GCOS
KEEPING WATCH OVER OUR CLIMATE

WMO

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Intergovernmental Oceanographic Commission

International Science Council

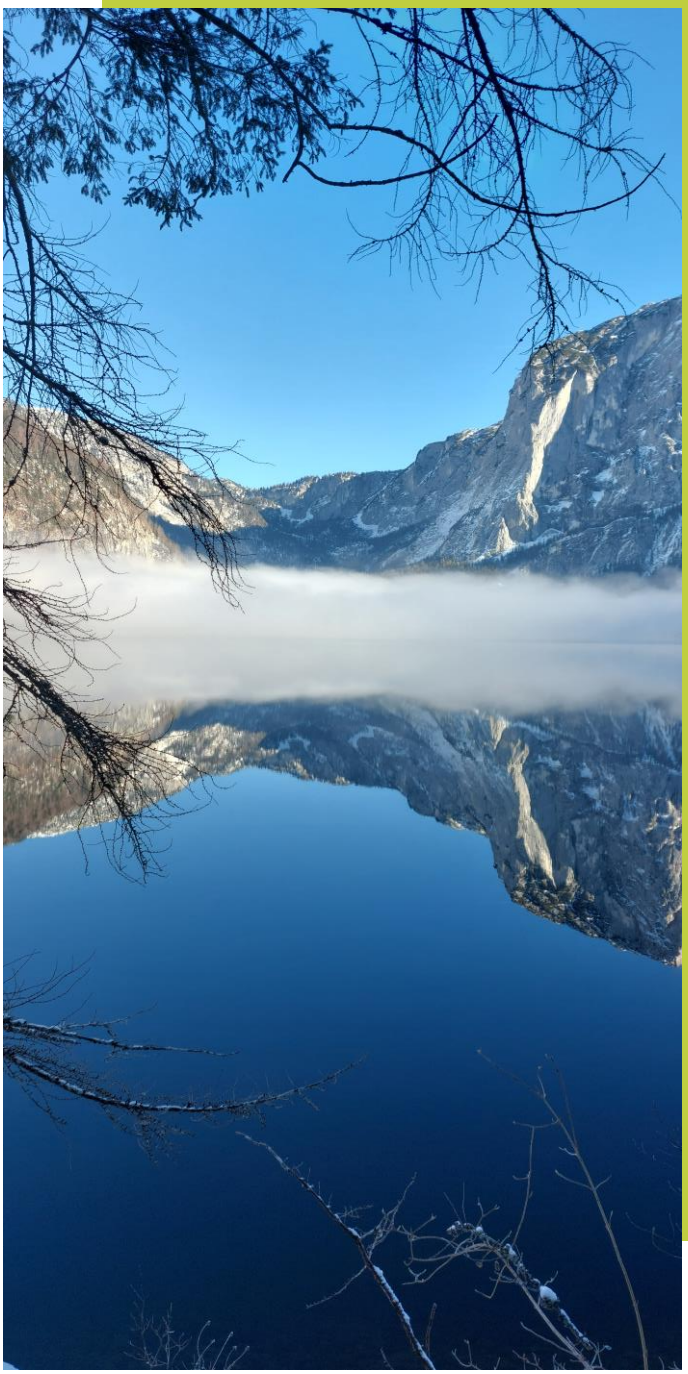
UN environment programme

GCOS

Global Climate Observing System

Austrian Inventory Report

2025



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Foreword

In recent years, extreme weather events such as droughts, storm damage, heavy rainfall and forest fires have increased dramatically, causing billions of euros of damage worldwide each year. Policy makers have to face changing climate conditions and their possible impact on various aspects of life.

A deep understanding of the climate system's past, present, and future is essential for making informed decisions regarding climate adaptation and protection measures.

Long-term series of climate measurements are essential for our knowledge of the interactions between the climate, ecosystems and human activities. In Austria, we can count on long-standing meteorological data collections, the longest starting in 1767 at Kremsmünster, which builds the basis for research on climate change. Not only temporal, but also spatial continuity is the deciding factor for successful climate monitoring. Therefore, supporting and promoting monitoring networks on an international level is a major task when dealing with climate change.

The Global Climate Observing System (GCOS) of the World Meteorological Organization (WMO) is such an effort. It was founded to identify and coordinate monitoring networks worldwide. It also supports countries in setting up monitoring networks especially when public funding is poor.

Although in Europe public funding of monitoring networks is relatively high, even in Austria important initiatives like glacier or permafrost monitoring are partly depending on third party funding. This creates not only financial uncertainties, but also possible discontinuations of valuable long time series.

This report is the result of the effort, taken on by GeoSphere Austria in its role as Austria's national GCOS coordinator, to provide an overview of various programs for collecting the essential climate variables in Austria. The report may help to facilitate the access and interdisciplinary use of this data.

We want to thank all national partner institutions and organizations for their productive collaboration on the Austrian GCOS Report and the readers for their interest.

Ing. Mag. Sylvia Bauer-Beck

Administrative Director General

Dr. Andreas Schaffhauser

Scientific Director General

Introduction

Figure 1: Wagrain-Tappenkarsee

The landscape of Austria consists of high mountains and valleys in the west and lowlands in the east. While this composition may be perceived as quite idyllic, it poses a major challenge when it comes to measuring meteorological parameters and monitoring long-term climate changes. For example, observing meteorological parameters in the extreme conditions of an Alpine summit, places higher demands on the instruments used.

In Austria, several institutions have their own observation networks designed for their specific needs. These networks form the fundamental basis for understanding the effects of climate change.

Different aspects of change need to be monitored, ranging from landslides due to melting permafrost to forests or plants affected by pests. These changes and modifications in our environment make it increasingly important to document the changes and share experiences with other countries.

The Global Climate Observing System (GCOS) is a Co-sponsored Program of the World Meteorological Organisation (WMO). Its aim is the collection and provision of climate observation data sets to facilitate improved management of the impacts and consequences of climate variability and present and future climate change.

National coordination is essential for a global climate monitoring system. Therefore, a national GCOS coordination office was established in Austria in 2012 (Austrian GCOS Secretariat), located at the national weather service, GeoSphere Austria. Regular meetings have been set up, with the participation of several institutions, where their financial problems and difficulties in the measurement of essential climate variables are discussed.

This report provides an overview of climate monitoring in Austria in cooperation with governmental institutes, universities and alpine organisations. The first part gives short introductions to the participating institutes. The second part is divided into two climate monitoring areas, the atmospheric climate observing system and the terrestrial climate observing system.

Each institution presents its climate observation network and measurement methods. An information sheet summarises where to find the data sets and lists the contact person appointed by the institution.

This document is a record of climate observations in Austria according to the Implementation Plan of the WMO Global Climate Observing System (GCOS).

More information on the impacts of climate change in Austria can be found in the APCC Assessment Report on Climate Change in Austria 2.0 – AAR2, which is based on the IPCC structure and process. In this comprehensive work, renowned experts from the Austrian climate community present the state of knowledge on climate change in Austria and its impacts, mitigation and adaptation strategies, as well as the known political, economic and social issues involved.

Essential Climate Variables of GCOS

The Global Climate Observing System (GCOS) currently specifies 55 Essential Climate Variables (ECVs). An Essential Climate Variable (ECV) is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate.

An ECV must be critical to the characterisation of the climate system and its changes. It is technically feasible to observe or derive the variable on a global scale using proven, scientifically understood methods. The generation and archiving of data on the variable is affordable, relying mainly on coordinated observing systems using proven technology and, where possible, making use of historical data sets.

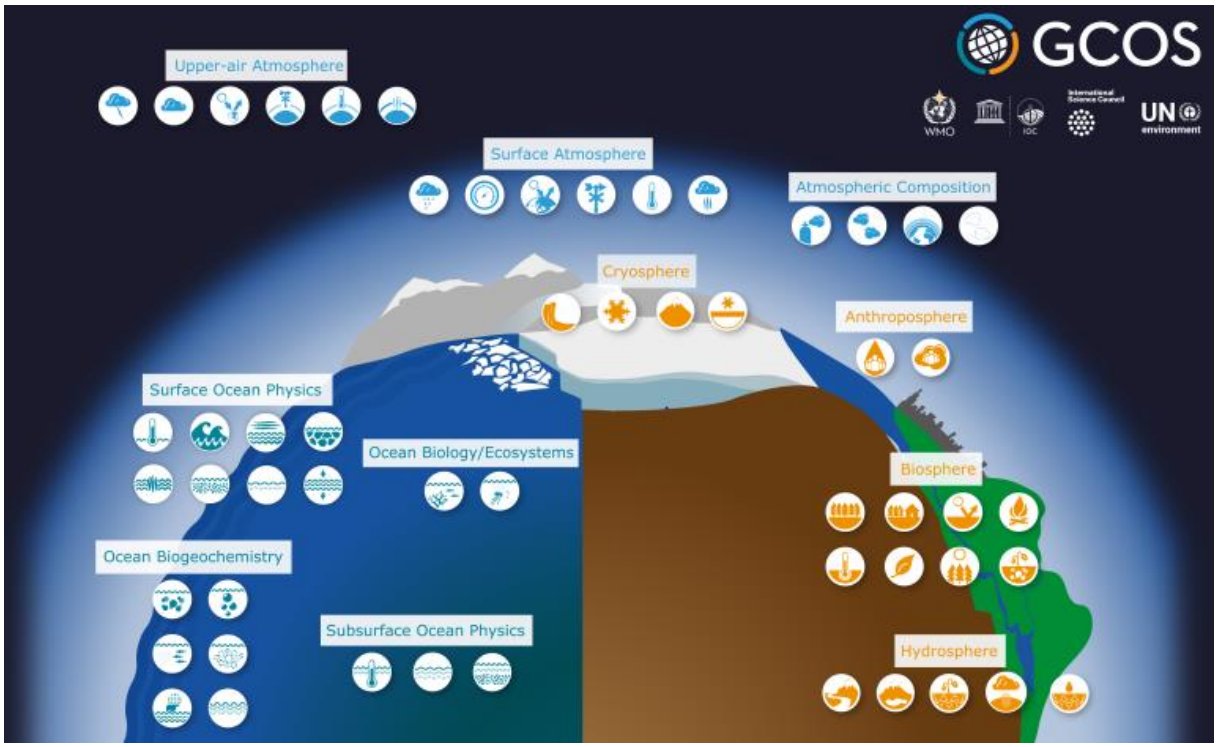


Figure 2: Essential Climate Variables
(https://gcos.wmo.int/site/global-climate-observing-system-gcos/essential-climate-variables)

The following tables give an overview of all measured ECVs in Austria. Since there are no oceanic observations in Austria, the respective ECVs are omitted from the tables.

Essential Climate Variables - GCOS							
Report	Institution	Atmosphere - Surface					
		Precipitation	Pressure	Radiation budget	Temperature	Water vapour (Humidity)	Wind speed and direction
VAMES	Austro Control	x	x		x	x	x
Aerodrome Met stations	Austro Control	x	x		x	x	x
Austrian Weather Radar Network	Austro Control	x					
Tuxer Alps	BFW - Austrian Research Center for Forests	x		x	x	x	x
Torrent Research Areas	BFW - Austrian Research Center for Forests	x		x	x	x	x
Monitoring hydrological data of forest ecosystems	BFW - Austrian Research Center for Forests	x			x	x	x
UV-Radiation	BOKU – University of Natural Resources and Life Sciences			x			
Air quality monitoring of the federal states	Amt der Burgenländischen Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Amt der Kärntner Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Amt der Niederösterreichischen Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Amt der Oberösterreichischen Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Amt der Salzburger Landesregierung			x	x	x	x

Table 1: ECV – Atmosphere Surface

Essential Climate Variables - GCOS							
Report	Institution	Atmosphere - Surface					
		Precipitation	Pressure	Radiation budget	Temperature	Water vapour (Humidity)	Wind speed and direction
Air quality monitoring of the federal states	Amt der Steiermärkischen Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Amt der Tiroler Landesregierung			x	x	x	x
Air quality monitoring of the federal states	Institut für Umwelt und Lebensmittelsicherheit des Landes Vorarlberg	x		x	x	x	x
Air quality monitoring of the federal states	Vienna's Municipal Department 22	x	x	x	x	x	x
Air quality monitoring network	Environment Agency Austria	x	x	x	x	x	x
Climate Monitoring	GeoSphere Austria	x	x	x	x	x	x
Sonnblick Observatory	GeoSphere Austria	x	x	x	x	x	x
ARGE LWD – Austrian snow station network	Avalanche warning services in Austria LWD	x			x	x	x
BSRN - Baseline Surface Radiation Network	GeoSphere Austria			x			
ARAD - Solar and terrestrial radiation monitoring networks	GeoSphere Austria			x			
Climate Monitoring Hydrological Service of Austria	Hydrological Service of Austria	x			x	x	x
ISMN - In situ soil moisture observations	TU Wien	x			x		

Table 2: ECV – Atmosphere Surface

Essential Climate Variables - GCOS						
Report	Institution	Upper Atmosphere				
		Earth radiation budget	Lightning	Temperature	Water vapour	Wind speed and direction
Radiosonde	Austro Control			x	x	x
UV-Radiation	BOKU - University of Natural Resources and Life Sciences	x				
Radiosonde	Geosphere Austria			x	x	x
Sonnblick Observatory	Geosphere Austria	x		x	x	x
BSRN - Baseline Surface Radiation Network	Geosphere Austria	x				
ARAD - Solar and terrestrial radiation monitoring networks	Geosphere Austria	x				

Table 3: ECV – Upper Atmosphere

Essential Climate Variables – GCOS						
Report	Institution	Atmospheric Composition				
		Aerosols	Carbon dioxide, methane and other greenhouse gases	Ozone	Precursors for aerosols and ozone	Clouds
VAMES	Austro Control					x
Aerodrome Met stations	Austro Control					x
Air quality monitoring of the federal states	Amt der Burgenländischen Landesregierung	x		x	x	

Table 4: ECV – Atmospheric Composition

Essential Climate Variables – GCOS						
Report	**Institution**	**Atmospheric Composition**				
		Aerosols	**Carbon dioxide, methane and other greenhouse gases**	**Ozone**	**Precursors for aerosols and ozone**	**Clouds**
Air quality monitoring of the federal states	Amt der Kärntner Landesregierung	x		x	x	
Air quality monitoring of the federal states	Amt der Niederösterreichischen Landesregierung	x		x	x	
Air quality monitoring of the federal states	Amt der Oberösterreichischen Landesregierung	x		x	x	
Air quality monitoring of the federal states	Amt der Salzburger Landesregierung	x		x	x	
Air quality monitoring of the federal states	Amt der Steiermärkischen Landesregierung	x		x	x	
Air quality monitoring of the federal states	Amt der Tiroler Landesregierung	x		x	x	
Stratospheric Ozone	BOKU - University of Natural Resources and Life Sciences			x		
Air quality monitoring of the federal states	Institut für Umwelt und Lebensmittelsicherheit des Landes Vorarlberg	x		x	x	
Air quality monitoring of the federal states	Vienna's Municipal Department 22	x		x	x	
Air quality monitoring network	Environment Agency Austria	x	x	x	x	
Sonnblick Observatory	GeoSphere Austria	x	x	x	x	x
Climate Monitoring	GeoSphere Austria					x

Table 5: ECV – Atmospheric Composition

Essential Climate Variables - GCOS						
Report	Institution	Land Hydrology				
		Groundwater	Lakes	River discharge	Terrestrial water storage	Soil moisture
Torrent Research Areas	BFW- Austrian Research Center for Forests	x		x		
Tuxer Alps	BFW- Austrian Research Center for Forests			x		
Monitoring hydrological data of forest ecosystem	BFW- Austrian Research Center for Forests					x
Terrestrial Water Monitoring Hydrographical Service of Austria	Hydrological Service of Austria	x	x	x	x	x
ISMN- In situ soil moisture observations	BfG – Bundesanstalt für Gewässerkunde (D), TU Wien					x
ESA CCI and C3S Soil Moisture Climate Data Records	TU Wien					x
ASCAT surface soil moisture data records	Tu Wien, GeoSphere Austria					x

Table 6: ECV – Land Hydrology

Essential Climate Variables – GCOS					
Report	Institution	Land Cryosphere			
		Glaciers	Ice sheets and ice shelves	Permafrost	Snow
Glacier Monitoring Program	Austrian Alpine Club	x			
ARGE LWD – Austrian snow station network	Avalanche warning services in Austria LWD				x
Torrent Research Areas	BFW- Austrian Research Center for Forests				x
Tuxer Alps	BFW- Austrian Research Center for Forests				x
Snow Monitoring	ENVEO IT GmbH				x
Glaciers, Ice Sheets and Ice Shelves	ENVEO IT GmbH	x	x		
Borehole temperature monitoring at 'Open-Air-Lab Kitzsteinhorn'	Georesearch Forschungsgesellschaft mbH			x	
Sonnblick Observatory	GeoSphere Austria	x		x	x
Snow Monitoring	GeoSphere Austria, Hydrological Service of Austria (eHYD)			x	x
Glacier Monitoring	GeoSphere Austria, IGF, ÖAW	x			
Glacier Monitoring	IGF, ÖAW	x			
ISMN- In situ soil moisture observations	BfG – Bundesanstalt für Gewässerkunde (D), TU Wien				x
Snow Measurement Program	TIWAG Tiroler Wasserkraftwerke AG				x
Glacier Gössnitzkees	Graz University of Technology, University of Graz	x			
Permafrost Monitoring	GeoSphere Austria			x	
Graz Permafrost Monitoring Network	Graz University of Technology, University of Graz			x	
Matterhorn Cryosphere Observatory	University of Innsbruck	x		x	

Table 7: ECV – Land Cryosphere

Essential Climate Variables – GCOS									
Institution	Report	Land Biology							
		Above-ground biomass	Albedo	Fire	Faction of absorbed photosynthetically active radiation (FAPAR)	Land cover	Land surface temperature	Leaf area index	Soil carbon
Phenology	GeoSphere Austria							x	
VODCA – The global, long-term microwave vegetation optical depth (VOD) climate archive	TU Wien	x							
National Forest Inventory of Austria	BFW- Austrian Research Center for Forests	x				x		x	

Table 8: ECV – Land Biology

Contributing Institutes

Abteilung Waldschutz/Fachbereich Luftgüte

https://www.tirol.gv.at/umwelt/luftqualitaet

The Tyrolean air-quality-monitoring network is affiliated to the Department of Forest conservation, Office of the Tyrolean Government and is headquartered in Innsbruck Bürgerstraße 36 and Langer Weg 27. The basis for the monitoring network is the "Immissionsschutzgesetz-Luft" as well as the "Ozongesetz" (both laws for ambient air quality). The major tasks of the working group are the measurement and assessment of ambient air pollutant concentrations and to ensure that measurements are of high quality and are comparable over the long term. Measured data provide the main decision support tool in the administrative proceedings to improve the protection of human health, animal and plant life from air pollution.

The air quality network of Tyrol was implemented in 1973. Since then a network of 19 fixed stations has been built up, which is operated by 7 employees at the moment. Air quality data is collected automatically throughout the day and year. The monitoring stations are located in urban agglomerations, near hotspots like motorways and industries but also in rural regions. Because of a close cooperation with the Environment Agency Austria (Umweltbundesamt - UBA) concerning the quality management system all measurements are fully comparable. The collected data are freely available for both, private users and public institutions.

Air Quality Monitoring Network

https://www.salzburg.gv.at/themen/umwelt/luft

The air-measuring network of Salzburg as a part of the environmental department belongs to the local government of Salzburg and is headquartered in the City of Salzburg, Michael-Pacher-Straße 36. The main task of the monitoring network is the execution of the "Immissionsschutzgesetz-Luft" and the "Ozongesetz" (law for ambient air quality). Therefore the main aim of the institution is the control of the permanent protection of human health, animal and plant life, reductions of immissions and preservation of best air quality.

The air quality network of Salzburg started in 1978 with monitoring air quality. Since then a network of 13 fixed stations and about 3 mobile stations has been built up. Data of the main pollutants are collected automatically throughout the day and year. The connected calibration laboratory ensures the high quality of the measured data and is supplemented with the standards of the Environment Agency Austria (UBA).

All data are published daily, monthly and yearly in reports and can be accessed from the webpage.

Amt der Burgenländischen Landesregierung

https://www.burgenland.at/themen/umwelt/luftguete/

The Air Quality Network of Burgenland is a part of the department for natural reserve at the government of Burgenland and is located in Eisenstadt. The main task is to measure air pollution in Burgenland. The Basis for these measurements is the Austrian law for ambient air quality „Immissionsschutzgesetz – Luft“ and the „Ozongesetz“. Therefore the main aim is the control of the permanent protection of human health, animal and plant life, reduction of immissions and preservation of best air quality. The Air Quality Network of Burgenland started in 1994 and only measured ozone and nitrogen dioxide and meteorological data at two measuring points. Since then the network was increased to three fixed stations and three mobile ones, which are now operated by 3 employees. Data are collected automatically throughout the day and year. The monitoring stations are located in urban agglomerations and also in rural regions. The collected data are freely available for both private and public institutions.

Amt der Kärntner Landesregierung

https://www.ktn.gv.at/Themen-AZ/Uebersicht?thema=11

Meteorological measurements within the Provincial Government of Carinthia (Amt der Kärntner Landesregierung) are performed by the Department 8 – Environment, Nature Protection, climate protection coordination - headquartered in Klagenfurt am Wörthersee, Flatschacher Straße 70. With its more than 400 employees the department is responsible for the protection of soil, water and air in the province of Carinthia. The spectrum of the department is broadly diversified with the areas of waste management and environmental remediation, energy management and grants, water rights, water management, hydrography, lakes research, climate protection and adaptation, sustainability, air quality improvement, geology and soil protection, strategic environmental assessment, nature protection, environmental control, acoustic and electrical engineering, safety and process engineering, radiation protection, shipping and motor and air traffic. Through the use of synergies of all these areas the department is the main contact point for all matters relating to environment, water, nature and energy in Carinthia.

ARGE LWD

http://www.lawinen.at/

The ARGE LWD is an informal consortium linking all regional avalanche warning services in Austria. The ARGE LWD includes the avalanche warning services of the Provinces Vorarlberg, Tyrol, Salzburg, Carinthia, Styria, Upper and Lower Austria. Most avalanche warning services were founded in the mid-1960s and provide since the early days public avalanche forecasting or warning products and safety advisories. The most prominent product is the avalanche bulletin, which is issued on a daily basis during winter season by the regional avalanche forecasting centres for their Province. In order to provide high-quality avalanche danger assessments throughout the warning products, the various regional Avalanche Warning Services established and continuously maintain an intensive network of observers and automated measurements. In total, the consortium obtains snow measurements from 186 automated weather stations, which represents one of the densest snow and weather station networks in mountainous terrain worldwide. ARGE LWD’s experts represent Austria in numerous international organizations and associations such as e.g. the EAWS Technical Advisory Board and ISSW Steering Committee.

Austrian Alpine Club

https://www.alpenverein.at/portal/museum-archiv/gletschermessdienst/index.php
https://www.facebook.com/alpenverein

The “Oesterreischer Alpenverein” was founded in 1862, merged with the “Deutscher Alpenverein” in 1873 and was re-founded in 1945 as “Österreichischer Alpenverein” (Austrian Alpine Club) following WW2. The Austrian Alpine Club initiated a glacier monitoring program for in 1891. Within this program, focus is given on length changes but at some selected glaciers surface elevation as well as velocity changes are monitored as well. Glacier length changes are measured annually within the framework of this program at some 90-100 glaciers depending on field work conditions. This program is one of the longest glacier monitoring programs. Regular measurements of length variations in Austria at single glaciers have been started even earlier. Since 1879, glaciological surveys have been carried out almost annually at for instance Pasterze Glacier, Glocknergruppe (Glockner Mountains) representing one of the longest time series of continuous glacier monitoring worldwide. The glacier monitoring service is currently managed voluntarily by Gerhard Karl Lieb and Andreas Kellerer-Pirklbauer (both from the Department of Geography and Regional Science, University of Graz). Currently, some 25 volunteers with their individual teams carry out the length changes. That's around 10% of all Austrian glaciers. The results are presented annually at a press conference, published in the magazine “Bergauf” (run by the Austrian Alpine Club) and forwarded to the international research community (such as the World Glacier Monitoring Service https://wgms.ch/). Data is also freely accessible on the digital library system for data PANGAEA.

Austrian Research Center for Forests

https://www.bfw.gv.at/

The Austrian Research Centre for Forests (BFW) is a multidisciplinary research and training institution and holds the legal status of an institution under public law. The BFW supports the economic, ecological and socially sustainable development of the society and its environment through the preparation of scientific guidelines and the dissemination of knowledge concerning the multi-functional utilisation of natural resources. In pursuance of research, monitoring and knowledge transfer the BFW focuses its work on the strategic and thematic fields of forest management, forest and climate, bioenergy, biodiversity and natural hazards. The BFW is organized in six Research Departments, two Forest Training Centres, and several internal service units. Currently the BFW employs approximately 380 people of which about 150 are researchers. At the European level, the BFW and its Departments provide leadership in fields of forest inventory, harmonization and monitoring issues, forest growth modelling and soil carbon and nitrogen cycling and modelling with a special focus on soil ecology.

Austro Control GmbH

https://www.austrocontrol.at/

"Austro Control GmbH" (ACG) was founded in 1994 as a privatized successor organization of the former "Federal Office for Civil Aviation" which had been founded in 1955. ACG is an air navigation service provider responsible for the provision of air traffic control services, including the technical infrastructure, aeronautical information management services as well as aeronautical meteorological services for airspace users. The sole shareholder of ACG is the State of Austria and its Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK). The headquarter building as well as the ATCCV (Air Traffic Control Centre Vienna) are located in Vienna, where also the MET-Headquarters can be found. The operational meteorological service is currently in the process of being centralized at the MET Operations Center Vienna, which is located at the Vienna airport, from where aviation meteorological reports and forecasts and warnings for all airports are going to be provided. This process is going to be finalized in July 2024. Beside the observations at the six Austrian international airports ACG operates, in close cooperation with GeoSphere Austria, the fully automated VAMES network, consisting of 50 stations. ACG experts represent Austria in international organizations like ICAO.

ENVEO-Environmental Earth Observation Information Technology GmbH

http://www.enveo.at/

ENVEO-Environmental Earth Observation Information Technology GmbH in Innsbruck, Austria, is an engineering company founded in 2001 with main business activities in the field of remote sensing research and services in climate monitoring, hydrology, meteorology, and cryospheric studies. The scope of activities and expertise comprises the development of techniques for remote sensing data analysis and satellite data exploitation, including product generation and services for snow and glacier monitoring, hydrology and water management, polar research, and geo-hazard monitoring. From the beginning ENVEO has also contributed to the development of concepts and techniques for advanced satellite systems in environmental monitoring. Climate related products generated from satellite data within ESA and EC contracts, made available to the public, include time series of snow cover extent with global and regional coverage, regional maps of glacier area extent and surface velocity, and maps of ice motion covering the Greenland and Antarctic ice sheets.

GEORESEARCH Forschungsgesellschaft

https://www.georesearch.ac.at

GEORESEARCH is a private, non-profit research institution with core competencies in geomorphology, geoinformatics, and remote sensing. GEORESEARCH focuses on high-alpine regions and investigates climate-driven surface and subsurface changes, related natural hazards and their impacts on lives and assets. GEORESEARCH was founded in 2016 and has since then collaborated with more than 50 national and international research partners and has supported governmental institutions and private enterprises with tailored research and knowledge transfer to reduce natural hazards and to strengthen climate resilience. Research activities have included rock slope stability assessments, landslide monitoring and early warning, glacier and permafrost degradation studies, quantitative risk analyses, geophysical investigations and InSAR/remote sensing analyses.

GeoSphere Austria

https://www.geosphere.at

GeoSphere Austria is the Federal Institute for Geology, Geophysics, Climatology and Meteorology since January 1, 2023. It was formed by the merger of the Geologische Bundesanstalt (GBA) and the Zentralanstalt für Meteorologie und Geodynamik (ZAMG). As the national geological, geophysical, climatological and meteorological service, GeoSphere Austria plays an important role in increasing Austria's resilience and disaster preparedness. By contributing to a prevention-oriented approach to climate change, Geosphere Austria aims to secure a sustainable development of Austria. GeoSphere Austria employs about 500 people, with locations in Vienna at the Hohe Warte and the Neulinggasse. Regional offices are located in Linz, Salzburg, Innsbruck, Graz and Klagenfurt. In addition, GeoSphere Austria operates the Sonnblick Observatory in Salzburg, the Conrad Observatory near Pernitz and a geophysical test site near Melk (both in Lower Austria).

Graz University of Technology

https://www.tugraz.at/
https://www.facebook.com/tugraz

The Graz University of Technology (German: Technische Universität Graz, short TU Graz) is a public research university located in Styria, Austria. It was founded in 1811 by Archduke John of Austria and is the oldest science and technology research and educational institute in Austria. It currently comprises seven faculties/96 institutes and is a public university. It offers 19 bachelor's and 36 master's study programmes (of which 20 are in English) across all technology and natural sciences disciplines. Doctoral training is organised in 14 English-speaking doctoral schools. The university has more than 13,000 students, and around 1,900 students graduate every year. The Graz University of Technology and the University of Graz (UNI Graz) co-operate in teaching and research of natural sciences. The university has a staff of 3,935. Research areas are combined in five fields of expertise. TU Graz, the University of Leoben and TU Wien form the network Austrian Universities of Technology (TU Austria) with more than 45,000 students and 11,000 staff. The Institute of Geodesy (IfG) was founded in 2015 and covers main topics in geodesy. Research and teaching are related to satellite- and airborne-based techniques and applications, geospatial data analysis, location-based services, environmental monitoring and Earth system modeling. The institute consists of four working groups (WGs), i.e., Navigation, Remote Sensing and Photogrammetry, Geoinformation, and Theoretical Geodesy and Satellite Geodesy. The working group on Remote Sensing and Photogrammetry focusses on six mayor research topics, i.e., Photogrammetry and Digital Elevation Models (DEMs), Surface Stability & Changes, Machine Learning, Cryosphere, Mountain Hazards, and Cultural Heritage Documentation.

HYDRO Austria

https://ehyd.gv.at/

https://info.bml.gv.at/themen/wasser/wasser-oesterreich/hydrographie

Hydrographical Service of Austria (HYDRO Austria) was founded in 1894 and is tasked with quantification of the water cycle in the country. The Division Water Balance (Hydrographical Central Bureau) is part of the Federal Ministry of Agriculture, Forestry, Regions and Water Management (BML http://www.bml.gv.at) and coordinates the work of the Hydrographical Services in the nine provincial governments. The Hydrographical Service of Austria currently operates the largest hydro-meteorological monitoring network in Austria. The network consists of 891 discharge, 963 precipitation and 3954 groundwater stations. Acquisition, processing and validation of hydrological data is consistent across the organisation.

Hydrographical Central Bureau publishes monthly and yearly reports on the water cycle in the Austrian Water Balance Bulletin (Wasserhaushalt Österreich) and Austrian Hydrographical Yearbook (Hydrographisches Jahrbuch von Österreich), respectively.

IGF

https://www.oeaw.ac.at/

The Institute for Interdisciplinary Mountain Research of the Austrian Academy of Sciences is investigating the effects of global change on mountain regions. Climate change and globalization in terms of the relations of humans with the environment in cultural landscapes, mountain cities and in protected mountain areas are the subject of disciplinary, but also inter- and transdisciplinary research. The disciplinary research in cryospheric sciences focusses on Alpine sites and on process studies which are often based on long time series and are aiming at developing and validating tools and methods for application to the world's mountain glaciers.

LUIS – Steiermärkisches Luftgütemessnetz

https://www.umwelt.steiermark.at/

The Styrian Air Quality Network is part of the regional government of Styria/Austria. The main task of the monitoring network are measurements of ambient air quality due to the EU air Quality Directive (2008/50/EC) and the Austrian law for ambient air quality "Immissionsschutzgesetz Luft". T Therefore, the main aim of the air quality measurement network is to monitor pollutant concentrations to permanently protect human health, animal and plant life, reduce emissions and maintain the best air quality.

The air quality network of Styria started in the late 1970s with measurement of SO_2 at industrial hot spots. Since 1989 all data were stored in our Air Quality Database. Now a network of 38 39 fixed stations and 3 mobile stations has been built up, which is currently operated by five employees. The monitoring stations are located in urban agglomerations, near traffic routes and industrial sites but also in rural regions. Because of a close cooperation with the Environment Agency Austria (Umweltbundesamt - UBA) concerning the quality management system the air quality measurements are fully comparable. The collected data are freely available for both private and public institutions.

NUMBIS - NÖ Luftgütemessnetz

https://www.noe.gv.at/luft

The NÖ Luftgütemessnetz is affiliated to the Amt der NÖ Landesregierung and is headquartered in St. Pölten, Landhausplatz 1. The main task of the monitoring network is the execution of the "Immissionsschutzgesetz Luft" (law for ambient air quality). Therefore the main aim of the institution is the control of the permanent protection of human health, animal and plant life, reductions of immissions and preservation of best air quality.

The air quality network of Lower Austria started in 1984 with monitoring air quality. Since then a network of 38 fixed stations and 4 mobile stations has been built up, which is now operated by six employees. Data are collected automatically throughout the day and year. The monitoring stations are located in urban agglomerations, near hotspots like motorways and industries and also in rural regions. Because of a close cooperation with the Environment Agency Austria (Umweltbundesamt - UBA) concerning the quality management system the measurements are fully comparable. The collected data are freely available for both private and public institutions.

Oberösterreichisches Luftmessnetz

https://www.land-oberoesterreich.gv.at/657.htm

The Upper Austrian air-measuring network belongs to the office of the Upper Austrian government and is headquartered in Linz, Goethestraße 86. The main task of the monitoring network is the execution of the "Immissionsschutzgesetz - Luft" (law for ambient air quality). Therefore the main aim of the institution is the control of the permanent protection of human health, animal and plant life, reductions of immissions and preservation of best air quality.

The air quality network of Upper Austria started in 1977 with monitoring air quality. Since then a network of 15 fixed stations and about 4 mobile stations has been built up, which is now operated by twelve employees. Data of the main pollutants are collected automatically throughout the day and year. The connected calibration laboratory is a European reference laboratory in the Aquila network.

For other pollutants samples are collected and analysed in our laboratory. The monitoring stations are located in urban agglomerations, near hotspots like motorways and industries and also in rural regions. The collected data are freely available for both private and public institutions.

Umweltbundesamt

https://www.umweltbundesamt.at/

With more than 600 staff members from 55 scientific disciplines, the Environment Agency Austria is the largest organisation of experts in the environment sector in Austria and a leading adviser in environmental matters. The Environment Agency builds bridges between the economy, science and politics at national and international level and develops perspectives on the sustainable development of society.

The Environment Agency Austria has a demonstrable track record of successful projects in more than 60 countries – from the new EU Member States to the Western Balkans, the Middle East, the Maghreb countries and Asia. In its capacity as adviser the Environment Agency Austria advises UN and EU institutions and is active as a partner in more than 200 national, European and international networks, bodies, and working groups.

Umweltinstitut Vorarlberg

https://vorarlberg.at/-/luftgueteueberwachung-in-vorarlberg

Ambient air quality monitoring has been carried out in Vorarlberg since the 1970s. Initially, classical air pollutants like sulfur dioxide and carbon monoxide were our main concern. At the end of the 1980s the ozone problem was recognized and remains to this day, a central theme. Our interests further include a particular concern for traffic caused air pollution by nitrogen dioxides, particulate matter, carbon monoxide and benzene. Together with results from meteorological investigations, air quality data provide the essential basis for developing measures to maintain clean air. Data on ambient air concentrations are recorded at stationary and mobile measuring sites and analysed in the air-quality-monitoring information-centre of the Environmental Institute.

Activities:

- operating the ambient air-quality monitoring network and continuous monitoring and assessment of air-quality
- problem oriented air-quality investigations
- calculation of the dispersion of air pollutants
- determining the causes and consequences of air pollution
- documenting and publishing air quality data
- producing air quality assessment reports

University of Graz

https://www.uni-graz.at
https://www.facebook.com/universitaetgraz

The University of Graz was founded in 1585 and is therefore Austria's second oldest university. Many excellent scientists, amongst them six Nobel laureates, have taught and researched at this university. With some 30,000 students and 4,700 employees this university is one of the largest in the country. The university is divided into six faculties, the two largest ones are the Faculty of Arts and Humanities and the Faculty of Natural Sciences. The other faculties are the Faculty of Law; the Faculty of Business, Economic and Social sciences; the Faculty of Environmental, Regional and Educational Sciences; and the Faculty of Catholic Theology. In total, more than 70 institutes and departments are related to these faculties. The Department of Geography and Regional Science, linked to the Faculty of Environmental, Regional and Educational Sciences, has a strong research history related to the effects of climate change on mountains and arctic regions. This department focuses on a strong cooperation with a variety of national and international partners in the field of environmental issues including glaciers and permafrost, sustainable development and educational matters. In the broad field of glaciology, several scientists at this department carry out field, remote sensing and modelling studies at different glacier and permafrost areas in the Austrian Alps but also the high Arctic. In addition, the Department of Earth Sciences, linked to the Faculty of Natural Sciences has a strong background and long history in alpine hydrogeology. Research has been conducted particularly related to runoff dynamics and storage capacity of (high-) alpine aquifers and their impact on downstream rivers for more than 15 years. Aquifer and thus catchment characterisation is also focused on periglacial landforms (mainly on rock glaciers) in crystalline and karstic environment that is further analysed / applied in terms of climate change impact.

University of Innsbruck

https://www.uibk.ac.at/
http://data.permasense.ch
http://www.permos.ch

The University of Innsbruck (UIBK) has a dedicated research focus area on Mountain Regions structured into several research centers. The Networked Embedded Sensing Center at UIBK specializes on researching and monitoring fundamentals of the mountain cryosphere, especially at very high altitude and in steep topography. Focus of our activities since the mid 2000's is in the Western Alps. Among others, together with further international partners we are entertaining the Matterhorn Cryosphere Lab, a cross-border, multi-decade observatory covering a full North to South transect from base to summit including ground as well as atmosphere variables. For this purpose a publicly accessible datacenter is operated in Innsbruck. Furthermore we are active as contractual partner in the Swiss Permafrost Monitoring Network PERMOS where specifically we are responsible for monitoring and developing the Rock Glacier Velocity (RGV) ECVs with a total of ~40 permanent GNSS stations. Outside the GCOS objectives we are additionally active in seismic monitoring of high mountain areas.

University of Natural Resources and Life Sciences (BOKU)

https://boku.ac.at/en/

The University of Natural Resources and Life Sciences or BOKU, Vienna was founded in 1872. The first study programmes offered were Agriculture, Forestry and Environmental Engineering.

The University of Natural Resources and Life Sciences, Vienna, the "Alma Mater Viridis", is the University of Sustainability and Life Sciences. It is BOKU's task to make a key contribution to the conservation and protection of resources for future generations through its wide variety of expertise. Combining natural sciences, engineering plus social and economic sciences, its aim is to increase knowledge of the ecologically and economically sustainable use of natural resources. With 11,000 students and 2,900 staff, BOKU is one of Europe's leading life science universities.

University of Salzburg

https://www.plus.ac.at/geoinformatik/forschung/

The University of Salzburg is proud of its long history in glaciology and high mountain research. Today the LTER site Oberes Stubachtal is a long-range research site with a main focus on the measurement of glacier front variation and annual mass balance, going along with water budget estimations within the catchment area of the lake Weißsee. The research site, including the Stubacher Sonnblickkees (SSK) is located in the Hohe Tauern Range (Eastern Alps) in the south of Salzburg Province. The mass balance record was the first one established in the Hohe Tauern region and is one of the two dozen longest series worldwide. For more than 20 years the Interfaculty Department of Geoinformatics (Z_GIS) has supported the research activities and monitoring programs at Sonnblickkees in many ways: Monitoring glaciers with various data capture and photogrammetric methods as well as geospatial analysis workflows are the key methods.

Vienna University of Technology

https://tuwien.at/mg/geo/rs/
https://www.tuwien.at/

The Vienna University of Technology (TU Wien) was founded in 1815 as „k. k. polytechnisches Institut“, making it the first University of Technology of today’s German-speaking area. TU Wien staff comprises about 140 professors, 3300 scientific staff and 1300 non-scientific staff. Over 28,000 students are enrolled. With its eight faculties – mathematics and geo-information, physics, technical chemistry, informatics, civil engineering, architecture and regional planning, mechanical engineering and business science, electrical engineering, and information technology – TU Wien covers the classic engineering disciplines.

The Department of Geodesy and Geoinformation (GEO) of TU Wien is one of the world-leading research units on retrieving and monitoring soil moisture and other land-surface variables (irrigation, droughts, vegetation, fire risk) by remote sensing and on ground measurements. Many of the algorithms and products developed by the unit have been transferred into operational data services, including the Copernicus Climate Change Service (C3S), ESA’s Climate Change Initiative for Soil Moisture and Anthropogenic Water Use (CCI SM), the International Soil Moisture Network (ISMN), and the free Quality Assurance for Soil Moisture (QA4SM) online validation service. The ISMN, which is the world’s largest database of global in situ soil moisture observations, has been developed, operated and maintained by GEO from 2008 until December 2022.

Vienna’s Air Quality Monitoring Network

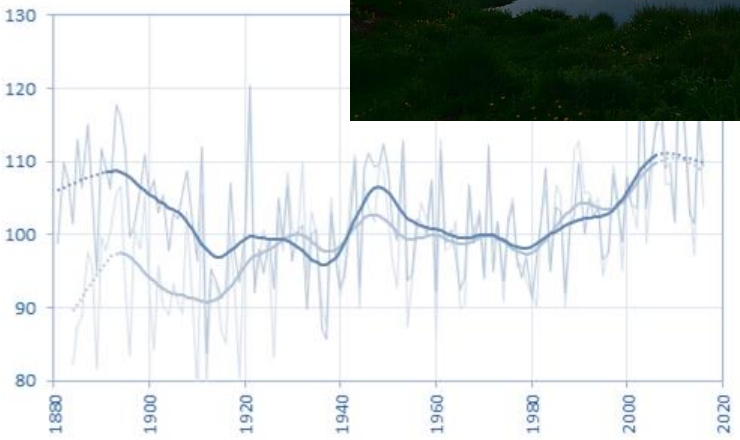
http://www.wien.gv.at/umweltschutz/
https://www.wien.gv.at/umweltschutz/

Vienna´s air quality monitoring network is affiliated to the “Amt der Wiener Landesregierung” and is headquartered in Vienna, Dresdnerstraße 45. The basis for the responsibilities and tasks of the monitoring network is the federal pollution act (Immissionsschutzgesetz Luft). Therefore, the main aim of the institution is to control and manage the permanent protection of human and animal health and plant life, reduction of immission load and preservation of best air quality. The evaluation of measures concerning the reduction of the amount of air pollutants is accomplished with long-term datasets.

Vienna’s Air Monitoring Network is a real-time monitoring system and consists of 17 stationary measurement stations, which are located at roadsides, in the urban background, in industrial zones and in the rural fringes of the city. It provides information on current values of air components (sulfur dioxide, nitrogen dioxide, carbon monoxide, ground-level ozone and particulate matter). Current hourly average values are accessible on the websites of the “Environmental Protection in Vienna” (Municipal Department 22) and the “Environment Agency Austria”.

In addition to the collection, recording and analysis of air pollutant values, meteorological parameters are also measured (wind direction, wind velocity, air temperature, air pressure, sunshine duration, precipitation). All datasets are based on half-hourly average values and the longest series extend back to 1986.

The data providers of the federate states in Austria are responsible for the quality of their own data. Because of a comprehensive quality management system and the close cooperation with the Environment Agency Austria (Umweltbundesamt - UBA), measurements are fully comparable. The collected data are freely available for both private users and public institutions.



Atmospheric Observations

Surface

Climate Monitoring GeoSphere Austria

Silke Adler (GeoSphere Austria), Barbara Chimani (GeoSphere Austria)

The GeoSphere Austria offers meteorological data from 235 semi-automatic weather stations (TAWES), 53 full automatic weather stations (VAMES) in cooperation with Austro Control (ACG), and about 147 climate stations, which additionally provide observer-based meteorological information.

The longest measurement period of climate data can be found in Kremsmünster (since 1767), in Vienna (since 1775) and in Innsbruck (since 1777). From about 20 observation stations in 1852, the meteorological service rose to more than 200 observing stations in 1896. Climate observations of the most important meteorological parameters, such as temperature, pressure, precipitation and humidity, were recorded by observers daily - initially at 07, 14 and 21 local mean time (LMT).

During the annexation of Austria (1938), the climate observation archive had been moved to the Reichswetterdienst in Berlin, where most of the hard copies had been destroyed during World War II. Due to this break, most climate observations in Austria do not start before 1948. Only a few data duplicates could be retained and building now the basis for long-term studies in Austria (Vienna, Salzburg, Graz, Innsbruck, Sonnblick). In 1980, the observing weather stations became semi-automatic weather stations (TAWES) too.

The semiautomatic weather stations (TAWES) take measurements of air temperature, wind speed, wind direction, pressure and relative humidity and transmit the data at a rate of 10 minutes. Information on precipitation is crucial for several applications and so records are sent every minute. After thorough quality checks and corrections, the measurement and observation data is stored at GeoSphere Austria's climate database.

