientists and encourages dialogue between these scientists. This means there is not only a sharing of infrastructure and data but also a sharing of know-how and specific expertise, improving the efficiency of research efforts and allowing the participating scientists to tackle "bigger" or more complex problems.

To establish a powerful IT-linkage between the participating infrastructures the following steps are proposed: First there needs to be an exchange of information regarding the infrastructures. This means not only technical information but also information on the administrative and organisational structures in place. This information will be gathered by visiting every major institution doing computational or data-driven science in VAO. These visits, taking the form of well-prepared workshops, should give all parties the possibility to get to know each other on a technical as well as organisational and administrative level.

Subsequently, areas need to be evaluated where collaboration is possible and mutually beneficial (again from a technical and an organisational point of view). On these grounds first simple use cases (like “I want to share my data in the VAO pool” or “I want to use data from institution x in my workflow”) will be developed. Finally concrete steps towards implementing these use cases will we developed.

In a second iteration the implemented use cases will be critically evaluated and modified, if needed. Further questions like “Is the data which is provided collaboratively being used?”, “What can we do to optimise the user experience with the data?”, “Can we collaboratively provide more useful simulations to the scientists?” will be addressed and discussed in workshops and online meetings.

In addition to these concrete steps, there will be a look into the more distant future. A possible co-development of additional tools and services in the context of VAO will be evaluated.

As the collaborative efforts yield the first results, new possibilities arising from these efforts will be made public in the respective meetings and workshops that will be held in the context of VAO. All parties in VAO should be able to benefit from these new possibilities. If educational measures are necessary to harvest the full potential of these new possibilities special workshops and training programs need to be developed and conducted. This way we hope to achieve and foster collaboration not only on an administrative and technical but also on a scientific level.

One main objective is that this VAO infrastructure becomes an integral part of the everyday work flows of scientists participating in VAO. An active user community is essential to keeping the infrastructure alive. Critical feedback is encouraged to make sure the infrastructure is running well and developing in a way that allows addressing future issues / challenges.

In addition to all the practical immediate benefits a further advancement of the AlpEnDAC will improve the visibility of the Virtual Alpine Observatory and all its participants on a European level. This makes the AlpEnDAC a fundamental part of an international VAO strategy.

5 VAO Governance

In order to guide the advancement of the VAO a board consisting of the representatives of participating observatories and facilities and representing their countries has been formed.

Tasks of the VAO-Board are:

- Preparing the strategy to develop VAO further
- Exchanging information about ongoing and planned research projects to avoid duplication of work, and to allow for collaboration and sharing of data and knowledge
- Supporting uniform processes for usage of instruments, data validation, data gathering
- Informing the national administrative bodies about VAO
- Informing the national scientific community about VAO
- Helping to increase VAO's visibility (e.g., by preparing activity reports for politicians, stakeholders, the general public)
- Organizing regular scientific and technological VAO symposia

The VAO-Board is supported by the VAO Office. The VAO Office represents a central contact point for scientists and stakeholders to get information about available data, whom to contact in order to get access to station's infrastructures, etc.

List of VAO-Board-Members

Austria	Meteorologisches Observatorium Hoher Sonnblick (ZAMG)	Dr. Elke Ludewig	Head of ZAMG Sonnblick Observatory
France	Observatoire des Sciences de l'Univers de Grenoble (OSUG)	Dr. Michel Dietrich PD Dr. Hans-Werner Jacobi	Directeur de Recherche au CNRS, ISTerre, Directeur OSUG Directeur Adjoint de l'Observatoire des Sciences de l'Univers de Grenoble
Germany	Umweltforschungsstation Schneefernerhaus (UFS)	Markus Neumann Prof. Dr. Michael Bittner Dr. Simone von Loewenstern	Managing Director, UFS GmbH UFS Scientific Coordinator UFS Consortium Board at Bavarian State Ministry of the Environment and Consumer Protection
Italy	EURAC Research	Dr. Marc Zebisch	Head of Institute for Earth Observation
Slovenia	Slovenian Environment Agency University of Otlica	Dr. Klemen Bergant Prof. Dr. Samo Stanic	Director of Meteorological Office, Ljubiljana Head of the Centre for Atmospheric research, University of Nova Gorica
Switzerland	Höhenforschungsstation Jungfraujoch Gornergrat (HFSJG)	Prof. Dr. Markus Leuenberger Prof. Dr. Silvio Decurtins	Director HFSJG, Climate and Environmental Physics, Physics Institute, University of Bern President HFSJG, Department of Chemistry and Biochemistry, University of Bern

List of associated VAO-Partners

Georgia	Abastumani Astrophysical Observatory (AAO)	Prof. Dr. Goderdzi Didebulidze	Ilia State University, Tiblisi
Norway	Arctic Lidar Observatory for Middle Atmospheric Research (ALOMAR)	Dr. Michael Gausa	Head of Technology Department, Director of Sciences and Technology

Scientific challenges - Overview

The overarching scientific challenges that the VAO will address in the upcoming decade are part of the following research fields:

I) Atmospheric and climatic variability	
Challenge 1	Understanding the coupling mechanisms among atmosphere, clouds and land surface and their changes in view of impact on the greenhouse effect
Challenge 2	Understanding the impact of the Alps (mountains) on atmospheric dynamics in the middle atmosphere (10-100km height)
Challenge 3	Understanding if there is an impact of climate change on the characteristics of cosmic radiation in the atmosphere
Challenge 4	Monitoring and understanding of the contamination of the Alps
Challenge 5	Impact of meteorological extremes in the Alps and surrounding regions on natural hazards
II) Climate impact on Alpine environment, hazards and risks	
Challenge 6	Understanding the dynamics of the Alpine vegetation in response to climate (change)
Challenge 7	Interrelation of the environment with seismic activity
III) Alpine water cycle	
Challenge 8	Understanding the Alps as a water tower for the pre-Alpine regions under climate change conditions
IV) Environment and human health	
Challenge 9	Understanding the impact of pollutants, radiation and meteorological stress on human health
V) Improving the Infrastructure	
Challenge 10	Improving the validation of satellite-based measurements through in-situ and remote sensing measurements
Challenge 11	Establish a powerful IT-linkage between all observatories, high-performance computing centres and data repositories (e.g. further develop AlpEnDAC)