Swiss polar research

Pioneering spirit, passion and excellence



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra


120° 00' 00" W
90° 00' 00" W
60° 00' 00" W
30° 00' 00" W
60° 00' 00" N
USA
USA (ALASKA)
CANADA
RUSSIA
GREENLAND (DK)
ICELAND
FINLAND
NORWAY
SWEDEN
CANADA
NEEM
Ice Core Project
GREENLAND (DK)
NGRIP
Ice Core Project
Swiss
Camp
Swiss
Tower
Summit
Ilulissat (Jakobshavn)
Jakobshavn Isbrae
Camp IV
GRIP
ICE Core Project
Summit Camp
Drilling
camp Foxx
EGIG Route
De Quervain Route
Cecilia Nunatak
Dye-3
Ice Core Project
Schweizerland
Mont Forel
Ammassalik
Denmark
Strait
ICELAND
ATLANTIC OCEAN
ARCTIC
0
Data compiled by: FDFA, STS, CMC-Geoservices
Remarks: The boundaries and names shown, as well as the designations used on this map do not imply official endorsement or acceptance by


180° 00′ 00″ W
120° 00′ 00″ E
90° 00′ 00″ E
60° 00′ 00″ E
SIBERIA
Yenisey
Kara Sea
Franz Josef Land (RU)
RUSSIA
80° 00′ 00″ N
Ny Ålesund
Zeppelin measuring station
Barents Sea
SPITSBERGEN (N)
70° 00′ 00″ N
FINLAND
NORWAY
Arctic Circle
SWEDEN
Norwegian Sea
Research sites
Research station
Camp
Ice core drilling with Swiss participation
Route
250
500 km
Switzerland
0° 00′ 00″ E
30° 00′ 00″ E

"I HAVE NO SPECIAL TALENT. I AM ONLY PASSIONATELY CURIOUS." Albert Einstein

Passion and curiosity, a thirst for knowledge and a pioneering spirit coupled with a dash of adventure were also hallmarks of the natural scientists and mountaineers of landlocked Switzerland who began exploring the Arctic from the 18th century and laid the cornerstone for the country's expertise in polar research.

The region known as Schweizerland in East Greenland for example, which was named after its discoverers, is a testimony to Swiss research and exploration. The highest summit in these mountains is called Mont Forel in honour of the Genevan scientist, François-Alphonse Forel, whose support for and promotion of the 1912 expedition led by Alfred de Quervain was crucial.

Today, researchers from Switzerland – particularly in the interdisciplinary field of climate research – rank among the best in the world. They participate in research on the very specific climate conditions and ecosystems of the two polar regions that are impacted by the way we manage natural resources and which, in turn, have consequences for the weather and climate that we experience. Their results make a significant contribution to improving our understanding of the world's ecosystem; they make it possible to reveal not only the past but also to make predictions for the future of our planet. And they help political decisions to be made on leaving behind an environment worth living in for the coming generations.

The special interest that Swiss researchers have in the Arctic and Antarctic can also be explained by the close relationship between polar and high altitude research, which is more connected than at first appears. Large parts of Switzerland were formed by glaciers and ice, and parts of the Alps are covered with snow and ice all year round. As is the case in the Arctic, we are also seeing glacier recession and "warmer" winters in Switzerland.

Polar research – as can be evidenced by this publication – is international. And achievements in this field can rarely be attributed to one individual alone, but rather to a team. It is absolutely necessary that scientists from all over the world pool their resources and efforts, and work in international and multidisciplinary teams that transcend national borders. That is why Swiss researchers work closely together with their colleagues abroad, predominantly from the eight member states of the Arctic Council and one of the states party to the Antarctic Treaty.

Switzerland ratified the treaty in 1990 which stipulates that the uninhabited Antarctic may only be used for peaceful purposes, in particular scientific research and tourism. In contrast to the Arctic, the use of natural resources in the Antarctic is forbidden.

The Arctic Council was established in 1996 to balance the interests of the Arctic states and the indigenous peoples of the Arctic region. It coordinates research and development projects in order to promote climate protection and security in a region which has up to two million inhabitants. Both the Antarctic Treaty and the Arctic Council embody concerns and objectives shared by Swiss foreign policy: to actively contribute to stability and peace in the world.

Switzerland's major involvement in the Arctic and Antarctic research networks is also significant in terms of its foreign policy. Just as Swiss diplomacy endeavours to open doors for our researchers abroad, so do they – through their participation in international teams – contribute to the worldwide promotion of Swiss expertise in research and innovation.