At the 147 climate stations, observations are made three times a day: at 06 UTC, at 12 UTC and at 18 UTC (before 1972 at 07, 14 and 21 LMT). They include the current weather conditions and development (e.g. type of cloud, lower cloud limit, visibility, type of precipitation), which cannot be detected satisfactorily by an automatic sensor. Historically, these daily records have been transmitted to GeoSphere Austria or the responsible regional office by mail in the form of a climate sheet once a month. At GeoSphere Austria, these climate records were archived and entered into a database starting in 1984. Since 2012, direct input of the observation into the database has been possible using an online tool called KSE (Klima-Synop-Eingabe). This allows immediate access and quality control of the data.

The meteorological network also includes SYNOP stations, most of them are semiautomatic weather stations (TAWES) which report hourly or once a day. At the synoptically important time of 06 UTC and 18 UTC next to the automatic measurements of the TAWES stations, observers or supervisors make about 45 additional observations according to WMO specifications.

The data are transmitted via the Global Telecommunication System (GTS). The data set of these SYNOP stations can be found in the WMO Information System (WIS) Program of the World Meteorological Organization (WMO).

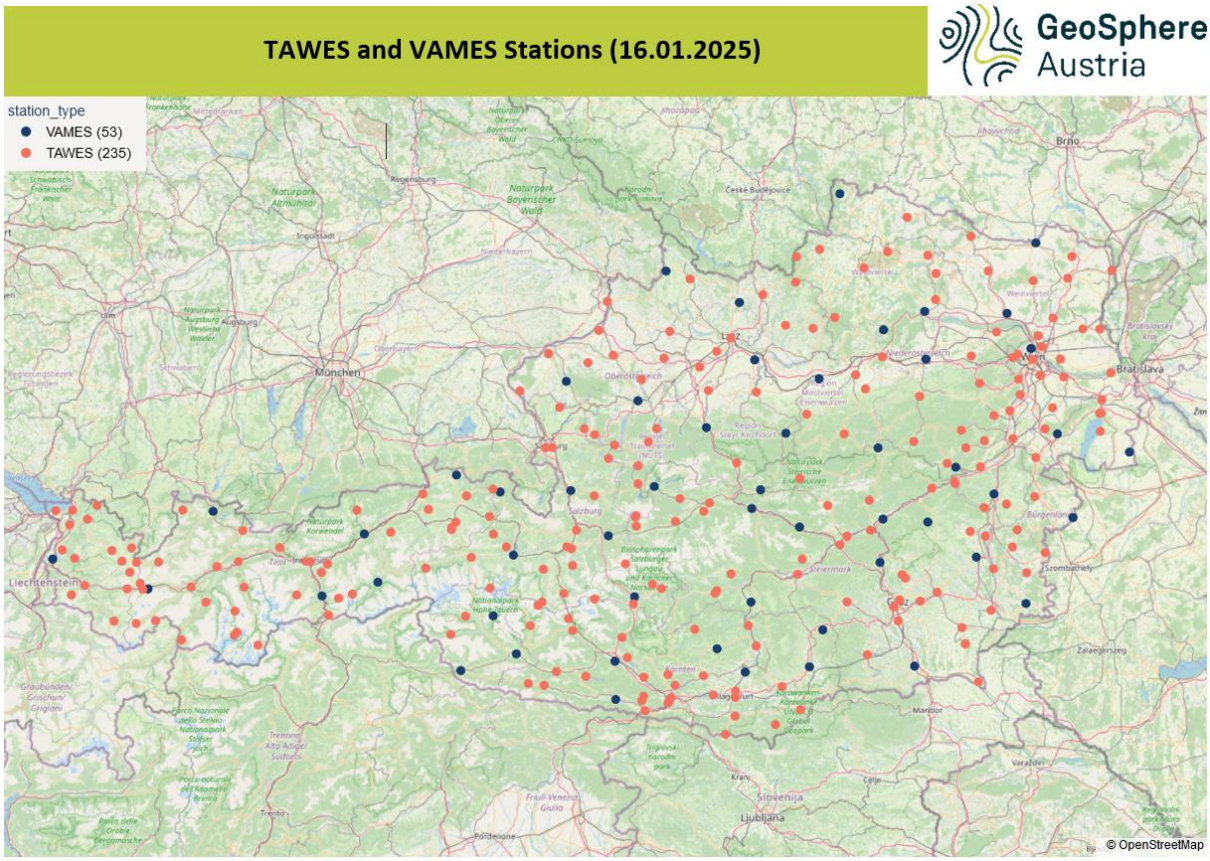


Figure 3: TAWES and VAMES stations of Austria.

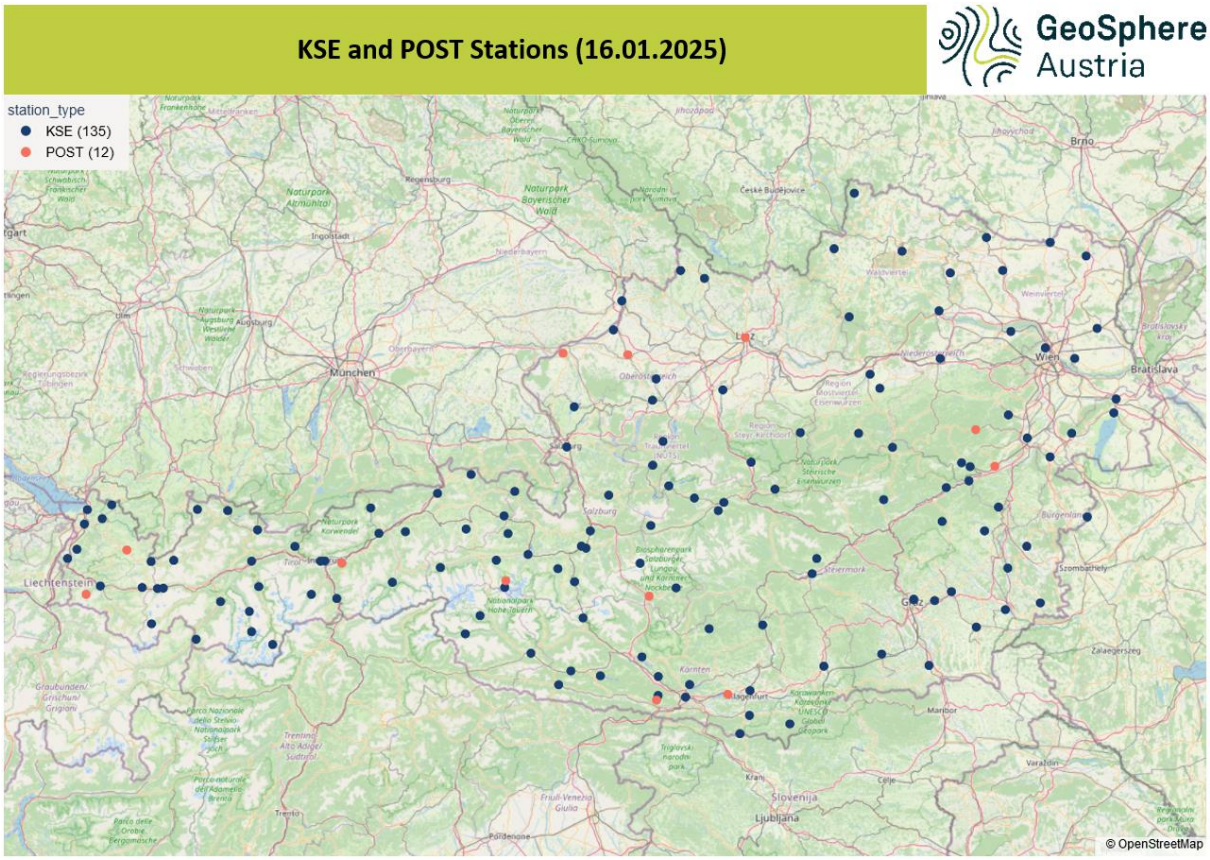


Figure 4: Manual observing stations of Austria.

The observed climate data of the GeoSphere Austria are also used for special projects like Copernicus, SPARTACUS or HISTALP.

HISTALP is an international dataset to provide information on the long-term climate evolution in the Alpine region. The dataset consists of monthly homogenised temperature, pressure, precipitation, sunshine and cloudiness records for about 150 station located in the „Greater Alpine Region“ (GAR, 4-19 deg E, 43-49 deg N, 0-3500 m asl). The longest temperature and air pressure series extend back to 1760, precipitation to 1800, cloudiness to the 1840s and sunshine to the 1880s. Such long-term datasets are essential to estimate the significance of current climate evolutions. Nevertheless, due to the length of those series they are subject to changes like improvements in the instrumentation, necessary relocations due to improved knowledge on e.g. impact of buildings or due to changes in the surrounding, changes in the observation times, etc. In order to get a realistic climate signal from those time series, those effects have to be removed. This process is called homogenisation.

The national data providers do quality control of the data. Homogenisation of the time series is done afterwards to remove artificial “climate signals” that are solely caused by effects on the measurement like the relocation of the stations or changes in the instrumentation. Additionally, corrections for the early instrumental bias have been applied.

Homogenisation is currently being revised. Updates of the time series are done annually, depending on the availability of the data.

In addition to the stations data, gridded datasets of temperature and precipitation are available. A gridded dataset on precipitation based on the HISTALP stations is available at https://cds.climate.copernicus.eu/datasets/insitu-gridded-observations-alpine-precipitation?tab=overview.

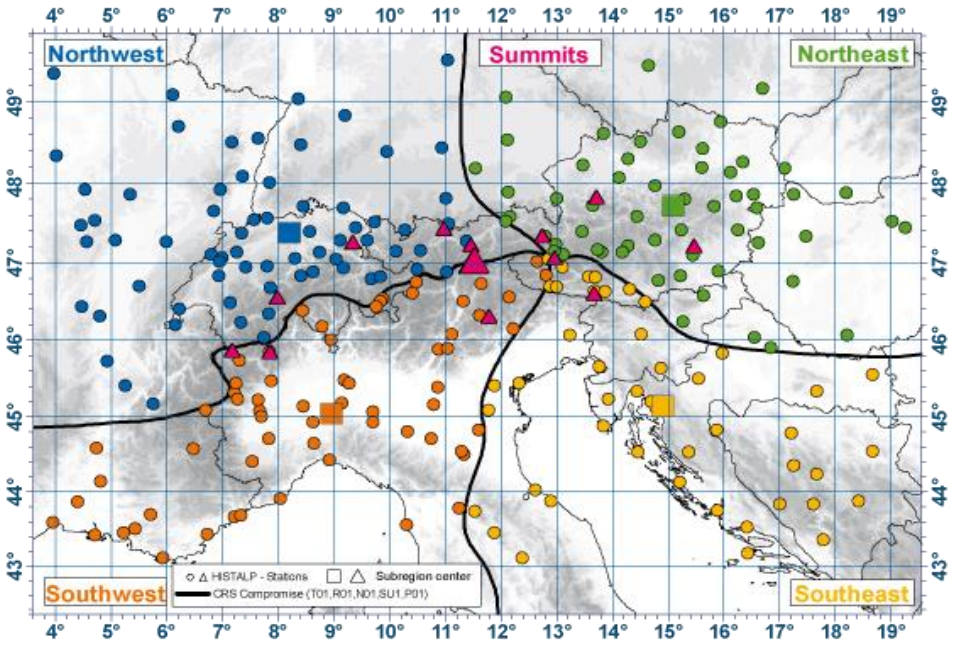


Figure 5: Network of HISTALP stations and regionalisation into different climate regions (colours). Small points and triangles represent the stations, big symbols the centre of the subregions. Triangles represent mountain stations (Due to data restrictions data of France and Switzerland can not be downloaded via the HISTALP-data centre).

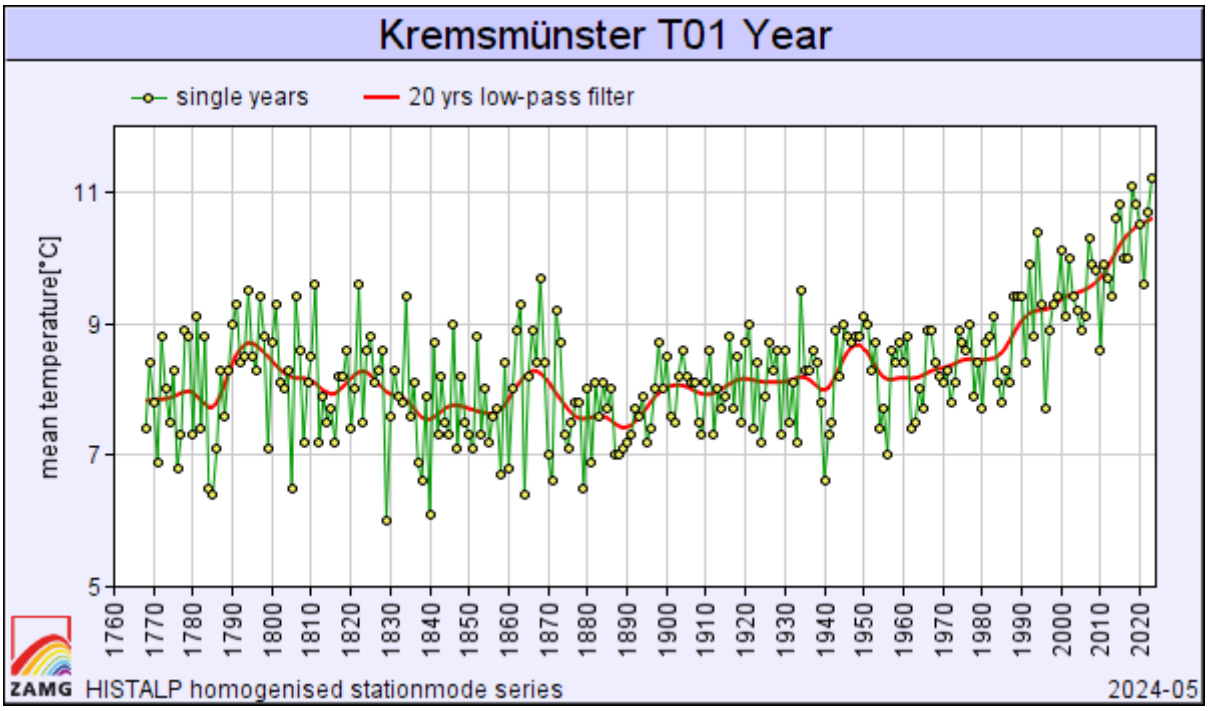


Figure 6: Homogenised time series of annual homogenised air temperature of Kremsmünster (Austria).

Essential Climate Variables - Atmospheric Observations – Surface
GeoSphere Austria

Parameter measured/observed	air temperature, wind (speed and direction), relative humidity, air pressure, clouds, sunshine duration, precipitation, global radiation visibility, present weather, cloud base, cloud amount, snow depth, new snow depth Histalp: homogenized monthly data of temperature, precipitation, mean station level pressure and sunshine duration
Starting date	01.03.1767 Kremsmünster
Temporal Resolution	air temperature, wind speed, wind direction, relative humidity, sunshine duration, global radiation, pressure: 10-minute data. precipitation: 1-minute-data data are also available hourly, daily or monthly Histalp: monthly data
Observational Network	Austrian TAWES network, about 310 stations Histalp: Long term time series of the Alpine region from the national observation networks of the participating countries
Stations	20 essential stations and 96 additional stations located throughout Austria (9.53 - 17.16 deg E, 46.37 - 49.02 deg N) Histalp: About 150 stations located in the Greater Alpine region (4-19 deg E, 43-49 deg N)
Data Portal	GeoSphere Austria: https://data.hub.geosphere.at/ HISTALP: www.zamg.ac.at/histalp WIGOS: https://community.wmo.int/en/activity-areas/WIGOS Part of WIGOS are: OSCAR: https://oscar.wmo.int/surface/#/

	WIS: https://gisc.dwd.de/angular-frontend/home WDQMS: https://wdqms.wmo.int/
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	HISTALP (Homogenized monthly long-term climate dataset) WIGOS (WMO Integrated Global Observing System) WIS (WMO Information System) OSCAR (Observation Systems Capability Analysis and Review Tool) WDQMS (WIGOS Data Quality Monitoring System) GCOS (Global Climate Observing System) EGOS (Evolution of Global Observing System)
Data Submission	data contribution according to WMO specifications Histalp: Most of the stations are updated once a year
Licenses	general GeoSphere Austria data conditions, essential stations: CC-BY 3.0 AT Histalp: free of charge, provided the sources are acknowledged
Use Limitation	no limitation but fee depending on usage conditions Histalp: **for non-profit research**
Data Format	data download as CSV File, PDF-File, HTML-File
Data Access	open access daily and monthly data: https://data.hub.geosphere.at/ access by registration is also available
Data Quality	The national data providers do data quality control. The data is homogenized afterwards.
Performance Monitoring	Data availability is supervised by GeoSphere Austria, but depends on the national data providers.
Publications	Once a year an annual Dataset is produced and made public on Datahub GeoSphere Austria: https://data.hub.geosphere.at/ Regular newsletters (3 times a year) on the long term climate evolution in Austria Further publications on the dataset can be found on the HISTALP-webpage: www.zamg.ac.at/histalp
Contact (National correspondent, focal point)	Focal Point: GCOS: Silke Adler, silke.adler@geosphere.at WIGOS: Auer Martin, auer.martin@geosphere.at WDQMS: Paul Anita, anita.paul@geosphere.at WIS: Paul Anita, anita.paul@geosphere.at Pichler Michael, Michael.Pichler@austrocontrol.at OSCAR: Silke Adler, silke.adler@geosphere.at TAWES: Roland Potzmann, roland.potzmann@geosphere.at, dpru@geosphere.at HISTALP: histalp@geosphere.at
Remarks	

VAMES Austro Control GmbH

Michael Pichler (Austro Control GmbH), Markus Kerschbaum (Austro Control GmbH)

VAMES (**V**oll **A**utomatisches **M**eteorologisches **E**rfassungs **S**ystem) has been established as an aviation weather observation network within Austria to provide weather information. It is a very successful cooperation project between the national weather service GeoSphere Austria and the aviation weather service, which is a department of the air traffic services ACG. Based on the existing TAWES network from GeoSphere Austria with about 260 stations, 50 stations along valley flight tracks, which are used by general aviation, have been chosen to extend them with visibility/present weather detection sensors (VAISALA PWD22) and ceilometers with cloud coverage algorithm (VAISALA CL31). The extension began in 2011 with 10 stations per year and has been completed at the end of 2016. Raw data are collected by GeoSphere Austria and delivered to ACG, with an availability of more than 98%. Austro Control adds convective information generated by a cell detection tool (TS, VCTS and CB), AUTOMETARs are produced in the WMO No. 306 METAR format. AUTOMETARs are disseminated within Austria and Germany continuously every 10 minutes and used e.g. for briefing purposes or GAFOR preparation and monitoring.

Quality control is done by GeoSphere Austria with data monitoring software and by ACG in form of continuously supervising by the operational service at the meteorological watch office in Wien Schwechat.

Content of the AUTOMETAR reports:

- Wind speed (TAWES sensor)
- Wind direction (TAWES sensor)
- Meteorological visibility from VAISALA PWD 22
- Present weather:
    - from VAISALA PWD 22
    - TS and VCTS information from convection module (generated product of lightning and weather radar information)
- Height of cloud base from VAISALA CL31
- Cloud amount by algorithm from VAISALA CL31
- Type of cloud in case of CB from convection module (generated product of lightning and weather radar information)
- Temperature at 2 m above ground (TAWES sensor)
- Dew point (TAWES sensor)

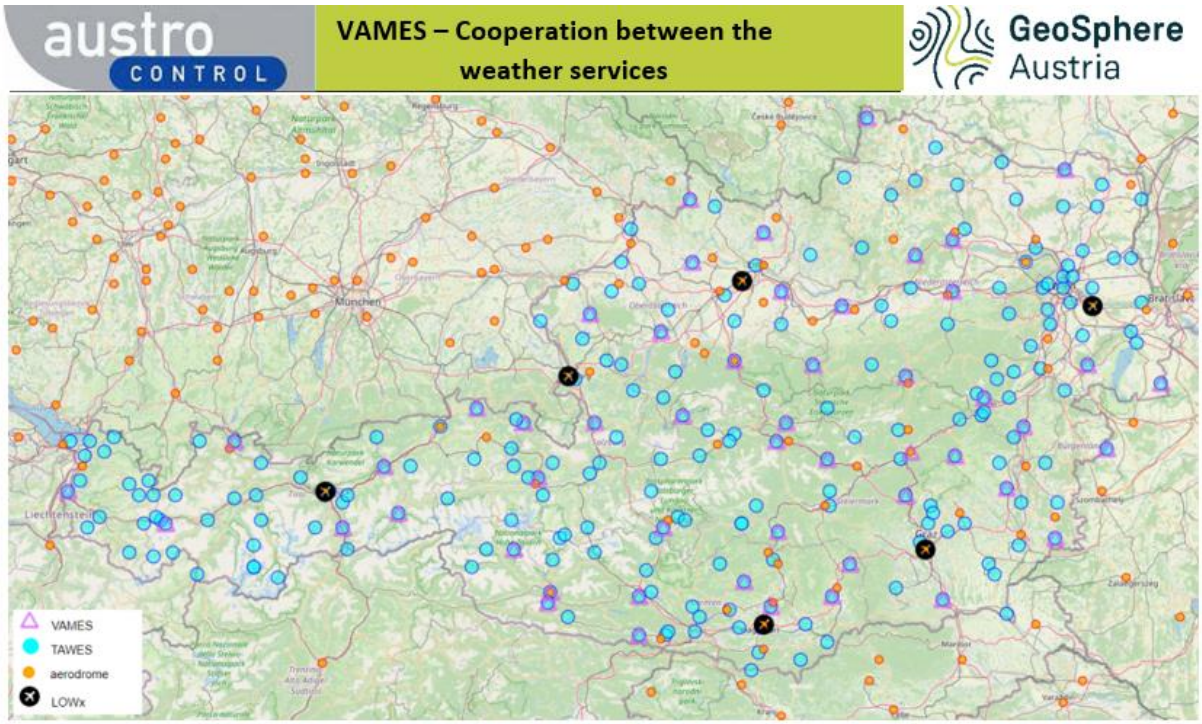


Figure 7: Stations within Austria (Status 11.03.2024)

List of stations:

11070 Krems
11171 Mariazell
11188 Aspang
11335 Laa/Thaya
11380 Reichenau/Rax
11389 St.Pölten
11393 Lutzmannsburg
11395 Andau
11190 Eisenstadt
11024 Jauerling
11063 Rottenmann
11167 Hall/Admont
11173 Fischbach
11198 Güssing
11249 Frohnleiten
11296 Leibnitz
11229 St.Andrä/Lavanttal
11362 Kalwang
11370 Kapfenberg
11390 Hartberg
11018 Amstetten
11200 Kals
11201 Sillian
11204 Lienz
11214 Preitenegg
11371 Golling
11220 Neumarkt
11225 Weitensfeld
11237 St.Veit an der Glan
11259 Hermagor
11272 Spittal an der Drau
11007 Kollerschlag
11021 Litschau
11050 Reichenau im Mühlkreis
11105 Feldkirch
11131 Kössen
11311 St.Anton am Arlberg
11314 Reutte
11325 Jenbach
11329 Steinach in Tirol
11330 Mayrhofen
11002 Enns
11049 Mattighofen
11056 Vöcklabruck
11058 Waizenkirchen
11140 Lofer
11144 Zell am See
11148 St.Michael im Lungau
11341 Weyer
11347 Micheldorf
11356 Bad Aussee

Essential Climate Variables - Atmospheric Observations – Surface
Austro Control (ACG)

Parameter measured/observed	wind, visibility, present weather, cloud base, cloud amount (according to ICAO 1-3-5 rule), temperature, dew point are used to prepare AUTOMETARs
Starting date	Cooperation between ACG and GeoSphere Austria was started on 9th November 2011.
Temporal Resolution	10-minute data
Observational Network	Austrian TAWES network
Stations	50 VAMES-stations as part of the TAWES network
Data Portal	AUTOMETARs are officially disseminated by ACG within Austria via proprietary network and to Germany.
Supervising Organization	Depends on the type of sensor: ACG: visibility, present weather and cloud information GeoSphere Austria: all other TAWES sensors
National and/or international Networks or Programs	N/A
Data Submission	update every 10 minutes, 24 h a day
Licenses	AUTOMETARs are disseminated free of charge
Use Limitation	For use in Aviation Meteorology only
Data Format	METAR Code Form (FM-15 according WMO No. 306)
Data Access	Via ACG Aviation Weather website (registration only with pilot license possible)
Data Quality	Quality control is done by ACG and GeoSphere Austria
Performance Monitoring	Continuously supervised by ACG and GeoSphere Austria
Publications	No publications available
Contact (National correspondent, focal point)	met-info@austrocontrol.at
Remarks	

Aerodrome Met stations in Austria

Michael Pichler (Austro Control GmbH), Markus Kerschbaum (Austro Control GmbH)

Aerodrome meteorological stations at Austrian international aerodromes have been established in 1955 with the foundation of the Federal Office for Civil Aviation. In 1994, the current ANSP (Air Navigation Service Provider) Austro Control GmbH (ACG) was founded. Since then, is has been responsible for providing aeronautical meteorological services in Austria. ACG is the designated and certified provider of aeronautical meteorological services at the six Austrian major airports as well as for the Austrian FIR (Flight Information Region). These services include, based on ICAO, WMO and EASA-regulations and requirements, the meteorological observation (METAR/SPECI, MET Report), forecasts (TAF) and warnings for the airports. In regard to the FIR ACG provides warning messages for aircraft in flight (SIGMET), a low-level significant weather chart for the alpine area together with Meteo Swiss, dedicated services for Air Traffic Controllers, flight consultation and briefing for pilots and several other meteorological services.

Following the international standards and recommendations of ICAO it is required that each provide meteorological observations and standardized reports in the MET REPORT, SPECIAL and METAR format. Hourly SYNOPs are automatically generated for all international airports these stations.

The quality control of SYNOPs is performed by GeoSphere Austria, while aviation meteorological reports are monitored by ACG. This quality monitoring is performed on a continuous 24-hours basis at the MET Center Vienna, which is located in the air traffic control tower at the Vienna airport.

Measured parameters at each station are:

- Wind speed
- Wind direction
- Prevailing visibility
- Visibility runway specific
- Runway Visual Range
- Present weather
- Height of cloud base
- Cloud amount
- Temperature at 2 m and 5 cm above ground
- Dew point
- Air pressure QNH
- Sunshine duration
- Snow depth

ACG is also preparing dedicated climatologic statistics, based on ICAO requirements, for each airport on a yearly basis. These statistics provide a perfect overview on the probability of certain wind directions, wind speed, low visibilities and more. As an example, Table 9 shows the statistic of RVR for runway 16/34 at Vienna airport.

AERODROME CLIMATOLOGICAL SUMMARY
LOWW / MODEL A1

LAT / LONG: 48.11 N / 16.57 E ELEVATION: 183M RUNWAY: 16/34
PERIOD OF RECORD: 2013 - 2023 PERIOD: JANUARY 01 - 31
TOTAL NUMBER OF OBSERVATIONS: 16350

FREQUENCIES (PER CENT) OF THE OCCURENCE OF RUNWAY VISUAL RANGE (IN METRES) AND/OR HEIGHT OF THE BASE OF THE LOWEST CLOUD LAYER (IN METRES) OF BKN OR OVC EXTENT BELOW SPECIFIED VALUES AT SPECIFIC TIMES

TIME (UTC)	RVR/Hs					#OBS.
	<50	<200	<350	<550	<1500	
	-	-	<30 (100 ft)	<60 (200 ft)	<90 (300 ft)	
0000				5.6	8.5	341
0030			0.3	6.5	8.5	340
0100				5.9	8.5	341
0130				5.6	8.5	341
0200				6.2	9.7	341
0230				4.7	8.5	341
0300				5.3	8.2	341
0330				5	8.8	340
0400				4.7	10	341
0430			0.3	4.4	9.4	340
0500			0.6	6.5	9.7	341
0530				5.9	10	341
0600				6.2	10.6	340
0630			1.2	7.6	12.1	340
0700			1.5	8.2	12	341
0730			2.1	7.9	11.7	341
0800			1.8	7.1	11.2	338
0830			1.5	6.7	10.6	341
0900			1.5	6.5	9.1	341
0930			0.9	6.5	9.1	341
1000			0.6	5.9	9.4	341
1030			0.6	5.3	8.2	341
1100				4.7	8.2	341
1130				3.8	8.2	340
1200				2.6	6.2	341
1230				2.6	6.5	340
1300				2.9	6.5	341
1330				3.2	6.7	341
1400				3.2	7.1	340
1430				2.6	5.9	340
1500				3.5	5.9	340
1530				3.5	5.9	341
1600			0.3	4.1	5.9	340
1630			0.3	3.8	5.9	340
1700			0.6	4.1	6.2	340
1730			0.6	4.1	6.2	341
1800				4.4	6.2	340
1830			0.3	5	6.7	341
1900			0.3	4.7	6.5	341
1930				4.4	6.5	341
2000				4.4	5.6	341
2030				3.8	5.6	341
2100				3.2	6.2	341
2130				3.5	7.3	341
2200				3.5	7	341
2230				4.4	8.2	341
2300				5.3	8.8	341
2330			0.3	5.6	9.1	340
TOTAL			0.3	4.9	8.1	16350

Table 9: Aerodrome Climatological Summary

Essential Climate Variables - Atmospheric Observations – Surface
Austro Control (ACG)

Parameter measured/observed	wind, visibility, RVR (Runway Visual Range), present weather, cloud base, cloud amount (1-3-5 rule), temperature, dew point, QNH are used to prepare MET REPORT, SPECIAL, METAR and SYNOP
Starting date	since 1955
Temporal Resolution	Sensor values are available every 10 seconds.
Observational Network	ACG internal proprietary network
Stations	One stations at each of the six Austrian international aerodromes
Data Portal	met-info@austrocontrol.at
Supervising Organization	ACG
National and/or international Networks or Programs	ICAO RODEX (Regional OPMET Data Exchange), ICAO AFS (Aeronautical Fixed Service)
Data Submission	METAR, MET REPORT, SPECIAL: Update every 30 minutes or depending on weather situation, sent via ICAO AFS and WMO GTS. SYNOP updated hourly, sent via WMO GTS
Licenses	Free of charge for aviation use
Use Limitation	For use in Aviation Meteorology only
Data Format	MET REPORT, SPECIAL (according to ICAO Annex 3) METAR, SYNOP (according WMO No. 306)
Data Access	METAR: Access by registration with pilot license or via VOLMET Austria MET REPORT, SPECIAL access for pilots via ATIS
Data Quality	Quality control is done by ACG
Performance Monitoring	Continuously supervised by ACG
Publications	No publications available
Contact (National correspondent, focal point)	met-info@austrocontrol.at
Remarks	

UV Radiation

Stana Simic (BOKU)

Only about 5 % of the solar radiation reaching the earth's surface is in the ultraviolet range. Although it's a small portion, UV radiation has a major impact on the biosphere. Solar radiation with wavelengths shorter than 290 nm is entirely blocked by the Earth's ozone layer, whereas UV radiation with longer wavelengths is only partially absorbed. But it is this small portion in the UV-B range (290-315 nm) which is of great significance since it causes various chemical and physical reactions on molecular structures in biological cells. While human exposure to UV radiation is very important and does have beneficial effects, it is a major risk factor for the development of skin cancer.

Measurements of UV Radiation in Austria

UV radiation is monitored at two stations in Austria: Hoher Sonnblick (47.05 N, 12.95 E, 3106 m) and Groß-Enzersdorf (48.20 N, 16.57 E, 156 m) (see Figure 7). The measurements have been carried out since 1994 and 1998 respectively by the Institute of Meteorology and Climatology (BOKU-Met) of the "University of Natural Resources and Life Sciences" (BOKU) and are financed by the "Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology" (BMK).

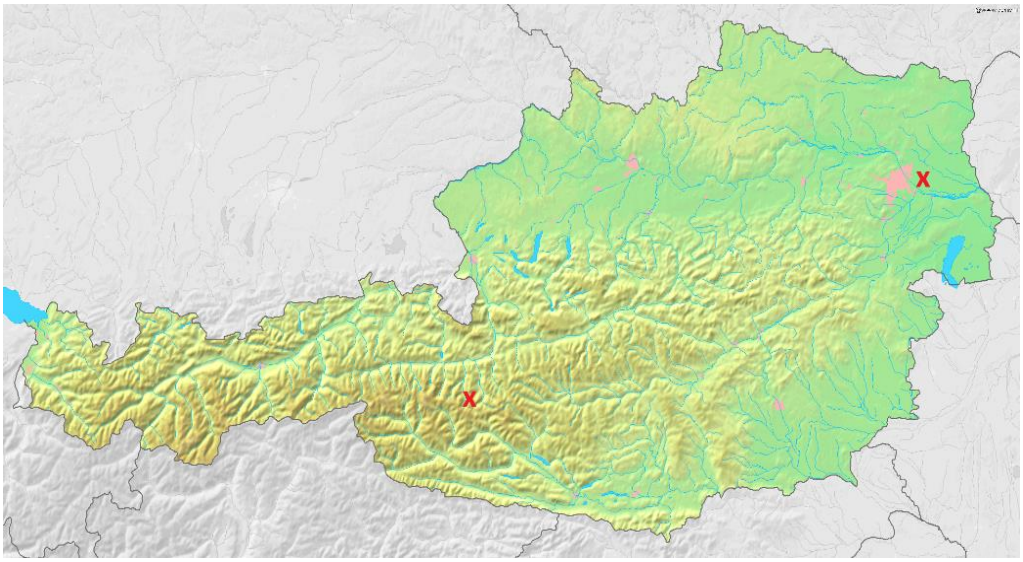


Figure 8: UV measurement sites in Austria: Groß-Enzersdorf (top-right) near the large city Vienna in a lowland basin at 156 m and Hoher Sonnblick (bottom-left) on a mountain peak at 3106 m elevation.

Spectral UV measurements at Sonnblick observatory are continuously performed with a Brewer MkIV spectrophotometer and with a Bentham DM150 spectroradiometer. The Brewer spectroradiometer measures global UV irradiance, total ozone column and sulphur dioxide column. The Bentham spectroradiometer measures global spectral UV irradiance. Metrological equipment at Groß-Enzersdorf consist of a mobile Bentham DM150 spectroradiometer, a broadband UV-B biometer and ancillary instruments and sensors measuring additional meteorological parameters.

The spectral UV irradiance datasets meet the high quality-standards of the "Network for the Detection of Atmospheric Composition Change" (NDACC) and are among the longest in Europe. Instrument comparisons and the dataset of previous years confirm that a high quality was reached.

The motivation for long-term measurements of the UV irradiance at a high spectral resolution is due to its pronounced influence on the biosphere and therefore also on human health. Spectrally resolved

long-term UV measurement datasets, combined with various weighting functions, the many biological, ecological and health-related influences of UV radiation can be quantified and studied

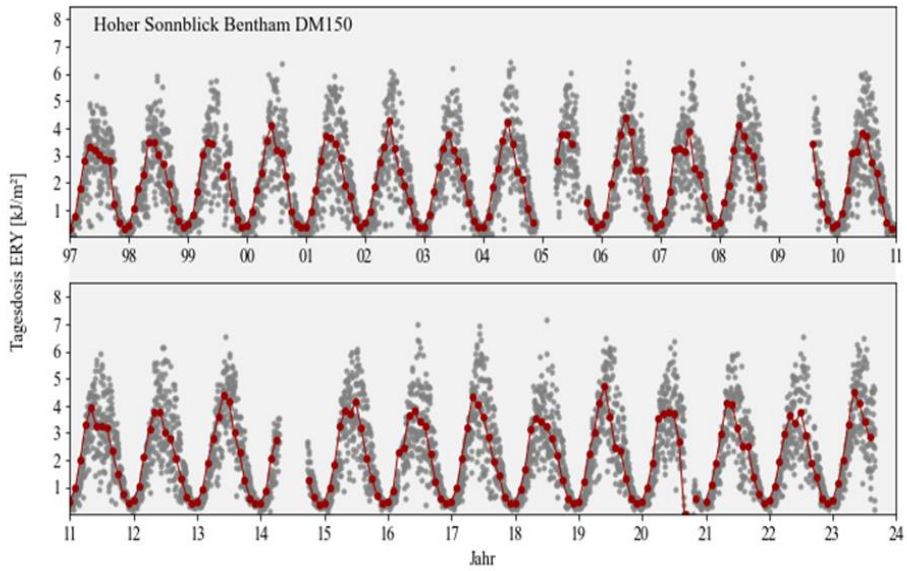


Figure 9: Daily sums and monthly averages of erythemally weighted UV irradiance measured at Hoher Sonnblick.

The Austrian UV-B Measurement Network

It is known that exposure to UV radiation has beneficial as well as detrimental effects on the human body. While it is absolutely crucial for endogenous vitamin D photosynthesis, overexposure can acutely lead to sunburn and chronically induce skin cancer development. Therefore, it is a high priority to provide the public with high-quality UV measurement data. The Austrian UV-B measurement Network is financed by the "Federal Minister for Climate Action, Environment, Energy, Mobility, Innovation and Technology" (BMK) and was established in 1998. Since 1999, it consists of 13 stations, equipped with UV biometers, spread throughout Austria. The Section for Biomedical Physics (https://www.i-med.ac.at/dpmp/bmp/) at the Medical University of Innsbruck and the CMS Ing. Dr. Schreder Company together maintain the UV-B measurement grid continuously. The UV index data is continuously published in 10-minute intervals at http://www.uv-index.at.

Figure 10: The Inge Dirmhirn UV Measuring Station at Sonnblick Observatory with Bentham spectral radiometer in foreground and the Brewer spectrophotometer in background.

Essential Climate Variables - Atmospheric Observations – Surface
BOKU

Parameter measured/observed	spectral UV irradiance, erythemally-weighted UVB radiation
Starting date	01.01.1994
Temporal Resolution	30-minute intervals for spectral UV irradiance 10-minute intervals for erythemally-weighted UVB radiation
Observational Network	Two spectrophotometers and two UV biometers
Stations	Two spectrophotometers and two UV biometers, one of each located in Groß-Enzersdorf, near Vienna and the high Alpine observatory Hoher Sonnblick (3106 m)
Data Portal	UV-B data: https://uv-index.at/ Spectral UV radiation data: NDACC: https://ndacc.larc.nasa.gov/instruments/working-groups/spectral-uv
Supervising Organization	BOKU, BMK
National and/or international Networks or Programs	NDACC (international Network for the Detection of Atmospheric Composition Change)
Data Submission	Via FTP to a Server located at BOKU
Licenses	general BOKU data conditions
Use Limitation	**For research only**
Data Format	**ASCII**
Data Access	Downloadable data at NDACC data centre
Data Quality	Data quality control is done by NDACC and is a very high standard
Performance Monitoring	The instruments and data availability are supervised by the work group „UV Radiation and Ozone“ at the Institute of Meteorology and Climatology, BOKU University
Publications	Annual publications at NDACC newsletter Further publications are listed here: https://forschung.boku.ac.at/de/researcher/1FB6B6489C0B9BFD
Contact (National correspondent, focal point)	Dr. Stana Simic BOKU University, Institute of Meteorology and Climatology (BOKU-Met) Gregor-Mendel-Straße 33, 1180 Wien Telefon: (+43) (0)1 47654-81430, https://boku.ac.at/wau/met
Remarks	

Solar and terrestrial radiation monitoring networks (ARAD)

Marc Olefs (GeoSphere Austria), Florian Geyer (GeoSphere Austria)

10-minute average values of global radiation are currently measured at 247 TAWES stations of GeoSphere Austria using a Schenk Star Pyranometer (black dots in Figure 11). Beside this routine measurement network, GeoSphere Austria and Austrian University partners operate a high accuracy radiation measurement network (ARAD; red dots in Figure 11). ARAD ("**A**ustrian **Rad**iation") is a long-term measurement project for solar radiation and thermal radiation of the atmosphere in Austria. Currently, the temporal and spatial variations of the radiative components (global, direct and diffuse incoming solar radiation and incoming longwave radiation are recorded at six sites (Vienna, Sonnblick, Graz, Innsbruck, Kanzelhöhe, Klagenfurt) using very high quality instruments.

ARAD is a scientific research project lead by the GeoSphere Austria in collaboration with the University of Innsbruck, the Karl-Franzens-University Graz and the University of Natural Resources and Life Sciences (BOKU) in Vienna. ARAD provides very accurate data of the temporal and spatial changes of the radiation components of the sun and atmosphere. Besides a continuous survey of our climate, these data can also be used to verify and improve regional climate models and weather forecasting models.

Integration in international networks

Since 2013 the ARAD Station Sonnblick is part of the baseline surface radiation measurement network BSRN (see separate chapter). Data of the TAWES Stations Grossenzersdorf, Salzburg/Freisaal, Bregenz, Innsbruck/Airport, Sonnblick (ARAD Station), Klagenfurt/Airport, Graz/University and Vienna Hohe Warte is regularly transmitted (every 3 months) to the World Radiation Data Centre (WRDC) in Saint Petersburg (Russia). BSRN and ARAD measurements are used at the European Centre for Medium Range Weather Forecasts (ECMWF) to evaluate forecasts of downward fluxes of shortwave and longwave radiation.

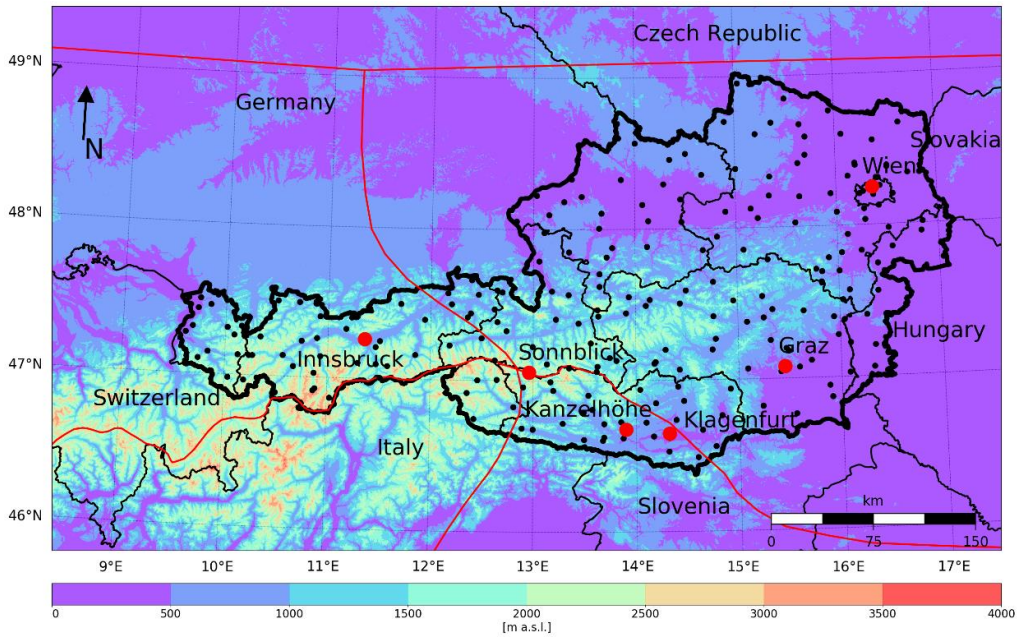


Figure 11: Topographic map (colour-coded elevations) with ARAD stations (red points), TAWES stations measuring GLO (black points) and the coarse resolution subregions (CRSs, red lines) defined as regions with common climatic variability

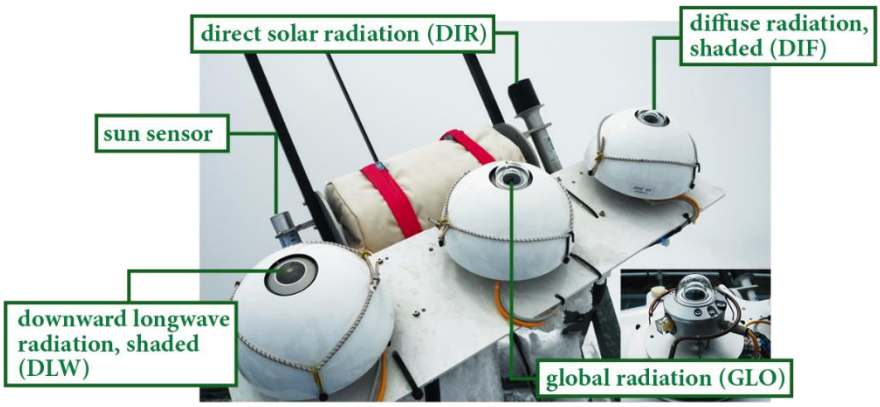


Figure 12: Typical ARAD station: suntracker with different radiation sensors. The picture in the lower right corner shows a pyranometer without radiation shield exposing the heating and ventilation system (PMOD-VHS).

GeoSphere Austria ARAD Partners

Essential Climate Variables - Atmospheric Observations – Surface
GeoSphere Austria

Parameter measured/observed	ARAD Network: global radiation, diffuse radiation, direct solar radiation, longwave incoming radiation TAWES Network: global radiation
Starting date	1953 (first station Vienna Hohe Warte)
Temporal Resolution	ARAD Network: 1-min averages (based on 1 Hz sampling), min/max (1 Hz) TAWES Network: 10-min average values (based on 1-minute averages based on 0,1 Hz samplings)
Observational Network	TAWES, ARAD
Stations	TAWES: 241 stations; ARAD: 6 stations
Data Portal	TAWES: klima@geosphere.at
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	The ARAD network is a collaborative effort of GeoSphere Austria together with the following national partners: University of Innsbruck, Graz and BOKU 6 stations: ARAD (national), one of them being a BSRN station (international): Sonnblick

Data Submission	TAWES: 10-min, ARAD: 1-min, GeoSphere Austria internal data transfer
Licenses	TAWES: general GeoSphere Austria data conditions, ARAD: GeoSphere Austria and partner conditions
Use Limitation	TAWES, ARAD: no limitation but fee depending on usage conditions
Data Format	Time-series in GeoSphere Austria data base
Data Access	restricted access, contact: klima@geosphere.at https://data.hub.geosphere.at/
Data Quality	TAWES: Quality control is done by GeoSphere Austria / Division Climate and Environment Service / Section Data Quality Analysis. ARAD: strict data quality management following BSRN guidelines www.zamg.ac.at/strahlung
Performance Monitoring	GeoSphere Austria
Publications	Olefs, M., Baumgartner, D. J., Obleitner, F., Bichler, C., Foelsche, U., Pietsch, H., Rieder, H. E., Weihs, P., Geyer, F., Haiden, T., and Schöner, W.: The Austrian radiation monitoring network ARAD – best practice and added value, Atmos. Meas. Tech., 9, 1513-1531, doi:10.5194/amt-9-1513-2016, 2016.
Contact (National correspondent, focal point)	ARAD: Marc Olefs (marc.olefs@geosphere.at), Florian Geyer (florian.geyer@geosphere.at) GeoSphere Austria: dpru@geosphere.at
Remarks	

BSRN - Baseline Surface Radiation Network

Marc Olefs (GeoSphere Austria), Florian Geyer (GeoSphere Austria)

The Baseline Surface Radiation Network (BSRN) is the most prominent, worldwide observational ground-based network for surface radiation fluxes and was established in the early 1990s (Ohmura et al., 1998) by the World Climate Research Programme (WCRP). BSRN provides measurements with high accuracy and high temporal resolution, and comprises currently 50 sites in different climate regimes (König-Langlo et al., 2013; bsrn.awi.de; Figure 13 and Figure 14). In Austria, the ARAD station Sonnblick (3106 m a.s.l.), is also included in the BSRN network (SON; since January 2013; https://bsrn.awi.de/stations/listings/).

The objectives of BSRN are:

- monitor the background (least influenced by immediate human activities which are regionally concentrated) short-wave and long-wave radiative components and their changes with the best methods currently available
- provide data for the validation and evaluation of satellite-based estimates of the surface radiative fluxes and
- produce high-quality observational data for comparison to climate model (GCM) calculations and for the development of local regionally representative radiation climatologies.
- to serve as a baseline for national radiation monitoring networks (e.g. TAWES in Austria).

The sites are equipped with four broadband radiation sensors, which are suitable to BSRN requirements, mounted on a suntracker, for measurements of global (GLO), direct (DIR) and diffuse (DIF) solar radiation and downward longwave radiation (DLW). The suntracker allows correct tracking of the solar path, guarantees the continuous alignment of the pyrheliometer to record DIR and ensures continuous shading of the pyranometer for measurements of DIF and the pyrgeometer for measurements of DLW. All radiation sensors used within ARAD are state-of-the-art thermopile instruments with specifications well within the limits recommended and accepted by BSRN. Following the ISO 9060 classification, all pyranometers used within ARAD are secondary standard instruments and all pyrheliometers are first-class instruments.

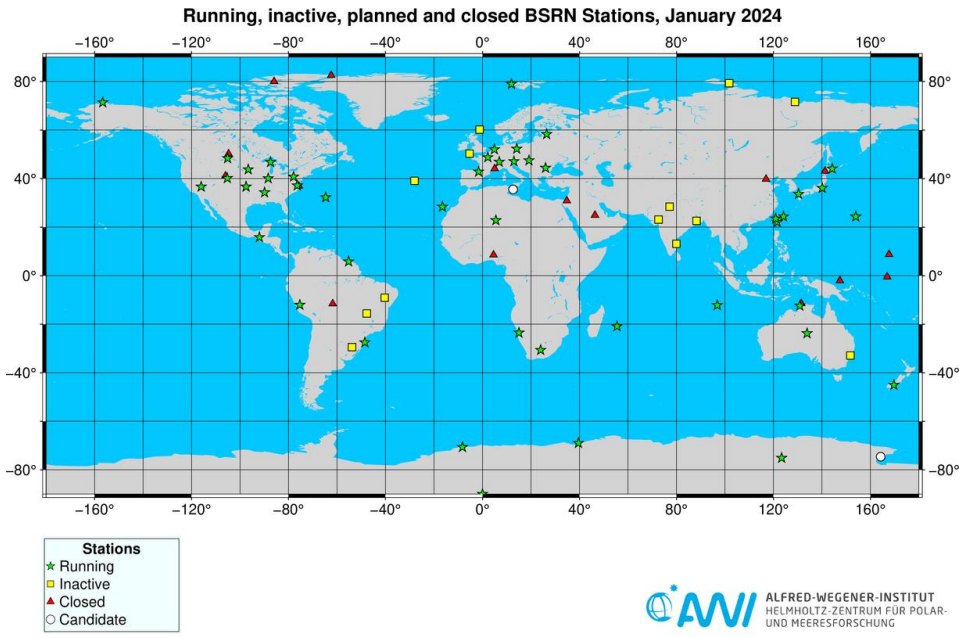


Figure 13: Map of the BSRN stations (world)

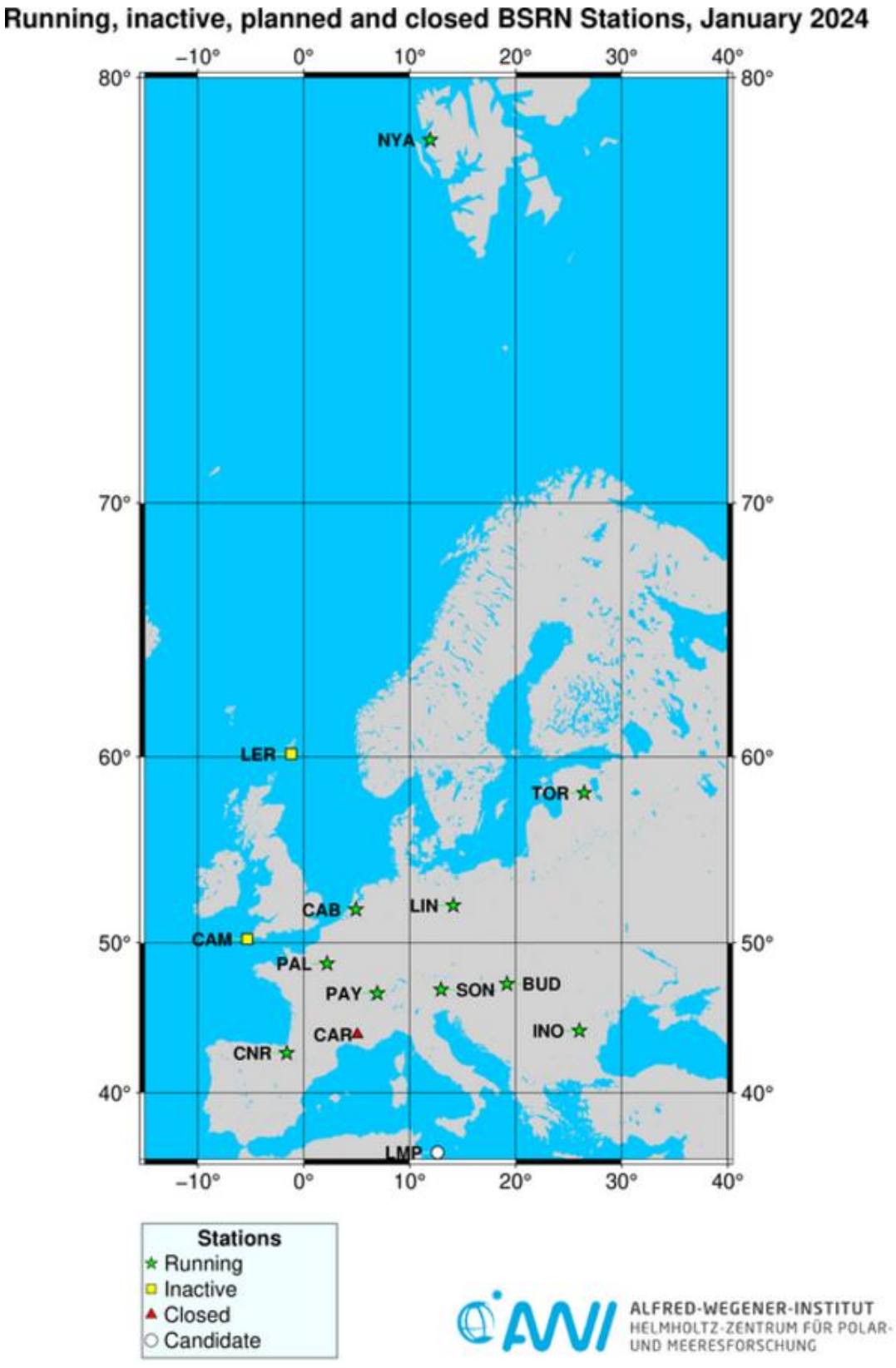
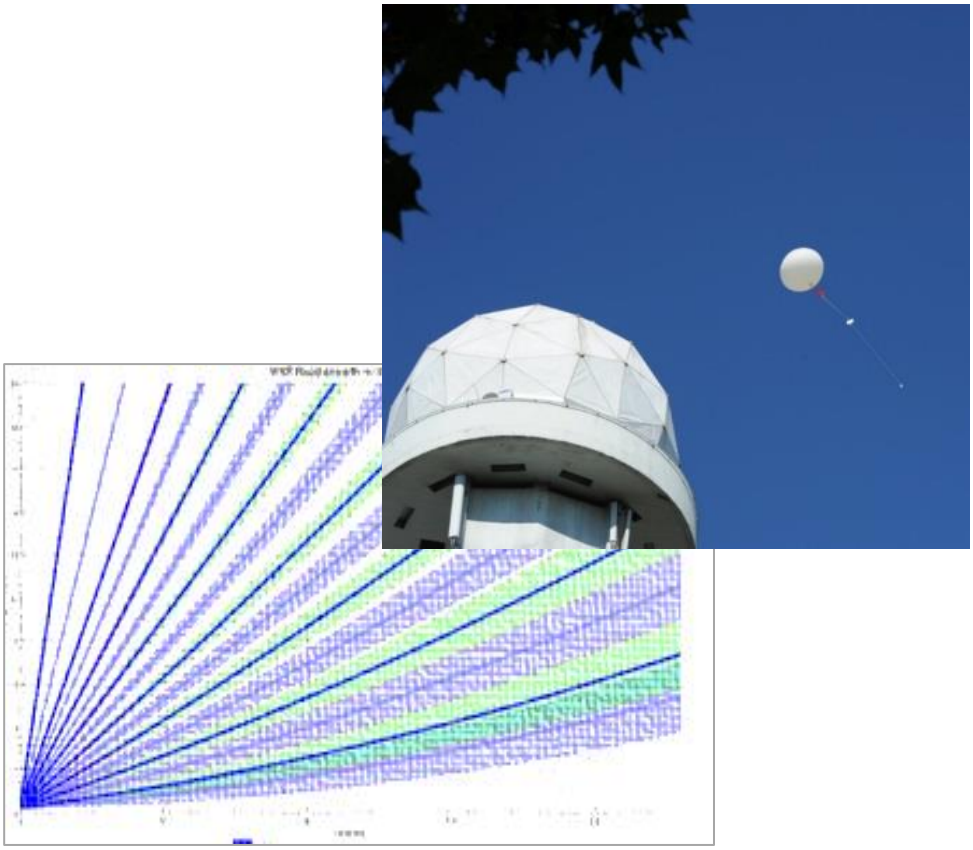


Figure 14: Map of the BSRN stations (Europe)

Essential Climate Variables – Atmospheric Observations – Surface
GeoSphere Austria

Parameter measured/observed	Shortwave solar radiation: global radiation, diffuse radiation, direct solar radiation. Longwave radiation: longwave incoming radiation
Starting date	1.1.2011
Temporal Resolution	1-Min averages (based on 1 Hz sampling), Min/Max (1 Hz)
Observational Network	BSRN
Stations	Sonnblick
Data Portal	https://bsrn.awi.de/
Supervising Organization	Word Radiation Monitoring Center (WRMC – data management), GEWEX
National and/or international Networks or Programs	ARAD (national)
Data Submission	monthly, ftp
Licenses	Specific license details: https://bsrn.awi.de/data/data-retrieval-via-pangaea/
Use limitation	Data can be made available for bona fide research purposes at no cost.
Data Format	
Data Access	Free after acceptance of data release guidelines https://dataportals.pangaea.de/bsrn/
Data Quality	Each station scientist is responsible for his station (strict BSRN quality standard/guidelines).
Performance Monitoring	GeoSphere Austria und WRMC (bsrn.awi.de)
Publications	Data are citable via PANGAEA (DOI). Driemel, A., Augustine, J., Behrens, K., Colle, S., Cox, C., Cuevas-Agulló, E.König-Langlo, G. (2018). Baseline Surface Radiation Network (BSRN): structure and data description (1992–2017). *Earth System Science Data*, *10*(3), 1491–1501. https://doi.org/10.5194/essd-10-1491-2018 Olefs, Marc (2022): Basic measurements of radiation at station Sonnblick (2013-01 et seq). GeoSphere Austria, Wien, PANGAEA, https://doi.org/10.1594/PANGAEA.946389
Contact (National correspondent, focal point)	Amelie Driemel (amelie.driemel@awi.de) – WRMC Marc Olefs (marc.olefs@geosphere.at) - Station Scientist Sonnblick (SON), Florian Geyer (florian.geyer@geosphere.at) – Data Publisher Sonnblick (SON)
Remarks	



Atmospheric Observations

Upper Air

Radiosonde GeoSphere Austria

Silke Adler (GeoSphere Austria), Roland Potzmann (GeoSphere Austria)

Since 1952 radiosonde ascents have been carried out twice a day (0 UTC, 12 UTC) at the GeoSphere Austria. A probe is transported by a weather balloon to heights of 30 to almost 40 km. This probe continuously measures air temperature, humidity and air pressure and transmits the recorded data to the ground station with a radio signal in cycle only seconds long. From 1956, a radar was used to determine the position of the balloon, and since the end of the 1990s, GPS has also been available for this purpose. The wind speed and wind direction are calculated from the change in the position between two (or more) time steps.

Despite new measurement methods being available, such as the installation of sensors on commercial aircraft (AMDAR), the radiosonde data remain an indispensable basis for weather models. Apart from the limited number of airports, too few AMDAR system data is available, especially during the night (0 UTC) due to take-off and landing prohibitions. Radiosonde data provide important information for the meteorologist for short-term forecasts and for the estimation of thunderstorm probability (stability of the atmospheric stratification). In winter, the knowledge of the temperature and humidity profile helps to forecast fog.

The temporal homogeneity of this measuring system can only be ensured with a certain effort, which poses a problem when using it for monitoring climate (changes). While instruments for ground based measurements at a station are usually used over many years or even decades, radiosonde devices can only be used for one ascent. High demands are also placed on the sensors, which are intended to measure accurately over a temperature range of 40° C to -90° C and a pressure range of less than 5 hPa to 1000 hPa. Particularly at low pressure with simultaneous solar irradiation, the sensors will be heated up by the solar radiation and therefore the temperature is measured systematically too high compared to the actual air temperature. During the observation period of more than 50 years, various radiosonde models with different systematic measurement errors were used at the radio probe station in Vienna.

Modern radio probes show only slight systematic measurement errors and GCOS explicitly recommends the use of radio probes with very well-known measuring characteristics.

Essential Climate Variables - Atmospheric Observations – Upper Air
GeoSphere Austria

Parameter measured/observed	wind, temperature, dew point, pressure.
Starting date	1.1.1952
Temporal Resolution	2 RASO ascents per day
Observational Network	GUAN (Global Upper Air Network) RASO of GeoSphere Austria
Stations	11035 Wien Hohe Warte
Data Portal	GeoSphere Austria: dpru@geosphere.at, roland.potzmann@geosphere.at
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	GUAN (Global Upper Air Network)
Data Submission	GTS (Global Telecommunication System). Two times a day
Licenses	TEMP Data are disseminated free of charge
Use Limitation	no limitation but fee depending on usage conditions
Data Format	TEMP (according WMO No. 306) Bufr (since 2016)
Data Access	
Data Quality	Quality control is done by GeoSphere Austria / Division for Data, Methods, Modelling / Section Quality Control System
Performance Monitoring	Performance monitoring is done by GeoSphere Austria.
Publications	No publications available
Contact (National correspondent, focal point)	dpru@geosphere.at, roland.potzmann@geosphere.at
Remarks	

Radiosonde Austro Control GmbH

Michael Pichler (Austro Control GmbH), Markus Kerschbaum (Austro Control GmbH)

Radio soundings are made by ACG since 1994 on behalf of the Austrian Military at the aerodromes in Linz (LOWL), Graz (LOWG) and Innsbruck (LOWI) once per day at in the Austrian Aeronautical Information Publication (AIP, ENR 5.3) published times. Since 2016, all three stations are equipped with VAISALA AUTOSONDE AS15 systems which are fully automated operating systems, each with a maximum load of 24 radiosondes on a carousel launcher. VAISALA RS41 sondes are used with parachutes and TOTEX balloons filled with hydrogen.

Besides the radio soundings, ACG also detects and reports data from the sondes after the burst of the balloon, which are exchanged as well via the WMO-networks.

Quality control is done by GeoSphere Austria with data monitoring software and by ACG in form of continuous supervision by the operational service at the meteorological watch office in Wien Schwechat.

Main components are:

- Sounding converting system SPS311
- Local workstation including sounding software
- Remote workstation
- Logic controller and support facility
- Balloon launcher
- Carousel and support facility for RS41 radiosondes
- Gas cassettes
- Periphery tools including GC25 and UPS
- Antennas (Telemetry, GPS and navigational aid)
- RS41 Radiosondes with dry batteries)

Essential Climate Variables - Atmospheric Observations – Upper Air
Austro Control (ACG)

Parameter measured/observed	wind, temperature, dew point, pressure
Starting date	Since 1994 ACG is conducting radio soundings on behalf of the Austrian Military.
Temporal Resolution	1 RASO ascent per day per station. Optional ascents if required by Military
Observational Network	ACG internal network
Stations	11010 (Linz Airport), 11240 (Graz Airport), 11120 (Innsbruck Airport)
Data Portal	met-info@austrocontrol.at
Supervising Organization	ACG
National and/or international Networks or Programs	GUAN (Global Upper Air Network)
Data Submission	GTS (Global Telecommunication System)
Licenses	TEMP Data are disseminated free of charge
Use Limitation	No limitation but fee depending on usage conditions
Data Format	TEMP (according WMO No. 306) DESC (according WMO No. 306) BUFR (since 2016)
Data Access	
Data Quality	Quality control is done by ACG & GeoSphere
Performance Monitoring	Continuously supervised by ACG.
Publications	No publications available
Contact (National correspondent, focal point)	met-info@austrocontrol.at
Remarks	

Austrian Weather Radar Network

Michael Pichler (Austro Control GmbH), Markus Kerschbaum (Austro Control GmbH)

The operational weather radar network in Austria is operated by ACG for aeronautical purpose and consists of 4 stations (Figure 15 and Figure 16), where 2 stations are situated at lower altitudes close to international airports and others are mountain sites above altitudes of 2000 m msl. All weather radars are manufactured by Enterprice Electronics Corporation (EEC) and operate at C band (5600-5650 MHz) fully polarized. The four weather radars have been renewed between 2010 and 2013. The new radar type is DWSR-5001C/SDP/CE (antenna pedestal mounted receiver) including 500 kW solid-state modulator, EEC IQ2 signal processor, 4.2 m sandwich antenna and AFC 6 m stealth radome with hydrophobic coating.

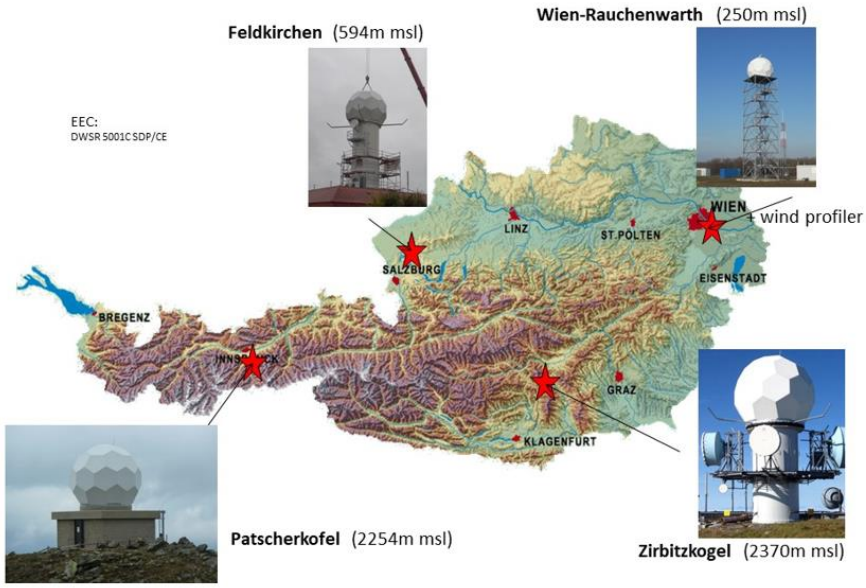


Figure 15: Austrian Weather Radar Network.

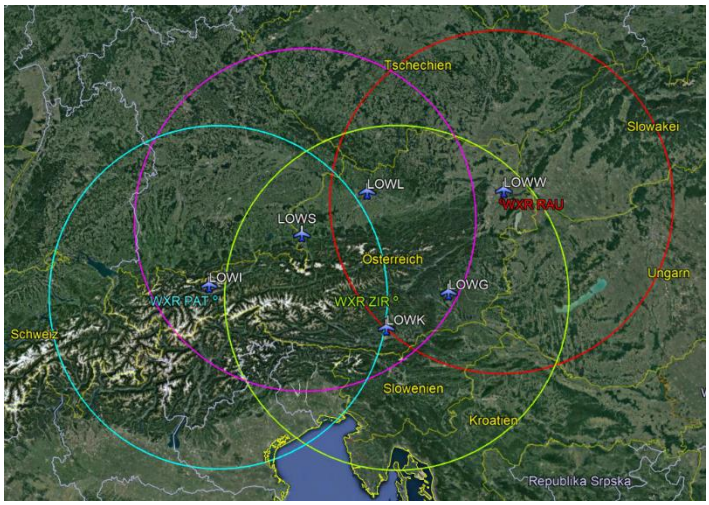


Figure 16: Weather radar data coverage using range of 224 km (cyan-Patscherkofel, magenta-Feldkirchen, red-Rauchenwarth, green-Zirbitzkogel).

The radars use two interleave scans (Figure 17) with elevation angles from -2.0 to 65 degrees. Each half scan consists of 8 elevations (approx. duration of 2.5 min) by applying variable antenna rotation speeds. The latest two half scans are combined and updated every 2.5 min for Austrian composite production. Subsequent full volume scan covers 16 elevations, too. For each half scan, the scan sequence is from top to bottom.

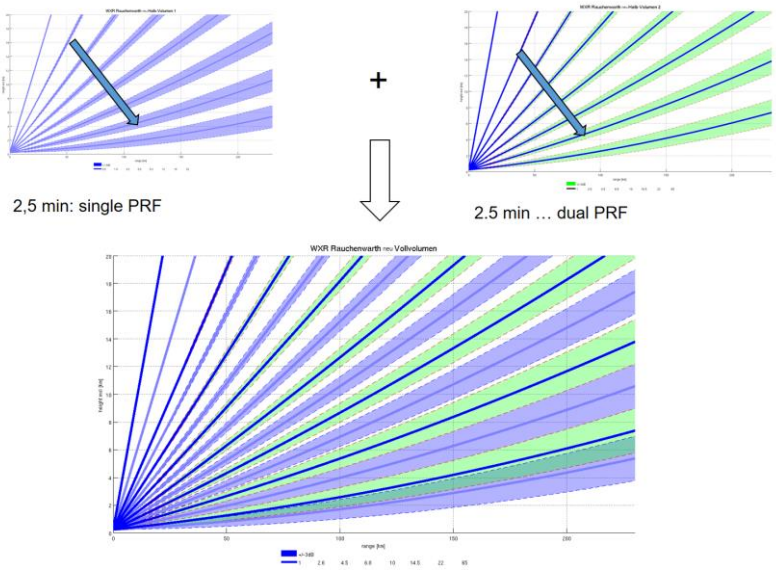


Figure 17 Interleave scan strategy. Full volume scan consists of two half scans of different elevations (3dB beam width is coloured in blue for half-scan 1 and green for half scan 2).

Vertically pointing bird bath scans for ZDR calibration are executed every 15 min. To increase the unambiguous Doppler velocity, dual PRF (pulse repetition frequency) sampling is applied on the second half scan (Figure 18). Spatial resolution is approximately 0.9 degree azimuthal and 250 m in radial by using pulse width of 0.8 µs. Cartesian composite products are created for 1 km resolution in 2.5 min resolution.

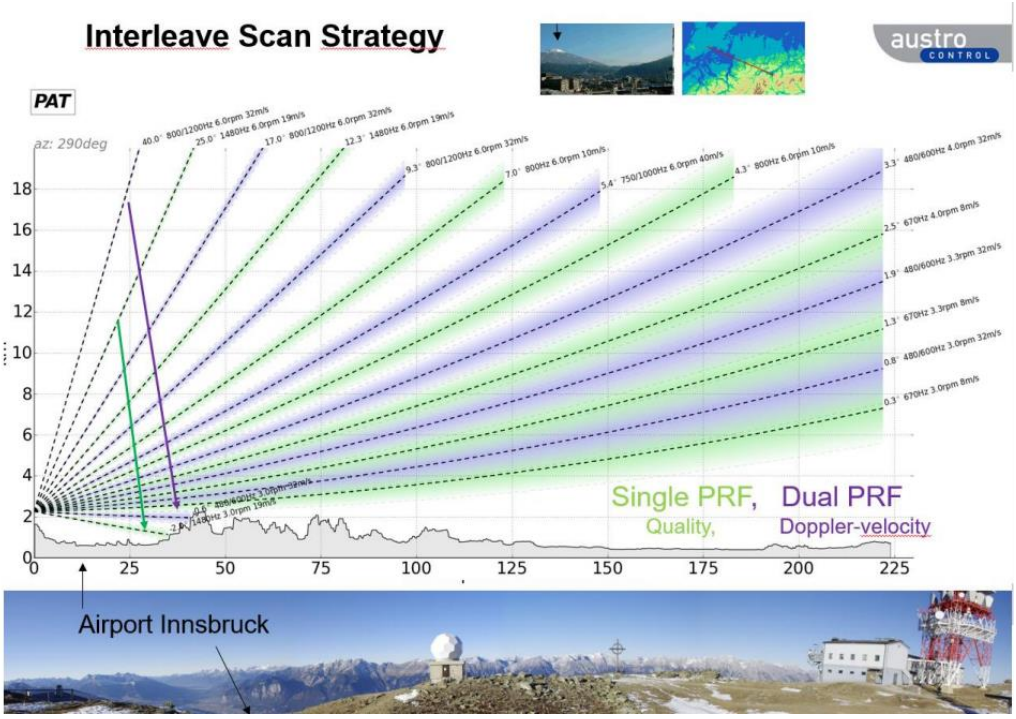


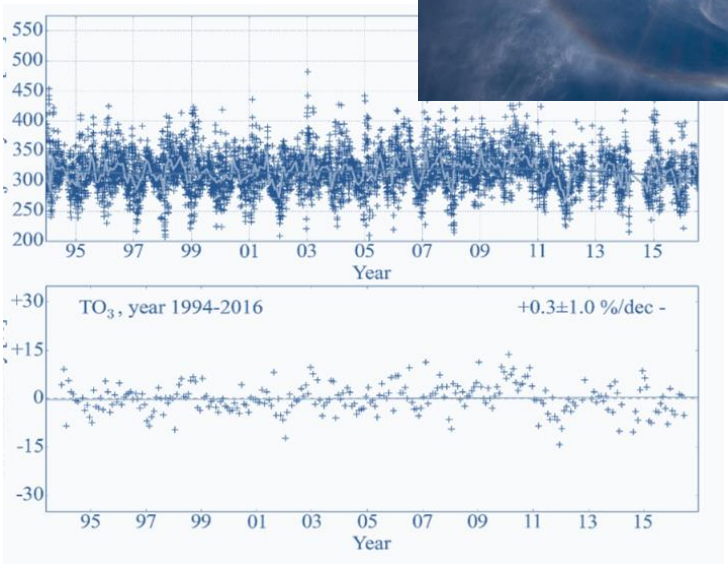
Figure 18: Weather radar Patscherkofel interleave scan strategy and applied pulse repetition frequencies, antenna rotation speed and unambiguous Doppler velocity for each sweep.

Austrian weather radars collect following moments in simultaneous transmission and reception of horizontally and vertically polarized waves: radar reflectivity, Doppler velocity, spectral width, and the polarimetric moments as differential reflectivity, copolar cross-correlation coefficient and differential phase.

References:

http://www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/NET_166_ext_abs.pdf

http://www.meteorologie.at/docs/OEGM_bulletin_2012_2.pdf



Atmospheric Observations

Composition

Stratospheric Ozone

Stana Simic (BOKU)

The major part of atmospheric ozone (about 90 %) is found in the stratosphere in heights of 15 to 55 km. The maximum concentration varies with latitude and season between heights of 20 and 25 km. Ozone has the ability to strongly absorb UV radiation. Therefore, no radiation with wavelengths shorter than 290 nm (harmful UV-C radiation) reaches the Earth's surface and its lifeforms. Thus, the ozone layer is an essential part for the wellbeing of life on Earth. Considering the heavy ozone depletion of the past decades it is of outermost importance to precisely and continuously monitor stratospheric ozone.

Measurements of Stratospheric Ozone in Austria

Total ozone column using the Brewer MkIV #093 spectrophotometer has continuously been measured at the High-Alpine Observatory Hoher Sonnblick (47.05 N, 12.95 E, 3106 m) since 1994 and is the only ozone measurement station in Austria. Measurements are carried out by the Institute of Meteorology and Climatology (BOKU-Met) of the "University of Natural Resources and Life Sciences" (BOKU) and are financed by the "Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology" (BMK).

The long-term dataset of total ozone is a fundamental part in understanding the ozone layer above Austria in its present state and to predict its future development and changes. The Montreal Protocol proves successful because the reduction in the concentration of ozone-depleting substances has led to a slight recovery in total ozone, which can be observed. At the same time, an increase in total ozone variability, caused by the changing meteorological parameters under the changing global climate, can be seen. Because of these climate-ozone interactions, it is very important to closely monitor the ozone layer under the influence of future changing climate.

Vertical ozone profiles can be measured with the Brewer spectrophotometer too and are routinely produced since 1994, using the so called Umkehr-method. These profiles are interesting because the influencing factors on the top of the stratosphere are entirely different to the bottom. Near the tropopause, (approx. 15 km) dynamic influences dominate ozone concentration while near the stratopause (approx. 50 km) photochemical processes prevail.

The Montreal Protocol, initiated in 1987, marked a significant milestone in ozone layer protection. Since then, the concentration of ozone-depleting substances (ODS) in the atmosphere has decreased by 20%. Without this agreement, UV radiation in mid-latitudes would have increased by about 20% between the early 1990s and today, and is projected to increase fourfold by 2100.

These findings are drawn from a study published in Scientific Reports, which also involved the Institute of Meteorology and Climatology at the University of Natural Resources and Life Sciences Vienna (BOKU-Met) (https://doi.org/10.1038/s41598-019-48625-z).

As ozone-depleting substances decline, the expected increase in ozone content in the upper stratosphere (32 to 48 kilometers altitude) is achieved. Conversely, ozone concentration in the lower stratosphere (approximately 15 to 24 kilometers altitude) has steadily declined since 1987. Given that 40% of ozone is globally distributed at this altitude, the progression of recovery in this layer holds significant implications for the future. However, the extent of climate change's influence on ozone layer recovery remains inadequately understood, emphasizing the critical importance of scientific assessments on ozone depletion and recovery status.

The total ozone column at Hoher Sonnblick shows no signs of recovery, but identifying a trend in the strong year-to-year, daily, and seasonal variability is very difficult. The effects of tropospheric dynamics on tropopause height, lower stratospheric temperature, and air mass changes play a crucial role in the

day-to-day variability of the total ozone column. Climate-change-driven effects such as tropospheric warming and changes in polar vortex dynamics have long-term influences on the ozone layer. How strongly climate change will affect the expected recovery of the ozone layer is not yet well understood, which further underscores the importance of ozone research and monitoring.

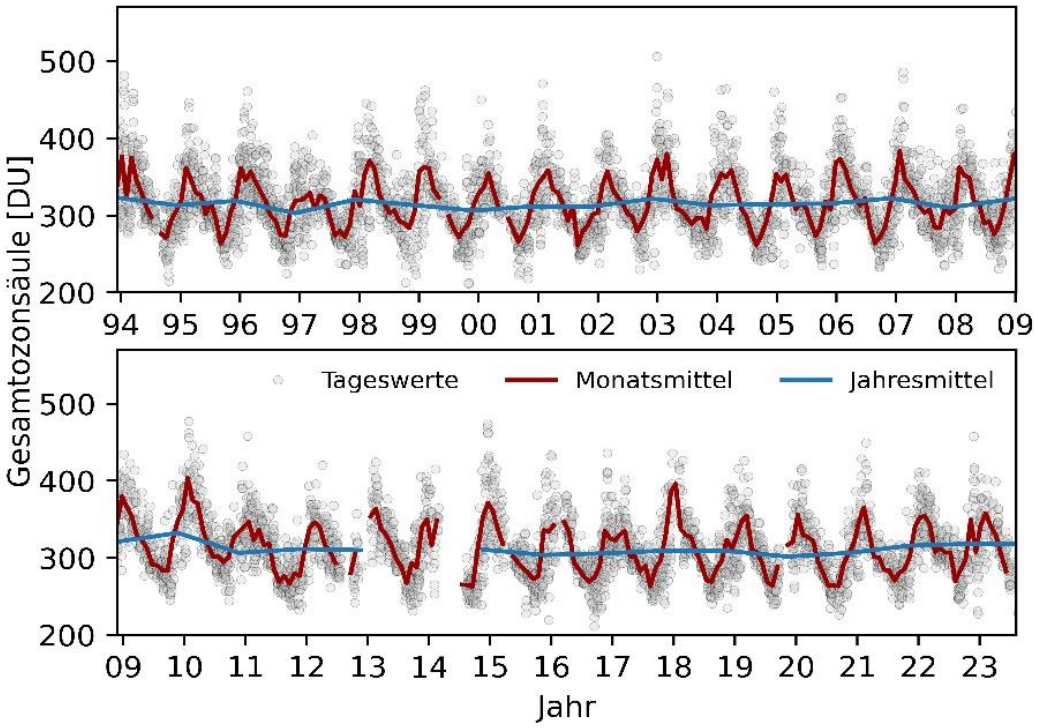


Figure 19: The complete time series with daily, monthly and yearly values of total ozone column at Hoher Sonnblick (1994-2023)

Essential Climate Variables – Atmospheric Observations – Composition
BOKU

Parameter measured/observed	total ozone column and vertical ozone profiles
Starting date	01.01.1994
Temporal Resolution	Daily datasets of total ozone and vertically resolved ozone.
Observational Network	Sonnblick Observatory
Stations	A Brewer MkIV spectrophotometer located at High Alpine Observatory Hoher Sonnblick.
Data Portal	European Brewer Network: https://eubrewnet.aemet.es/eubrewnet NDACC: https://ndacc.larc.nasa.gov/ BOKU: https://imp.boku.ac.at/Strahlung/messwert.htm
Supervising Organization	BOKU, BMK
National and/or international Networks or Programs	European Brewer Network: https://eubrewnet.aemet.es/eubrewnet NDACC: https://ndacc.larc.nasa.gov/instruments/working-groups/spectral-uv
Data Submission	The log Files of the Brewer instrument are transferred daily to a server at BOKU.
Licenses	general BOKU data conditions
Use Limitation	Use for research only
Data Format	ASCII
Data Access	Total ozone column is made publicly available at: https://imp.boku.ac.at/Strahlung/messwert.htm
Data Quality	High-quality standard of NDACC
Performance Monitoring	The instrument and data availability are supervised by the work group „UV Radiation and Ozone“at the Institute of Meteorology and Climatology at University of Natural Resources and Life Sciences, Vienna (BOKU).
Publications	Publications are listed here: https://forschung.boku.ac.at/de/researcher/1FB6B6489C0B9BFD
Contact (National correspondent, focal point)	Dr. Stana Simic BOKU University, Institute of Meteorology and Climatology (BOKU-Met) Gregor-Mendel-Straße 33, 1180 Wien Telefon: (+43) (0)1 47654-81430, https://boku.ac.at/wau/met
Remarks	

Air quality monitoring network

Iris Buxbaum (Umweltbundesamt)

The Environment Agency Austria (Umweltbundesamt) operates the Austrian background monitoring network. Air pollutants and meteorological parameters are measured at seven stations (Figure 20).

The objectives of the measurements are the assessment of

- the large-scale background levels,
- the trend of background levels,
- the long-range transport of air pollutants and
- the monitoring of compliance with limit and target values for the protection of human health and for the protection of ecosystems and vegetation according to the Ozone Act, the Ambient Air Quality Act and related ordinances.

Some of these stations are integrated into international monitoring programs. Three of the sites (Illmitz, Vorhegg and Zöbelboden) are part of the co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP) under the UNECE Convention on Long-range Transboundary Air Pollution (Geneva Air Convention). Furthermore, the Zöbelboden site is integrated into the Integrated Monitoring program for long-term ecosystem monitoring under the Air Convention. The monitoring site at Sonnblick is part of the "Global Atmosphere Watch" program (GAW) of the World Meteorological Organization (WMO). The monitoring results are used for the investigation of large-scale pollutant transports across Central Europe and the long-term monitoring of pollutant trends in the alpine region.

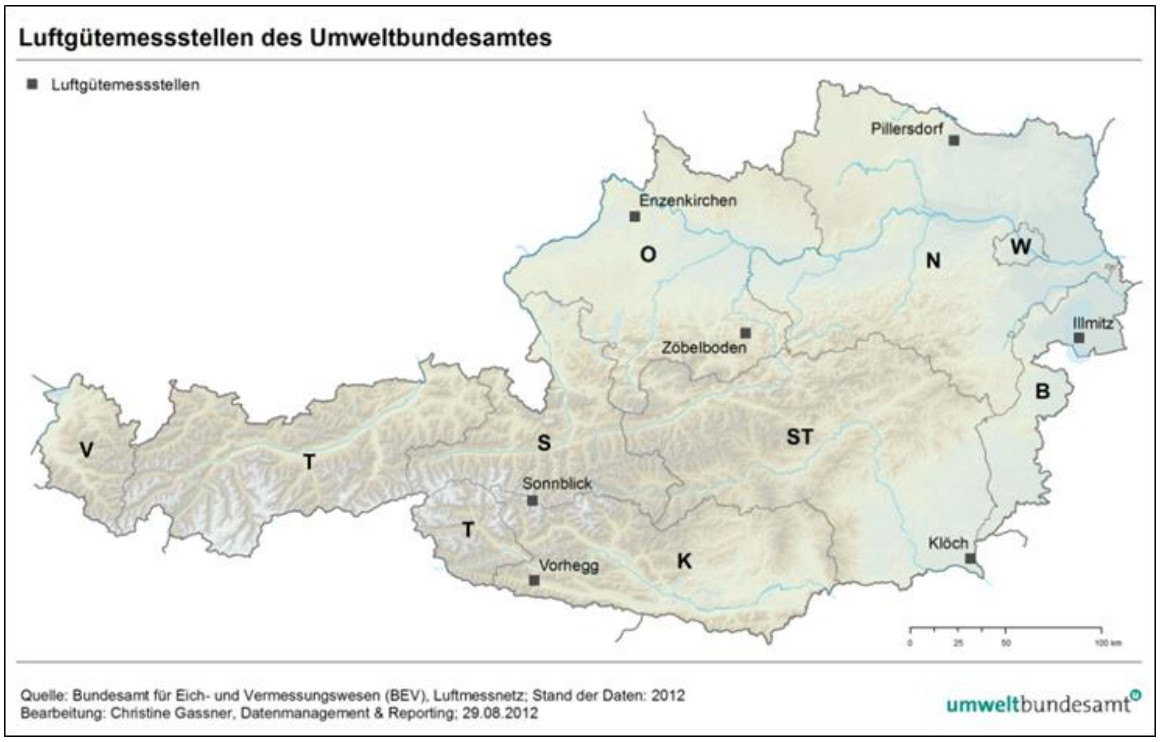


Figure 20: Network of air quality monitoring stations of the Environment Agency Austria.

Essential Climate Variables – Atmospheric Observations – Composition
Umweltbundesamt

Parameter measured/observed	Ozone, sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, methane, particulate matter (PM_{10}, $PM_{2,5}$, PM_1), ultrafine particles, black carbon, heavy metals (As, Cd, Hg, Ni, Pb), PAH, VOC, EC/OC, ammonia Air temperature and humidity, wind speed and direction, pressure, precipitation, sunshine duration, global irradiation, surface radiation balance
Starting date	Enzenkirchen since 03.06.1998 Illmitz since 01.01.1978 Klöch since 01.08.1995 Pillersdorf since 27.02.1992 Sonnblick since 01.01.1989 Vorhegg since 11.12.1990 Zöbelboden since 01.09.1993
Temporal Resolution	Half-hour mean values, daily mean values for gravimetric particulate matter measurements, monthly and yearly mean values for heavy metals, PAH, VOC, EC/OC
Observational Network	Austrian background air quality monitoring network according to the Austrian Ambient Air Quality Act and Ozone Act
Stations	Enzenkirchen, Illmitz, Klöch, Pillersdorf, Sonnblick, Vorhegg, Zöbelboden https://www.umweltbundesamt.at/umweltthemen/luft/messnetz/unsere-luftguetemessstellen
Data Portal	Contact: luft@umweltbundesamt.at Webpage: https://www.umweltbundesamt.at/umweltthemen/luft/daten-luft Open Data Portal for Ozone: https://www.data.gv.at/katalog/dataset/8b3b3cdf-2be6-4f0b-8c86-f6be67e5b002 Dashboard Ammonia: https://www.umweltbundesamt.at/umweltthemen/luft/luftschadstoffe/ammoniak European Air Quality Portal (by EEA -European Environment Agency): https://aqportal.discomap.eea.europa.eu/ Data from Sonnblick site: https://www.sonnblick.net/en/data/data-viewer/ GAW World Data Centre for Reactive Gases (WDCRG, http://www.gaw-wdcrg.org/) and World Data Centre for Greenhouse Gases (WDCGG, https://gaw.kishou.go.jp/) Data from EMEP-sites: http://ebas.nilu.no/
Supervising Organization	Umweltbundesamt (Environment Agency Austria) www.umweltbundesamt.at
National and/or international Networks or Programs	GAW - Global Atmosphere Watch Programme (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.htmlhttps://community.wmo.int/activity-areas/gaw) EMEP - European Monitoring and Evaluation Programme (http://www.emep.int/)

Data Submission	Up-to-date air quality data and yearly submission of validated data
Licenses	CC-BY-4.0 https://creativecommons.org/licenses/by/4.0/deed.de
Use Limitation	No limitations, references to data sources are obligatory.
Data Format	Download of the data as csv (European Air Quality Portal, WDCGG), as NASA-Ames Files (EMEP, WDCRG) or as .json (OpenData Portal for Ozone) Contact luft@umweltbundesamt.at for data as .xlsx
Data Access	Download via various data portals (see **Data Portal**) or contact luft@umweltbundesamt.at Open access
Data Quality	Data quality control is done by the Environment Agency Austria according to the requirements of the Directive 2008/50/EC and Directive 2004/107/EC. Data quality objectives as laid down in Directive 2008/50/EC and Directive 2004/107/EC. Up-to-date data are not validated.
Performance Monitoring	Data availability is supervised by the Environment Agency Austria.
Publications	Monthly and yearly reports (in German, download via https://www.umweltbundesamt.at/luft-monatsberichte and https://www.umweltbundesamt.at/luft-jahresberichte)
Contact (National correspondent, focal point)	Contact: luft@umweltbundesamt.at
Remarks	

Air quality monitoring of the federal states of Austria

Elisabeth Scheicher (Amt der NÖ Landesregierung)

Air pollution control in Austria is the responsibility of the individual countries.

At the air quality stations the parameters SO_2, NO_x, CO, O_3, PM_{10}, $PM_{2,5}$ are measured. Additionally the meteorological parameters wind speed, wind direction, temperature and at a few stations radiation balance, global radiation and relative humidity are observed. A detailed overview of the position of the measuring points and the measured parameters can be found

https://www.umweltbundesamt.at/umweltthemen/luft/messnetz/messstellenuebersicht#Nieder%C3%B6sterreich

The measured values are recorded and stored as half-hour values in the database. The quality assurance is carried out by the technicians of each office of the regional government. An annual comparison with the Umweltbundesamt ensures the comparability of the measurements in Austria.