The projects presented in this brochure show how they play a natural role in what is fundamental to Swiss foreign policy: they demonstrate that Switzerland, as a global leader in research, innovation and technology, assumes its share of the responsibility in solidarity with the rest of the world to solve the great mysteries of our planet and to tackle the biggest challenges facing our existence.

This brochure aims to bring you closer to the work of our scientists and share in the adventure of Swiss polar research.

I hope you enjoy reading it.



Didier Burkhalter
Federal councillor and head of the Federal Department of Foreign Affairs FDFA

SWISS POLAR SCIENCE: FROM PIONEERING SPIRIT TO EXCELLENCE IN RESEARCH

Swiss scientists belong to the world leaders in polar research. This may seem astonishing at first glance, as Switzerland, a landlocked country in the heart of Europe, traditionally does not belong to the grand seafaring nations. However, history shows that the impact of glaciers and ice on everyday life in Switzerland directed the attention of Swiss scientists and explorers towards the polar regions from early on – especially the large ice sheets in Greenland and Antarctica. On the other hand, the growing 19th-century awareness that glaciers the size of Greenland do exist led to the ultimate breakthrough of ice age theories put forward by Swiss and other scientists. These explained many of the landscape and topographic features of Switzerland.

Swiss polar researchers also made their mark in 1912, a unique but also tragic year for polar discovery. A highlight of that year was the Greenland expedition of Alfred de Quervain, who crossed Greenland from west to east and succeeded in bringing all members of the expedition safely back to Switzerland. In the same year, explorers were most active in Antarctica. They included Swiss lawyer and ski champion Xavier Mertz, who lost his life at the end of the tragic Australian expedition led by Douglas Mawson.

Although most reports focus on the heroic efforts made during such expeditions, all these teams set out to gain new scientific knowledge. For example, de Quervain performed extensive meteorological and geomagnetic observations along the way and measured a complete topographic profile of the Greenland ice sheet along his route, an immense scientific achievement at that time.

The "Expédition Glaciologique Internationale au Groenland" (EGIG) was founded in Grindelwald, Switzerland, during 1956. Its first Greenland traverse was carried out in 1959 with many Swiss scientists and explorers taking part. At this time, the EGIG was already equipped with precision instruments – for example, those for geodetic surveying. It also had track vehicles and airborne support. The EGIG route was repeated in 1967–68 and during the early 1990s. This enabled scientists to observe temporal changes in glacier mass. About the same time, a new scientific field was growing – the study of past climate and greenhouse gas information stored in polar ice cores. It was pioneered, among others, by the late Hans Oeschger at the University of Bern.

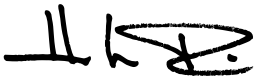
Technological possibilities have soared with the advent of satellite imaging and geodetic positioning, and Swiss scientists now also make substantial contributions in monitoring the Greenland and Antarctic ice sheets using these remote techniques. However, field observations remain an

essential part of climatological and glaciological studies.

Swiss polar research traditionally focused on polar glaciology and climate. But over recent decades it has greatly expanded its spectrum, and Swiss scientists now also investigate the biology and biogeochemistry in the Southern Ocean or the coupling of climate, permafrost, and vegetation in tundra regions. They study atmospheric circulation, air pollution in polar regions, and the effect of snow on climate. They reconstruct past climates archived in ice, marine and lake sediments, and perform geological studies that provide information about the history of the ice sheets.

As Switzerland has no polar institute as such, the Swiss science community reaches these interdisciplinary goals in multinational collaborations, through international science programmes and active participation in non-governmental organisations such as the Scientific Committee for Antarctic Research and the International Arctic Science Committee. Accordingly, the aim of research has shifted from exploration and discovery to understanding Earth System processes. This is crucial to explaining the role of polar regions for our planet as well as to studying their sensitivity to future global warming caused by human activities.

With climate change ahead of us, the role of polar science in providing critical knowledge for these sensitive regions will certainly grow, and the Swiss science community intends to continue to make important contributions to this field. This brochure outlines the areas in which Swiss science is already most active.



Prof. Hubertus Fischer
On behalf of the Swiss Committee on Polar and High Altitude Research, a Committee of the Swiss Academies of Arts and Sciences



Foxx drilling camp on the Greenland Ice Sheet.
© Claudia Ryser, ETH Zurich

THE IMPACT OF CLIMATE CHANGE ON THE GREENLAND ICE SHEET

The Greenland Ice Sheet is the second-largest store of fresh water on Earth. Observations show that there has been a strong increase in atmospheric temperatures and surface melt during the last decade, and that ice flow into the sea is accelerating. These findings have raised concerns that the Greenland Ice Sheet will lose even more ice in a future warmer climate. If the ice sheet were to melt completely the level of the sea would rise by six metres.