Overview of the individual measuring networks:

Burgenland

Gabriele Wieger (Amt der Burgenländischen Landesregierung)

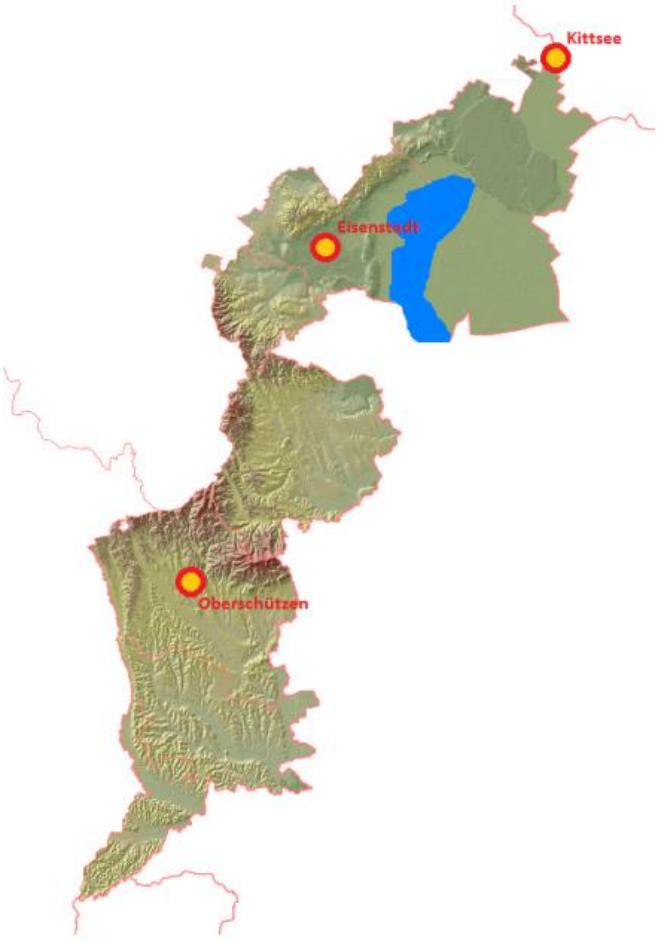


Figure 21: Monitoring stations, Burgenland.

Essential Climate Variables - Atmospheric Observations – Composition
Amt der Burgenländischen Landesregierung

Parameter measured/observed	SO2, NOx, NO, NO2, CO, O3, PM10, PM2,5, BTEX, wind, air temperature, global radiation, relative humidity
Starting date	1994 (only few stations), the development of the whole network was done in 1997
Temporal Resolution	Half-hour mean values , BTEX as yearly mean values, PM2,5 as daily mean values
Observational Network	Burgenländisches Luftgütemessnetz
Stations	3 fix and 3 mobile stations
Data Portal	http://www.burgenland.at/themen/umwelt/luftguete
Supervising Organization	Amt der Burgenländischen Landesregierung
National and/or international Networks or Programs	
Data Submission	Half-hourly
Licenses	none
Use Limitation	none
Data Format	MySQL-Datenbase
Data Access	Download via various data portals (see Data Portal) or contact post.a4-luft@bgld.gv.at Open access
Data Quality	Data quality control is done by Amt der Burgenländischen Landesregierung
Performance Monitoring	Data availability is supervised by the Amt der Burgenländischen Landesregierung
Publications	Monthly and yearly reports, and also reports of special measurements
Contact (National correspondent, focal point)	post.a4-luft@bgld.gv.at
Remarks	

Carinthia

Johannes Maurer (Amt der Kärntner Landesregierung)

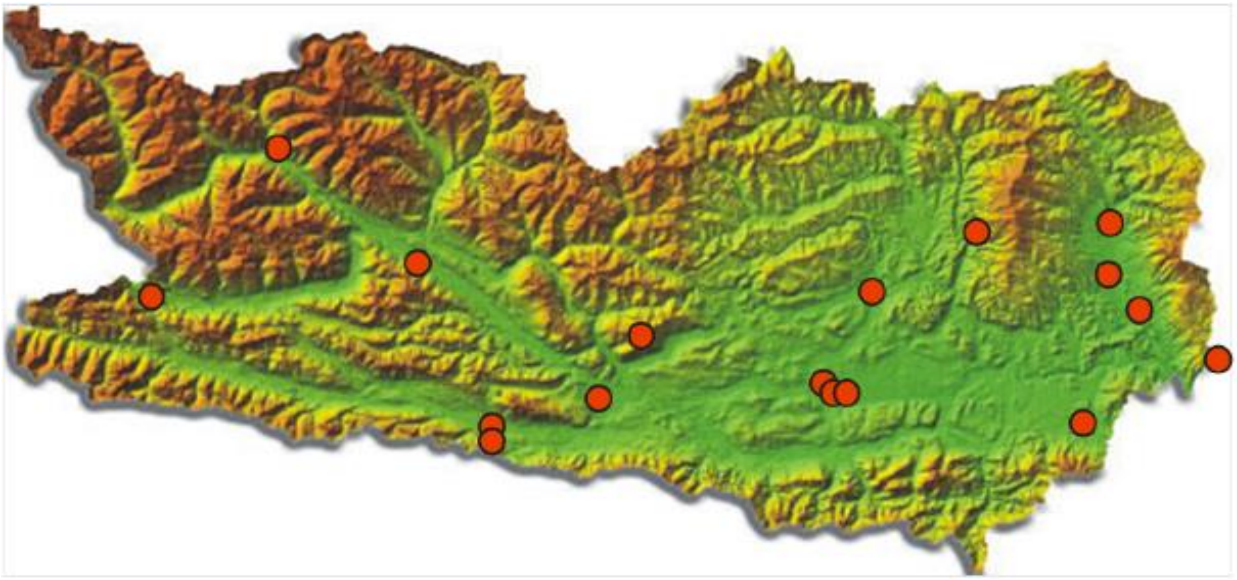


Figure 22:Monitoring stations, Carinthia.

Essential Climate Variable - Atmospheric Observation – Composition
Amt der Kärntner Landesregierung

Parameter measured/observed	Sulfur dioxide (SO_2), nitrogen oxides (NO_x, NO, NO_2), ozone (O_3), fine dust (PM_{10}, $PM_{2,5}$), carbon monoxide (CO), benzene, benzo(a)pyrene (B(a)P), heavy metals in PM_{10} (lead, cadmium), meteorological parameters (air temperature, relative humidity, wind direction, wind speed)
Starting date	From late 1990 onwards
Temporal Resolution	Half-hourly, daily, monthly and annual means
Observational Network	LGMK
Stations	Circa 25 air quality measurement stations in Carinthia
Data Portal	https://www.ktn.gv.at/Verwaltung/Amt-der-Kaerntner-Landesregierung/Abteilung-8/Schnell%20gefunden www.umweltbundesamt.at/luft Meteorological data only on request since they are mainly used for the assessment of the recorded air pollutant concentrations or air pollutant dispersion conditions, and therefore generally neither published nor transmitted to other data networks
Supervising Organization	Provincial Government of Carinthia, Department 8 – Environment, Nature Protection and climate protection coordination , Subdivision Environmental inspection, waste management
National and/or international Networks or Programs	None
Data Submission	Half-hour to annual mean values, transmission path of the continuously recorded measurement data is UMTS, the data are forwarded to the Austrian immission data network (IDV)
Licenses	None
Use Limitation	None
Data Format	ODV = Data format of the Austrian immission data network
Data Access	Generation of Austrian wide uniform time-series through the website of the Umweltbundesamt GmbH www.umweltbundesamt.at/luft/ Region wide to a limited extent through https://www.ktn.gv.at/Verwaltung/Amt-der-Kaerntner-Landesregierung/Abteilung-8/Schnell%20gefunden Meteorological data only on request since they are mainly used for the assessment of the recorded air pollutant concentrations or air pollutant dispersion conditions, and therefore generally neither published nor transmitted to other data networks
Data Quality	Daily data checks are performed by the Provincial Government of Carinthia, Department 8 – Environment, Nature Protection and climate protection coordination, Subdivision Environmental inspection, waste management. From this point, the data are considered as seen and are referred to as provisional data. Final inspection is carried out within the framework of the preparation of the annual report - from this point they are also available to fulfil the national reporting requirements (UBA-EU).

	The comparability and traceability of the measured data is ensured by at least one annual link to primary or reference standards of a reference laboratory and by the regular participation in ring tests.
Performance Monitoring	Provincial Government of Carinthia, Department 8 – Environment, Nature Protection and climate protection coordination , Subdivision Environmental inspection, waste management
Publications	According to the IG-L or Ozone Law, daily reports, monthly reports and annual reports are created and published https://www.ktn.gv.at/Verwaltung/Amt-der-Kaerntner-Landesregierung/Abteilung-8/Schnell%20gefunden
Contact (National correspondent, focal point)	Provincial Government of Carinthia, Department 8 – Environment, Nature Protection and climate protection coordination , Subdivision Environmental inspection, waste management Abt8.post@ktn.gv.at Umweltbundesamt GmbH, Spittelauer Lände 5, 1090 Wien office@umweltbundesamt.at
Remarks	

Lower Austria

Elisabeth Scheicher (Amt der NÖ Landesregierung)

Figure 23: Monitoring stations, Lower Austria (NÖ).

Essential Climate Variable - Atmospheric Observation – Composition
Amt der Niederösterreichischen Landesregierung

Parameter measured/observed	SO2, NOx, NO, NO2, CO, O3, PM10, PM2,5, B(a)P, wind, temperature, radiation balance, global radiation, relative humidity
Starting date	01.10.1984 (only a few station) the development of the whole network was done in 1990
Temporal Resolution	30 minute values
Observational Network	NUMBIS (Niederösterreichisches Umwelt- Beobachtungs- und Informationssystem)
Stations	38 stations as part of the air quality network
Data Portal	https://www.data.gv.at/ http://numbis.noe.gv.at/Numbis/diagramme.jsp post.bd4numbis@noel.gv.at
Supervising Organization	Amt der NÖ Landesregierung
National and/or international Networks or Programs	
Data Submission	https://www.data.gv.at/: Hourly, but only one complete day available http://numbis.noe.gv.at/Numbis/diagramme.jsp previous years and actual year, half mean values, hourly and daily mean values
Licenses	Measurements are disseminated free of charge.
Use Limitation	None
Data Format	xls, csv, txt, ascii, pdf
Data Access	Open access for data.gv.at Open access for http://numbis.noe.gv.at/Numbis/diagramme.jsp Access by contact via mail to numbis.at (post.bd4numbis@noel.gv.at)
Data Quality	Quality control is done by Amt der NÖ Landesregierung
Performance Monitoring	by Amt der NÖ Landesregierung
Publications	Monthly and annual report published at www.numbis.at/publikationen
Contact (National correspondent, focal point)	post.bd4numbis@noel.gv.at
Remarks	

Upper Austria

Regina Pürmayr (Amt der OÖ Landesregierung)

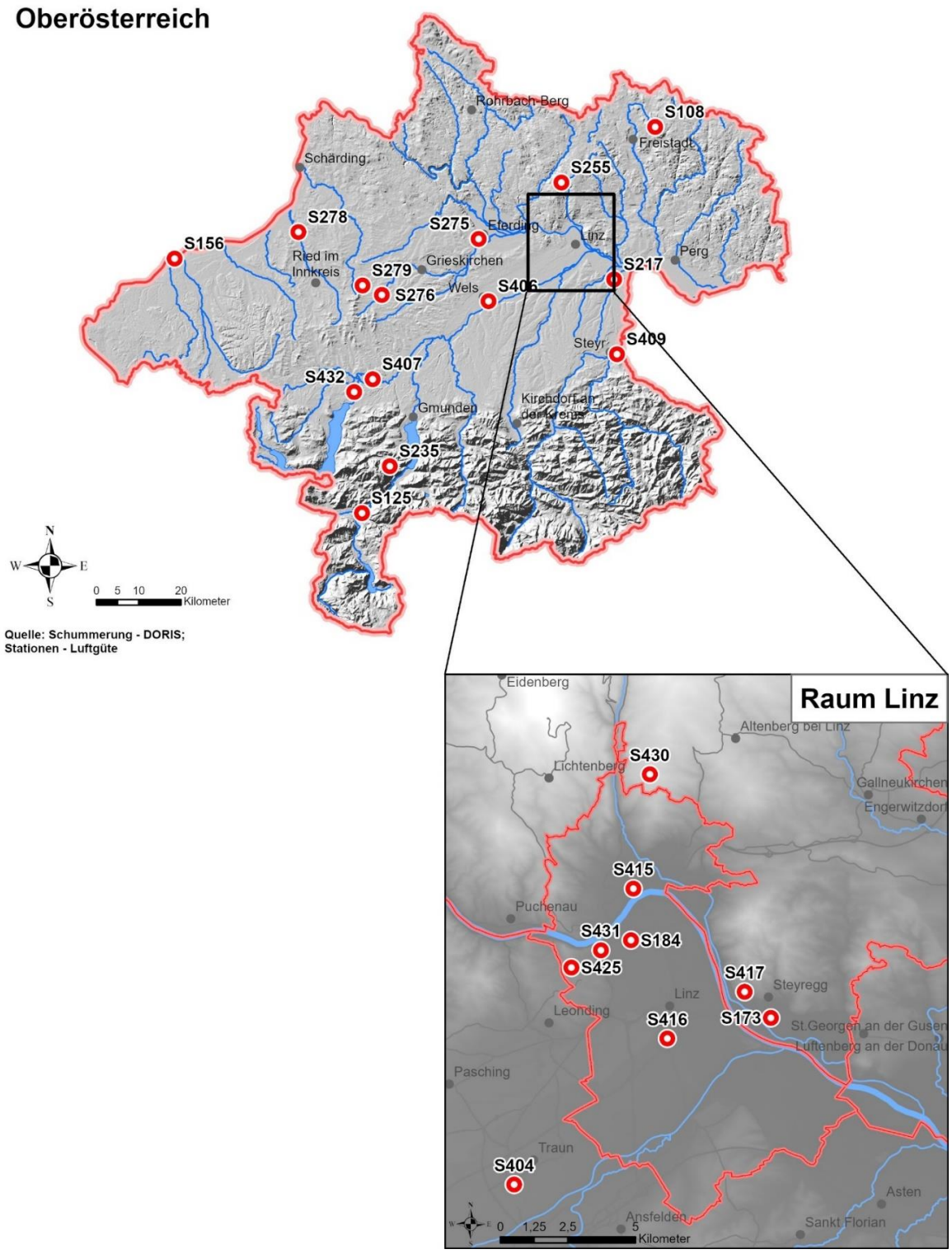


Figure 24: Monitoring stations, Upper Austria (OÖ).

Essential Climate Variable - Atmospheric Observation – Composition
Amt der Oberösterreichischen Landesregierung

Parameter measured/observed	SO2, NOx, NO, NO2, CO, O3, PM10, PM2,5, B(a)P, benzene, heavy metals, wind, temperature, radiation balance, global radiation, relative humidity, light pollution
Starting date	01.02.1977 (only a few stations) the development of the main network was done in 1984, but the locations of various stations have changed since then
Temporal Resolution	B(a)P and benzene monthly, heavy metals yearly, PM10 and PM2,5 daily, other 30 minute values
Observational Network	OÖ Luftmessnetz
Stations	19 stations as part of the air quality network
Data Portal	www.land-oberoesterreich.gv.at/Luftgüte_und_Meteorologie www.land-oberoesterreich.gv.at/Lichtmessnetz www.land-oberoesterreich.gv.at/opendata www.data.gv.at/ us-goethe.post@ooe.gv.at
Supervising Organization	Amt der Oö Landesregierung
National and/or international Networks or Programs	
Data Submission	Half-Hourly
Licenses	Measurements are disseminated free of charge.
Use Limitation	None
Data Format	xls, csv, txt, ascii, json
Data Access	Open access for data.gv.at Access by contact via mail to Land Oberösterreich (us-goethe.post@ooe.gv.at)
Data Quality	Quality control is done by Amt der Oö Landesregierung
Performance Monitoring	by Amt der Oö Landesregierung
Publications	Monthly and annual report published at Luftgüteberichte und Messprogramme
Contact (National correspondent, focal point)	Amt der Oö Landesregierung Direktion Umwelt und Wasserwirtschaft Abteilung Umweltschutz 4021 Linz, Goethestraße86 us-goethe.post@ooe.gv.at
Remark	

Salzburg

Alexander Kranabetter (Amt der Salzburger Landesregierung)

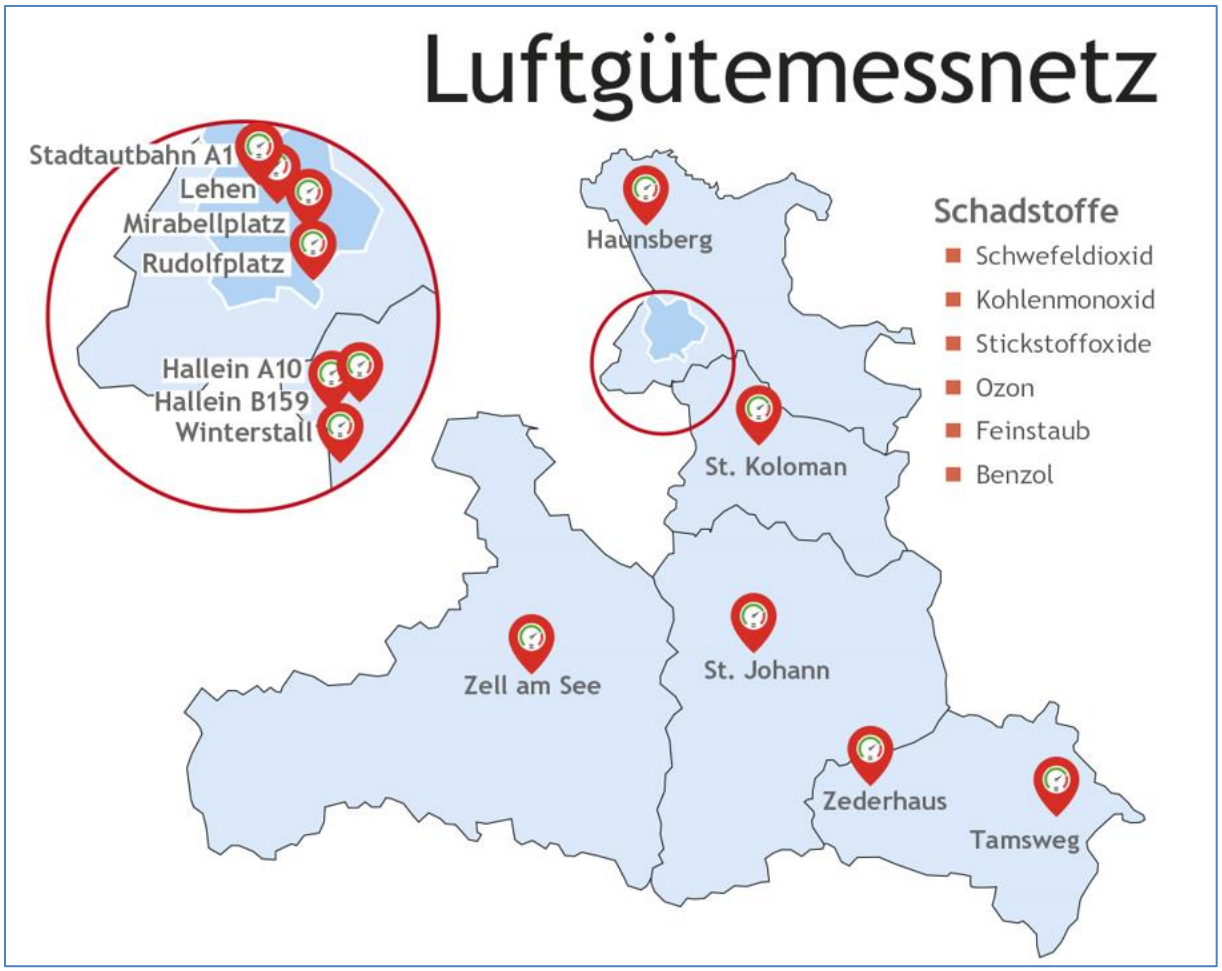


Figure 25: Monitoring stations, Salzburg.

Essential Climate Variable - Atmospheric Observation – Composition
Amt der Salzburger Landesregierung

Parameter measured/observed	SO_2, NO_x, NO, NO_2, CO, O_3, NH3, PM_{10}, $PM_{2,5}$, B(a)P, EC, BC, particle number, benzene, heavy metals, wind, temperature, radiation balance, global radiation, relative humidity
Starting date	01.10.1978 (only a few stations) the development of the whole network was done in 1988
Temporal Resolution	B(a)P , EC, heavy metals yearly, PM_{10} and $PM_{2,5}$ daily, other 30 minutes value
Observational Network	Section 5, Salzburger Luftgütemessnetz
Stations	16 stations as part of the air quality network
Data Portal	https://www.salzburg.gv.at/themen/umwelt/luft http://service.salzburg.gv.at/ogd/client/ luftmessnetz@salzburg.gv.at
Supervising Organization	Amt der Salzburger Landesregierung
National and/or international Networks or Programs	
Data Submission	Half-Hourly
Licenses	Measurements are disseminated free of charge
Use Limitation	**None**
Data Format	**Csv**
Data Access	Open access for data by http://service.salzburg.gv.at/ogd/client/
Data Quality	Quality control suits to Immissionsschutzgesetz & RL 2008/50/EG
Performance Monitoring	by Amt der Salzburger Landesregierung
Publications	Daily, monthly and annual reports: https://www.salzburg.gv.at/themen/umwelt/luft/luftberichte
Contact (National correspondent, focal point)	Land Salzburg Abteilung 5: Natur- und Umweltschutz, Gewerbe Referat 5/02: Immissionsschutz Ulrich-Schreier-Straße 18, 5020 Salzburg Telefon: +43 662 8042-4592 Email: luftmessnetz@salzburg.gv.at
Remarks	

Styria

Thomas Pongratz (Amt der Steiermärkischen Landesregierung)

Figure 26: Monitoring stations, Styria (https://www.umwelt.steiermark.at/cms/ziel/2060750/DE/).

Essential Climate Variable - Atmospheric Observations – Composition
Amt der Steiermärkischen Landesregierung

Parameter measured/observed	SO_2, NO_x, NO, NO_2, CO, O_3, PM_{10}, $PM_{2,5}$, B(a)P, benzene, ultra fine particles wind speed and direction, temperature, , global radiation relative humidity
Starting date	Data since 1989 are stored in the Air quality database
Temporal Resolution	30 minute values
Observational Network	LUIS (Landesumweltinformation Steiermark)
Stations	39 air quality monitoring stations + 9 meteorological stations
Data Portal	Air quality measurements and meteorological measurements: www.umwelt.steiermark.at/cms/ziel/2061730/DE/: Online data portal: www.umwelt.steiermark.at/cms/ziel/2060750/DE/ luft@stmk.gv.at
Supervising Organization	Amt der Steiermärkischen Landesregierung
National and/or international Networks or Programs	
Data Submission	twice an hour (30 minutes mean values)
Licenses	Measurements are disseminated free of charge. Disclaimer and terms of use: www.umwelt.steiermark.at/cms/beitrag/10795434/2054533/
Use Limitation	**None**
Data Format	Data are available as xls File.
Data Access	Free access via online data portal: www.umwelt.steiermark.at/cms/ziel/2060750/DE/
Data Quality	Quality control is done by Amt der Steiermärkischen Landesregierung
Performance Monitoring	Performance monitoring is done by Amt der Steiermärkischen Landesregierung.
Publications	Monthly and annual data reports Air Quality plans and Programs Reports of mobile air quality measurements. Studies concerning Air Quality were published at www.umwelt.steiermark.at/cms/ziel/18437939/DE/
Contact (National correspondent, focal point)	luft@stmk.gv.at
Remarks	

Tyrol

Andreas Krismer (Fachbereichsleitung, Amt der Tiroler Landesregierung)

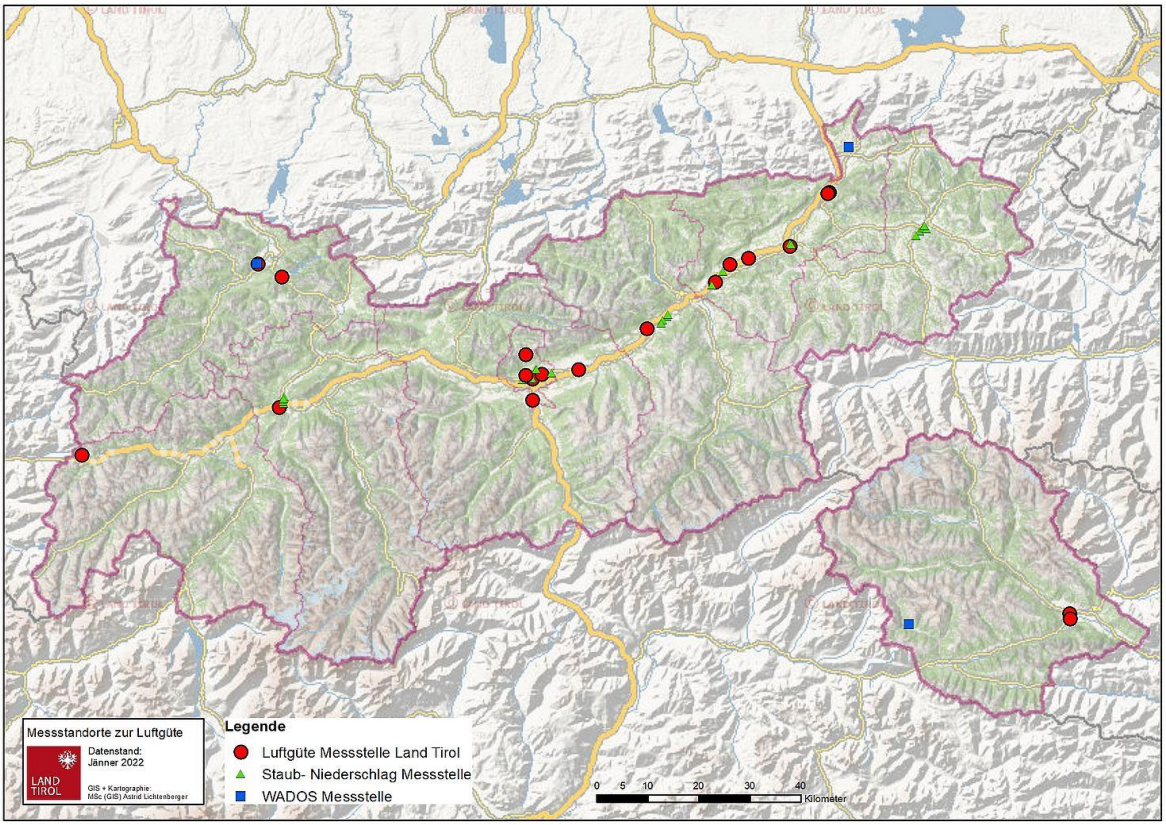


Figure 27: Monitoring stations, Tyrol.

Essential Climate Variable - Atmospheric Observations – Composition
Amt der Tiroler Landesregierung

Parameter measured/observed	SO_2, NO_x, NO, NO_2, CO, O_3, PM_{10}, $PM_{2,5}$, B(a)P, benzene, wind, temperature, global radiation, relative humidity
Starting date	1973 (only a few stations) most of the development of the actual network was done within 1995 and 2005.
Temporal Resolution	30 minute values except gravimetric PM_{10}-measurements (daily mean)
Observational Network	Tiroler Luftmessnetz
Stations	19 stations as part of the air quality network
Data Portal	Immissionsdatenverbund - Umweltbundesamt Contact Person: Spangl Wolfgang wolfgang.spangl@umweltbundesamt.at +43 (1) 31304 5861 Metadata: https://www.tirol.gv.at/umwelt/luftqualitaet/informationen-zum-tiroler-luftguetemessnetz/
Supervising Organization	Amt der Tiroler Landesregierung
National and/or international Networks or Programs	Immissionsdatenverbund - Umweltbundesamt
Data Submission	Half-hourly
Licenses	Measurements are free of charge.
Use Limitation	none
Data Format	Contact: Spangl Wolfgang wolfgang.spangl@umweltbundesamt.at +43 (1) 31304 5861
Data Access	Contact: Spangl Wolfgang wolfgang.spangl@umweltbundesamt.at +43 (1) 31304 5861
Data Quality	Quality control is done by Amt der Tiroler Landesregierung; The quality control matches the requirements of the “IG-L Messkonzeptverordnung” and the “Ozonmesskonzeptverordnung”.
Performance Monitoring	by Amt der Tiroler Landesregierung/Abt.Waldschutz/Fachbereich Luftgüte
Publications	Monthly and annual report published at https://www.tirol.gv.at/umwelt/luftqualitaet/aktuelle-luftqualitaet-und-messberichte-fuer-tirol/ https://www.tirol.gv.at/umwelt/luftqualitaet/jahresberichte/
Contact (National correspondent, focal point)	Contact: Spangl Wolfgang wolfgang.spangl@umweltbundesamt.at +43 (1) 31304 5861
Remarks	

Vorarlberg

Bernhard Anwander (Institut für Umwelt und Lebensmittelsicherheit des Landes Vorarlberg)

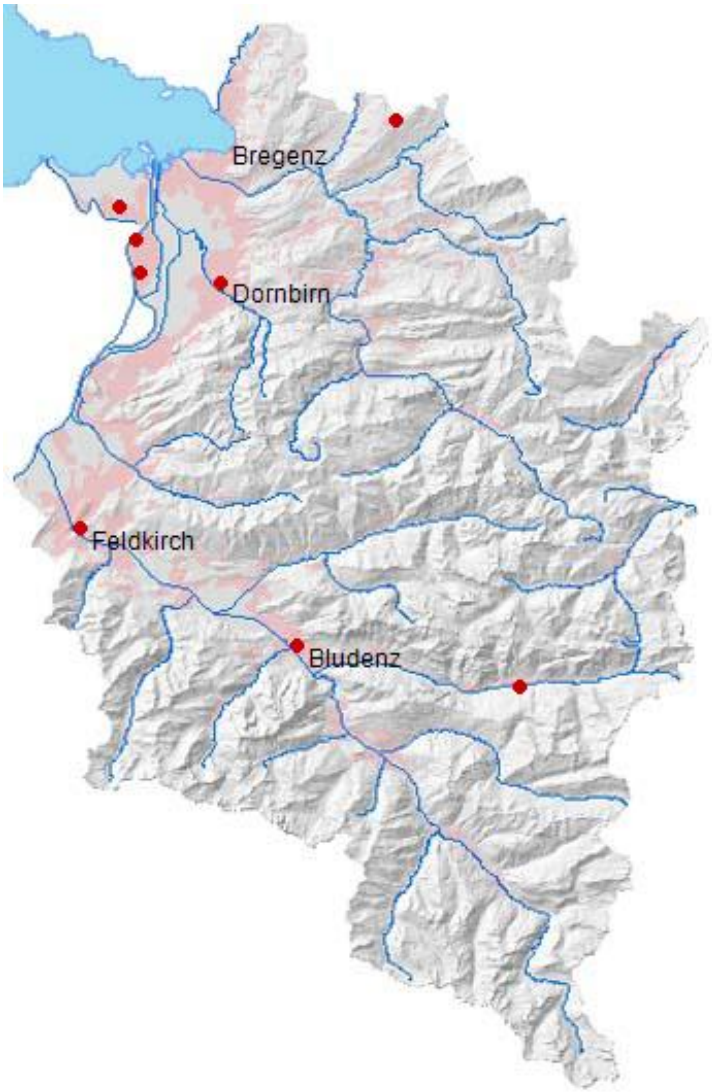


Figure 28: Monitoring stations, Vorarlberg.

Essential Climate Variable - Atmospheric Observation – Composition
Institut für Umwelt und Lebensmittelsicherheit des Landes Vorarlberg

Parameter measured/observed	SO_2, NO_x, NO, NO_2, CO, O_3, PM_{10}, $PM_{2,5}$, B(a)P, wind, temperature, radiation balance, global radiation, relative humidity, precipitation
Starting date	some data time series begins in 1980, but stations may vary
Temporal Resolution	B(a)P monthly composite samples, benzene every 4th day, SO2 (Diffusive Sampler) monthly samples, PM_{10} and $PM_{2,5}$ daily, other 30 minutes value
Observational Network	Air quality monitoring network
Stations	9 stations as part of the air quality network
Data Portal	https://vorarlberg.at/-/luftgueteueberwachung-in-vorarlberg
Supervising Organization	Umweltinstitut des Landes Vorarlberg
National and/or international Networks or Programs	
Data Submission	
Licenses	Measurements are disseminated free of charge.
Use Limitation	None
Data Format	xls, csv
Data Access	Access by contact via mail to Umweltinstitut (umweltinstitut@vorarlberg.at)
Data Quality	Quality control is done by Umweltinstitut
Performance Monitoring	by Umweltinstitut
Publications	Daily, monthly and annual report published at https://vorarlberg.at/web/land-vorarlberg/contentdetailseite/-/asset_publisher/qA6AJ38txu0k/content/luftguete-monatsberichte-und-jahresberichte?article_id=168351
Contact (National correspondent, focal point)	umweltinstitut@vorarlberg.at
Remarks	

Vienna

Rainer Plank (MA22)

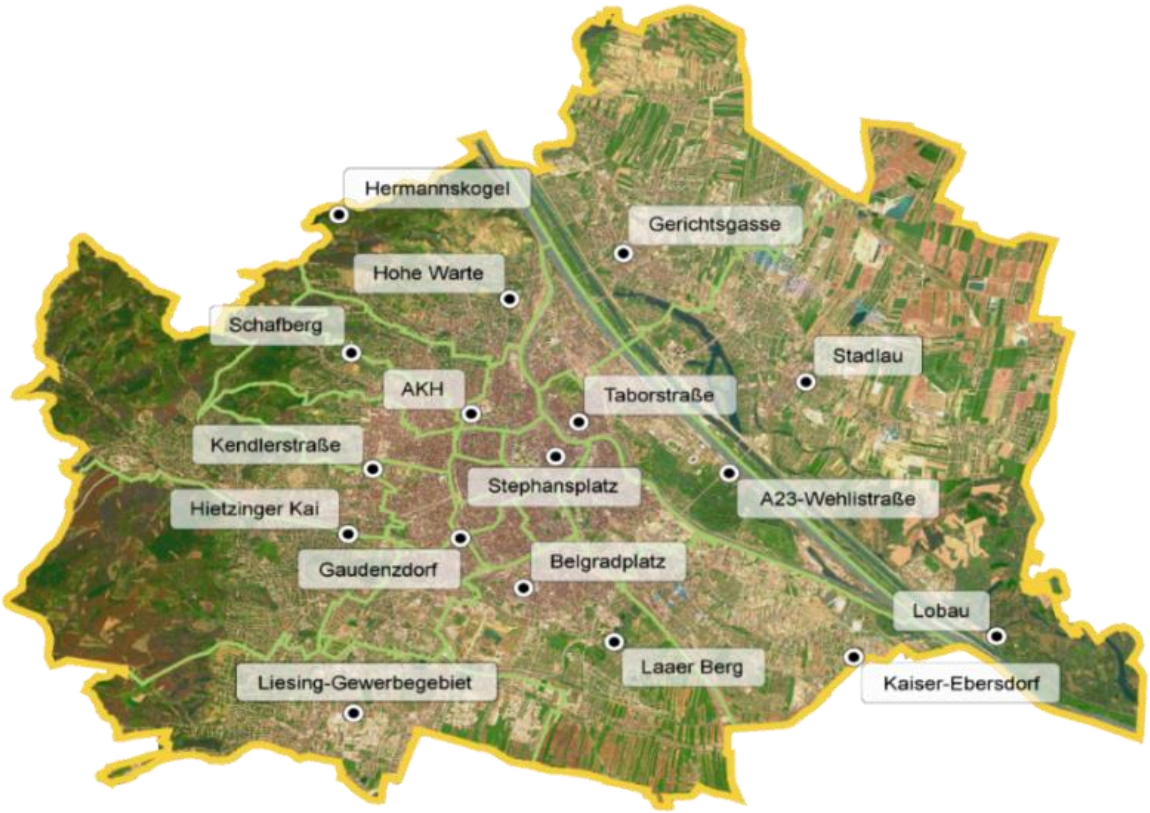


Figure 29: Monitoring stations, Vienna.

Essential Climate Variable – Atmospheric Observations – Composition
MA22

Parameter measured/observed	wind direction, wind speed, air temperature, air pressure, sunshine duration, precipitation sulfur dioxide, nitrogen monoxide, nitrogen dioxide, carbon monoxide, ground-level ozone and particulate matter (PM_{10}, $PM_{2,5}$), heavy metals (Pb, As, Cd, Ni), benzene, benzo(a)pyrene
Starting date	First monitoring sites in 1986
Temporal Resolution	Half-hourly averaged (not heavy metals, benzene, benzo(a)pyrene)
Observational Network	City of Vienna Municipal Department 22 – Environmental Protection Air Quality Monitoring Network
Stations	17 measuring stations located in Vienna (urban environment, traffic-oriented locations, recreation area and industrial zone)
Data Portal	https://www.wien.gv.at/ma22-lgb/luftgi.htm
Supervising Organization	City of Vienna
National and/or international Networks or Programs	Environment Agency Austria (Umweltbundesamt) http://www.umweltbundesamt.at/
Data Submission	real-time
Licenses	CC BY-NC
Use Limitations	For non-profit research
Data Format	on request (cvs, Excel, …) or download or api
Data Access	Download via Municipal Department 22 – Environmental Protection in Vienna – homepage https://www.wien.gv.at/umwelt/luft/messwerte/berichte.html https://www.data.gv.at/ (Luftmessnetz: aktuelle Messdaten Wien)
Data Quality	Data quality control is done by Vienna's Municipal Department 22
Performance Monitoring	Data availability is supervised by Vienna's Municipal Department 22
Publications	daily, weekly, monthly and yearly reports Further publications on the dataset can be found at the web-site of Vienna's Municipal Department 22: https://www.wien.gv.at/ma22-lgb/luftgi.htm half-hourly averaged real time data https://www.data.gv.at/ (Luftmessnetz: aktuelle Messdaten Wien)
Contact (National correspondent, focal point)	Contact: luft@ma22.wien.gv.at
Remarks	

Sonnblick Observatory - High-altitude research station

Elke Ludewig (GeoSphere Austria)

The Sonnblick Observatory (SBO), established in 1886, it is a high-altitude research station at 3.106 m a.s.l., operated by GeoSphere Austria. SBO is one of WMO's Centennial Observing Stations with the longest climatological time series at such altitude. SBO is part of several WMO monitoring and research programs having a focus on climate and environmental research. Numerous institutions (e.g. TU-Vienna, BOKU-Vienna, Environmental Agency –Austria) for monitoring tasks and research purposes use the SBO. In the 1980s, the Sonnblick Observatory was connected to the power supply system, which for the first time allowed measurements to be made in an almost emission-free environment.

Since then, environmental monitoring has been continuously developed. Measurements of trace gases started in 1998, measurements of greenhouse gases were added to the monitoring in 1999, aerosol measurements since 2010 and selected reactive gases since 2002. The Sonnblick Observatory is part of several international measuring networks, like NDACC (Network for the Detection of Atmospheric Composition Change) since 1997, BSRN (Baseline Surface Radiation Network) since 2011 and since 2016, it was upgraded to a global GAW (Global Atmosphere Watch) station.

Figure 30: The hut Zittelhaus and the Sonnblick Observatory in 2019

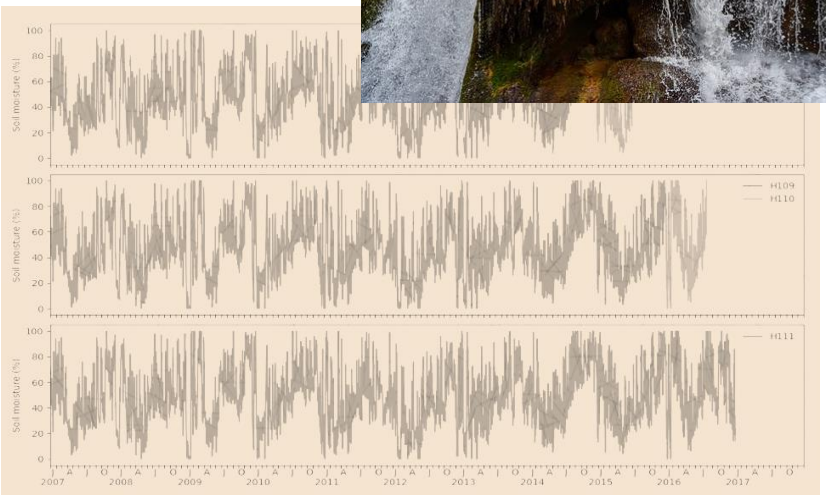
Beside the atmosphere, the Sonnblick Observatory also focuses on the biosphere and the cryosphere considering the WMO programme GCW (Global Cryosphere Watch) and including measurements from the glacier Pasterze. Additional the SBO is a station within the European research infrastructure activities ACTRIS and the eLTER program. The Sonnblick Observatory operates constantly, around the clock, all year long. A minimum of two technicians work at the site on a routine basis, which is one important advantage for the data quality control. Data is uploaded to the world databases in near real time or on an annual basis. The SBO data portal gives an overview of data.

Figure 31: The Sonnblick Observatory with its measuring platforms and towers. The observatory is located in Austria at the alpine ridge between the provinces Salzburg and Carinthia at 3.106m altitude. It was established in 1886 having the focus on atmosphere, cryosphere and biosphere. Research and monitoring is defined within the program called ENVISON (Enviromental Research and Monitoring SONNBLICK).

Essential Climate Variables – Atmospheric Observations – Composition
Sonnblick Observatory

Parameter measured/observed	**Meteorological parameters (1886 - ongoing)** air temperature, relative humidity resp. dew point temperature, precipitation, snow depth, air pressure, global radiation, direct beam solar radiation, wind speed, wind direction, sun shine duration, electrical field strength, clouds, visibility **Additional meteorological parameters** **(2011 - ongoing):** direct radiation, diffuse radiation, global radiation, longwave radiation **(1994/97 - ongoing):** spectral UV, total column ozone, UV-B **Trace gases, selected reactive gases** **(1989 - ongoing):** surface O_3 **(1999 - ongoing):** CH_4, CO_2 **(2002 - ongoing):** CO, NO, NO_x, NO_2, SO_2 **(2022 - ongoing):** H_2O **Aerosols (2010-ongoing):** particulate mass concentration, mass concentration of major chemical components, particle number concentration, particle number size distribution, light absorption coefficient at 7 wavelengths, light scattering coefficient at 3 wavelengths, equivalent black carbon (BC) concentration, total suspended particles matter (TSP) **Precipitation Chemistry (1983/84-ongoing):** Hydrogen ion (H+), pH in precipitation, electrical conductivity, inorganic anions (Cl^-, NO_3^-, SO_4^{2-}), inorganic cations (Na^+, NH_4^+, K^+, CA^{2+}, Mg^{2+}) and since 2017 isotopes **Snow Chemistry (1987 - ongoing):** snow profiles, chloride, nitrate, sulphate, sodium, ammonium, potassium, magnesium, calcium, hydrogen **Permafrost (2007/08 - ongoing)**: temperature in different layers **Glaciology** **(1986/87 - ongoing):** mass balance Goldbergkees **(1998/99 - ongoing):** mass balance Kleinfleisskees **(2012/13 - ongoing):** mass balance Pasterze mass change, meteorological data, outflow rate, snow coverage **Radioactivity** **(1984 - ongoing):** ambient dose rate **(1996 - ongoing):** Be-7 **(2003 - ongoing):** Radon-222 **Air glow via GRIPS 16 Mesopause (80 - 100 km)** OH rational temperature, peak and band intensities An overview can be found here.
Starting date	Measurements began in 1886 and the measuring program continues to evolve. Exact starting times of the respective monitoring can be found in the list of parameters.

Temporal Resolution	Data sets are mostly available as minute averages. Some final checked data sets are only available as ten-minute or half-hour values, time resolutions depending on the world data center.
Observational Network	TAWES, HISTALP, WMO-GTS, WMO-GAW (global station), WMO-GCW, ACTRIS-ERIC, NDACC, ARAD, BSRN, NDMC, eLTER
Stations	**Full name of the site:** Sonnblick Observatory **Short name of the site:** SBO **GPS coordinates:** 47.054018786°N, 12.9576927483°E **Altitude:** 3.106m **City:** The station Sonnblick Observatory is located at Mt. Hoher Sonnblick, close to the villages Rauris, Kolm Saigurn, Heiligenblut in Austria. **Data:** All measurements are performed directly at the Sonnblick Observatory station and its surroundings. Glaciological measurements of the Pasterze are additionally coordinated by the Sonnblick Observatory.
Data Portal	data can be retrieved via the world data centres, or via the Sonnblick Observatory https://data.sonnblick.net/
Supervising Organization	Bundesanstalt für Geologie, Geophysik, Klimatologie und Meteorologie (GeoSphere Austria)
National and/or international Networks or Programs	TAWES, HISTALP, WMO-GTS, WMO-GAW, WMO-GCW, ACTRIS-ERIC, NDACC, ARAD, BSRN, NDMC, eLTER, VAO, MONAIRNET, ENVISON
Data Submission	depending on the network, yearly and monthly data submission, partly near-real time to SBO data base
Licenses	data free of charge for research, access fees can apply
use limitation	**None**
Data Format	different data formats possible, mostly requested .csv
Data Access	access rules of the data centres, registration
Data Quality	data quality meets the standards of the respective monitoring programme. Data control is carried out by employees of GeoSphere Austria and partner institutions such as TU Vienna, BOKU, Umweltbundesamt GmbH, etc.
Performance Monitoring	data availability is supervised by GeoSphere Austria, but also depends on the partner institutions high performance less data gaps
Publications	list of papers: https://www.sonnblick.net/en/science/publications/ data viewer: https://www.sonnblick.net/en/data/data-viewer/ yearly summary of research activities in the Sonnblick Brochure: https://www.sonnblick.net/en/data/download-portal/reports/
Contact (National correspondent, focal point)	common contact: dion@geosphere.at direct contact to the Sonnblick Observatory: https://www.sonnblick.net/en/contact/
Remarks	In addition to GeoSphere Austria, various institutions contribute to the Sonnblick Observatory's data set.



Terrestrial Observations

Hydrosphere

Climate Monitoring Hydrographical Service of Austria

Lovrenc Pavlin (BML, Hydrographical Central Bureau)

Hydrographical Service of Austria (HYDRO Austria) currently operates 967 climate-monitoring stations. Most stations are equipped with automatic continuously measuring sensors, however at many stations an observer also taking daily measurements or regular control measurements. Typical station consists of a rain gauge, air temperature sensor and snow depth sensor. Additional parameters like air humidity, wind speed and direction, global radiation and evaporation are available at specific locations.

Monitoring network is maintained by the Hydrological Services of Austrian federal states. External contractual observers undertake daily measurements. The Hydrographical Central Bureau assures the data is collected, checked and validated consistently across the country. It also collects, publishes and distributes the data.

Longest rainfall time-series start in the 1850s. These are daily rainfall sums, which are always measured between 07:00 UTC+1 of previous day till 07:00 UTC+1 of the current day. First continuously measured rainfall time-series start in the 1950 with wider adoption in the 1980s. Air temperature was in the past measured daily at 07:00, 14:00 and 21:00 UTC+1, however since the adoption of continuous temperature measurements only control measurements are carried out. Snow depth and snowfall is also measured at least daily at 07:00 UTC+1. Continuous measurements are transmitted via radio or GSM network at a rate of 5-15 minutes. Data is first stored at the provincial Hydrographical Service where it is checked for errors. Final validation of the data if performed by the Hydrographical Central Bureau.

Validated precipitation, snow depth and snowfall time series since 1971 as well as rainfall observations of the last 72 hours are freely available on the eHYD Portal (ehyd.gv.at). Additional data is available free of charge on request from the Hydrographical Central Bureau (wasserhaushalt@bml.gv.at).

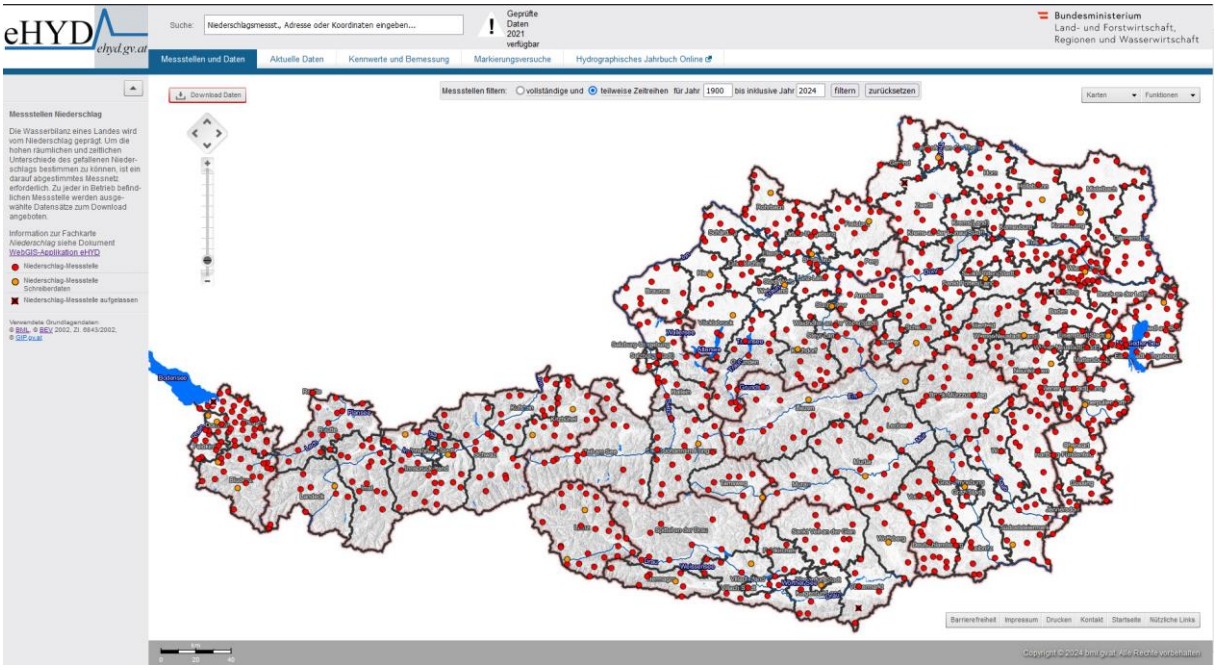


Figure 32: Overview of the Rainfall monitoring network of Hydrographical Service of Austria on the eHYD Data Platform (ehyd.gv.at).

Essential Climate Variables - Terrestrial Observations – Hydrosphere
Hydrographical Service of Austria

Parameter measured/observed	precipitation, snow depth, snowfall, air temperature, relative humidity, wind, global radiation,
Starting date	Precipitation, snow depth, snowfall, air temperature: 1893 relative humidity: 1995 wind: 2003 global radiation: 2008 On eHyd data since 1971 is available.
Temporal Resolution	precipitation: 1-5 minutes or daily snowfall, snow depth, hourly: precipitation of the last 72 hours
Observational Network	Network of Hydrographical Service of Austria
Stations	precipitation, new snow depth, snow depth about 950 stations in Austria
Data Portal	http://ehyd.gv.at/
Supervising Organization	Hydrographical Central Bureau at Federal Ministry of Agriculture, Forestry, Regions and Water management, Division I/3, Water Balance
National and/or international Networks or Programs	Hydrographical Service of Austria
Data Submission	partially hourly, partially yearly
Licenses	Free of charge, provided the sources are acknowledged CC-BY-NC
Use Limitation	For non-profit research
Data Format	csv
Data Access	Varying, partially restricted
Data Quality	Data quality control by Hydrographical Central Bureau
Performance Monitoring	Data availability is supervised by Hydrographical Central Bureau
Publications	Hydrographical yearbook – hydrological annual overview in relation to the long term mean values https://wasser.umweltbundesamt.at/hydjb/
Contact (National correspondent, focal point)	Hydrographical Central Bureau: wasserhaushalt@bml.gv.at
Remarks	

Terrestrial Water Monitoring Hydrographical Service of Austria

Lovrenc Pavlin (BML, Hydrographical Central Bureau)

Hydrographical Service of Austria (HYDRO Austria) is monitoring all main components of the water cycle in Austria. As part of terrestrial water monitoring it is currently operating over a 1000 river discharge/water level stations and over 3000 groundwater stations.

The longest daily discharge time-series start in 1828 at the station Stein-Krems. Such long time-series are extremely important for a reliable statistical analysis flood analysis, which is the basis for many regulations in the flood risk areas. The network expanded more rapidly after the establishment of the HYDRO Austria in the 1893. By the 1970s, it already consisted of more than 500 stations and continuous water level measurements started to be rolled out. Today almost all stations are measuring water levels and water temperature in 15 min intervals. Many of them are transmit data in real time over GSM or radio signal. With the real-time data, the Hydrographical Services can continuously run flood-forecasting models, which are integral for the flood protection of the civil population.

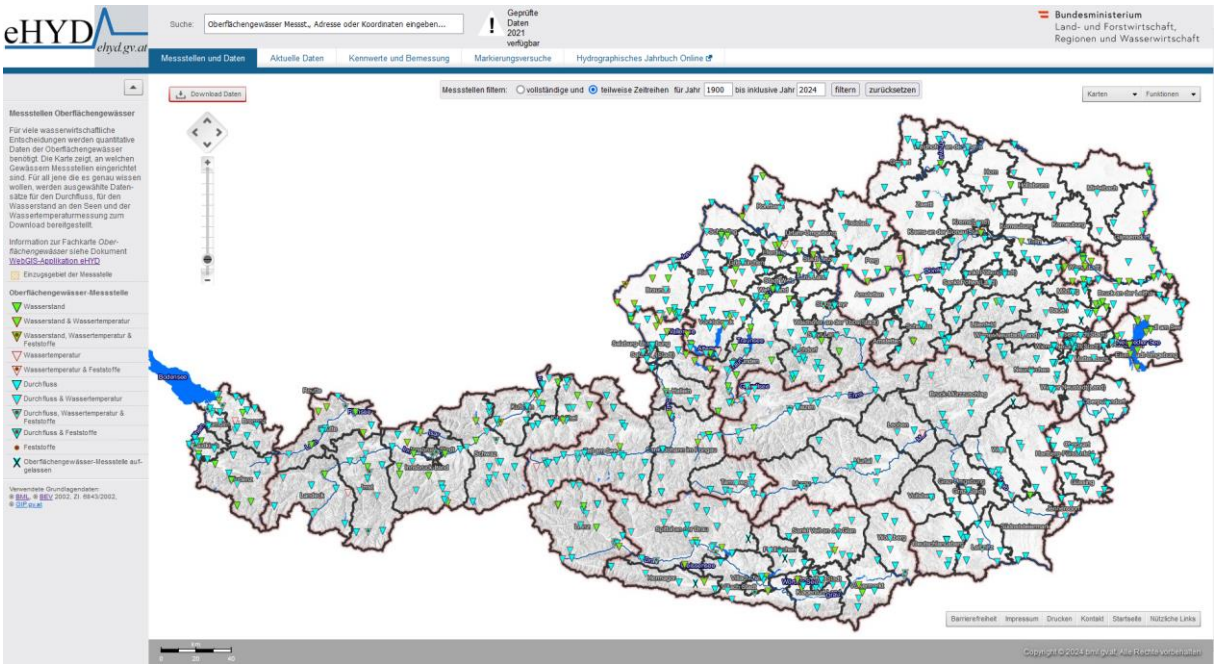


Figure 33: Overview of Surface water monitoring network of Hydrographical Service of Austria on the eHYD Data Platform (ehyd.gv.at).

The regular monitoring of groundwater levels of HYDRO Austria started in 1930s with a greater network expansion since 1960s. As is the case with the surface monitoring stations, also many groundwater stations now transmit data over GSM or radio signal with an hourly interval. Groundwater monitoring data is necessary for assessing the quantitative status of aquifers, which in turn insures responsible and sustainable management of these resources.

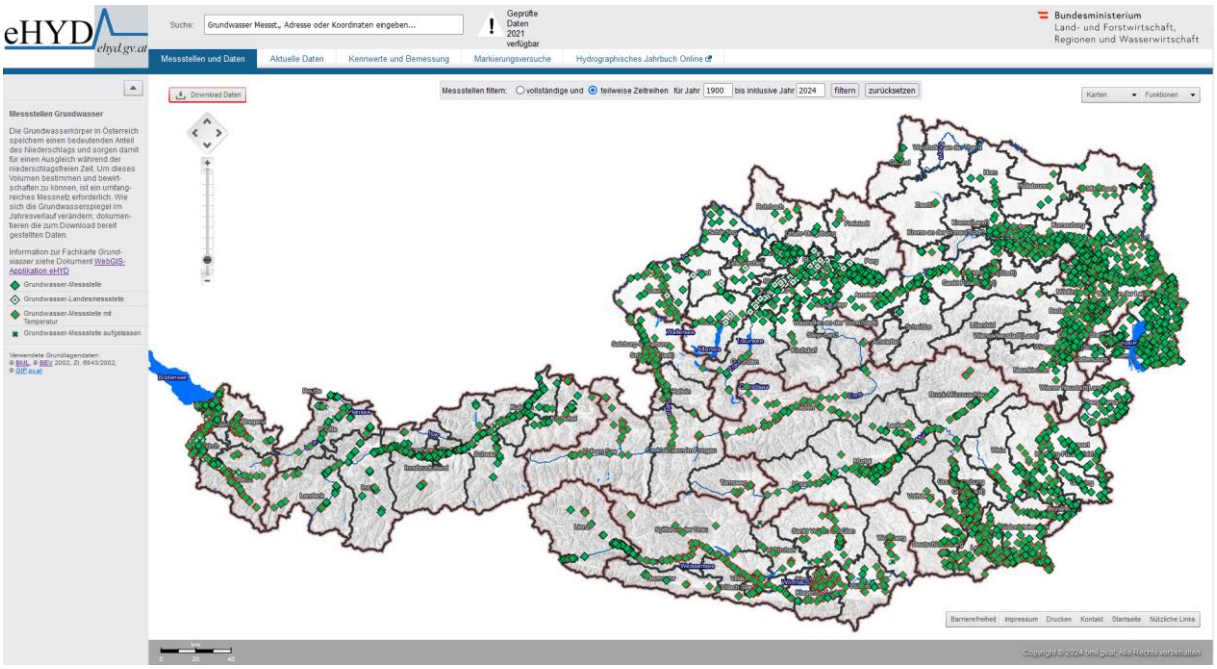


Figure 34: Overview of Groundwater monitoring network of Hydrographical Service of Austria on the eHYD Data Platform (ehyd.gv.at).

Provincial Hydrographical Services are maintaining the monitoring stations and collecting, correcting and validating the data. The Hydrological Central Bureau performs the final quality check and publishes the data together with yearly characteristics in the hydrographical yearbook.

Surface- and groundwater monitoring data of HYDRO Austria is freely available. Daily surface water and monthly groundwater data is available on eHYD (ehyd.gv.at) the Data Portal of HYDRO Austria. Data with higher temporal resolution is available on request at wasserhaushalt@bml.gv.at. Current observations are available on either eHYD or Data Portals of individual provincial Hydrographical Services.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
Hydrographical Service of Austria

Parameter measured/observed	river discharge and water level, water temperature, groundwater level and temperature
Starting date	discharge, water level - earliest time series on eHYD 1950 groundwater level, groundwater temperature - earliest time series on eHYD 1966
Temporal Resolution	discharge, water level: daily groundwater level, groundwater temperature: monthly
Observational Network	Network of Hydrographical Service of Austria
Stations	discharge, water level, water temperature: about 800 stations groundwater level, groundwater temperature: about 3800 stations
Data Portal	http://ehyd.gv.at/
Supervising Organization	Hydrographical Central Bureau at Federal Ministry of Agriculture, Forestry, Regions and Water management, Division I/3, Water Balance
National and/or international Networks or Programs	Hydrographical Service of Austria
Data Submission	The data are updated once a year
Licenses	Free of charge, provided the sources are acknowledged CC-BY-NC
Use Limitation	For non-profit research
Data Format	csv
Data Access	Varying, partially restricted
Data Quality	Data quality control by Hydrographical Central Bureau
Performance Monitoring	Data availability is supervised by Hydrographical Central Bureau
Publications	Hydrographical yearbook – hydrological annual overview in relation to the long term mean values https://wasser.umweltbundesamt.at/hydjb/
Contact (National correspondent, focal point)	Hydrographical Central Bureau: wasserhaushalt@bml.gv.at
Remarks	

Tuxer Alps

Reinhard Fromm (BFW)

The units 'Snow and Avalanches' and 'Torrent Processes and Hydrology' of the Department of Natural Hazards operate 6 stations in the Tuxer Alps with different configurations. The main objectives are investigations of the hydrological processes in the catchment and themes concerning the snowpack and snow avalanches. Depending on research questions of projects, the configurations of the stations changed and they will be adapted to fit the requirements in future. In this context, additional data acquisitions were performed (automated terrestrial laser scanning – spatial distribution of snow; photogrammetry with images taken by remotely piloted systems – snow depth maps and orthophotos).

Essential Climate Variables - Terrestrial Observations – Hydrosphere
BFW

Parameter measured/observed	air temperature, humidity, wind speed and direction, gusts, global radiation, reflected shortwave radiation, incoming outgoing longwave radiation precipitation, river discharge, snow height, snow water equivalent, snow temperatures, snow surface temperature, soil temperatures
Starting date	different, first data February 2006
Temporal Resolution	1 min, 10 min It depends on the station and parameter.
Observational Network	long term data acquisition of the Institute of Natural Hazards
Stations	Tarntalerboden, Lizumerboden, Snowpillow, Lizumbach, Mölsbach, Finkenberg
Data Portal	no
Supervising Organization	Department of Natural Hazards, Austrian Research Centre for Forests (BFW)
National and/or international Networks or Programs	Hydrological data are used by the Hydrological Service. Snow and weather data are used by the Avalanche Warning Service.
Data Submission	automatic data collection: intervals 2 - 4 hours
Licenses	different, depending on work contracts
Use Limitation	different, depending on work contracts
Data Format	csv
Data Access	Hagen, K., Köhler, A., Markart, G., & Fromm, R. (2023). Daily snow water equivalent and snow depth data from the valley Wattental in the Tuxer Alpen, Tyrol, Austria [dataset] [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7845618 https://lawinen.report/ https://www.lawis.at/station/
Data Quality	simple automatic quality check
Performance Monitoring	Data availability is supervised by BFW

Publications	Data were used in several publications concerning snow avalanche research and hydrological investigations. e.g., Helfricht K., Hartl L., Koch R., Marty C., Olefs M. (2018). Obtaining sub-daily new snow density from automated measurements in high mountain regions. Hydrol. Earth Syst. Sci., 22, 2655–2668, 2018 https://doi.org/10.5194/hess-22-2655-2018 Aschauer J., Michel A., Jonas T., Marty C. (2023). An empirical model to calculate snow depth from daily snow water equivalent: SWE2HS 1.0. Geosci. Model Dev., 16, 4063–4081, 2023 https://doi.org/10.5194/gmd-16-4063-2023 Markart, G., A. Römer, G. Bieber, H. Pirkl, K. Klebinder, A. Ita, B. Jochum, B. Kohl, K. Motschka (2014): Assessment of shallow interflow velocities in Alpine catchments for the improvement of hydrological modeling. In: Lollino, G., Arattano M., Rinaldi M., Giustolisi O., Marechal J.C. and Grant G.E. (Editors): Engineering Geology for Society and Territory – Volume 3, River Basins, Reservoir Sedimentation and Water Resources, Springer, 611-616. Assessment of Shallow Interflow Velocities in Alpine Catchments for the Improvement of Hydrological Modelling | SpringerLink
Contact (National correspondent, focal point)	reinhard.fromm@bfw.gv.at karl.hagen@bfw.gv.at
Remarks	Additional data acquisitions were carried out in the test site. This includes terrestrial laser scanning and photogrammetry, which uses images taken with remotely piloted systems. Results are snow depth maps, spatial snow depth changes, depositions of snow avalanches, orthophotos, landslides, etc. In addition, investigations on development of near surface interflow were treated in the test catchments using rain simulation, tracer insertion, geoelectric equipment. Results are e.g., bandwidths of near surface interflow velocity for typical substrates in the Tuxer Alps, new insights in contribution of interflow to catchments runoff in different types of precipitation events.

Torrent Research Areas – Monitoring data

Karl Hagen (BFW)

Since the beginning of settlements in the alpine space, natural hazards such as torrents have been a major threat to human beings. Increasing conflicts between natural geophysical processes and increasing human demands on natural resources require improved protection strategies and protection measures. Occurrence probability and potential impacts of this risk in terms of damages to property define the degree of the risk. Natural hazards cannot be totally avoided through targeted countermeasures but certain risk management strategies and actions may be derived thereof: prevention before, reaction during and rebuilding after the disaster.

Data for process analyses are collected within monitoring systems implemented in torrent research areas. These are equipped with a large number of measuring instruments. For nearly 50 years the Department of Natural Hazards of the BFW has been engaged in research in the Alpine region recording measuring data at extreme sites. Data series of this duration provide also a good insight into the evolution of climate parameters. Extrapolations derived from it are suitable for comparison with results from climate change models or supplement them with regard to their informative value. This is useful because climate change models describe a simplified picture of reality based on the size of the data grid they use.

Figure 35: Location of the Torrent Research Areas (TORA)

Location Oselitzenbach was closed 2020.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
BFW

Parameter measured/observed	precipitation, air temperature, wind speed and direction, humidity, snow height and water equivalent, global radiation river discharge, groundwater (level and temperature)
Starting date	earliest time series in 1969
Temporal Resolution	5 min, 15 min, 1 hour, daily, weekly, depending on parameters
Observational Network	long term series of the Alpine region and Alpine lowland from BFW
Stations	about 15 stations located in Lower Austria and Carinthia
Data Portal	no
Supervising Organization	Department of Natural Hazards, Austrian Research Centre for Forests (BFW)
National and/or international Networks or Programs	no
Data Submission	daily GSM calls, weekly data transmissions of Excel files
Licenses	different, depending on work contracts
Use Limitation	different, depending on work contracts
Data Format	text, .mis, .xlsx, access, ascii
Data Access	restricted
Data Quality	Data quality control is done by employees of BFW.
Performance Monitoring	Data availability is supervised by BFW.
Publications	BFW reports, (former: FBVA reports)
Contact (National correspondent, focal point)	Contact: Gerhard.markart@bfw.gv.at
Remarks	

ISMN - In situ soil moisture observations

Irene Himmelbauer & Wouter Dorigo (TU Wien, BfG)

The International Soil Moisture Network (ISMN, https://ismn.earth/) is a unique and global in situ (on ground) soil moisture data base, easily and freely accessible for scientific use (Dorigo et al., 2021). Initiated in 2009 through international cooperation (TU Wien GEO, ESA, CEOS, GEWEX, GTN-H, GCOS-TOPC, etc.), the ISMN realized the need for storing and maintaining global, long term, reliable (harmonized and quality controlled) in situ soil moisture measurements crucial for the validation and improvement of satellite soil moisture products, land surface-, climate-, and hydrological models.

Following, building and improving upon standardized measurement protocols and quality techniques, the ISMN evolved into a widely used in situ data source (surface and sub-surface) collaborating with a myriad of data organizations on a global scale who share their data with the ISMN on a voluntary basis. With its 80 networks and more than 3000 stations (see Figure 36 and Figure 37) dating from 1952 up to near real time, the ISMN provides benchmark data for several operational services such as ESA CCI Soil Moisture, the Copernicus Climate Change (C3S) - and Global Land Service (CGLS), the online validation tool QA4SM, etc. In general, ISMN data is widely used in a variety of scientific fields with hundreds of studies making use of ISMN data even beyond the soil moisture community (e.g. climate, water, agriculture, disasters, ecosystems, weather, biodiversity, etc.).

Between 2009 and 2022, the ISMN was developed, hosted, operated and maintained by GEO and funded through several different programs by the European Space Agency (Soil Moisture and Ocean Salinity – SMOS- mission, IDEAS+, Quality Assurance for Earth Observation – QA4EO). A huge success was celebrated in 2021 by finding long term financial support for the ISMN through the German Ministry of Digital Infrastructure and Transport with five full time positions, guaranteeing a stable future for the ISMN. Within a following 19 month planning, training and relocation phase, the ISMN was successfully transferred on December 12th 2022 from TU Wien to the new hosts in Koblenz Germany at the International Centre for Water Resources and Global Change (ICWRGC), and the German Federal Institute for Hydrology (BfG). While we, within the GEO remote sensing and CLIMERS groups, are really happy that the globally acknowledged and widely used ISMN has now a stable future and was transferred in the very capable hands of the new ISMN team in Germany, we want to state at this point, that it is a missed opportunity for Austrian innovation and R&D to not keep the future of the ISMN in Austria.

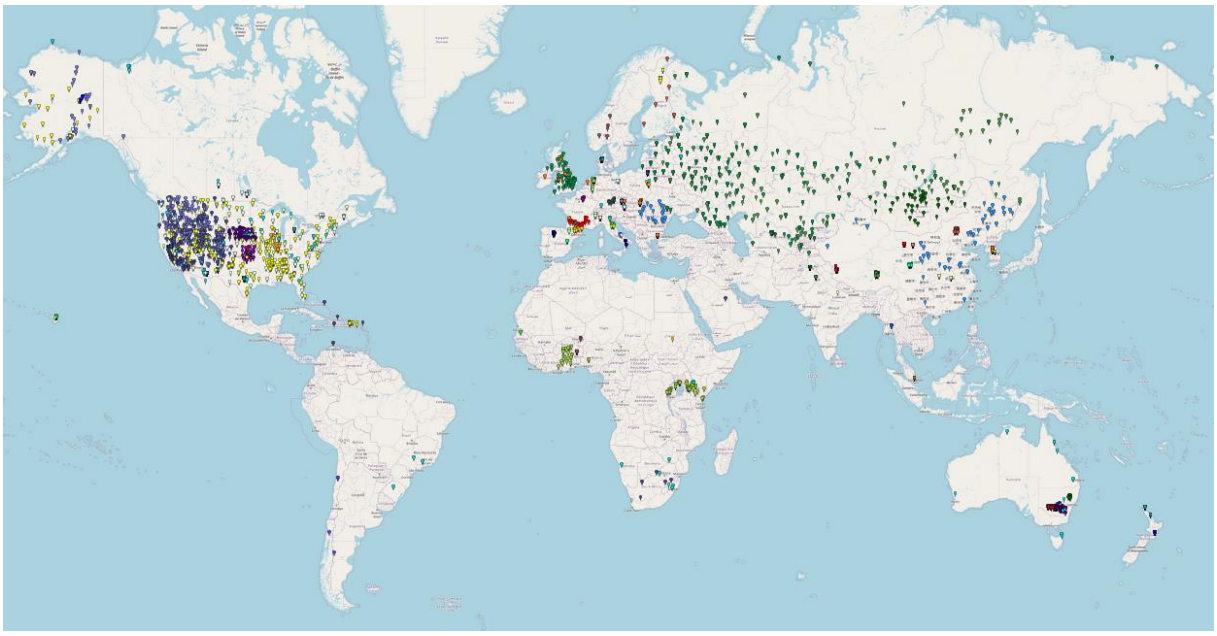


Figure 36: Overview of stations contained in the ISMN. Note: there is one historical station in Antarctica (data availability from 2003 - 2009) which is not covered on that map but can be viewed on the ISMN data viewer: https://ismn.earth/en/dataviewer/

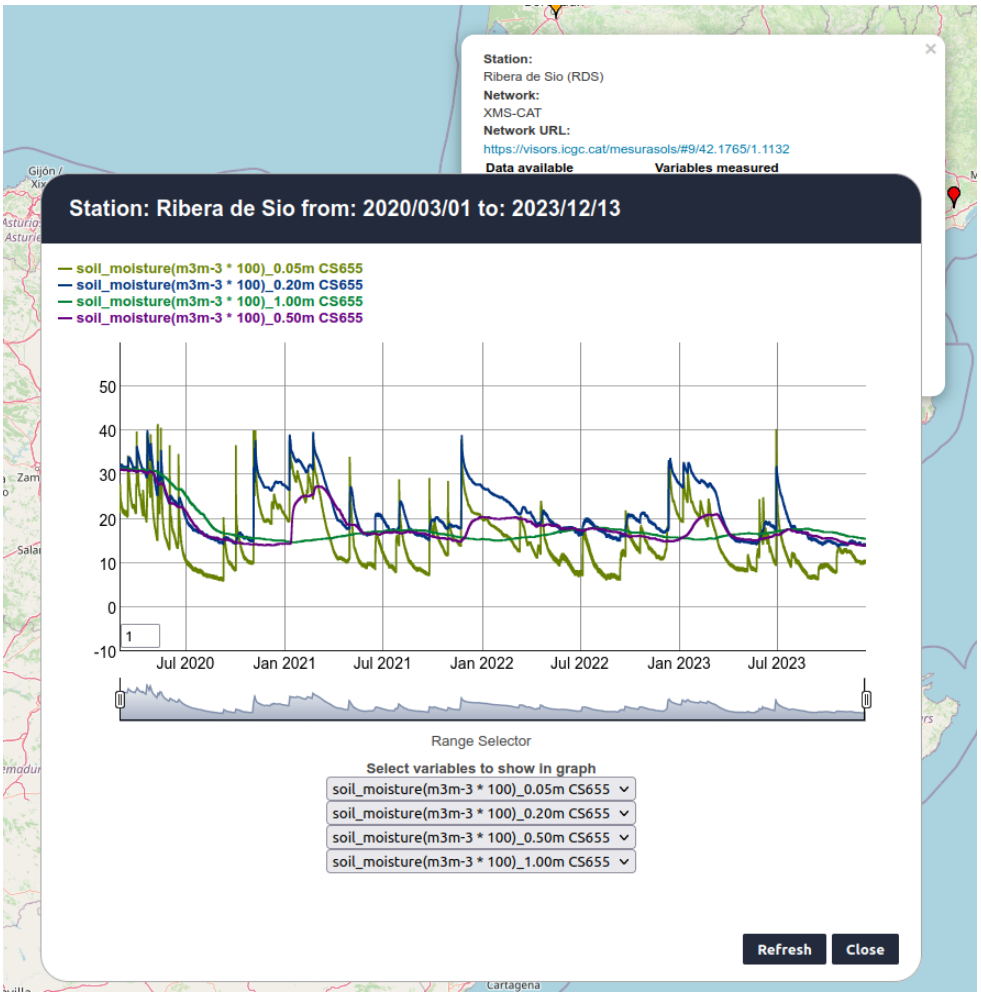


Figure 37: Example of soil moisture in different soil depth layers (0.05 m, 0.2 m, 0.5m, 1 m) for station Ribera de Sio of the XMAS-CAT network located close to the Pyrenean mountain range in Catalonia/Spain.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
TU Vienna, BfG

Parameter measured/observed	Soil moisture, soil temperature, air temperature, precipitation, snow depth, snow depth equivalent, soil properties
Starting date	Earliest observations from 1952
Temporal Resolution	Mainly 1 hourly, sometimes 2 hourly
Observational Network	Various individual data providers (~75) and networks (~80)
Stations	~3000 (globally distributed)
Data Portal	https://ismn.earth
Supervising Organization	TU Wien (<12/2022), (12/2022<) BfG Germany and ICWRGC
National and/or international Networks or Programs	ISMN, currently sponsored long term by the German Ministry for Transport and Digital Infrastructure
Data Submission	Observations, ranging from historical records (no updates any longer), to irregular updates (every few years), to regular updates (once a year), to automated daily updates, using various data exchange protocols (email, ftp, https, etc.)
Licences	Free of charge, data origin shall be acknowledged and referenced (see https://ismn.earth/en/terms-and-conditions)
Use Limitation	For scientific use only, no onward distribution
Data Format	Downloaded datasets are provided in text format (csv/zip)
Data Access	Access by free registration
Data Quality	All datasets implemented in the ISMN have to run through a series of automated quality control procedures. Each observation is then associated by a quality indicator (see also https://ismn.earth/en/data/flag-overview).
Performance Monitoring	Supervised by TU Wien (<12/2022) and (12/2022<) BfG Germany and ICWRGC , although data availability depends on the individual data providers.
Publications	Dorigo, W., Himmelbauer, I., Aberer, D., Schremmer, L., Petrakovic, I., Zappa, L., Preimesberger, W., Xaver, A., Annor, F., Ardö, J., Baldocchi, D., Bitelli, M., Blöschl, G., Bogena, H., Brocca, L., Calvet, J.-C., Camarero, J. J., Capello, G., Choi, M., Cosh, M. C., van de Giesen, N., Hajdu, I., Ikonen, J., Jensen, K. H., Kanniah, K. D., de Kat, I., Kirchengast, G., Kumar Rai, P., Kyrouac, J., Larson, K., Liu, S., Loew, A., Moghaddam, M., Martinez Fernandez, J., Mattar Bader, C., Morbidelli, R., Musial, J. P., Osenga, E., Palecki, M. A., Pellarin, T., Petropoulous, G. P., Pfeil, I., Powers, J., Robock, A., Rüdiger, C., Rummel, U., Strobel, M., Su, Z., Sullivan, R., Tagesson, T., Varlagin, A., Vreugdenhil, M., Walker, J., Wen, J., Wenger, F., Wigneron, J. P., Woods, M., Yang, K., Zeng, Y., Zhang, X., Zreda, M., Dietrich, S., Gruber, A., van Oevelen, P., Wagner, W., Scipal, K., Drusch, M., and Sabia, R. (2021). The International Soil Moisture Network: serving Earth system science for over a decade. Hydrology and Earth System Sciences, 25, 11, 5749--5804. https://doi.org/10.5194/hess-25-5749-2021 Dorigo, W.A., Xaver, A., Vreugdenhil, M., Gruber, A., Hegyiová, A., Sanchis-Dufau, A.D., Zamojski, D., Cordes, C., Wagner, W., and Drusch, M. (2013). Global Automated Quality Control of In situ Soil Moisture data from the International Soil Moisture Network. Vadose Zone Journal. https://acsess.onlinelibrary.wiley.com/doi/10.2136/vzj2012.0097 A list of other relevant publications can be found online: https://ismn.earth/en/publications/
Contact (National correspondent, focal point)	**TU Wien:** Wouter Dorigo: wouter.dorigo@geo.tuwien.ac.at Irene Himmelbauer: irene.himmelbauer@geo.tuwien.ac.at

	BfG and ICWRGC, Germany: ISMN coordinator Matthias Zink: Zink@bafg.de Full team: ismn@bafg.de
Remarks	This is the last entry of the ISMN within the Austrian GCOS report, the ISMN has switched officially in 2022 from the GCOS Austria group to the GCOS Germany group

ESA CCI and C3S Soil Moisture Climate Data Records

Alexander Gruber (TU Wien), Wouter Dorigo (TU Wien), Wolfgang Preimesberger (TU Wien), Pietro Stradiotti (TU Wien)

Soil moisture is a key land surface variable that is involved in the exchange of water and heat between the land surface and the atmosphere. It affects vegetation growth along with the formation of precipitation and runoff, with direct consequences for the agricultural yield. Soil moisture also plays an important role in the climate system and affects the predictability of the atmosphere on subseasonal to seasonal time scales, which is important for weather and climate forecasting.

Consistent long-term climate data records of soil moisture, in line with the "systematic observation requirements for satellite-based products for climate" as defined by GCOS, are created within the European Space Agency (ESA) Climate Change Initiative (CCI) for soil moisture (SM) project (https://climate.esa.int/en/projects/soil-moisture/), led by TU Wien. In the ESA CCI SM project, soil moisture retrievals from different active and passive microwave satellite missions (Figure 38) are merged into three products: the "ACTIVE", the "PASSIVE", and the "COMBINED" (Gruber et al., 2019). These products provide daily global estimates of soil moisture on a quarter degree regular grid from 1978 (PASSIVE and COMBINED) or 1991 (ACTIVE) until the present. Quality flags and uncertainty estimates are provided as well. New product versions are released in September each year, including both the latest algorithmic advances and dataset extensions until the end of the previous year.

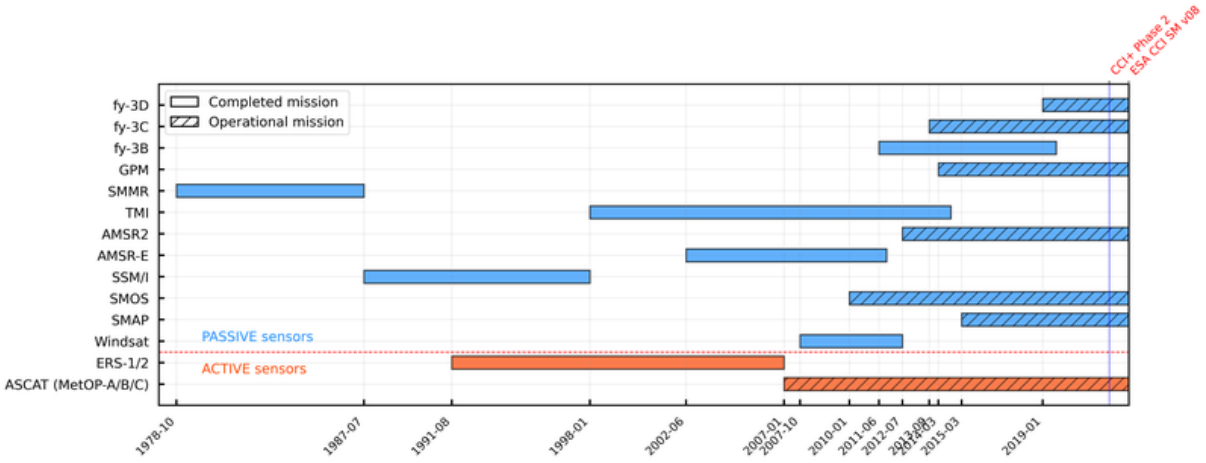


Figure 38: Lifetimes (x-axis) of the passive (blue) and active (orange) satellite missions (y-axis) merged into the ESA CCI SM product version v08.

In addition to the ESA CCI SM products, so-called Climate Data Records (CDR), and Interim-CDR (ICDR) using the same merging algorithm are produced on behalf of the Copernicus Climate Change Service (C3S), accessible through the C3S Climate Data Store (CDS; https://cds.climate.copernicus.eu/). While the CDR is extended each year and intended to have sufficient length, consistency, and continuity to detect climate variability and change, the ICDR provides short-delay access to current data with a 10-day latency where consistency with the CDR baseline is expected but was not extensively checked. In the CDS, 10-daily and monthly averages of the CDR and ICDR are provided as well.

The ESA CCI and C3S soil moisture products have been used in a wide range of scientific domains, including the study of climate variability and change, land-atmosphere interactions, global biogeochemical cycles, hydrological and land surace modelling, drought applications, and meteorology (Dorigo et al., 2017). They are also being used in the yearly State of the Climate Report of the Bulletin of the American Meteorological Society (BAMS) and the yearly European Commission's European State of the Climate (ESotC) report (Figure 39).

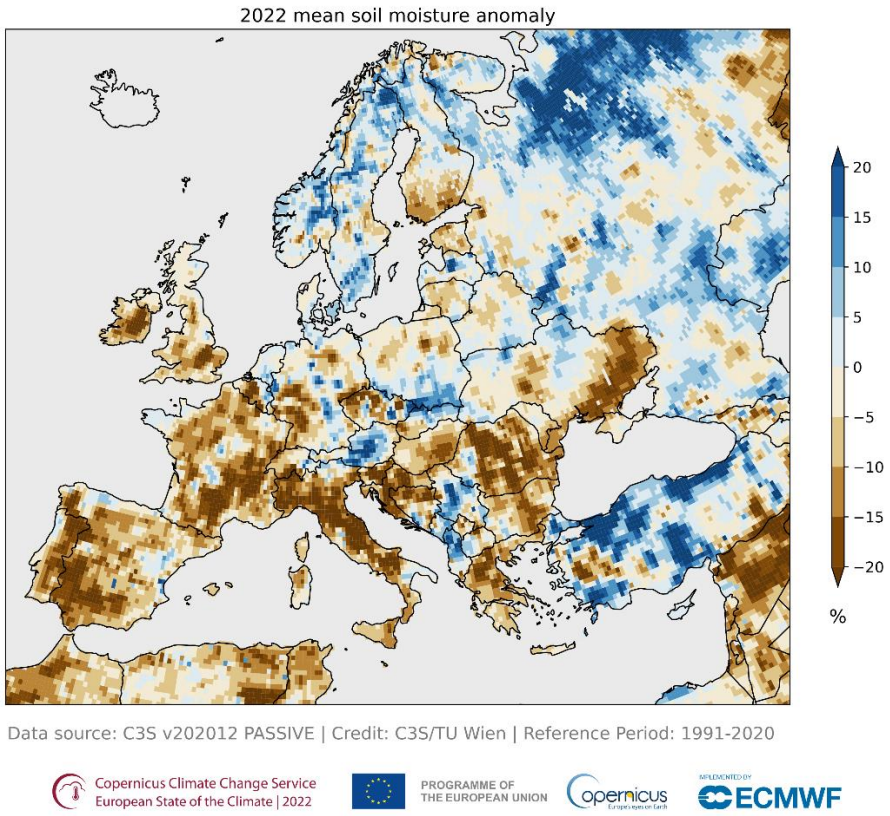


Figure 39: Annual soil moisture anomalies (%) from satellite soil moisture observations. The anomalies are expressed as a percentage of the annual average for the 1991–2020 reference period. Iceland is masked out in grey because little data are available. Data source: C3S Satellite Soil Moisture. Credit: C3S/ECMWF/TU Wien.

References:

Gruber, A., Scanlon, T., van der Schalie, R., Wagner, W., & Dorigo, W. (2019). Evolution of the ESA CCI Soil Moisture climate data records and their underlying merging methodology. *Earth System Science Data*, 11(2), 717-739.

Dorigo, W., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E., Hamer, P., Hirschi, M., Ikonen, J., de Jeu, R., Kidd, R., Lahoz, W., Liu, Y., Miralles, D., Mistelbauer, T., Nicolai-Shaw, N., Parinussa, R., Pratola, C., Reimer, C., van der Schalie, R., Seneviratne, S., Smolander, T., & Lecomte, P. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions. *Remote Sensing of Environment*, 203, 185-215.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
TU Vienna

Parameter measured/observed	Surface soil moisture
Starting date	1978
Temporal Resolution	Daily, 10-daily, monthly
Observational Network	
Stations	
Data Portal	CCI: https://climate.esa.int/en/projects/soil-moisture/ C3S: https://cds.climate.copernicus.eu/datasets/
Supervising Organization	TU Wien
National and/or international Networks or Programs	
Data Submission	
Licences	Creative Commons Attribution 4.0 International
Use Limitation	**No onward distribution**
Data Format	Gridded, NetCDF
Data Access	
Data Quality	
Performance Monitoring	
Publications	
Contact (National correspondent, focal point)	Wouter Dorigo: wouter.dorigo@tuwien.ac.at
Remarks	

ASCAT surface soil moisture data records

Sebastian Hahn (TU-Wien), Alexander Jann (GeoSphere Austria), Wolfgang Wagner (TU-Wien)

In the framework of the Satellite Application Facility on Support to Operational Hydrology and Water Management (http://hsaf.meteoam.it/), several soil moisture products are generated on a regular basis and distributed to users. Besides Near Real Time (NRT) products targeted for Numerical Weather Prediction (NWP) systems, are Climate Data Records (CDR) important for re-analysis of historic events. These Surface Soil Moisture (SSM) CDRs represent the top-most soil layer (< 5 cm) and are expressed in relative units degree of saturation (0% dry and 100% fully saturated soil). The SSM CDRs are derived from backscatter measurements of the Advanced Scatterometer (ASCAT) on-bard the series of Metop satellites. ASCAT is an active radar instrument operating in C-band (5.255 GHz) and on-board the three Metop satellites: Metop--A (launched October 2006 and decommissioned November 2021), Metop--B (launched September 2012) and Metop--C (launched November 2018). Currently (2024) Metop-B and Metop-C satellites share the same sun-synchronous 29--day repeat cycle orbit and are shifted by half an orbital period (approximately 51 minutes).

The TU Wien soil moisture retrieval algorithm [1, 2] is used to derive relative surface soil moisture information from the ASCAT backscatter measurements. The retrieval represents a physics-based change detection method exploiting the multi-angle measurement capabaility of fan-beam scatterometer. The SSM retrieval algorithm requires long-term backscatter measurements (> 3 years) to model the incidence angle dependency of backscatter, which allows to normalize backscatter to a common reference incidence angle. The relative surface soil moisture estimates are derived by scaling the normalized backscatter between the lowest/highest backscatter observations corresponding to the driest/wettest soil conditions.

Depending on the version of the algorithm and the version of the ASCAT Level 1b input data, CDRs can be different from version to another. Therefore, users are advised to use the latest ASCAT SSM CDR product available. Since a CDR is a self-contained data set and it is not foreseen to manipulate the data retrospectively, extensions of the CDR are provided regularly. It is important to use the same version of the SSM retrieval algorithm and ASCAT Level 1b input data in order to get a compliant extension of the CDR product, a so-called Intermediate CDR (ICDR). The processing of an ICDR is maintained until a new ASCAT SSM CDR is released.

The ASCAT SSM CDR and ICDR products are one of the main input data sets for the European Space Agency's Climate Change Initiative for Soil Moisture (ESA CCI SM) responsible for generating consistent quality-controlled long-term (1978–2018) climate data records for soil moisture [3]. Both, active- and passive-microwave-based soil moisture products are quality-controlled, harmonized, merged and distributed globally to the climate user community. In general, ASCAT soil moisture products have been used for various applications, including but not limited to: rainfall estimation, flood forecasting, drought monitoring and landslide prediction [4].