Swiss Scientists are primarily involved in field research into the dynamic behaviour of the Greenland Ice Sheet and the surface melt process, focusing on changes in the ice mass and ice flow dynamics on the west coast of Greenland. These field investigations provide the basis for further scientific research and are complemented by methods using satellites for measuring and providing images (remote-sensing) and computer models.

Researchers from the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL) in collaboration with the Federal Institute of Technology Zurich (ETHZ) and the University of Colorado at Boulder (USA) have been taking measurements since 1990 as part of a long-term programme at the Swiss Camp station. The measurements have enabled them to confirm an increase in ice melt. The station, located on the western slope of the ice sheet, has recorded a 3°C rise in temperature and an inland migration of the snowline by 50 km since it began taking measurements.

Swiss Camp also serves as a test site for the 18 automatic weather stations located across the entire ice sheet that form the Greenland Climate Network (GC-Net) collectively. The network is the basis for climate information and monitoring, weather forecasting, satellite sensor validation, process studies, and regional climate model validation.

At the summit of the ice sheet (3,300 metres above sea level) Swiss researchers from the ETHZ and WSL have been conducting long-term monitoring projects in atmospheric research at the 50-metre-high Swiss Tower, and they have been working on the Surface Baseline Radiation Network (BSRN) experiment since 2000. These projects measure and record changes in the Earth's radiation field, which may be related to climate change.

A group of researchers from the ETHZ discovered that a thick layer of relatively warm ice facilitates the high flow velocities of the ice stream from the Jakobshavn Isbrae glacier, and carried out the first deep drillings in the ice flow and its environment. More recent field investigations and modelling by Swiss researchers and partners from US universities have shown that the recent doubling in flow velocity of Jakobshavn Isbrae to over 14 km per year is due to a lack of stability caused by its rapidly retreating floating terminus.

The findings have shown that half of the motion visible at the surface is due to sliding at the glacier base – even in the cold wintertime. During the warm summer season, the sliding contribution increases up to 90%. This has been shown by further measurements taken by the ETHZ in collaboration with its US partners. These were made by drilling vertical holes through 700 metres of ice to the glacier base. Water pressure variations and ice deformation were observed using sensors at the bottom and inside the ice mass. Sliding processes in the remote under-ice environment control the flow velocity of the ice and therefore the present shape and future evolution of the ice sheet.

KEY FIGURES

COUNTRY/REGION: Arctic, Greenland
VARIOUS PROJECTS, INCLUDING:
"Real-time Observations of the Greenland Under-Ice Environment"
Project period: 2010–2014
"Understanding long-term outlet glacier calving dynamics"
Project start: 2014
"Surface processes glacio-hydrology and englacial modeling of the Greenland Ice Sheet"
Project period: 1990–2014
"Climate and surface baseline radiation network monitoring on top of the Greenland ice sheet"
Project start: 2000
BUDGET: about CHF 20,000,000
SWISS CONTRIBUTION: CHF 7,000,000
PARTNERSHIP: University of Colorado, Boulder (United States), University of Texas, Austin (United States), Dartmouth College, Hanover, NH (United States), Los Alamos National Laboratory, Los Alamos, NM (United States), NASA Goddard Space Flight Center, Greenbelt, MD (United States), University of Alaska, Fairbanks (United States), Geography Department, Durham University (UK).