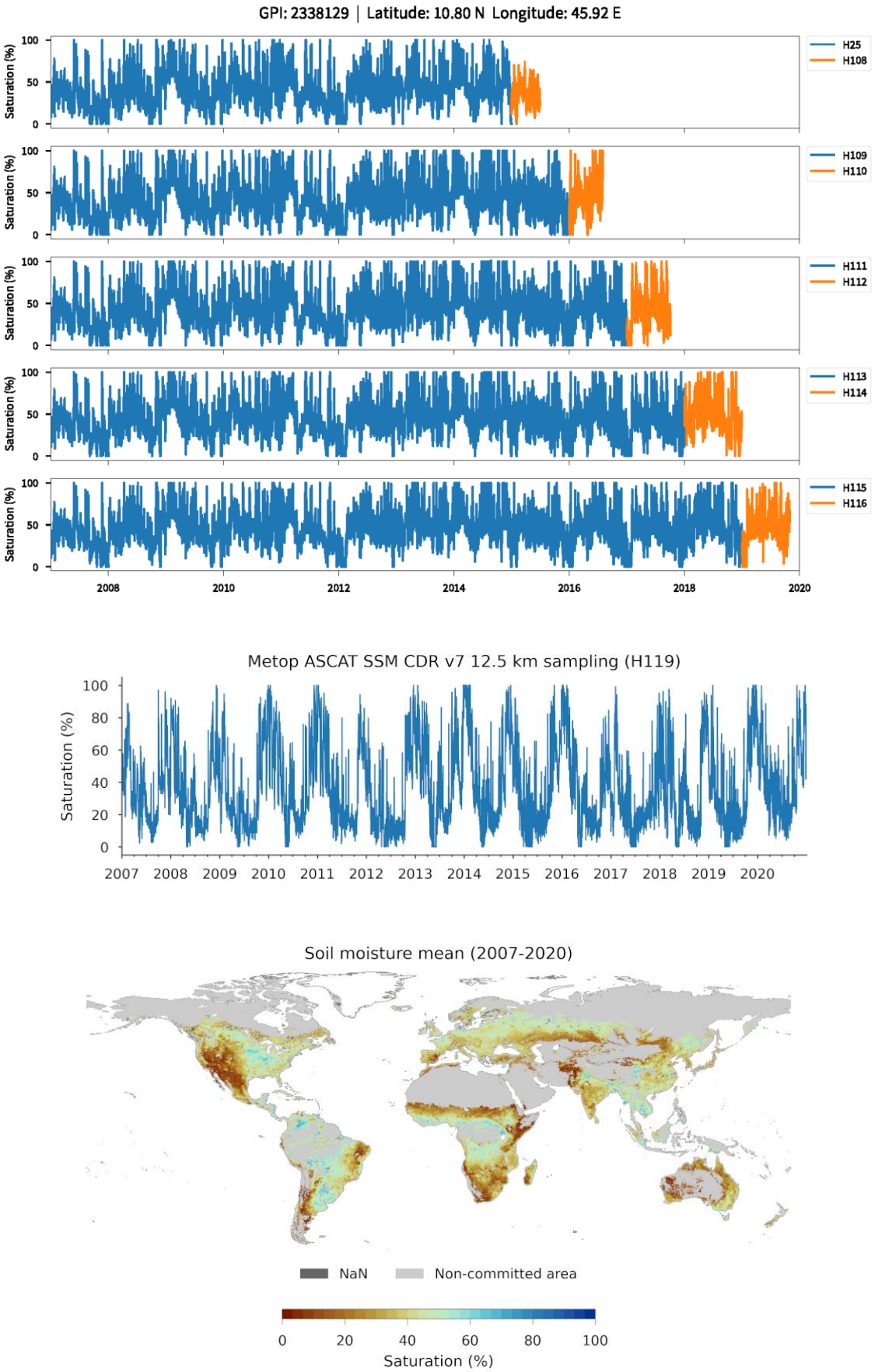


Figure 40: ASCAT Surface Soil Moisture Climate Data Record time series example (top) and mean soil moisture conditions 2007-2020 (bottom).

References:

[1] W. Wagner, G. Lemoine, and H. Rott, "A method for estimating soil moisture from ERS scatterometer and soil data," *Rem.Sens.Environ.*, **70,** 191–207 (2009).

[2] V. Naeimi, K. Scipal, Z. Bartalis, S. Hasenauer, and W. Wagner, "An Improved Soil Moisture Retrieval Algorithm for ERS and METOP Scatterometer Observations," *IEEE Trans. Geosci. Remote Sensing*, **47,** 1999–2013 (2009).

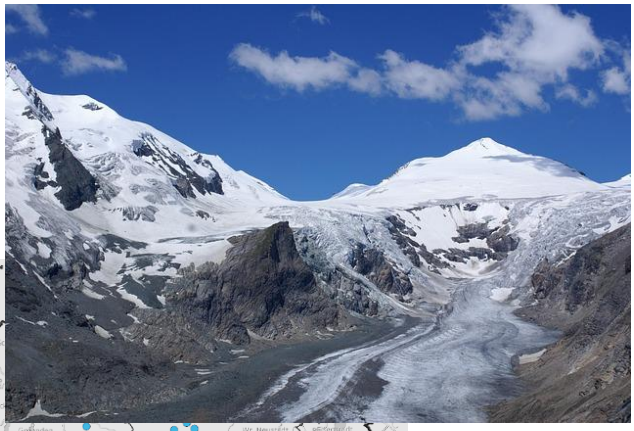
[3] Gruber, A., Scanlon, T., van der Schalie, R., Wagner, W., & Dorigo, W. (2019). Evolution of the ESA CCI Soil Moisture climate data records and their underlying merging methodology. Earth System Science Data, 1-37.

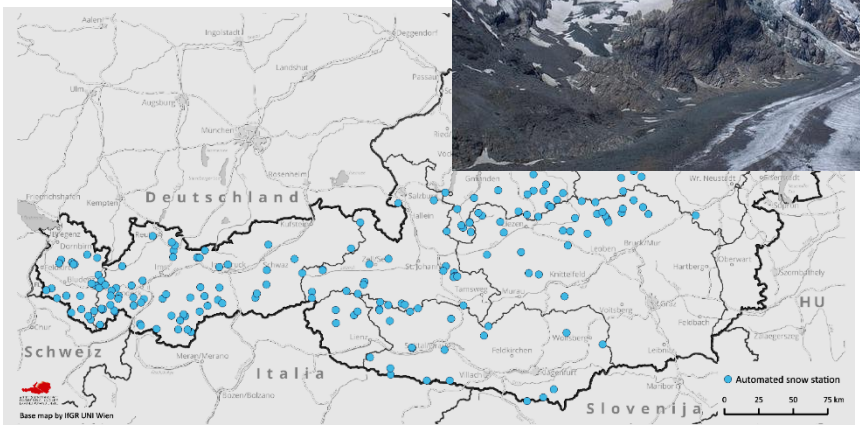
[4] L. Brocca et al., "A Review of the Applications of ASCAT Soil Moisture Products," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 10, no. 5, pp. 2285-2306, May 2017.

Additional source used: S. Hahn, T. Melzer, S. Elefante (2017): „Product User Manual (PUM): Metop ASCAT Soil Moisture CDR and offline products". Project documentation, EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management, revision 0.6.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
TU Vienna, GeoSphere Austria

Parameter measured/observed	Soil moisture
Starting date	2007-01-01
Temporal Resolution	Regular, every 12h – 36h
Observational Network	ASCAT on-board Metop-A, Metop-B and Metop-C
Stations	
Data Portal	http://hsaf.meteoam.it/
Supervising Organization	TU Wien
National and/or international Networks or Programs	EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management
Data Submission	FTP, ftp://ftp.meteoam.it/
Licenses	
Use Limitation	EUMETSAT Data Policy: https://www.eumetsat.int/data-policy/eumetsat-data-policy.pdf
Data Format	NetCDF, BUFR
Data Access	Access by registration
Data Format	NetCDF, BUFR
Data Access	Access by registration
Data Quality	
Performance Monitoring	http://hsaf.meteoam.it/documents/PVR/H111_ASCAT_SSM_CDR_PVR_v0.3.pdf
Publications	http://doi.org/10.15770/EUM_SAF_H_0009
Contact (National correspondent, focal point)	Wolfgang.Wagner@geo.tuwien.ac.at Apostolos.Giannakos@geosphere.at
Remarks	





Terrestrial Observations

Cryosphere

SNOW Monitoring of Austria

Marion Greilinger (GeoSphere Austria)

Snow parameters, which are regularly obtained, are snow height, snow water equivalent and snow covered area. The first two are obtained in situ, the latter by remote sensing methods. Snow height measurements are available since the end of the 19th century for several stations.

Standard measurements include snow depth, advanced records also provide Snow water equivalent (SWE) and snow temperature. Based on the existing TAWES network from GeoSphere Austria with about 280 stations, 120 stations contribute to regular, quality controlled snow monitoring of snow depth. Measurements are available from 750 further sites which are maintained by local authorities (HD – Hydrografischer Dienst) and distributed via the eHyd portal on federal level. Additional records are collected by the avalanche services. This comprises additional parameters and locations.

SWE measurements are obtained regularly at 54 sites. 48 are part of the HD network (weekly intervals), four are maintained by the avalanche warning services (15 minutes intervals). In addition, a published record of SWE and snow temperatures by the TIWAG-Tiroler Wasserkraft AG is available for the Kühtai station in Tyrol, starting in 1990. The BFW (Bundesforschungszentrum für Wald) maintains an experimental site at Lizum/Walchen in Tyrol.

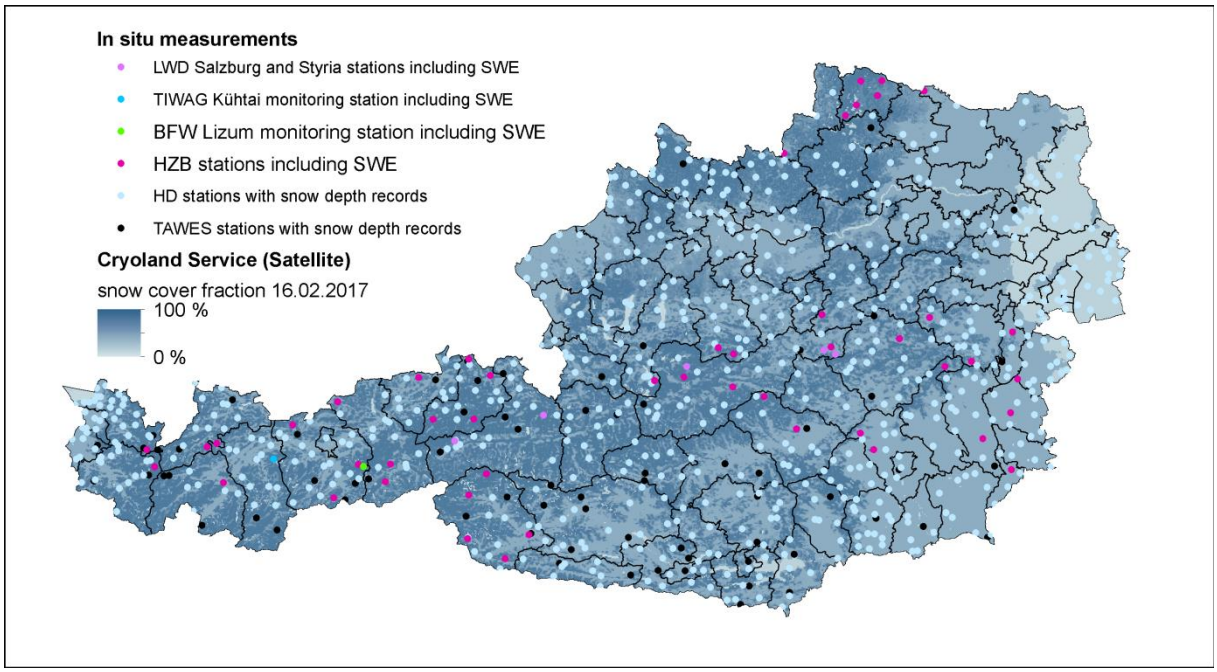


Figure 41: Overview of the stations. (2017)

An annual summary of the records is published by the section 'Wasserhaushalt' (HZB) of the BMLRT. This includes averages, maxima and snow cover duration.

Satellite snow coverage fraction maps are regularly available since 2000 and are updated as part of the Copernicus services. Daily maps with 1 km spatial resolution are disseminated via the CryoLand Portal. They are currently based on MODIS records and will soon be extended with records from Sentinel-3 SLSTR/OLCI.

Snow water equivalent records:

- Hydrographical Central Bureau (HD; since 01.12.1980)
- Avalanche warning services (Salzburg: since 07.10.2008, Styria: since 17.11.2010)
    - Hinterwildalpen
    - Maria Alm
    - Neukirchen/Wildkogel
    - Lawinenstein (2010-2012)
    - Wildalpen/Siebensee
- TIWAG: Kühtai, since 1990
- BFW: Lizum/Walchen

Municipal Department 31 – Vienna Water (MA 31 Wiener Wasser): since 21.01.2016

The University of Graz led a project called KryoMon.AT - Cryosphere Monitoring Austria, where numerous research institutions in Austria, compile the first comprehensive overview of the decline of permafrost, snow and ice in the Austrian Alps in a report.

Essential Climate Variables - Terrestrial Observations – Cryosphere
GeoSphere Austria, eHYD

Parameter measured/observed	Snow height
Starting date	manual observation since 01.01.1911 at 13 stations automatic measurements since 3.11.2004
Temporal Resolution	daily
Observational Network	TAWES, eHYD
Stations	74 stations as part of the TAWES network. 723 HD – Hydrografischer Dienst
Data Portal	https://ehyd.gv.at/ https://data.hub.geosphere.at/
Supervising Organization	GeoSphere Austria BMLFUW – Abteilung VII/3 – Wasserhaushalt
National and/or international Networks or Programs	TAWES, eHYD
Data Submission	automatic
Licenses	eHYD: CC-BY-NC TAWES: general GeoSphere Austria data conditions
Use Limitation	Varying, partly for research only
Data Format	csv
Data Access	Varying, partially restricted
Data Quality	Data quality under the responsibility of the individual institutions providing the data.
Performance Monitoring	Regularity by GeoSphere Austria, regularity by HD
Publications	
Contact (National correspondent, focal point)	eHyd: wasserhaushalt@bmlrt.gv.at TAWES: roland.potzmann@geosphere.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
TIWAG

Parameter measured/observed	Snow water equivalent, Snow temperature
Starting date	TIWAG: Kühtai 1990 Avalanche warning service, Salzburg: since 07.10.2008 Avalanche warning service, Styria: since 17.11.2010 Municipal Department 31 – Vienna Water (MA 31 Wiener Wasser): since 21.01.2016 Hydrographical Central Bureau, Tyrol: since 01.12.1980 BFW: Lizum, since February 2006
Temporal Resolution	TIWAG: Kühtai 15 min Avalanche warning service /MA 31: 10 min Hydrographical Central Bureau, Tyrol: weekly
Observational Network	
Stations	TIWAG: Kühtai Avalanche warning service /MA 31: Hinterwildalpen, Maria Alm, Neukirchen/Wildkogel, Lawinenstein, Wildalpen/Siebensee Hydrographical Central Bureau, Tyrol: 24 stations in Tyrol BFW: Lizum
Data Portal	TIWAG: Kühtai Link
Supervising Organization	TIWAG-Tiroler Wasserkraft AG, Hydropower planning department, Innsbruck, Austria Avalanche warning service, Salzburg, Austria Avalanche warning service, Styria, Austria Municipal Department 31 – Vienna Water Hydrographical Central Bureau of Austria BFW-Austrian Research Center for Forests
National and/or international Networks or Programs	
Data Submission	Technical report, once
Licenses	CC BY, BFW: depending on work contracts
Use Limitation	BFW: depending on work contracts
Data Format	csv
Data Access	Open, BFW: restricted
Data Quality	
Performance Monitoring	TIWAG Avalanche warning service, Salzburg, Austria Avalanche warning service, Styria, Austria Municipal Department 31 – Vienna Water Hydrographical Central Bureau of Austria BFW- Austrian Research Center for Forests
Publications	
Contact (National correspondent, focal point)	Global Cryosphere Watch - Focal Point Elke Ludewig, elke.ludewig@geosphere.at
Remarks	

SNOW Monitoring - ENVEO

Thomas Nagler (ENVEO), Helmut Rott (ENVEO), Gabriele Schwaizer (ENVEO)

Satellite Observations – Area covered by Snow

Medium resolution optical satellite data (Terra MODIS, S-NPP/NOAA-20 VIIRS, Sentinel-3A/B SLSTR) are used for the daily monitoring of the area covered by snow on a European to Global scale. Temporal coverage of the daily snow cover extent products depends on the satellite used for the product generation and started in late February 2000 with Terra MODIS acquisitions.

Satellite Observations – SAR Wet Snow (SWS)

Sentinel-1 Synthetic Aperture Radar (SAR) data over selected mountain regions in Europe are used for monitoring the wet snow extent, indicating snow layers with liquid water content. The repeat pass observation interval is 6 days from 2017 – 2021 with two Sentinel-1 satellites in orbit, and 12 days before 2017 and since December 2021 with only one Sentinel-1 satellite in orbit. Spatial coverage per mountain region depends on the Sentinel-1 track. An overview on the regions used for the SAR Wet Snow generation is provided in Figure 42, indicated by the green shaded tiles.

Satellite Observations –Wet / Dry Snow (WDS)

Sentinel-1 SAR data and snow observations from Sentinel-2 MSI data acquired on the same date are used for discriminating wet and dry snow areas. The product is provided over the full EEA38+UK domain (Figure 42, all outlined tiles). Product generation started in 01.09.2016. Spatial and temporal resolution depends on the availability of overlapping Sentinel-1 and Sentinel-2 acquisitions of the same date. Additionally, snow must be observed from the Sentinel-2 data. An overview on the regions used for the Wet / Dry Snow generation is provided in Figure 42, indicated by all yellow and green shaded tiles.

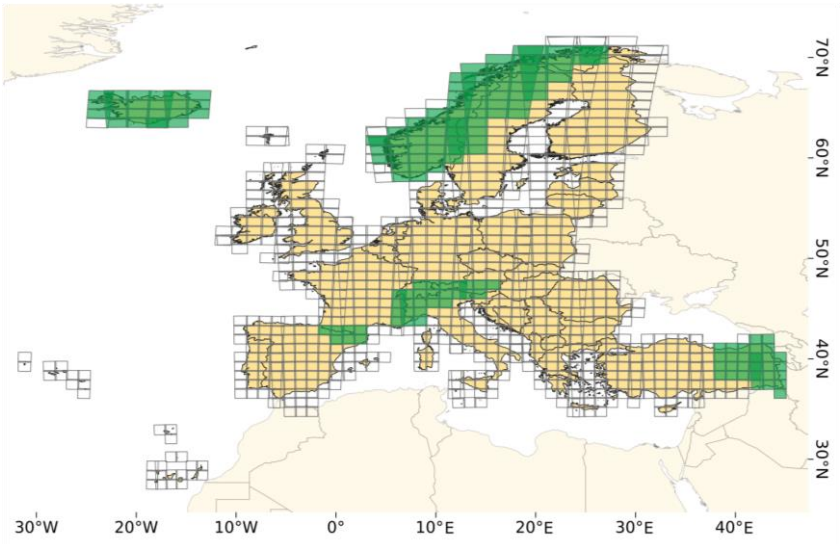


Figure 42: Spatial coverage of Wet / Dry Snow products (all yellow and green tiles) over the EEA38+UK domain, and of the SAR Wet Snow products (green shaded tiles) over selected mountain regions in Europe. The Wet/Dry Snow products and the SAR Wet Snow products are provided in Sentinel-2 tiles. Each Sentinel-2 tile covers about 100 km². © Figure from Pan-European High-Resolution Snow & Ice Monitoring of the Copernicus Land Monitoring Service – Product User Manual for Snow Products, available online at Link

Essential Climate Variables - Terrestrial Observations – Cryosphere
ENVEO, University Innsbruck

Parameter measured/observed	Area covered by snow (Fractional Snow Cover Extent) SAR based Wet Snow extent (SWS) in mountains Wet / dry snow extent (WDS) from combined SAR and optical satellite data of the same date
Starting date	24.02.2000 for area covered by snow 01.09.2016 (for SWS and WDS)
Temporal Resolution	Daily for area covered by snow 6 days / 12 days repeat pass for SWS Several days – weeks, depending on overlap of SAR and cloud free snow observations from optical satellite data
Observational Network	Area covered by snow: Terra MODIS, S-NPP/NOAA-20 VIIRS, Sentinel-3 SLSTR SWS: Sentinel-1 SAR WDS: Sentinel-1 SAR and Sentinel-2 MSI of the same date
Stations	n.a.
Data Portal	https://land.copernicus.eu/en/products/snow http://cryoportal.enveo.at/
Supervising Organization	ENVEO IT GmbH
National and/or international Networks or Programs	Copernicus Land Monitoring Service – Cryosphere (daily European and Northern Hemisphere snow cover extent, SAR Wet Snow and Wet/Dry Snow under lead of ENVEO) Copernicus Climate Change Service (C3S) Cryosphere (Global snow cover extent) (2024 – 2027, lead: ENVEO) ESA CCI+ Snow (Global Snow Cover Extent) (Phase 1: 2018 – 2022; Phase 2: 2022 – 2025, lead: ENVEO) EU FP7 project CryoLand (European Snow Cover Extent) (No. 262925, 2011 – 2015, lead: ENVEO)
Data Submission	Automated daily product generation and upload on server via FTP
Licenses	CC BY ENVEO NC ND Further details: http://cryoportal.enveo.at/disclaimer/ Data policy of Copernicus services: https://land.copernicus.eu/en/data-policy
Use Limitation	For research only Further details: http://cryoportal.enveo.at/disclaimer/ Copernicus services: full, open and free access. Further details: https://land.copernicus.eu/en/data-policy
Data Format	GeoTIFF, NetCDF, JPEG2000, HDF-4
Data Access	Access by Registration
Data Quality	Area covered by snow: Intensive validation activities since the EU FP7 project CryoLand (2011 – 2015), where this product was developed for Europe. Extended ongoing validation as part of the Copernicus Global Land Monitoring Service for Europe and the Northern Hemisphere. Products participated in the ESA QA4EO project SnowPEx - Satellite Snow Product Intercomparison and Evaluation Exercise (2014 – 2016, 2020 – 2022, lead: ENVEO).

	Product Quality Assessment Reports for daily snow cover extent products covering Europe and the Northern Hemisphere prepared by ENVEO for the Copernicus Global Land Monitoring Service are available at http://land.copernicus.eu/global/products/sce. Daily uncertainty layer, providing unbiased Root Mean Square Error per pixel for Europe available at http://neso1.cryoland.enveo.at/cryoclient/ SAR Wet Snow and Wet / Dry Snow: validation within ESA funded project (S14 Science – Snow, 2016 - 2020), and Copernicus High-resolution (water), snow and ice service for Europe (2020 – 2023, 2023 – 2027).
Performance Monitoring	Daily, automated procedure
Publications	Project related reports and documents Scientific publications on snow and ice parameters retrieved by means of remote sensing
Contact (National correspondent, focal point)	Gabriele Schwaizer: gabriele.schwaizer@enveo.at Thomas Nagler: thomas.nagler@enveo.at Helmut Rott: helmut.rott@enveo.at
Remarks	

Glacier Monitoring – GeoSphere Austria, IGF

Marion Greilinger (GeoSphere Austria), Andrea Fischer (IGF)

More than 900 glaciers have been identified within the Austrian Alps. Their properties are continuously monitored by in situ observations as well as remote sensing methods. This is achieved by combined effort on national level between a range of organizations including universities, research institutions, associations, companies and local authorities. These activities are embedded into international efforts such as the World Glacier Monitoring Service (WGMS). In situ observations require a substantial amount of physical commitment of many people and the use of automatized methods is limited. Volunteers therefore substantially contribute to the glacier service of the Austrian Alpine Club. Currently coordinated measurement of different parameters are performed at 92 glaciers in Austria and were initiated already in 1891 at single sites following a call of Eduard Richter, although single measurements also exist from earlier times. Data are regularly reported to the WGMS and to the corresponding data portals of the Global Terrestrial Networks for glaciers (GTN-G) and permafrost (GTN-P).

Of all glaciers in Austria only 10 % are monitored by length measurements and 1 % by actual mass balance retrievals. Mass balance measurements have started on Hintereisferner in 1952/53, with a continuous increase of sites since the 1960s whereas length measurements started already at the end of the 19th century at single sites. An annual summary of length and mass balance records is published by the section 'Wasserhaushalt' (HZB) of the BMLRT and in the bulletins of the Austrian Alpine Club.

Satellite and airborne data complement the ground based measurements. Glacier covered area is obtained in irregular intervals, depending on data availability. These inventories are part of international initiatives such as the Randolph glacier inventory (GLIMS) and the Climate Change Initiative of the European Space Agency.

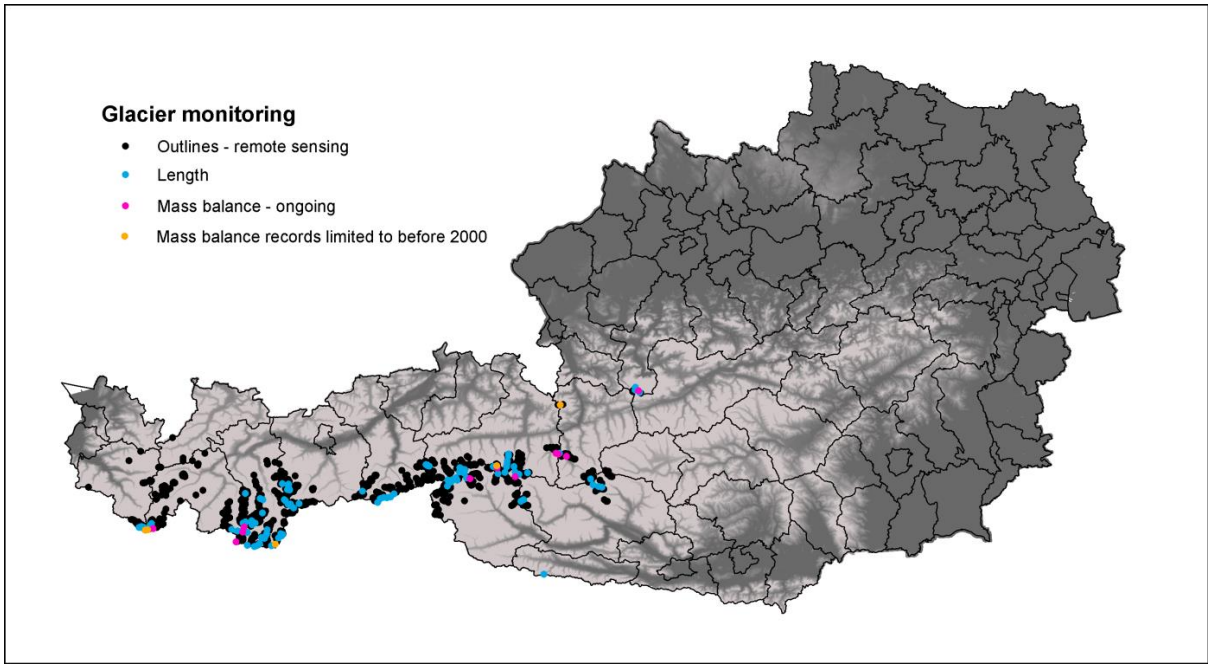


Figure 43: Overview of monitored glaciers (2021)

The University of Graz led a project called KryoMon.AT - Cryosphere Monitoring Austria, where numerous research institutions in Austria, compile the first comprehensive overview of the decline of permafrost, snow and ice in the Austrian Alps in a report.

Essential Climate Variables - Terrestrial Observations – Cryosphere
GeoSphere Austria

Parameter measured/observed	Glacier Elevation Change
Starting date	Depending on site GOK, FLK: since 2019 WUK: since 2021
Temporal Resolution	Annual
Observational Network	Sonnblick Integrated CryoNet Cluster
Stations	Goldbergkees (GOK) Kleinfleisskees (FLK) Wurtenkees (WUK)
Data Portal	No
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	WGMS
Data Submission	Planned to submit it annually to WGMS
Licenses	No formal license
Use Limitation	Free to use
Data Format	GeoTIFF
Data Access	Open Access on request
Data Quality	Data quality under the responsibility of the institution providing the data.
Performance Monitoring	Performed by the respective institutions responsible for the measurements.
Publications	In progress
Contact (National correspondent, focal point)	Bernhard Hynek: bernhard.hynek@geosphere.at Anton Neureiter: anton.neureiter@geophere.at
Remarks	None

Essential Climate Variables - Terrestrial Observations – Cryosphere
GeoSphere Austria

Parameter measured/observed	Glacier Area
Starting date	Depending on site GOK, FLK: since 2019 WUK: since 2021
Temporal Resolution	annual
Observational Network	Sonnblick Integrated CryoNet Cluster
Stations	Goldbergkees (GOK) Kleinfleisskees (FLK) Wurtenkees (WUK)
Data Portal	No
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	WGMS
Data Submission	Planned to submit it annually to WGMS
Licenses	No formal license
Use Limitation	Free to use
Data Format	Shape-File
Data Access	Open Access on request
Data Quality	Data quality under the responsibility of the institution providing the data.
Performance Monitoring	Performed by the respective institutions responsible for the measurements.
Publications	In progress
Contact (National correspondent, focal point)	Bernhard Hynek: bernhard.hynek@geosphere.at Anton Neureiter: anton.neureiter@geophere.at
Remarks	None

Essential Climate Variables - Terrestrial Observations – Cryosphere
GeoSphere Austria

Parameter measured/observed	Glacier Mass Balance
Starting date	Depending on site GOK: since 1988/89 FLK: since 1998/99 WUK: since 1982/83 PAS: since 1979/80 (since 2012/13 from ZAMG/GeoSphere Austria)
Temporal Resolution	annual
Observational Network	Sonnblick Integrated CryoNet Cluster
Stations	Goldbergkees (GOK) Kleinfleisskees (FLK) Wurtenkees (WUK) Pasterze (PAS)
Data Portal	No
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	WGMS
Data Submission	annually to WGMS
Licenses	No formal license
Use Limitation	Free to use
Data Format	Csv
Data Access	Open Access on request
Data Quality	Data quality under the responsibility of the institution providing the data. Minimal quality check by the WGMS.
Performance Monitoring	Performed by the respective institutions responsible for the measurements.
Publications	WGMS
Contact (National correspondent, focal point)	Bernhard Hynek: bernhard.hynek@geosphere.at Anton Neureiter: anton.neureiter@geophere.at
Remarks	None

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Glacier area
Starting date	1850
Temporal Resolution	Decadal or longer
Observational Network	World glacier monitoring service (WGMS)
Stations	All Austrian glaciers
Data Portal	https://doi.pangaea.de/10.1594/PANGAEA.844985
Supervising Organization	WGMS, http://wgms.ch/
National and/or international Networks or Programs	WGMS NSIDC
Data Submission	Irregular
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	CC-BY-3.0
Data Format	Shp, xls
Data Access	open access
Data Quality	
Performance Monitoring	
Publications	Fischer, Andrea; Seiser, Bernd; Stocker-Waldhuber, Martin; Mitterer, Christian; Abermann, Jakob (2015): Tracing glacier changes in Austria from the Little Ice Age to the present using a lidar-based high-resolution glacier inventory in Austria. The Cryosphere, 9(2), 753-766, doi:10.5194/tc-9-753-2015 Fischer, Andrea; Seiser, Bernd; Stocker-Waldhuber, Martin; Mitterer, Christian; Abermann, Jakob (2015): The Austrian Glacier Inventories GI 1 (1969), GI 2 (1998), GI 3 (2006), and GI LIA in ArcGIS (shapefile) format. PANGAEA, https://doi.org/10.1594/PANGAEA.844988 Fischer, A., Schwaizer, G., Seiser, B., Helfricht, K., and Stocker-Waldhuber, M.: High-resolution inventory to capture glacier disintegration in the Austrian Silvretta, The Cryosphere, 15, 4637–4654, https://doi.org/10.5194/tc-15-4637-2021, 2021.
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	To be updated

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Glacier mass balance Glacier area
Starting date	Varying
Temporal Resolution	Annual, seasonal
Observational Network	World glacier monitoring service (WGMS) LTER
Stations	Hallstätter Gletscher (since 2006/07)
Data Portal	doi:10.1594/PANGAEA.806609
Supervising Organization	WGMS, http://wgms.ch/
National and/or international Networks or Programs	WGMS LTER https://deims.org/2f8d9e1c-96e4-41fe-9754-c858883230f9
Data Submission	Annual, after the official WGMS “call for data”
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data. Minimal quality check by the WGMS itself.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	doi:10.1594/PANGAEA.806609
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW -IGF

Parameter measured/observed	Glacier mass balance Glacier area
Starting date	Varying
Temporal Resolution	Annual, seasonal
Observational Network	World glacier monitoring service (WGMS) WMO GCW LTER https://deims.org/5b93dfb3-906b-4ff4-a5fe-9a4948bda9eb
Stations	Jamtalferner (since 1988/89)
Data Portal	https://doi.org/10.1594/PANGAEA.818772
Supervising Organization	WGMS, http://wgms.ch/
National and/or international Networks or Programs	WGMS LTER https://deims.org/2f8d9e1c-96e4-41fe-9754-c858883230f9
Data Submission	Annual, after the official WGMS “call for data”
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data. Minimal quality check by the WGMS itself.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	doi:10.1594/PANGAEA.818772
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Glacier mass balance Glacier area
Starting date	Varying
Temporal Resolution	Annual, seasonal
Observational Network	World glacier monitoring service (WGMS) LTER https://deims.org/50a67a62-2800-4ffb-bf1f-82634d3257dd
Stations	Mullwitzkees (since 2006/07)
Data Portal	doi:10.1594/PANGAEA.806662
Supervising Organization	WGMS, http://wgms.ch/
National and/or international Networks or Programs	WGMS LTER https://deims.org/2f8d9e1c-96e4-41fe-9754-c858883230f9
Data Submission	Annual, after the official WGMS “call for data”
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data. Minimal quality check by the WGMS itself.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	doi:10.1594/PANGAEA.806662 Hartl, L., Seiser, B., Stocker-Waldhuber, M., Baldo, A., Lauria, M. V., and Fischer, A.: Glaciological and meteorological monitoring at Long Term Ecological Research (LTER) sites Mullwitzkees and Venedigerkees, Austria, 2006–2022, Earth Syst. Sci. Data, 16, 4077–4101, https://doi.org/10.5194/essd-16-4077-2024, 2024.
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Glacier mass balance Glacier area
Starting date	Varying
Temporal Resolution	Annual, seasonal
Observational Network	LTER https://deims.org/0c7e86cc-21b7-4550-b01c-226d54e8c406
Stations	Venedigerkees (since 2012)
Data Portal	doi:10.1594/PANGAEA.833232
Supervising Organization	WGMS, http://wgms.ch/
National and/or international Networks or Programs	WGMS LTER https://deims.org/2f8d9e1c-96e4-41fe-9754-c858883230f9
Data Submission	Annual, after the official WGMS “call for data”
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data. Minimal quality check by the WGMS itself.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	doi:10.1594/PANGAEA.833232 Hartl, L., Seiser, B., Stocker-Waldhuber, M., Baldo, A., Lauria, M. V., and Fischer, A.: Glaciological and meteorological monitoring at Long Term Ecological Research (LTER) sites Mullwitzkees and Venedigerkees, Austria, 2006–2022, Earth Syst. Sci. Data, 16, 4077–4101, https://doi.org/10.5194/essd-16-4077-2024, 2024.
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Glacier mass balance Ice temperatures Air temperature Global radiation Windspeed and direction
Starting date	2017
Temporal Resolution	Annual, seasonal, varying
Observational Network	LTER https://deims.org/0c7e86cc-21b7-4550-b01c-226d54e8c406
Stations	Summit Weißseespitze 3500 m (since 2017)
Data Portal	https://doi.org/10.1594/PANGAEA.939830
Supervising Organization	
National and/or international Networks or Programs	LTER https://deims.org/864da259-371e-4701-b72a-5295de28d6c6
Data Submission	Annual, after the official WGMS “call for data”
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data. Minimal quality check by the WGMS itself.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	Fischer, A., Stocker-Waldhuber, M., Frey, M. *et al.* Contemporary mass balance on a cold Eastern Alpine ice cap as a potential link to the Holocene climate. *Sci Rep* **12,** 1331 (2022). https://doi.org/10.1038/s41598-021-04699-2
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Displacement rate runoff
Starting date	varying
Temporal Resolution	Annual, seasonal
Observational Network	LTER https://deims.org/dataset/3550898d-a890-4694-85a0-d913d65368ee
Stations	Äußeres Hochebenkar (since 1938)
Data Portal	https://doi.org/10.1594/PANGAEA.861405
Supervising Organization	
National and/or international Networks or Programs	LTER
Data Submission	Annual
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	https://doi.org/10.1594/PANGAEA.861405 Kellerer-Pirklbauer A., Bodin X., Delaloye R., Lambiel C., Gärtner-Roer I., Bonnefoy-Demongeot M., Carturan L., Damm B., Eulenstein J., Fischer A., Hartl L., Ikeda A., Kaufmann V., Krainer K., Matsuoka N., Morra di Cella U., Noetzli J., Seppi R., Scapozza C., Schoeneich P., Stocker-Waldhuber M., Thibert E., Zumiani M. (2024): Acceleration and interannual variability of creep rates in mountain permafrost landforms (rock glacier velocities) in the European Alps in 1995–2022. Environmental Research Letters: Focus collection Perma-frost Vulnerability to Climate Change doi.org/10.1088/1748-9326/ad25a4 Hartl, L., Zieher, T., Bremer, M., Stocker-Waldhuber, M., Zahs, V., Höfle, B., Klug, C., and Cicoira, A.: Multi-sensor monitoring and data integration reveal cyclical destabilization of the Äußeres Hochebenkar rock glacier, Earth Surf. Dynam., 11, 117–147, https://doi.org/10.5194/esurf-11-117-2023, 2023.
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Glacier Monitoring Program of the Austrian Alpine Club

Andreas Kellerer-Pirklbauer-Eulenstein (University of Graz), Gerhard Lieb (University of Graz)

The monitoring of glacier length variations in Austria is traditionally organized and carried out by the Austrian Alpine Association (Österreichischer Alpenverein). This monitoring started as early as 1891 and is currently carried out at about 100 glaciers by research institutions or private persons who are responsible for defined mountain groups or regions. At a limited number of glaciers additional monitoring on surface velocities and height variations takes place. Data is collected by responsible persons appointed by the program manager (currently: Andreas Kellerer-Pirklbauer and Gerhard K. Lieb) and compiled to an annual report which is published in the association's journal "Bergauf" and in the internet (Lieb & Kellerer-Pirklbauer 2024). The association's special interest in glacier (and permafrost) variations is also related to the fact that its network of marked trails in the Alps is prone to potentially hazardous processes triggered by these changes.

The at present (January 2004) most recent freely accessible data set of glacier length changes comprise the glaciological year 2022/23 (Kellerer-Pirklbauer & Lieb 2024). Data of 93 Austrian glaciers were collected for the period summer/autumn 2022 to summer/autumn 2023 (variable period for each glacier depending on specific measurement dates). The measurements in 2023 have been carried out by 19 different teams led by one or two investigators each (altogether 24 team leaders). The 93 monitored glaciers are well distributed over the glaciated mountain ranges of the Austrian Alps and consider both small and some of the largest glaciers (up to ca.15 km²; e.g., Pasterze Glacier) in Austria. Therefore, this sample is representative for all present-day glaciers in Austria. Results of our analysis show that all but one of the observed glaciers (n=92) retreated. Monitoring activities were stopped at one glacier in 2023 (Weisssee Ferner) due to the lack of a measurable glacier size. The mean value of the glacier retreat rate of the 79 glaciers with metric data in 2022 and 2023 was 23.9 m/a (compared to 28.7 m/a in the previous year). This is the third highest value in the entire history of the glacier measurement service of the Austrian Alpine Club initiated 133 years ago (Figure 44). The highest retreat value measured at a single glacier was 203.5 m/a at Pasterze Glacier, Glocknergruppe (Glockner Mountains).

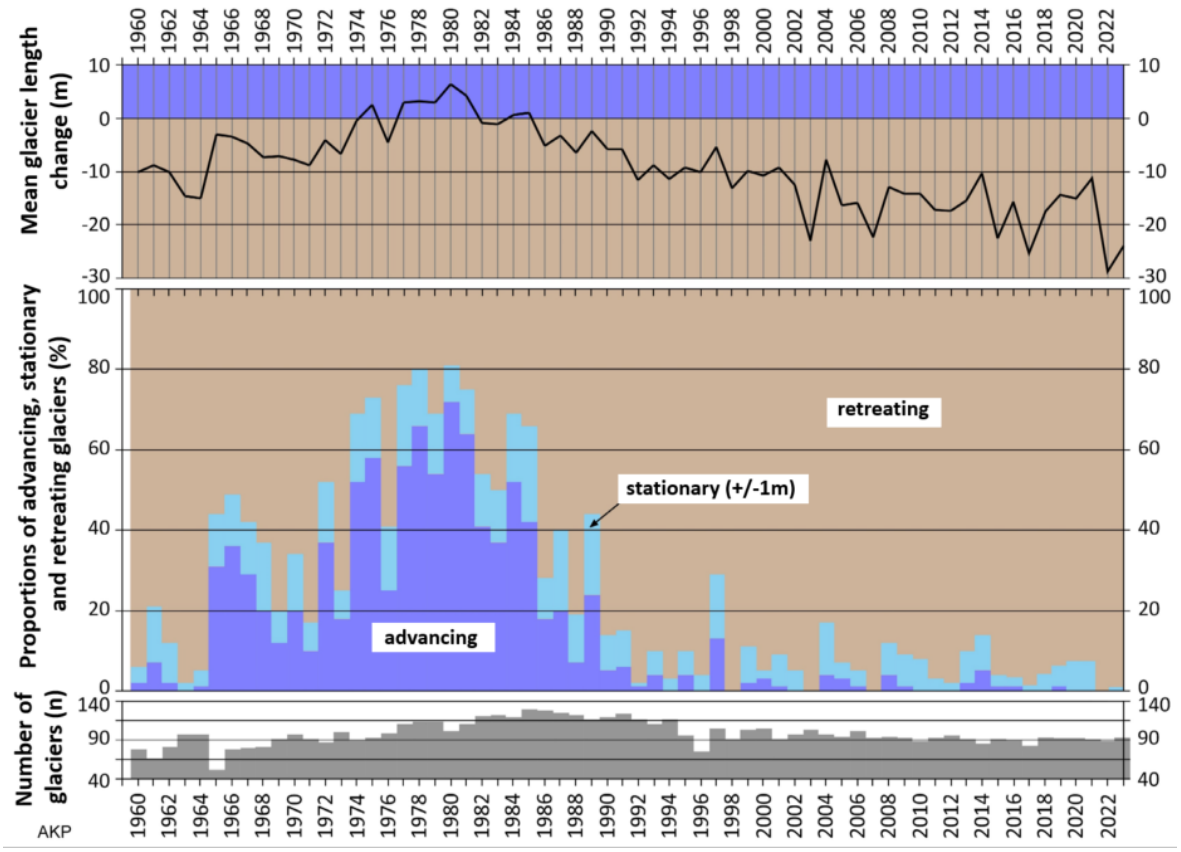


Figure 44: The mean change in glacier length (top), the proportions of the advancing, stationary and retreating glaciers (center), and the number of glaciers per year monitored between 1960 and 2023 (based on long-term data from the Austrian Alpine Club, cf. Lieb & Kellerer-Pirklbauer 2024).