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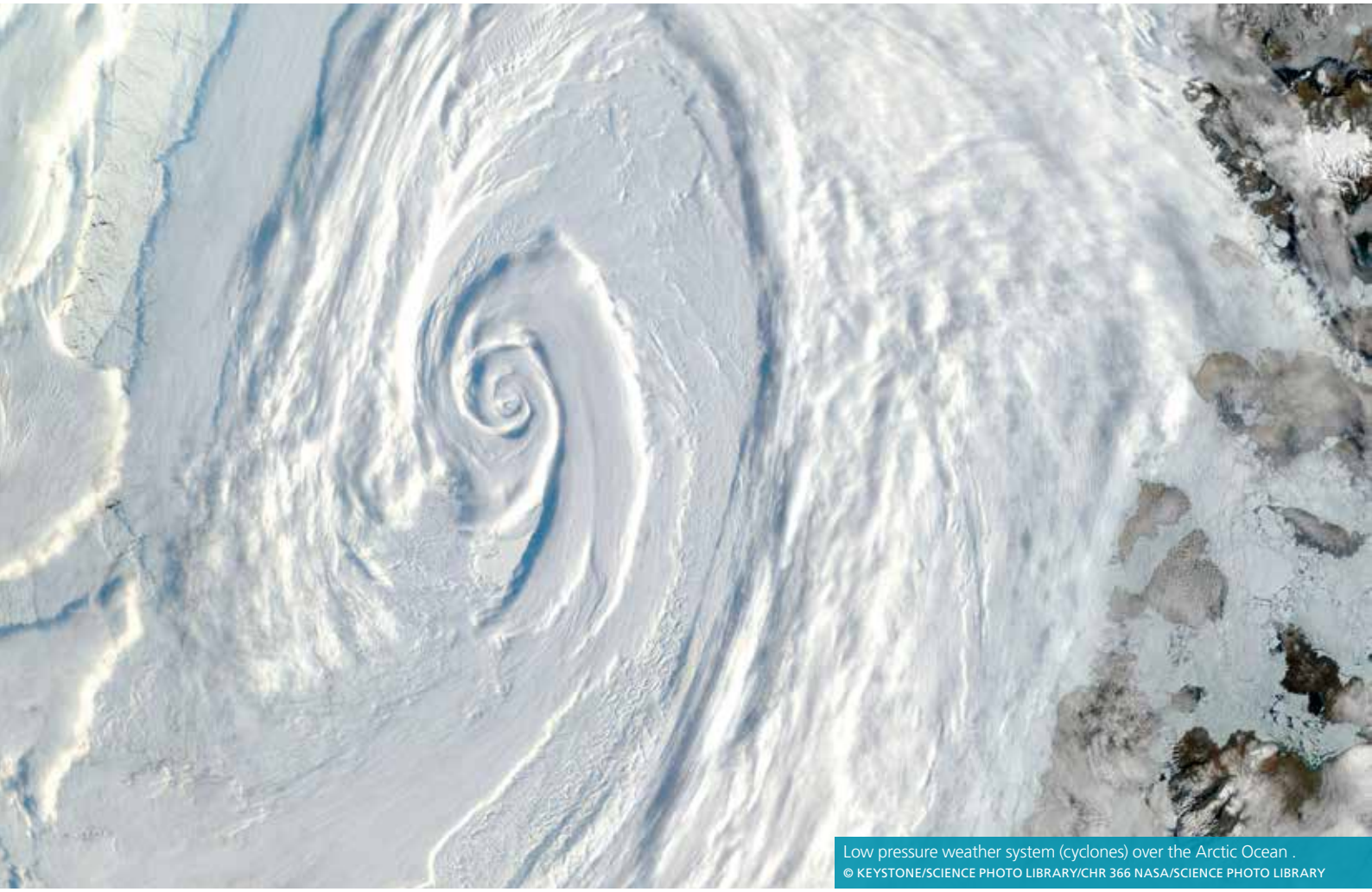
KONRAD STEFFEN
Professor of Climate and Cryosphere, ETH Zurich and EPF Lausanne, Director of the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL), Birmensdorf



MARTIN LÜTHI
Ph.D. senior researcher, Glaciology and Geomorphodynamics Group, Department of Geography, University of Zurich, vice-chair of the Swiss Committee for Polar and High Altitude Research, Swiss Academies of Arts and Sciences


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ANDREAS VIELI
Professor, Glaciology and Geomorphodynamics Group, Physical Geography Division, Department of Geography, University of Zurich



Low pressure weather system (cyclones) over the Arctic Ocean .
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SWISS CONTRIBUTION TO MODELLING OF POLAR OCEANIC AND ATMOSPHERIC CIRCULATIONS

Polar weather and climates are characterised by intense interactions between the ocean, ice, and the atmosphere in a topographically complex environment. A prominent example is the large-scale melting of ice induced by pole-ward excursions of warm air from mid-latitudes, as happened in Greenland during summer 2012.

High-resolution numerical models of the ocean and atmosphere have been developed to simulate complex flows in the polar regions. In addition, high-quality observation-based multi-decadal global datasets became available – so-called reanalyses – which serve to perform diagnostic studies of polar atmospheric circulation.

Swiss research in this field – particularly at the University of Bern and the Federal Institute of Technology Zurich (ETHZ) – makes an important contribution to better understanding these processes and phenomena in the polar regions. They encompass development of a regional high-resolution coupled atmosphere-ocean model in the South Atlantic, study of how oceanic eddies effect the overlaying atmosphere, analysis of cold air outbreaks from Antarctica, and study of water vapour transport to and heavy precipitation in polar regions.