References:

Kellerer-Pirklbauer A., Lieb G.K. (2024): Length changes of Austrian glaciers in 2022/2023 [dataset]. PANGAEA, https://doi.org/10.1594/PANGAEA.971350

Lieb G.K., Kellerer-Pirklbauer A. (2024): Gletscherbericht 2022/2023 – Sammelbericht über die Gletschermessungen des Österreichischen Alpenvereins im Jahr 2023. Bergauf 02/2024, 2–12. https://www.alpenverein.at/bk/bergauf/bergauf2024/Bergauf_2_2024/

Essential Climate Variables - Terrestrial Observations – Cryosphere
Austrian Alpine Club

Parameter measured/observed	Length of glaciers
Starting date	Varying (official initiation of the monitoring activities was in 1891; at some glaciers monitoring started earlier)
Temporal Resolution	Annual
Observational Network	Glacier monitoring service of the Austrian Alpine Club; World glacier monitoring service (WGMS) – front variation monitoring
Stations	Varying, depending on logistical (access) and snow cover conditions at the glacier terminus (93 glaciers for the glaciological year 2022/2023)
Data Portal	Annual reports from the Austrian Alpine Club (reports in the journal "Bergauf") – annual data from each glacier listed in a detailed table. https://www.alpenverein.at/portal/service/bergauf/ WGMS: https://wgms.ch/fogbrowser (description of each glacier and data download) PANGAEA: https://doi.pangaea.de/10.1594/PANGAEA.971350 (description of data and data download)
Supervising Organization	Austrian Alpine Club
National and/or international Networks or Programs	World Glacier Monitoring Service (WGMS) – front variation monitoring
Data Submission	Two-step submission system: (1) the individual monitoring teams (ca. 20) submit their reports and data to the program coordinator (2 people), who compile a national report and all data into a table; (2) table and report get published by the Austrian Alpine Club and – delayed – by the WGMS as well as Pangaea. Data submission via Email to the Austrian Alpine Club, WGMS and PANGAEA
Licenses	*CC BY-NC*
Use Limitation	*For research only*
Data Format	As a table in a pdf ("Bergauf" report) or as csv-file (WGMS, PANGAEA)
Data Access	Open access
Data Quality	Quality check by the individual team members as well as the program coordinators of the glacier monitoring service of the Austrian Alpine Club
Performance Monitoring	Annual reporting is crucial for the Austrian Alpine Club
Publications	Annual reports from the Austrian Alpine Club ("Gletscherbericht") written by the program managers http://www.alpenverein.at/portal/museum-archiv/gletschermessdienst/archiv-gletscherberichte/archiv-gletscherberichte.php Annual data reports with data overview and csv-tables written by the program managers (e.g.) Kellerer-Pirklbauer, A; Lieb, GK (2024): Length changes of Austrian glaciers in 2022/2023

	A first joint report about the Austrian monitoring activities related to the cryosphere was prepared for the glaciological year 2021/22 (https://doi.org/10.25364/402.2023.1). Data from this network were used in this report. Further annual reports should follow (project in progress).
Contact (National correspondent, focal point)	Head of the glacier service of the Austrian Alpine Club Andreas Kellerer-Pirklbauer (andreas.kellerer@uni-graz.at) Gerhard Lieb (gerhard.lieb@uni-graz.at)
Remarks	More information regarding the glacier monitoring service at https://www.alpenverein.at/portal/museum-archiv/gletschermessdienst/index.php

Glacier Gössnitzkees

Viktor Kaufmann (TU Graz), Andreas Kellerer-Pirklbauer-Eulenstein (University of Graz), Karl Krainer (University of Innsbruck), Thomas Wagner (University of Graz), Gerfried Winkler (University of Graz)

Goessnitzkees (12°45' E, 46°58' N) is a small debris-covered cirque glacier located in the Schober group of the Hohe Tauern range, Austrian Alps. The glacier covered an area of some 0.75 km² in 1997. In 1982 Goessnitzkees was included into the network of annual glacier measurements of the Austrian Alpine Club (ÖAV). Since 1982 until now all annual measurements (mid-September) on Goessnitzkees have been carried out by members of the Institute of Geography and Regional Science of the University of Graz (UNI Graz). From 1996 to 1998 a glacier study under the leadership of G.K. Lieb (Institute of Geography and Regional Science, UNI Graz) was carried out in order to reconstruct the glacier history of Goessnitzkees from 1850 (maximum extent of glaciation) until 1997 using historical maps, aerial photographs and field evidence. In 1996 the Institute of Geodesy of the Graz University of Technology selected Goessnitzkees as a test site for high-mountain studies. A three-dimensional geodetic network was installed for this purpose, comprising also some reference points of the previously described annual measurements for ÖAV. Since 1996 the Institute of Geodesy has been carrying out follow-on annual measurements on surface height change along a longitudinal profile and at 9 marked points on larger boulders. Furthermore, glacier flow velocity has been determined at the given marked boulders. Glacier length change has been derived from surveyed points defining the glacier terminus.

Essential Climate Variables - Terrestrial Observations – Cryosphere
University of Graz

Parameter measured/observed	Area, volume, glacier length, surface height, flow velocity
Starting date	Measurements on glacier length (see measurements of the Austrian Alpine Club) started in 1982 Geodetic measurement of glacier length, surface height change along a profile and flow velocity started in 1996 Photogrammetric glacier monitoring based on aerial photographs (1954-2018, manned with aerial cameras/unmanned using UAVs, multi-annual data take) Photogrammetric glacier monitoring based on terrestrial photographs (1988-2020, multi-annual)
Temporal Resolution	Multi-annual (photogrammetric measurements, annual (geodetic measurements)
Observational Network	None
Stations	Gössnitzkees only
Data Portal	Currently none. https://www.staff.tugraz.at/viktor.kaufmann/Goessnitzkees/
Supervising Organization	Institute of Geodesy, Working Group on Remote Sensing and Photogrammetry at the Graz University of Technology (TUG)
National and/or international Networks or Programs	Currently none

Data Submission	Currently none
Licenses	CC BY-NC
Use Limitation	For research only
Data Format	Thematic maps (pdf), graphs, tables (csv, xlsx)
Data Access	Open access on request
Data Quality	Check on oneself
Performance Monitoring	Check on oneself
Publications	Results of the geodetic monitoring are published on an annual basis: https://www.staff.tugraz.at/viktor.kaufmann/Goessnitzkees/ Detailed annual reports (diary) can be requested from the Viktor Kaufmann
Contact (National correspondent, focal point)	Team leader Viktor Kaufmann (viktor.kaufmann@tugraz.at)
Remarks	More information regarding the glacier monitoring on Gössnitzkees can be obtained from https://www.staff.tugraz.at/viktor.kaufmann/Goessnitzkees.html Kellerer-Pirklbauer, A., Bauer, A. and Proske, H. (2005): Terrestrial laser scanning for glacier monitoring: Glaciation changes of the Gößnitzkess glacier (Schober group, Austria) between 2000 and 2004. Conference Volume. 3rd Symposium of the Hohe Tauern National Park for Research in Protected Areas, 15-17 September 2005, Kaprun, Austria, 97-106. Kaufmann, V. and Ladstädter, R. (2008): Application of Terrestrial Photogrammetry for Glacier Monitoring in Alpine Environments. IAPRS, Vol. 37, Part B8, Proceedings of the 21st Congress of ISPRS, Beijing, China, 3-11 July 2008, 813-818. Kaufmann, V. and Ladstädter, R. (2008): Documentation of the Retreat of Gössnitzkees and Hornkees glaciers (Hohe Tauern Range, Austria) for the Time Period 1997-2006 by Means of Aerial Photogrammetry. Proceedings of the 6th ICA Mountain Cartography Workshop, 11-15 February 2008, Lenk, Switzerland, 115-123.

Glaciers, Ice Sheets and Ice Shelves - ENVEO

Thomas Nagler (ENVEO), Helmut Rott (ENVEO), Gabriele Schwaizer (ENVEO)

Satellite Observations – Glacier Outlines / Extent

High-resolution optical satellite data (e.g. Landsat 4/5 TM, Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2A/B/C MSI) are used for the generation of glacier outlines on a regional to global scale. The generation of the glacier outlines depend on the availability of cloud free acquisitions over the area of interest. The most recent satellite-based glacier extent inventory for the complete Alps was generated from selected Sentinel-2A acquisitions in late summer in 2015 and 2016.

Satellite Observations – Glacier Surface Classes

High-resolution optical satellite data (e.g. Landsat 4/5 TM, Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2A/B/C MSI) are used for the generation of glacier surface classification. For all glaciers in the Alps, Sentinel-2A/B scenes acquired during the melting seasons (May – September) of the years 2015 to 2021 and affected only by little cloud cover were used for the glacier surface classification. For selected regions, the time series was extended to the melting seasons 2022 and 2023.

Satellite Observations – Ice Surface Velocity and Grounding Lines

Repeat pass Synthetic Aperture Radar (SAR) satellite data, as available from Sentinel-1, ERS-1/2 or TerraSAR-X, are used for the generation of ice surface velocity and grounding line maps. Systematic monitoring of ice surface velocity is based on Sentinel-1 data (6 days repeat pass 2 satellites, 12 days repeat pass with 1 satellite) starting in late 2014 with focus on the glaciated areas of the Greenland Ice Sheet and Antarctica. Grounding lines are mapped several times a year since 2014, depending on data availability.

Satellite Observations – Calving Fronts

Calving fronts for selected key glaciers in Greenland are mapped from combined SAR from Sentinel-1 data, high-resolution optical satellite data from Sentinel-2 MSI data and Synthetic Aperture Interferometric Radar Altimeter (SIRAL) data from CryoSat several times a year since 2014, depending on data availability.

Essential Climate Variables - Terrestrial Observations – Cryosphere
ENVEO

Parameter measured/observed	Glacier outlines/extent, glacier surface classes, ice surface velocity, calving fronts, grounding lines
Starting date	Depends on parameter and available satellite data per region. Earliest products are from satellite images of the 1980s.
Temporal Resolution	Depends on the availability of satellite imagery. Ice surface velocity: 6-days 2017 - 2021, 12-days 2014 – 2017 and since 2022, monthly/seasonally/(multi-)annually before 2014 (depending on region) All other parameters: seasonally to (multi-annually), for selected dates
Observational Network	Sentinel-2 A/B/C MSI, Landsat 4/5 TM / 7 ETM+ / 8 OLI / 9 OLI-2, SPOT-5 HRG, Sentinel-1 A/B C-SAR, TerraSAR-X, ERS-1/2, CryoSat SIRAL
Stations	N.A.
Data Portal	http://cryoportal.enveo.at/
Supervising Organization	ENVEO IT GmbH
National and/or international Networks or Programs	Copernicus Climate Change Service (C3S) – Cryosphere (2024 – 2027) (Ice surface velocity for Greenland and Antarctica, Glacier outlines/extent for selected regions) (Lead: ENVEO) ESA CCI / CCI+ Glaciers (Phase 1: 2010 – 2013; Phase: 2 2015 – 2018; Extension: Phase 1: 2019 – 2021; Phase 2: 2022 - 2024) ESA CCI / CCI+ Greenland Ice Sheet (Phase 1: 2012 – 2014; Phase 2: 2015 – 2018; Extension: Phase 1: 2019 – 2021; Phase 2: 2024 - 2026) ESA CCI / CCI+ Antarctic Ice Sheet (2015 – 2018; Extension: Phase 1: 2019 – 2021; Phase 2: 2024 - 2026)
Data Submission	Frequency of data submission depends on parameter and available database (ranges between weekly and multi-annually updates). Upload on CryoPortal server via FTP.
Licenses	CC BY ENVEO NC ND. Further details: Link For products generated and disseminated via the Copernicus Climate Change Service (C3S): CC BY 4.0 (Creative Commons Attribution 4.0 International Public License)
Use Limitation	Glacier surface classes: for research only Further details: http://cryoportal.enveo.at/disclaimer/
Data Format	GeoTIFF, netCDF, ESRI Shapefile (depending on parameter)
Data Access	Access by Registration
Data Quality	Evaluation and intercomparison activities performed and documented within several ESA projects.
Performance Monitoring	Automated controlling of data on CryoPortal by ENVEO.
Publications	Project related reports and documents Scientific publications on snow and ice parameters retrieved by means of remote sensing
Contact (National correspondent, focal point)	Gabriele Schwaizer: gabriele.schwaizer@enveo.at Thomas Nagler: thomas.nagler@enveo.at Helmut Rott: helmut.rott@enveo.at
Remarks	

Permafrost Monitoring

Marion Greilinger (GeoSphere Austria)

Approximately 2.5 % of Austria is characterized by permanently frozen ground, which is overlain by a seasonally unfrozen layer (i.e. active layer). Such regions are addressed as permafrost areas. Further ca. 1.5 % of Austria are affected by deep seasonal frost, which has similar impacts on weathering processes. 23 skiing resorts, 31 reservoirs and 42 mountain huts are directly or indirectly influenced by permafrost and associated processes. Ground stability and thus infrastructure (water dams, supporting infrastructure, buildings) can be affected by ground temperature increase and permafrost thawing due to climate change. Furthermore, there is also a substantial impact on hydrology related to permafrost degradation. The modification of permafrost affected regions is therefore of ecological but also economic importance. A range of institutions are interested in systematic permafrost monitoring, e.g. several Austrian universities, geological surveys at national and regional scale, the Austrian Federal Service for Torrent and Avalanche Control, or several different alpine clubs. To date, no coordinated monitoring network has been established at the national level and a strategy for long-term observations is not implemented. This impedes the evaluation of the existing sparsely distributed measurements as well as the development of an understanding of underlying processes.

It is recommended to increase the number of monitoring sites based on the analyses of the current situation and exchange with stakeholders. This should include temperature measurements in deep boreholes and shallow boreholes close to the surface, geophysical surveys and ground movement measurements (rock glaciers, instable rock faces) as well as hydro(geo)logical measurements. In addition, a spatially continuous observation of surface movements with remote sensing methods is required. Demand is highest for entire Tyrol, the district of Zell am See, north-western Carinthia and south-eastern Vorarlberg.

Currently, there are seven deep boreholes for temperature measurements at Kitzsteinhorn, four at Hoher Sonnblick (both sites are located in the Hohe Tauern Range) and one deep borehole at the Dachstein Massif (Northern Calcareous Alps). The borehole at the Dachstein Massif is currently not working and requires major repair. Either ground temperature records from Kitzsteinhorn and Sonnblick are submitted on an annual basis to GTN-P (Global Terrestrial Network on Permafrost) or metadata is provided. Related permafrost/periglacial monitoring with other methods, including ground surface temperature (GST) measurements, geophysical observations, terrain movements and hydrology has been conducted at about 20 other sites in Austria.

During the last years rock glaciers in the Austrian Alps were intensely investigated related to their hydro(geo)logical impact on alpine head waters. A process-based understanding of the storage and runoff behaviour of rock glaciers was developed as a fundamental base for further discussion of runoff behaviour in alpine catchment in the light of climate change. Parallel the first Austrian-wide consistent and homogenized polygon-based inventory of rock glaciers (and their topographic catchments, see Figure 45) has been compiled using high resolution digital elevation model (1x1m spatial resolution). In total, 5769 rock glaciers were mapped, of which ~40 % are interpreted to be intact rock glaciers (containing permafrost); the remaining 60 % are interpreted to be relict (containing no permafrost).

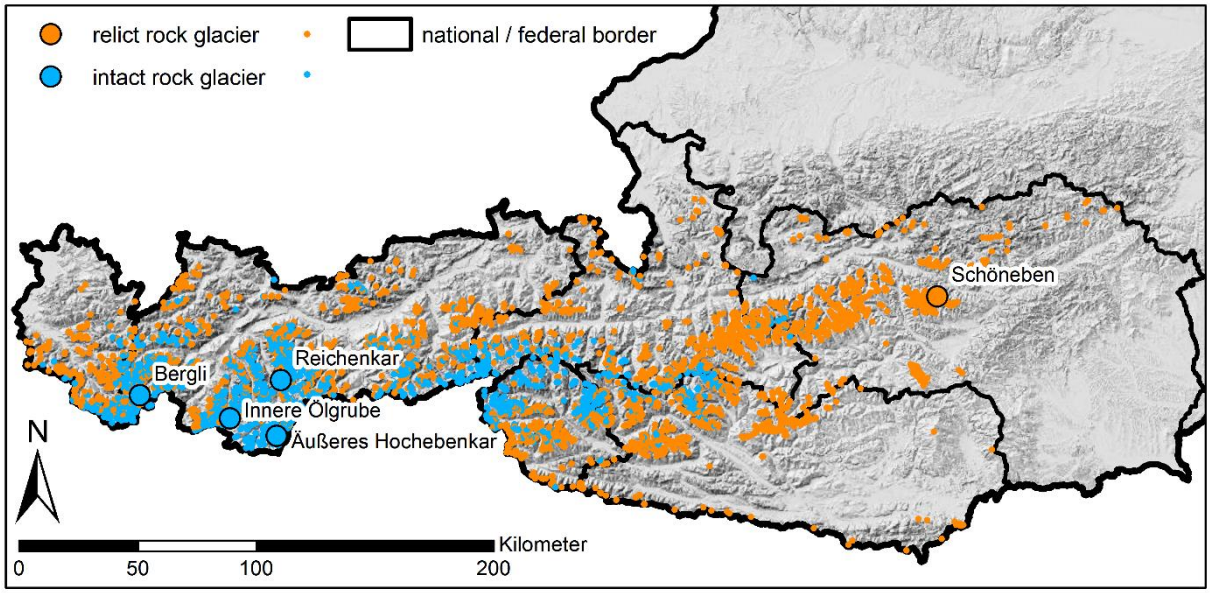


Figure 45: Overview of rock glaciers mapped in the Austrian Alps and the five test sites where discharge patterns were analysed. Rock glaciers are shown as centroid points within the Austrian national border distinguishing between relict and intact rock glaciers. Bergli (Silvretta Mountain Group), Innere Ölgrube and Äußeres Hochebenkar (Ötztal Alps); Reichenkar (Stubai Alps) and Schöneben rock glacier (Seckauer Tauern Range). From Wagner et al. (2020)

The University of Graz led a project called KryoMon.AT - Cryosphere Monitoring Austria, where numerous research institutions in Austria, compile the first comprehensive overview of the decline of permafrost, snow and ice in the Austrian Alps in a report.

Essential Climate Variables - Terrestrial Observations – Cryosphere
GeoSphere Austria

Parameter measured/observed	Permafrost Temperature (PT)
Starting date	2005
Temporal Resolution	Daily
Observational Network	Sonnblick Integrated CryoNet Cluster
Stations	GTN-P: AT 03
Data Portal	GTN-P database
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	GTN-P (Global Terrestrial Network on Permafrost) IPA (International Permafrost Association)
Data Submission	Annually to GTN-p
Licenses	No formal license
Limitation of Use	Free to use
Data Format	csv
Data Access	Open Access
Data Quality	Data quality under the responsibility of the institution providing the data.
Performance Monitoring	Performed by the respective institutions responsible for the measurements.
Publications	
Contact (National correspondent, focal point)	Bernhard Hynek: bernhard.hynek@geosphere.at Anton Neureiter: anton.neureiter@geophere.at
Remarks	None

Essential Climate Variables - Terrestrial Observations – Cryosphere
Georesearch, GeoSphere Austria, University of Graz

Parameter measured/observed	Ground temperature
Starting date	2007
Temporal Resolution	hourly (or at 10-minute intervals)
Observational Network	Sonnblick Observatory, Open Air Lab Kitzsteinhorn, GTN-P
Stations	Sonnblick Observatory (Hoher Sonnblick 1-3) Kitzsteinhorn (Kitzsteinhorn 1-5) Dachstein Massif (Koppenkarstein North Face)
Data Portal	www.gtnpdatabase.org
Supervising Organization	Georesearch, University of Graz, GeoSphere Austria
National and/or international Networks or Programs	AlpHaz (Munich Alpine Hazards and Mitigation Cluster), GTN-P (Global Terrestrial Network on Permafrost), IPA (International Permafrost Association)
Data Submission	partial annual upload to GTN-P database
Licenses	CC BY-NC
Use Limitation	For research only
Data Format	Csv
Data Access	Restricted
Data Quality	raw data
Performance Monitoring	systematic check
Publications	Wagner, T., Pleschberger, R., Kainz, S., Ribis, M., Kellerer-Pirklbauer, A., Krainer, K., Philippitsch, R., & Winkler, G. (2020). The first consistent inventory of rock glaciers and their hydrological catchments of the Austrian Alps, Austrian Journal of Earth Sciences, 113(1), 1-23. doi: https://doi.org/10.17738/ajes.2020.0001 Kellerer-Pirklbauer, A.; Lieb, G.K. (2017): Permafrost-Monitoring in den österreichischen Alpen: Ein Arbeitsbereich am Institut für Geographie und Raumforschung. In: GEOGRAZ. Grazer Mitteilungen der Geographie und Raumforschung. 60. 2017. 11-16. Kellerer-Pirklbauer A., Lieb G.K. (2016): Permafrost in Österreich 2014/15 – Ein erster nationaler Kurzbericht. In: Bergauf 03/2016, 51-53. Kellerer-Pirklbauer, A.,Bartsch, A., Gitschthaler, C., Reisenhofer, S., Weyss, G., Riedl, C., Avian, M. (2015). permAT – Long-term monitoring of permafrost and periglacial processes and its role for natural hazard prevention: Possible strategies for Austria (in German). 10.13140/RG.2.1.1115.4807. Boeckli, Lorenz; Brenning, A; Gruber, A; Noetzli, Jeannette (2012): Alpine permafrost index map. PANGAEA, https://doi.org/10.1594/PANGAEA.784450 Supplement to: Boeckli, L et al. (2012): Permafrost distribution in the European Alps: calculation and evaluation of an index map and summary statistics. The Cryosphere, 6, 807-820, https://doi.org/10.5194/tc-6-807-2012 StartClim2014: https://startclim.at/projektliste
Contact (National correspondent, focal point)	Claudia Riedl: claudia.riedl@geosphere.at Ingo Hartmeyer: ingo.hartmeyer@georesearch.at Andreas Kellerer-Pirklbauer: andreas.kellerer@uni-graz.at
Remarks	Satellite data based, modelled ground temperature data are made openly available through the ESA initiative GlobPermafrost http://www.globpermafrost.info

Essential Climate Variables - Terrestrial Observations – Cryosphere
ÖAW - IGF

Parameter measured/observed	Displacement rate runoff
Starting date	varying
Temporal Resolution	Annual, seasonal
Observational Network	LTER https://deims.org/dataset/3550898d-a890-4694-85a0-d913d65368ee
Stations	Äußeres Hochebenkar (since 1938)
Data Portal	https://doi.org/10.1594/PANGAEA.861405
Supervising Organization	
National and/or international Networks or Programs	LTER
Data Submission	Annual
Licenses	Creative Commons Attribution 3.0 Unported (CC-BY-3.0)
Use Limitation	For research only
Data Format	Csv
Data Access	open access
Data Quality	Data quality under the responsibility of the individual institutions providing the data.
Performance Monitoring	Performed by the respective institutions responsible for the measurements
Publications	https://doi.org/10.1594/PANGAEA.861405 Kellerer-Pirklbauer A., Bodin X., Delaloye R., Lambiel C., Gärtner-Roer I., Bonnefoy-Demongeot M., Carturan L., Damm B., Eulenstein J., Fischer A., Hartl L., Ikeda A., Kaufmann V., Krainer K., Matsuoka N., Morra di Cella U., Noetzli J., Seppi R., Scapozza C., Schoeneich P., Stocker-Waldhuber M., Thibert E., Zumiani M. (2024): Acceleration and interannual variability of creep rates in mountain permafrost landforms (rock glacier velocities) in the European Alps in 1995–2022. Environmental Research Letters: Focus collection Perma-frost Vulnerability to Climate Change https://iopscience.iop.org/article/10.1088/1748-9326/ad25a4 Hartl, L., Zieher, T., Bremer, M., Stocker-Waldhuber, M., Zahs, V., Höfle, B., Klug, C., and Cicoira, A.: Multi-sensor monitoring and data integration reveal cyclical destabilization of the Äußeres Hochebenkar rock glacier, Earth Surf. Dynam., 11, 117–147, https://doi.org/10.5194/esurf-11-117-2023, 2023.
Contact (National correspondent, focal point)	Andrea Fischer Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences andrea.fischer@oeaw.ac.at
Remarks	

Graz Permafrost Monitoring Network

Viktor Kaufmann (TU Graz), Andreas Kellerer-Pirklbauer-Eulenstein (University of Graz), Karl Krainer (University of Innsbruck), Thomas Wagner (University of Graz), Gerfried Winkler (University of Graz)

The "Graz Permafrost Monitoring Network" is an unofficial and loose cooperation between various partners and institutions with a spatial connection to Graz. Mainly motivated by the project ALPCHANGE, funded by the Austrian Science Fund in the period 2006-2011, researchers from the University of Graz and the Graz University of Technology established jointly an initial permafrost monitoring network at five different monitoring sites in the Hohe Tauern National Park, Carinthia, Central Austria, in 2006. Since then, the monitoring activities were expanded, run successfully and form one of the longest data series in Austria related to permafrost and periglacial processes. Methodically, this initial network was primarily based on ground temperature measurements (surface to near surface in shallow boreholes and blocky sediments), geodetic and photogrammetric surface velocity measurements of rock glaciers and surface change detection (e.g., rock fall) using either terrestrial laser scanning or photogrammetric approaches. Additional related activities – partly added over the years – include optical monitoring of geomorphic and nival processes in the rooting zone of rock glaciers (using automatic camera systems), meteorological monitoring (using simple and complex automatic weather stations), geophysical measurements (electrical resistivity tomography and seismic refraction), and water temperature, hydrochemistry and spring discharge monitoring at rock glacier springs (using different measurement and monitoring approaches). By 2025, the network expanded to 14 currently operating sites in the entire Central Alps of Austria, mainly in the Federal Provinces of Carinthia and Tyrol. Figure 46 gives an overview of the location of the different study sites, Table 10 summarises the main parameter-groups studied at the different sites.

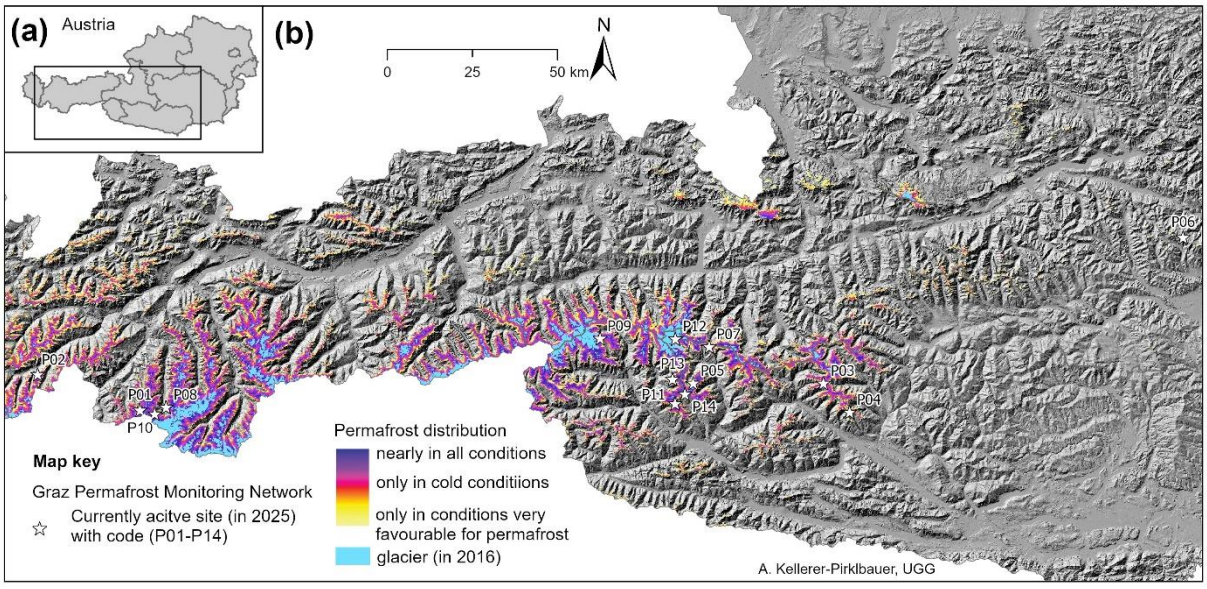


Figure 46: Location of the 14 different study areas considered by the Graz Permafrost Monitoring Network: (a) map of Austria with the extent of the relevant region in Austria considered by the monitoring activities by the Graz group; (b) distribution of the 14 sites. For further details regarding instrumentation and name of sites, refer to text and Table 10. Data source: Topography (KAGIS, Austria), Permafrost (Boeckli et al. 2012); Gletscher (Paul et al. 2020). (Map by Andreas Kellerer-Pirklbauer, UGG).

Code	Site	GT	RGV	HD	GP	Contact
P01	Arzkar/Radurschltal			X		UGE
P02	Berglerlochquelle/Paznauntal			X		UGE
P03	Dösen-Säuleck	X	X	X	X	UGG, TUG
P04	Hintereggengraben	X		X		UGG, UGE
P05	Hinteres Langtalkar-Kögelekar	X	X	X	X	UGG, TUG, GA
P06	Hochreichart-Schöneben	X		X	X	UGG, UGE
P07	Hochtor-Fallbichl	X			X	UGG
P08	Innere Ölgrube/Kaunertal			X		UGE
P09	Innerer Knorrkogel	X				UGG
P10	Krummgampen/Kaunertal			X		UGE
P11	Leibnitzkopf	X	X			UGG, TUG
P12	Pasterze-Burgstall	X			X	UGG, GA
P13	Tschadinalm	X	X			UGG, TUG
P14	Weissenkar	X	X			UGG, TUG

Table 10: List of sites with research activities by member of the Graz Permafrost Monitoring network (alphabetical order). Parameter: GT=ground temperature (surface and near-surface); RGV=rock glacier velocity; HD=hydrology; GP=geophysics; Institutions: UGG=University of Graz-Geography, UGE=University of Graz-Earth Sciences, TUG=Graz University of Technology, GA=GeoSphere Austria. For location of these 14 sites, see Figure 46.

Currently, the network is mainly operated by researcher from the University of Graz (Andreas Kellerer-Pirklbauer, Gerhard Karl Lieb, Wolfgang Sulzer, Thomas Wagner, Gerfried Winkler, Harald Zandler), the Graz University of Technology (Viktor Kaufmann, Tobias Bolch) and GeoSphere Austria (Michael Avian, Melina Frießenbichler). Reports about the activities in four working areas of the initial monitoring program period (Dösen-Säuleck, Hinteres Langtalkar-Kögelekar, Hochtor-Fallbichl, Pasterze-Burgstall) are regularly prepared for the Hohe Tauern National Park authority (e.g., Kellerer-Pirklbauer et al. 2024a). Publications related to different aspects of the monitoring activities appear in international journals (e.g., Brighenti et al. 2024, Kaufmann et al. 2021, Kellerer-Pirklbauer et al. 2024b, Seelig et al. 2024) or overview publication projects such as the annual “The State of Climate” book series (e.g., Pellet et al. 2024) or students’ textbooks (Kellerer-Pirklbauer et al. 2022). The rock glacier inventory and a review of the status quo in hydrogeological research of Austrian rock glaciers will be published in the official hydrogeological map of Austria (1:500000) and its explanation report in 2025 (chapter 6). The impact of rock glacier springs on the runoff of alpine headwaters in terms of climate change with a future perspective was investigated in the project RG-AlpCatch (Seelig et al., 2024; DaFNE 101561) Figure 47. gives impressions to field activities at different selected study sites related to ground temperature (surface and near-surface), rock glacier velocity and hydrological monitoring activities of the group.

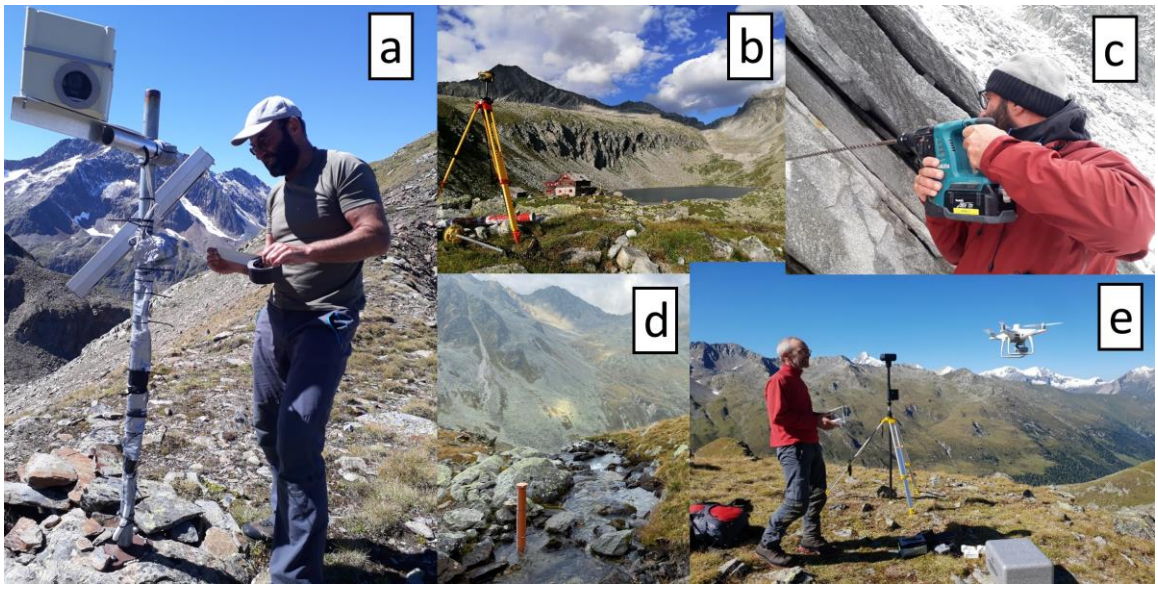


Figure 47: Terrestrial impressions of monitoring and maintenance activities in different study areas: (a) automatic camera systems at the site Hinteres Langtalkar-Kögelekar to monitor processes in the rooting zone of a rock glacier; (b) GNSS-Measurements at the site Dösen-Säuleck – base station with the rock glacier of interest in the far distances; (c) ground temperature monitoring at the site Dösen-Säuleck - drilling of a new shallow borehole; (d) spring monitoring in front of the Arzkar Rock Glacier (an active rock glacier) in the site Radurschltal; (e) UAV-based monitoring at the site Hinteres Langtalkar-Kögelekar (Photographs: a,b,c - A. Kellerer-Pirklbauer; d – T. Wagner; e – M. Avian)

References:

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Kellerer-Pirklbauer A., Lieb G.K., Kaufmann V., Avian M., Frießenbichler M., Eulenstein J. (2024a): Permafrost-Monitoring im Nationalpark Hohe Tauern Kärnten 2022-2024. 2. Zwischenbericht für 2022/23, 53 Seiten. https://www.parcs.at/nphtk/mmd_fullentry.php?docu_id=54088

Kellerer-Pirklbauer A., Bodin X., Delaloye R., Lambiel C., Gärtner-Roer I., Bonnefoy-Demongeot M., Carturan L., Damm B., Eulenstein J., Fischer A., Hartl L., Ikeda A., Kaufmann V., Krainer K., Matsuoka N., Morra di Cella U., Noetzli J., Seppi R., Scapozza C., Schoeneich P., Stocker-Waldhuber M., Thibert E., Zumiani M. (2024b): Acceleration and interannual variability of creep rates in mountain permafrost landforms (rock glacier velocities) in the European Alps in 1995–2022. Environmental Research Letters19 109501 https://doi.org/10.1088/1748-9326/ad25a4

Paul F., Rastner P., Azzoni R.S., Diolaiuti G., Fugazza D., Le Bris R., Nemec J., Rabatel A., Ramusovic M., Schwaizer G., Smiraglia C. (2020): Glacier shrinkage in the Alps continues unabated as revealed by a new glacier inventory from Sentinel-2. Earth System Science Data 12:1805-1821. https://doi.org/10.5194/essd-12-1805-2020

Pellet C., Bodin X., Cusicanqui D., Delaloye R., Kääb A., Kaufmann V., Thibert E., Vivero S., Kellerer-Pirklbauer A. (2024). Rock glacier velocity. In State of Climate 2023, Bull. Amer. Meteor. Soc.,105(8), pp. 44–46. https://doi.org/10.1175/BAMS-D-24-0116.1

Seelig S., Seelig M., Vremec M., Wagner T., Krainer K., Philippitsch R., Avian M., Haslinger K., Brielmann H., Fischer L., Leis A., Ribis M., Obwegs M., Hausleber M., Reszler C., Hann S., Mauthner-Weber R., Winkler G. (2024): Blockgletscher als Grundwasserspeicher in alpinen Einzugsgebieten und ihr Einfluss auf übergeordnete Flusssysteme unter dem Aspekt des Klimawandels (RGAlpCatch). Abschlussbericht. Wien. Bundesministerium für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft. https://dafne.at/projekte/rg-alpcatch

Essential Climate Variables - Terrestrial Observations – Cryosphere
University of Graz

Parameter measured/observed	Ground temperature (GT) – permafrost monitoring Rock glacier velocity (RGV) Hydrology (HD) – spring discharge, water temperature, isotopes, hydrochemistry) Additional data related to these parameters are collect at some study sites of the network such as e.g., automatic weather stations, automatic camera systems, geophysical measurements
Starting date	GT: since 2004 RGV: since 1995 (annually; selected back to 1950s) HD: since 2008
Temporal Resolution	GT: hourly RGV: annually (mainly) HD: hourly (or at shorter intervals)
Observational Network	GT: for the permafrost monitoring program of the Hohe Tauern National Park in Carinthia and Tyrol RGV: for the Global Terrestrial Network on Permafrost (GTN-P) HD: Schöneben and Berglerlochquelle belongs to the official monitoring network of the Hydrograhic Service of Austria
Stations	Graz Permafrost Monitoring network operates at 14 different study sites distributed over the federal states of Carinthia, Tyrol and Styria (for details refer to Table 10 [see document "Monitoring"])
Data Portal	GT: none RGV: under construction at the Global Terrestrial Network for Permafrost (GTN-P) HD: eHyd for stations related to Hydrographic Service; for other UGE sites none
Supervising Organization	GT: University of Graz RGV-geodetic-based: Graz University of Technology and University of Graz (depending on site) RGV-photogrammetry-based: University of Graz, GeoSphere Austria; Graz University of Technology (depending on site) HD: University of Graz
National and/or international Networks or Programs	National networks: KyroMon.AT (cf. https://unipub.uni-graz.at/obvugrveroeff/content/titleinfo/9405860); eHyd (cf. www.ehyd.gv.at) International programs: Global Terrestrial Network on Permafrost) International networks: IPA (International Permafrost Association)
Data Submission	Partial annual upload to GTN-P database, at the different federal province offices, part of the various reports (mostly unpublished project reports for the funding agencies)
Licenses	CC BY-NC
Use Limitation	For research only
Data Format	csv, xlsx, tif
Data Access	restricted

Data Quality	Quality check by the individual team members of this informal network
Performance Monitoring	Systematic plausibility check by the individual groups
Publications	Reports about the different research activities are regularly prepared for the different project funding agencies. Publications related to different aspects of the monitoring activities appear in international journals or other publication projects such as the annual "The State of Climate" book series. A first joint report about the Austrian monitoring activities related to the cryosphere was prepared for the glaciological year 2021/22 (https://doi.org/10.25364/402.2023.1). Data from this network were used in this report. Further annual reports should follow (project in progress).
Contact (National correspondent, focal point)	GT (depending on site): Andreas Kellerer-Pirklbauer (andreas.kellerer@uni-graz.at), Thomas Wagner (thomas.wagner@uni-graz.at) RGV-geodetic-based (depending on site): Viktor Kaufmann (viktor.kaufmann@tugraz.at); Andreas Kellerer-Pirklbauer (andreas.kellerer@uni-graz.at) RGV-photogrammetry-based (depending on site): Wolfgang Sulzer (wolfgang.sulzer@uni-graz.at); Harald Zandler (harald.zandler@uni-graz.at) ; Michael Avian (michael.avian@uni-graz.at); Viktor Kaufmann (viktor.kaufmann@tugraz.at) HD (depending on site: Gerfried Winkler (gerfried.winkler@uni-graz.at); Thomas Wagner (thomas.wagner@uni-graz.at); Andreas Kellerer-Pirklbauer (andreas.kellerer@uni-graz.at
Remarks	More information regarding the permafrost monitoring activities is found at the following sites: Permafrostmonitoring Nationalpark Hohe Tauern Kärnten https://www.parcs.at/nphtk/mmd_fullentry.php?docu_id=39746 eHyd of the Hydrographic Service of Austria https://ehyd.gv.at/

Permafrost Borehole temperature monitoring at ‘Open-Air-Lab Kitzsteinhorn’

Ingo Hartmeyer (GEORESEARCH)

The long-term research site ‘Open-Air-Lab Kitzsteinhorn’ (Central Alps, Austria) hosts a total number of seven boreholes intended for permafrost temperature monitoring. All boreholes were drilled into bedrock (calcareous mica-schist), perpendicular to the terrain surface. The borehole depth ranges from 18-39 m. All boreholes were equipped with polyethylene casings to prevent water entry, the annulus was filled with concrete. For temperature measurement, high-precision PT100 or PT1000 sensors (accuracy ±0.03-0.05 K) are used.

Currently (November 2024), five of the seven boreholes are operating. Out of these, four boreholes are located in a north-facing rock slope, one is located in a west-face (the two boreholes that are currently out of service are located inside a tunnel). The acquired borehole temperature data is transmitted daily. In 2024, the maximum active layer thickness reached 4.4 m, which represents a new peak value for the observation period (2016-2024).

In addition to the permafrost temperature boreholes, the ‘Open-Air-Lab Kitzsteinhorn’ features two deep permafrost boreholes for inclinometer measurements and three deep permafrost boreholes for piezometer measurements. Borehole measurements are complemented by comprehensive geotechnical measurements, which include anchor load cell measurements, crackmeter measurements and tiltmeter measurements.

Figure 48: Drilling works at the Kitzsteinhorn north-face on 11.10.2022 (Photo: Ingo Hartmeyer, GEORESEARCH)

Essential Climate Variables - Terrestrial Observations – Cryosphere
Georesearch

Parameter measured/observed	Permafrost temperature
Starting date	01.01.2016
Temporal Resolution	10 minute
Observational Network	GTN-P (Global Terrestrial Network for Permafrost) VAO (Virtual Alpine Observatory)
Stations	Open-Air-Lab Kitzsteinhorn
Data Portal	GTN-P (Global Terrestrial Network for Permafrost)
Supervising Organization	Georesearch Forschungsgesellschaft mbH
National and/or international Networks or Programs	International: GTN-P, VAO, AK Permafrost National: Kryomon.at
Data Submission	Once a year
Licenses	Refer to GTN-P Data Policy
Limitation of Use	**Non-commercial**
Data Format	CSV
Data Access	GTN-P Database
Data Quality	Quality controlled (outliers removed, timestamps checked, plausibility assessment)
Performance Monitoring	
Publications	
Contact (National correspondent, focal point)	Ingo.hartmeyer@georesearch.ac.at
Remarks	

Matterhorn Cryosphere Observatory

Jan Beutel (University of Innsbruck)

The since 2006 the Matterhorn has been gradually developed into a unique high-altitude, steep-bedrock mountain permafrost laboratory super site. The Matterhorn Cryosphere Observatory with monitoring activities on the North-Eastern aspect Hörnligrat ridge (CH) as well as the South-Eastern aspect Lion ridge (IT) are coordinated by the University of Innsbruck that also operates a publicly available datacenter.

Figure 49: Overview of the Matterhorn Cryosphere Observatory

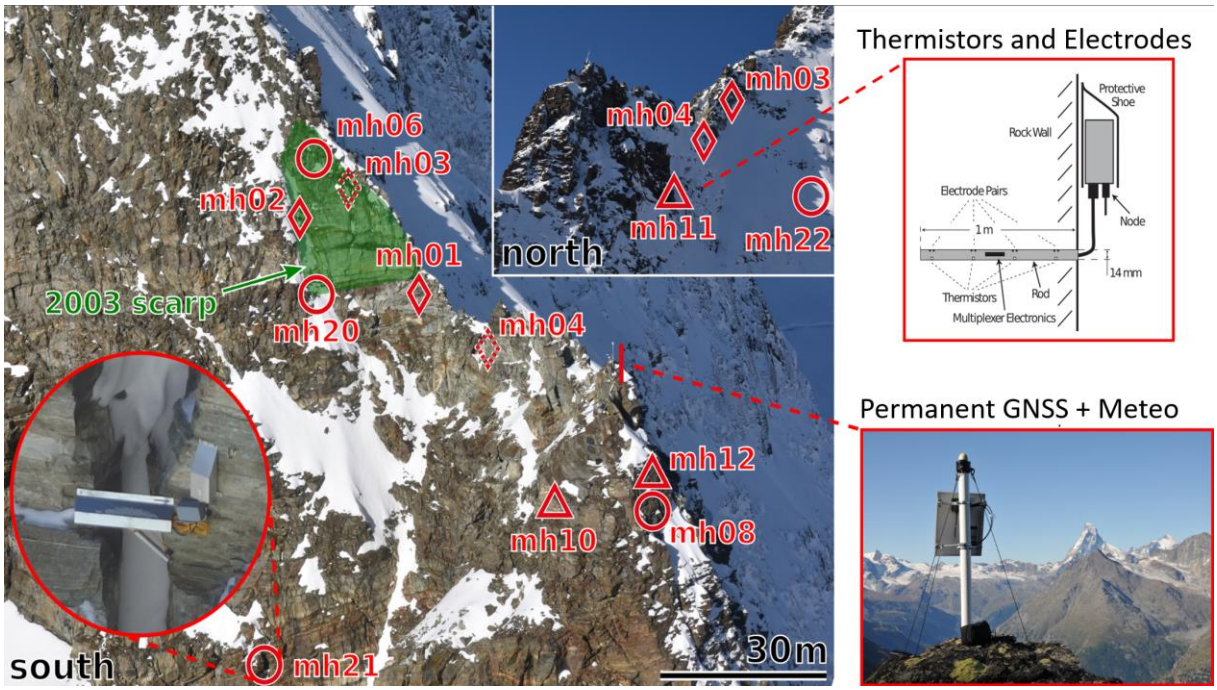


Figure 50: On the Hoernligrat ridge (CH) permafrost temperature, kinematics, hydrological, seimological as well as athmosperic parameters are measured at 3500 m and 4000 m asl respectively.

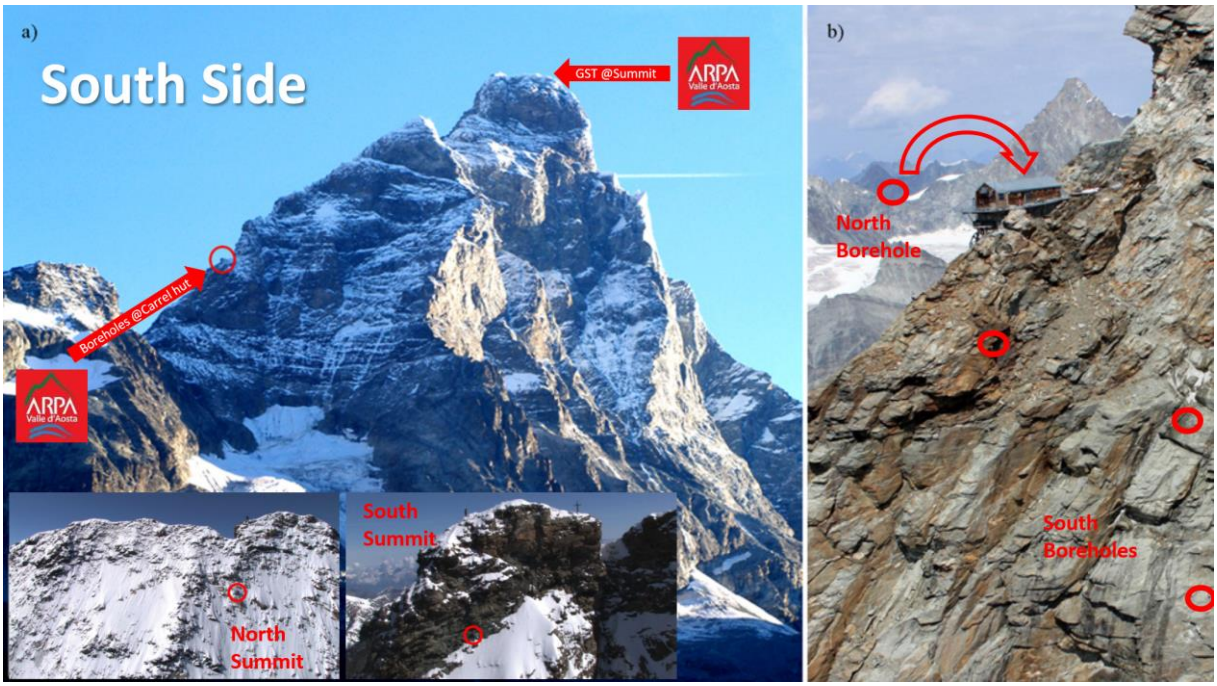


Figure 51: On the Lion ridge (IT) mainly permafrost temperature is monitored from 2500 m to the summit at 4478 m asl.

Figure 52: The main instrument used are small, battery powered wireless sensors.

Figure 53: At the Matterhorn and further sites, Rock Glacier Velocity (RGV) ECVs are measured using permanently installed GNSS stations with daily resolution.

Essential Climate Variables - Terrestrial Observations – Cryosphere
University of Innsbruck

Parameter measured/observed	Air temperature, wind speed and direction, water vapor, pressure, precipitation, surface radiation budget Permafrost Temperature (PT); Active Layer Thickness (ALT); Rock Glacier Velocity (RGV)
Starting date	Air temperature – 12/2010 Wind speed and direction – 12/2010 Water vapor – 12/2010 Pressure – 12/2010 Precipitation – 12/2010 Surface radiation budget – 06/2015 Permafrost Temperature – 07/2008 Active Layer Thickness – 07/2008 Rock Glacier Velocity – 12/2010
Temporal Resolution	2 min, in parts 30 sec raw, typical curated temporal resolution 1h/1d See https://doi.org/10.5194/essd-11-1203-2019 and https://doi.org/10.5194/essd-14-5061-2022 for details
Observational Network	PermaSense
Stations	Matterhorn (CH), Dirruhorn (CH, composite field site in Matter Valley), Aiguille du Midi (FR)
Data Portal	http://data.permasense.ch
Supervising Organization	University of Innsbruck
National and/or international Networks or Programs	Swiss Permafrost Monitoring Network PERMOS (CH) University of Zurich (CH) WSL Institute for Snow and Avalanche Research SLF (CH) ARPA Vallee d'Aosta (IT) Université Savoie-Mont-Blanc (FR)
Data Submission	In part via PERMOS/GCOS Switzerland Annual data publication via Pangaea
Licenses	CC-BY
Limitation of Use	**none**
Data Format	CSV
Data Access	Open access
Data Quality	See https://doi.org/10.5194/essd-11-1203-2019 and https://doi.org/10.5194/essd-14-5061-2022 for details
Performance Monitoring	University of Innsbruck
Publications	https://doi.org/10.5194/essd-11-1203-2019 https://doi.pangaea.de/10.1594/PANGAEA.967586 https://doi.org/10.5194/essd-14-5061-2022 https://doi.pangaea.de/10.1594/PANGAEA.948334
Contact (National correspondent, focal point)	Prof. Dr. Jan Beutel Networked Embedded Sensing Center University of Innsbruck +43 512 507 53443, jan.beutel@uibk.ac.at
Remarks	

ARGE LWD
Austrian snow station network

Christoph Mitterer (LWD-Tirol), Patrick Nairz (LWD-Tirol), Michael Butschek (GeoSphere Austria), Alexander Podesser (GeoSphere Austria)

The consortium of regional avalanche warning services in Austria (ARGE LWD) operates an intensive automated snow and weather station network to record snow and weather parameters relevant for high-quality avalanche danger assessments. The network consists of 186 snow stations (Figure 54) and represents one of the most sophisticated and densest automated station networks worldwide.

The objectives of the measurements:

- Provide information on snow and weather properties at a high temporal resolution to local and regional avalanche warning services and avalanche commissions.
- Provide the basis for daily local and regional avalanche danger assessments and/or forecast throughout various warning products and advisories.
- Provide the input for operational snow cover modelling.
- Provide the background for long-term statistical tools based on nearest-neighbor methods (e.g. NxD).

The network is partly owned by the Provincial Governments, communities and/or third party NGO's or companies such as e.g. the Austrian Railways (OEBB). Most measurement sites include two automated stations: a snow station and a wind station (not shown on the map below). While the wind station is mostly placed on exposed ridges or summits, snow stations are built in wind sheltered areas such as e.g. bowls. The name of the station speaks for its sensor equipment: Wind stations record parameters of wind and air temperature, while snow station focus on recording snow height, snow surface temperature and other relevant snow parameters (e.g. snow temperature and liquid water content).

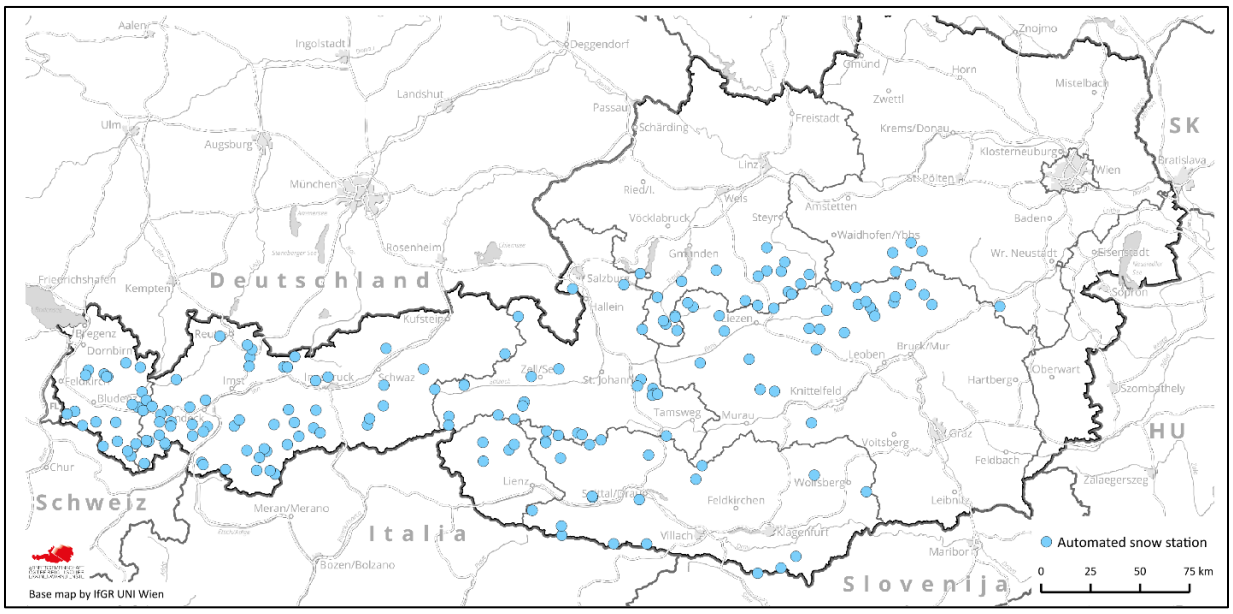
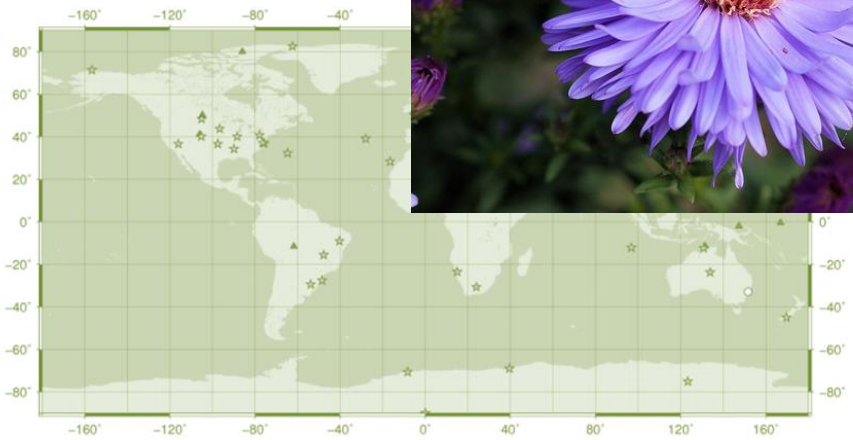


Figure 54: Network of snow stations operated by the consortium of regional Avalanche Warning Services in Austria (N = 186)

Essential Climate Variables - Terrestrial Observations – Cryosphere
LWD Tirol, Geosphere Austria

Parameter measured/observed	10-minute-mean: air temperature, relative humidity, wind speed, wind direction, global radiation, snow height, snow temperature, snow surface temperature 10-minute-maximum: wind speed, wind direction 10-minute-total: precipitation Actual value: snow water equivalent, snow liquid water content, snow ice content
Starting date	Considerable variation within the various avalanche warning services, but mostly starting from mid to end 1990s.
Temporal Resolution	10 minute
Observational Network	Observational network of the corresponding regional avalanche warning service grouped within the ARGE Lawinenwarndienste Österreich
Stations	Vorarlberg: N = 23 Tyrol: N = 68 Salzburg: N = 26 Upper Austria: N = 19 Styria: N = 28 Carinthia: N = 35 Lower Austria: N = 10
Data Portal	No explicit and uniform data portal available, but data can be obtained upon request or through various OGD interfaces of the Provincial Governments.
Supervising Organization	The Provincial Governments of the correspondent regional avalanche warning service.
National and/or international Networks or Programs	ARGE Lawinenwarndienste Österreich
Data Submission	Automatic data transfer via HTTP
Licenses	Free raw data
Limitation of Use	**For research purposes and operational warning only, non-commercial**
Data Format	CSV, ASCII, ZRXP
Data Access	Open access on request or OGD interfaces
Data Quality	Data quality is evaluated by the correspondent regional avalanche warning service
Performance Monitoring	Data availability is monitored by the correspondent regional avalanche warning service
Publications	Vorarlberg: Various graphs on www.lawis.at Tyrol: Various graphs on www.lawis.at Salzburg: Various graphs on www.lawis.at Upper Austria: Current 3-day graphs www.lawis.at Styria: Various graphs on www.lawis.at Carinthia: Current 3-day graphs on www.lawine.ktn.gv.at

	Lower Austria: Various graphs on www.lawis.at
Contact (National correspondent, focal point)	lawine@tirol.gv.at, lawine@lawine-steiermark.at lawine@ktn.gv.at post.bd3@noel.gv.at lawine@salzburg.gv.at
Remarks	



Terrestrial Observations

Biosphere

National Forest Inventory of Austria

Alexandra Freudenschuß (BFW)

The National Forest Inventory (NFI) of Austria is a large-scale forest monitoring programme covering the federal territory of Austria. The Austrian NFI is the main data provider for national and international reporting on Austria's forest resources. The results serve as basis for decisions in forest and environmental policy and are a valuable data source for numerous scientific projects. The planning, execution and evaluation is carried out by the Department of Forest Inventory of the Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW).

Until today, eight sample-based inventories have been carried out. The first inventory was conducted in the years 1961 - 1970, and was followed by the assessments in 1971 - 1980, 1981 -1985, 1986 - 1990, 1992 - 1996, 2000 – 2002, 2007 – 2009 and 2016 - 2021. Since then every year one sixth of the NFI plots are remeasured and annual updated results are available. While the first two NFIs were based on a temporary sampling grid, the subsequent inventories were carried out on a permanent grid consisting of approximately 5,500 clusters and 11,000 forest plots. The distance between the clusters is 3.89 km. The clusters have the shape of a square with 200 m side-length where the sample plots are located at the corners. At the sample plots numerous stand-, site- and tree-specific variables are assessed and form the basis for the periodic results of the Austrian NFI.

Furthermore, remote sensing techniques are used and continuously improved to supplement and enlarge the information about Austrian forests. With the help of Aerial Images and Orthophotos, Satellite Imagery and Airborne Laserscanning forest parameters like volume, biomass, forest area, forest types, increment, harvest and disturbances are determined (https://www.waldinventur.at).

Essential Climate Variables – Terrestrial Observations – Biosphere
BFW

Parameter measured/observed	Terrestrial data – 200 different stand-, site- and tree-specific parameters like e.g. land use, tree species, forest structure, above-ground biomass, elevation, slope, soil type, forest vegetation type, tree diameter and height.
Starting date	Inventory cycles started in 1961, since then eight NFIs had been conducted, since 2016 every year one sixth of the NFI plots are remeasured.
Temporal Resolution	Periodical assessments in 1961-1970, 1971-1980, 1981-1985, 1986-1990, 1992-1996, 2000-2002, 2007-2009, 2016-2021 and ongoing assessments.
Observational Network	Large-scale inventory with a sampling grid of 3.89 km x 3.89 km covering all federal territory.
Stations	5,500 clusters with approximately 11,000 plots located on forest land.
Data Portal	Results are available at the homepage https://www.waldinventur.at for national and sub-national levels for different topics (e.g. forest area, standing volume, increment, harvest). Plot data accessibility restricted.
Supervising Organization	Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW), Department of Forest Inventory
National and/or international Networks or Programs	The Austrian NFIs represents large-scale forest monitoring at national level. It is member of ENFIN – the European National Forest Inventory Network that promotes the harmonisation of forest information (http://enfin.info/).
Data Submission	Periodical update following each inventory cycle.
Licenses	Credits and attribution to BFW. No data sharing with others. No commercial use. No modification of data and results.
Use Limitation	**Research projects and non-commercial uses.**
Data Format	Stored in an Oracle® database. Data excerpts as xls or csv. Download of results as xls files.
Data Access	Open access download of results at the BFW homepage https://www.waldinventur.at. Availability of plot data is restricted.
Data Quality	Data undergo comprehensive quality checking in several steps. Data quality checks are performed by the BFW.
Performance Monitoring	Data availability is supervised by BFW.
Publications	The Department of Forest Inventory publishes and contributes to publications within the thematic frames: inventory methods, harmonization of NFIs, use of remote sensing, uncertainty, climate change, biodiversity, and wood availability.
Contact (National correspondent, focal point)	alexandra.freudenschuss@bfw.gv.at thomas.gschwantner@bfw.gv.at
Remarks	

Monitoring hydrological data of forest ecosystems

Karl Gartner (BFW)

The web portal WALDÖKODATEN was developed by the department of Forest Ecology and Soils of the Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW). It provides - daily updated - a large part of the ongoing ecological relevant measurements of the department, which belong to different ongoing projects of the department. At the moment the web portal is under reconstruction.It includes data, which come from the stations via remote access. The data are roughly checked and imported into a POSTGRESQL data base system. The data are aggregated to daily values and exported from this database to be shown in form of graphical form or to be downloaded in the form of CSV-files. Except for the data on changing stem circumferences, all data are shown and available online only for the last thirty days. This will change with the new version. A Google-map with the exact position of the measurement station completes the web site.

A simple quality control of the data is done before the data come into the database. For this reason, the data available from the web-portal are not final data sets. They can be changed by data analysis, which is done to get the corresponding results for the different projects. The use of the data for commercial use is not permitted.

The data comprise meteorological data of open field stations, air temperature and air humidity within the stand, soil temperature and soil moisture and measurements of changing stem circumference with the help of electronic girth bands.

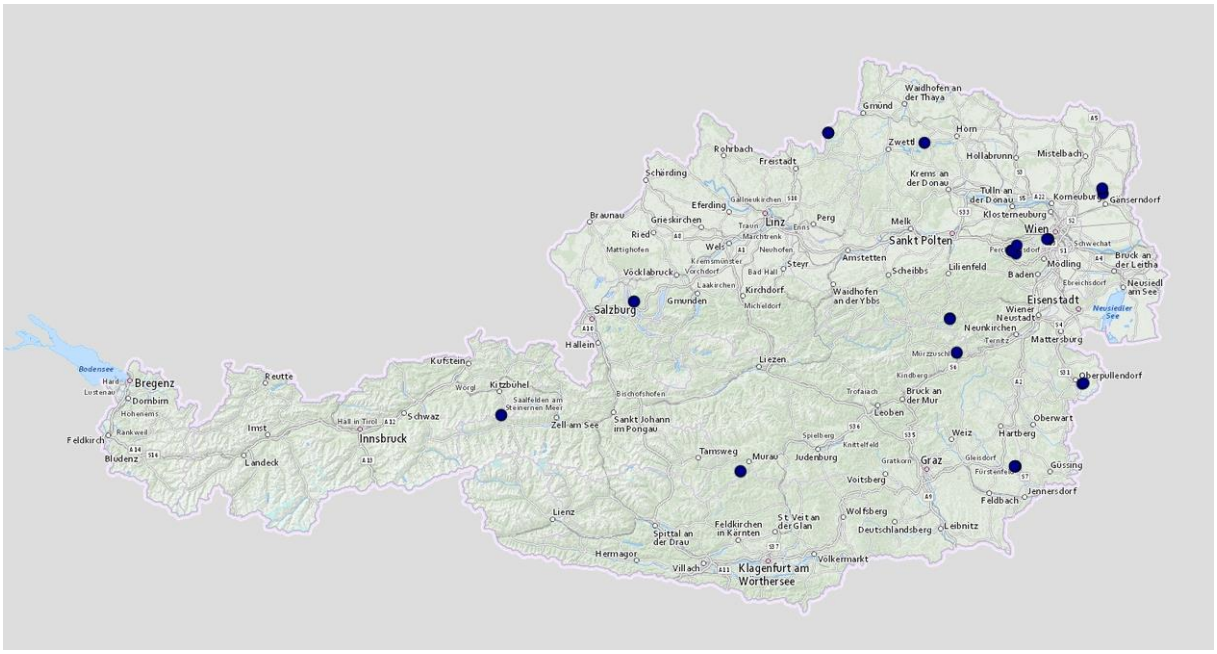


Figure 55: Location of the WALDÖKODATEN - stations. Also shown are the stations at the Gippel and in Neupölla and Matzen, which are at the moment not part of the WALDÖKODATEN-portal.

Essential Climate Variables – Terrestrial Observations – Biosphere
BFW

Parameter measured/observed	meteorological data (air temperature, air humidity, global radiation, wind speed, wind direction, precipitation) together with soil temperature and soil moisture
Starting date	earliest dataset starts at 06/1998
Temporal Resolution	differs from 15 to 60 minutes
Observational Network	long term monitoring of forest sites
Stations	about 10 stations distributed across Austria
Data Portal	http://bfw.ac.at/rz/bfwcms2.web?dok=8658 partly national data centres of the participating countries
Supervising Organization	Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW)
National and/or international Networks or Programs	ICP Forests
Data Submission	daily update
Licenses	CC BY-NC-SA
Use Limitation	**for non-profit research**
Data Format	Download of the data as csv
Data Access	Download via the Waldökodaten-homepage (http://bfw.ac.at/rz/bfwcms2.web?dok=8658) Open access to the last 30 days of data (otherwise see contact below)
Data Quality	Data quality is done by BFW.
Performance Monitoring	Data availability is supervised by BFW (see contact).
Publications	
Contact (National correspondent, focal point)	Contact: karl.gartner@bfw.gv.at
Remarks	

VODCA – The global, long-term microwave vegetation optical depth (VOD) climate archive

Ruxandra-Maria Zotta (TU Wien), Wouter Dorigo (TU Wien), Leander Moesinger (AWST GmbH)

Since the late 1970s, space-based microwave radiometers have measured Earth's surface radiation, enabling the derivation of Vegetation Optical Depth (VOD). This model-based parameter quantifies the attenuation of radiation due to the vegetation layer and is indicative of biomass, vegetation density, and vegetation water content. The sensitivity of VOD to the upper layer of vegetation increases with shorter wavelengths. Therefore, spatial and temporal patterns observed at higher frequencies, such as those in the C-, X- and Ku-bands, agree better with upper canopy dynamics, while lower frequency observations like P- and L-band correspond more closely to those of overall above-ground biomass (AGB), including branches and trunks (Schmidt et al., 2023). VOD's high temporal resolution facilitates the monitoring of vegetation changes, but limited sensor lifespans hinder long-term analyses. To overcome this problem, we must merge multiple VOD datasets into a consistent climate record. To this end, in 2019, we created the long-term Vegetation Optical Depth Climate Archive (VODCA v1; Moesinger et al., 2019; Moesinger et al., 2020). VODCA v1 combines VOD retrievals from the Special Sensor Microwave Imager (SSM/I) F8, F11 and F13, the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), The Advanced Microwave Scanning Radiometer (AMSR-E), WindSat and the Advanced Microwave Scanning Radiometer 2 (AMSR2) using the Land Parameter Retrieval Model (Owe et al ., 2008; van der Schalie et al., 2017). VODCA v1 provides separate VOD products for observations in different spectral bands, namely the Ku-band (period 1987 - 2017), X-band (1997 - 2018) and C-band (2002 - 2018). VODCA v1 data is available at a daily temporal resolution and 0.25° spatial resolution and is open access (https://doi.org/10.5281/zenodo.2575599). We provide temporal extensions upon request.

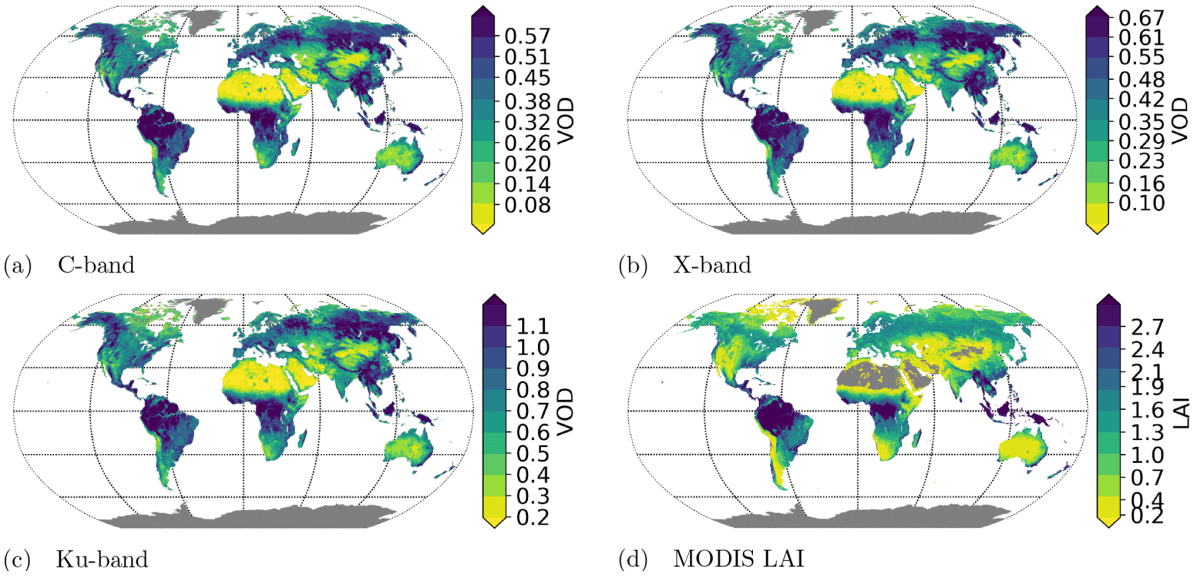


Figure 56: Average VOD for the C- (a), X-(b) and Ku-band (c), as well as MODIS LAI as reference, computed over the period 2002 – 2017

In 2024, we released VODCA v2 (Zotta et al., 2024a; Zotta et al., 2024b), which complements the existing dataset with two new products: VODCA CXKu and VODCA L. VODCA CXKu is a multi-frequency merged product of unprecedented coverage (34 years; 1987 - 2021), with lower random error levels and better temporal and spatial coverage than the single-frequency products from the original release.

This dataset is created by blending observations from the C-, X- and Ku frequencies and incorporates data from two additional sensors, SSM/I F17 and the Global Precipitation Measurement (GPM) Microwave Imager (GMI). VODCA CXKu is indicative of upper canopy dynamics. VODCA L is obtained by merging LPRM-derived VOD observations from the Soil Moisture and Ocean Salinity (SMOS) and the Soil Moisture Active Passive (SMAP) missions covering 2010 - 2021 and is indicative of above-ground biomass. The timeline of the sensors used in the VODCA datasets

As VOD is a vegetation parameter, for which no direct reference datasets, such as in situ measurements or model data, are available. Therefore, we assessed the temporal and spatial patterns of VODCA C-, X-, Ku and CXKu with respect to various vegetation datasets derived from satellite sensors in the optical (leaf area index (LAI), fraction of absorbed photosynthetically active radiation (fAPAR)) and microwave (ASCAT slope) domain. We also compared their patterns with two ground-based vegetation datasets: Normalized Microwave Reflection Index (NMRI) measurements obtained from GPS reflectometry and sapflow observations from the SAPFLUXNET network. The high-frequency VODCA products provide complementary information to optical vegetation indicators in studying the vegetation canopy response to climate variability and human impact. We recommend using them in studies focusing on short vegetation and broadleaf forests. The temporal and spatial sensitivity of VODCA L to biomass has been evaluated using yearly AGB maps and proved that VODCA L is able to capture inter-annual biomass change patterns.

VOD has been used in a wide range of applications, including monitoring drought and vegetation conditions, phenology analysis, biomass monitoring, estimating the likelihood of fire occurrence and monitoring fuel moisture, crop yield assessment and prediction, estimation of gross primary production and modelling of land evapotranspiration. Furthermore, VOD contributes to the understanding of ecosystem resilience and aids in assessing vegetation responses to precipitation.

VODCA has been used in the yearly State of the Climate Report of the Bulletin of the American Meteorological Society (BAMS) since 2020.

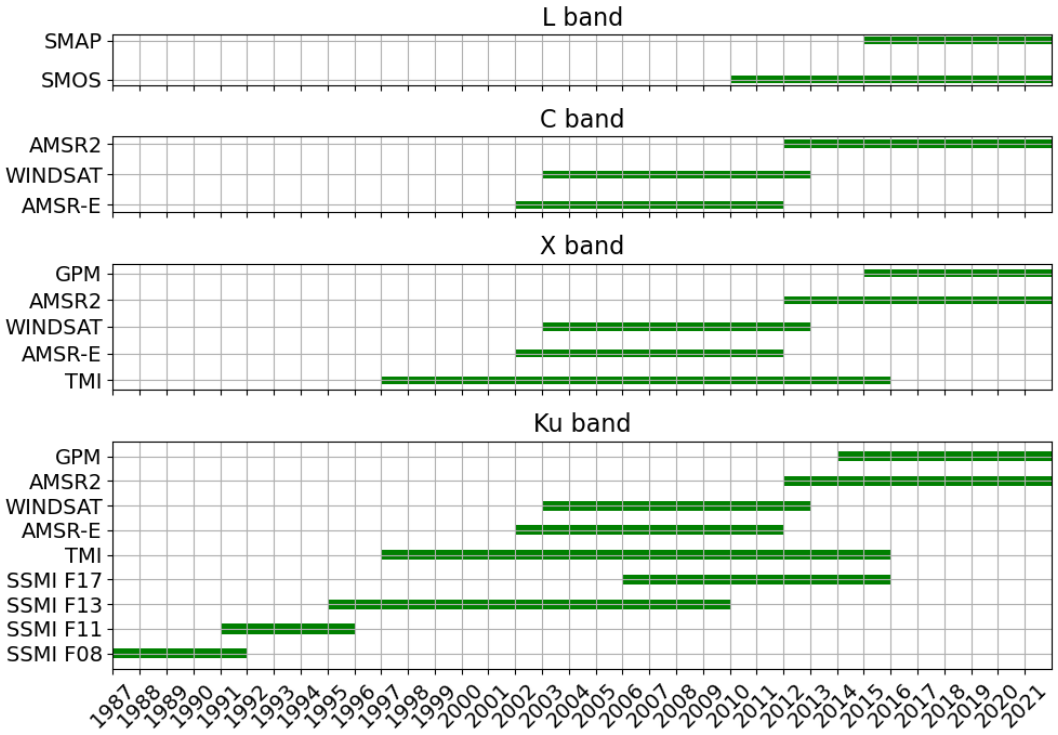


Figure 57: Life span of input sensors used in VODCA v2

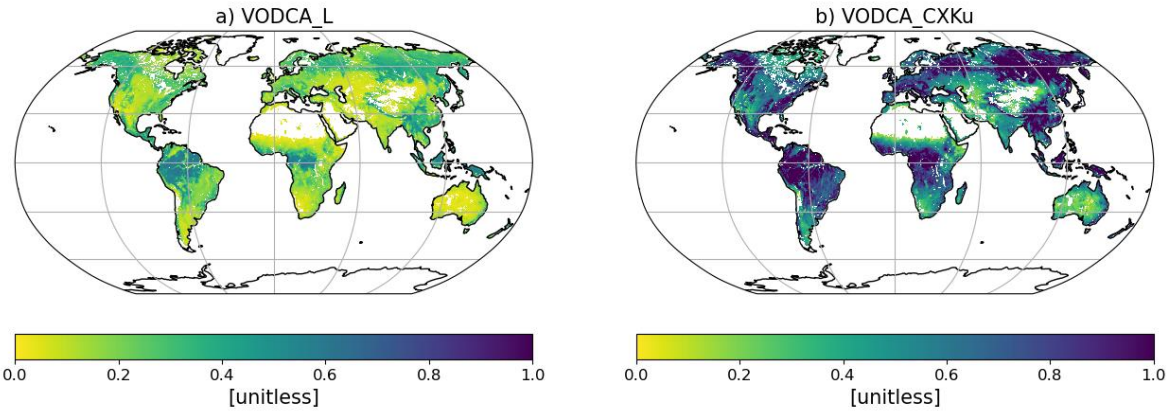


Figure 58: Temporally averaged VOD for (a) VODCA L and (b) VODCA CXKu for the period 2010 – 2021

References:

Moesinger, L., Dorigo, W., De Jeu, R., Van der Schalie, R., Scanlon, T., Teubner, I., & Forkel, M. (2019). The Global Long-term Microwave Vegetation Optical Depth Climate Archive VODCA (1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.2575599

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Van der Schalie, R., de Jeu, R. A., Kerr, Y. H., Wigneron, J.-P., Rodríguez-Fernández, N. J., Al-Yaari, A., Parinussa, R. M., Mecklenburg,S., and Drusch, M.: The merging of radiative transfer based surface soil moisture data from SMOS and AMSR-E, Remote Sensing of Environment, 189, 180–193, 2017.

Schmidt, L., Forkel, M., Zotta, R.-M., Scherrer, S., Dorigo, W. A., Kuhn-Régnier, A., van der Schalie, R., and Yebra, M.: Assessing the sensitivity of multi-frequency passive microwave vegetation optical depth to vegetation properties, Biogeosciences, 20, 1027–1046, 2023

Zotta, R.-M., Moesinger, L., van der Schalie, R., Vreugdenhil, M., Preimesberger, W., Frederikse, T., De Jeu, R., & Dorigo, W. (2024a). VODCA v2: Multi-sensor, multi-frequency vegetation optical depth data for long-term canopy dynamics and biomass monitoring (1.0.0) [Data set]. TU Wien. https://doi.org/10.48436/t74ty-tcx62

Zotta, R.-M., Moesinger, L., van der Schalie, R., Vreugdenhil, M., Preimesberger, W., Frederikse, T., de Jeu, R., and Dorigo, W.: VODCA v2: Multi-sensor, multi-frequency vegetation optical depth data for long-term canopy dynamics and biomass monitoring, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2024-35, in review, 2024b.

Essential Climate Variables - Terrestrial Observations – Hydrosphere
TU Vienna

Parameter measured/observed	Vegetation Optical Depth (VOD)
Starting date	Earliest observations from 1987
Temporal Resolution	Daily observations.
Observational Network	
Stations	
Data Portal	
Supervising Organization	TU Wien
National and/or international Networks or Programs	
Data Submission	
Licences	Creative Commons Attribution 4.0 International
Use Limitation	**For scientific use only**
Data Format	netCDF
Data Access	https://doi.org/10.5281/zenodo.2575599 https://researchdata.tuwien.at/records/t74ty-tcx62
Data Quality	
Performance Monitoring	
Publications	Moesinger et al., 2020; Zotta et al., 2024
Contact (National correspondent, focal point)	Wouter Dorigo: wouter.dorigo@tuwien.ac.at Ruxandra Zotta: ruxandra-maria.zotta@tuwien.ac.at
Remarks	

Phenology

Thomas Hübner (GeoSphere Austria)

Insight Phenology

The roots of the Phenological Observation Network of Austria reach back to 1851 when the predecessor organization of GeoSphere Austria, ZAMG was founded. An uninterrupted series of phenological observations extend back to 1946. The start of the longest observation series dates back to 1457, which is the date of grape harvest in the vineyards of Klosterneuburg (NÖ). Digitized data of phenological development of crop, vine, fruit plants, trees, shrubs, herbaceous and some animals is available from 1926 until today. Earlier years are still under digitization.

Figure 59: Salix caprea

Phenological observations are done by volunteering Citizen Scientists. By now, there are about 80 observers who either enter their observations online on www.phenowatch.at or still use the traditional paper pen method and mail the completed form to GeoSphere Austria. This set of observations is completed by data collected by smartphone app.

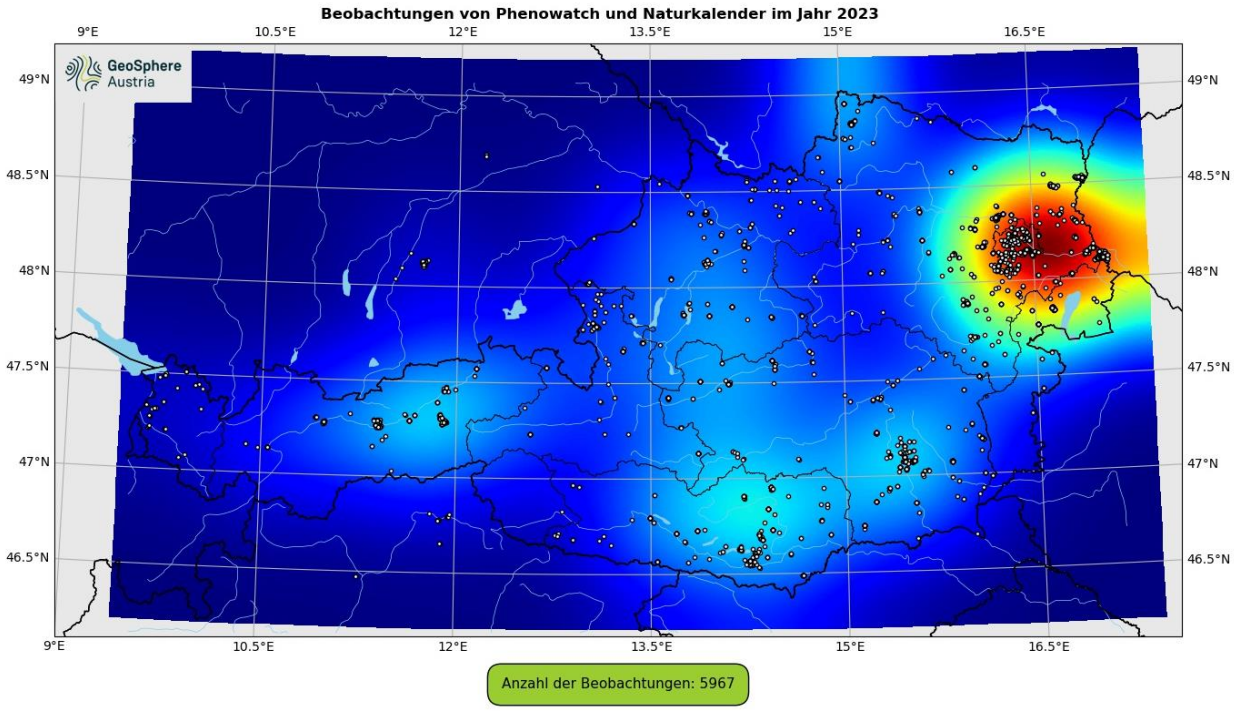

Figure 60: Location of phenological observations in 2023

Pocket tool for Citizen Scientists

In addition to observation at the classic phenology stations, there is also the possibility for the general population to actively support the phenology as a citizen scientist. The smartphone app "nature calendar" was developed to involve interested amateurs in the work of GeoSphere Austria.

In this way, the Citizen Scientists become contributors in climate change research and can understand it more easily through their own observations in their own environment. In this way, they also become multipliers and ambassadors for phenology.

The app for Android and iOS can be downloaded from the website www.naturkalender.at. There is also information about phenology and fact sheets about phenological pointer plants.

Europe-wide network

GeoSphere Austria is host of the Pan European Phenological database (PEP725) where all major phenological networks in Europe store their data for scientific research, it can be found at www.pep725.eu. The access is open to all interested parties and the download or support by GeoSphere Austria is free.

GeoSphere Austria is also a partner of the international Plant Gardens (IPG). This phenological network works with cloned plants to avoid influences of genetic predetermination. In Austria there are two IPG locations, the headquarters of GeoSphere Austria Wien and the regional office of GeoSphere Austria in Salzburg.

Figure 61: Prunus armeniaca

Essential Climate Variables – Terrestrial Observations – Biosphere
GeoSphere Austria

Parameter measured/observed	occurrence of certain states of development of plants, like first flowering or leaf colouring in DOY (day of year)
Starting date	1946 with interruptions and changing number of observation stations (not digitised before 1946, extend back to 1851)
Temporal Resolution	yearly occurrence per species, phase and location
Observational Network	National phenological network of Austria including their collaborations
Stations	all phenological stations in Austria (number species and phases may vary yearly)
Data Portal	portal for data entry and meta data www.phenowatch.at and www.naturkalender.at (starting in 2018) data portal for download etc. www.pep725.eu
Supervising Organization	GeoSphere Austria
National and/or international Networks or Programs	Paneuropean Phenological Database - PEP725 National Phenological Network of Austria (Phenowatch, Naturkalender) GCOS
Data Submission	Online submission via website continuously Annual data submission on posted paper form Submission via smartphone application
Licenses	CC-BY-NC
Use Limitation	**Non-commercial, non-profit research**
Data Format	download of the data as csv
Data Access	download via www.pep725.eu access by registration
Data Quality	First data quality control is done by boundary values during data entry and by review of the members of the phenology team at GeoSphere Austria. Other mechanisms are under development.
Performance Monitoring	Data availability is supervised by GeoSphere Austria
Publications	annual report of GeoSphere Austria
Contact (National correspondent, focal point)	Paneuropean Phenological Database - PEP725 Markus Ungersböck pep725@geosphere.at National Phenological Network of Austria (Phenowatch, Naturkalender, etc.) Helfried Scheifinger, Hans Ressl, Thomas Hübner phenowatch@geosphere.at thomas.huebner@geosphere.at
Remarks	

Annex

Financial Situtation of the Monitoring Systems

Continuation of the measurements ensured for the next years
Atmospheric Observations:

□ < 5 years □ 5-10 years □ > 10 years

Atmospheric Observations – Surface	
Climate monitoring - GeoSphere Austria	
VAMES - Austro Control	
Aerodrome Met stations - Austro Control	
Sunshine duration - GeoSphere Austria	
UV Radiation - BOKU	
Solar and terrestrial radiation ARAD - GeoSphere Austria	
BSRN - GeoSphere Austria	
Atmospheric Observations – Upper Air	
Radiosonde - GeoSphere Austria	
Radiosonde - Austro Control	
Austrian Weather Radar Network - Austro Control	
Atmospheric Observations - Composition	
Stratospheric Ozone - BOKU	
Air Quality Monitoring Network - Umweltbundesamt	
Air Quality Monitoring of federal states of Austria – Amt der Landesregierungen	
Sonnblick Observatory - GeoSphere Austria	

Table 11: Financial situation of the Atmospheric Observation Systems in Austria.

Continuation of the measurements ensured for the next years
Terrestrial Observations:

□ < 5 years □ 5-10 years □ > 10 years

Terrestrial Observations - Hydrosphere	
Climate Monitoring Hydrological Service of Austria	
Terrestrial Water Monitoring Hydrological Service of Austria	
Tuxer Alps - BFW	
Torrent Research Areas - BFW (Dez. 2024 closed)	
ESA CCI and C3S Soil Moisture Climate Date Records - TU Wien	
ASCAT surface soil moisture - TU Wien, GeoSphere Austria	
Terrestrial Observations - Cryosphere	
Snow Monitoring - GeoSphere Austria	
Snow Monitoring – Hydrological Service of Austria	
Snow Monitoring – ENVEO IT GmbH, Uni Innsbruck	
Glaciers Monitoring –GeoSphere Austria	
Glaciers Monitoring – ÖAW/IGF	
Glaciers Monitoring – Austrian Alpine Club	
Glaciers Monitoring – TU Graz, Uni Graz	
Glaciers Monitoring – ENVEO IT GmbH	
Permafrost Monitoring – GeoSphere Austria	
Permafrost Monitoring – ÖAW/IGF	
Permafrost Monitoring – TU Graz, Uni Graz	
Permafrost Kitzsteinhorn - Georesearch	
Permafrost Matterhorn – Uni Innsbruck	
ARGE LWD Austria	
Terrestrial Observations - Biosphere	
National Forest Inventory of Austria - BFW	
Monitoring hydrological data of forest ecosystems - BFW	
VODCA – TU Wien	
Phenology - GeoSphere Austria	

Table 12: Financial situation of the Terrestrial Observation Systems in Austria.

The GCOS Climate Monitoring Principles

1. **Spatial and Temporal Sampling:** It is critical for observations to sample the Earth system in such a way that climate-relevant diurnal, seasonal, interannual and long-term changes can be resolved. When the opportunity exists to fill gaps in the existing observing system high priority should be given to data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
2. **System Design:** Observing systems should encompass both in-situ and remote sensing platforms as appropriate based on their respective strengths and limitations. Climate monitoring requirements regarding appropriate spatial and temporal sampling, instrument precision and accuracy, and stability should be specified to observing system designers, operators, and instrument engineers at the outset of system design and implementation. Observing systems should include reference observations to ensure well characterized measurement time series traceable to SI and/or community standards with robustly quantified uncertainties that can be used with confidence. Periodic reviews should be conducted to assess the feasibility and benefits of incorporating new technologies into the observing systems.
3. **System Sustainability:** For in-situ observations, operation of historically uninterrupted stations and observing systems that meet the specified calibration, stability, and siting requirements should be maintained for as long as possible. For satellite measurements, continuity should be ensured through appropriate launch and orbital strategies. Relevant climate research observing systems and networks should be sustained and transitioned to operational status.
4. **System Change Management:** The impact of new systems or changes to existing systems should be assessed prior to implementation. A suitable period of overlap between new and old instruments and observing systems should be ensured for a period adequate to determine inter-instrument biases and maintain the homogeneity and consistency of time-series observations.
5. **Metadata:** In order to ensure the utility of the observations, the details and history of local conditions, site location, instruments, operating procedures, data processing algorithms, data errors and biases, and other factors pertinent to interpreting data (i.e., metadata) and their changes over time should be documented and treated with the same care as the data themselves.
6. **Calibration:** Prior to the deployment of a new instrument or observing platform, its technical characteristics, such as accuracy, precision, and stability, should be rigorously documented and calibrated in order to ensure consistency with climate-relevant requirements. Calibration should be traceable to SI units or to reference observations. Following deployment, all system components should be regularly recalibrated or otherwise evaluated to ensure the highest data quality.
7. **Data Quality and Homogeneity:** The quality and homogeneity of data should be regularly assessed as a part of routine operations. Random errors and biases in the observations should be identified and documented.
8. **Data and Metadata Preservation:** Data and metadata should be preserved for secure, long-term storage and retrieval in an appropriate repository according to relevant international standards.
9. **Data Access:** Data management systems that facilitate access, use, and interpretation of data and products should be included as essential elements of climate monitoring systems. These systems should facilitate open user access to climate products, metadata, and raw data,

including key data for delayed-mode analysis, in line with the WMO Unified Data Policy (Resolution 1).

10. **Data Exploitation:** The collected observations should be used to generate datasets of ECVs. In order to keep pace with evolving technologies, climate-relevant requirements, and methods, these datasets should be sustained, regularly assessed, and reprocessed as needed.

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*The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

The previous version of the climate monitoring principles was adopted by UNFCCC COP-9 in 2003, with Decision 11/CP.9. In 2022, the GCOS Implementation Plan, Action C1 "Develop monitoring standards, guidance and best practices for each ECV", Activity C1.4 "Review the GCOS climate monitoring principles", raised the need to update these principles, considering the significant advancements in best practices and monitoring capabilities occurred in the last two decades.