There are many unknown aspects of the coupling between the ocean and atmosphere at scales below 100 km. Recent observations from the Southern Ocean revealed that small oceanic eddies with a diameter of typically 50 km and sea surface temperature anomalies of about 1°C can influence the overlying wind, cloud coverage, and precipitation. For instance, cloud coverage over cold oceanic eddies is on average smaller than in the surrounding area (see chart on the right). Using a newly developed coupled atmosphere-ocean regional model with a horizontal resolution of 10 km,

the mechanisms leading to these changes in atmospheric circulation induced by the ocean eddies could be consistently identified and quantified.

Cold air outbreaks are spectacular weather events of cold polar air masses that flow to lower latitudes (below 50 degrees latitude), leading to very intense heat and moisture uptake over the ice-free ocean and often to formation of hazardous small-scale cyclones, so-called polar lows (see chart on the left). These fairly small cyclones can lead to strong surface winds, and the associated adverse weather conditions can be a severe threat to polar operations (shipping, oil platforms). Reanalyses and numerical modelling have been used to investigate the climatology of cold air outbreaks, their formation mechanisms and the pathway to polar low formation. A detailed understanding of these processes is crucial for improving weather and climate prediction in polar regions.

Atmospheric transport processes in the opposite direction, *i.e.,* of warm and moist mid-latitude air to the polar regions, are essential for polar precipitation and maintaining the immense amount of ice stored in glaciers and ice sheets. Sophisticated algorithms have been developed to follow the motion of water through the atmosphere and to identify linkages between ocean evaporation, long-range transport, and precipitation. Measurements of the stable isotope composition in precipitation help to test the models against reality. This research has already contributed substantially to our interpretation of climate information archived in ice cores from Greenland and Antarctica.

The atmospheric processes leading to heavy precipitation have been analysed in detail for a particular region (Dronning Maud Land) in Antarctica. Strong, wavelike disturbances at about 10 km height propagating towards Antarctica prior to the event are key precursor signals for the precipitation later forming a surface cyclone in the Weddell Sea. The role of cyclones is to steer moist air from oceanic regions to a precipitation region where the coherent moist airstream impinges upon the steep coastal topography.

KEY FIGURES

VARIOUS PROJECTS, INCLUDING:
CHIRP II "Modeling the water cycle in a changing climate – a multi-scale interaction challenge" and
SOGate "Phytoplankton ecosystem control of the Southern Ocean biogeochemical gate"
BUDGET: about CHF 800,000
SWISS CONTRIBUTION: about CHF 800,000
FUNDING: ETH Zurich and Swiss National Science Foundation (SNSF)
PROJECT START: 2010
PARTNERSHIP: University of Melbourne (Australia), Institute for Marine and Atmospheric Research Utrecht (Netherlands)



Ocean eddies may cause circular cloud free areas.
© Nasa Johnson Space Center

NICOLAS GRUBER
Professor, Environmental Physics, Institute for Biogeochemistry and Pollutant Dynamics, ETH Zurich

OLIVIA ROMPPAINEN-MARTIUS
Professor, Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern

HARALD SODEMANN
Professor, Atmospheric Dynamics, Institute for Atmospheric and Climate Science, ETH Zurich
Geophysical Institute, University of Bergen (Norway)

CHRISTOPH WELKER
Ph.D, Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern

HEINI WERNLI
Professor, Atmospheric Dynamics, Institute for Atmospheric and Climate Science, ETH Zurich



Measuring Antarctic surface reflectivity.
© M. Schneebeli

SWITZERLAND'S LEADING ROLE IN POLAR RESEARCH ON SNOW

The importance of snow in the polar regions is demonstrated by numerous words indigenous peoples use to express all forms of snow conditions. In this respect, indigenous peoples of the Arctic and Alpine farmers hardly differ – a connection that also exists in snow science. In recent years, Switzerland has stepped up its research in the Arctic and Antarctic in order to put its international leading role in snow science to use in researching and resolving global issues. Thanks to development of new measurement techniques and computer models, Switzerland can make a significant contribution to snow science in the polar regions.

Snow is formed when water vapour and tiny water droplets in the atmosphere crystallise. When it falls to the ground in winter or throughout the year, it forms a snow cover that completely re-crystallises many times – as demonstrated by recent research at the WSL Institute for Snow and Avalanche Research (SLF) in Switzerland – because it is so close to melting point once on the ground.

Snow impacts global climate. The way in which sunlight is reflected varies depending on the size of what are known as snow grains. The SLF and the Swiss Federal Institute of Technology in Zurich (ETHZ) are taking a leading role in determining the size of these snow grains with their groundbreaking research on snow reflectance and the Earth's radiation balance.

Their work is being carried out in the Antarctic and Greenland (primarily at Summit Camp located at the apex of the Greenland Ice Sheet at 3,300 metres above sea level and at the Swiss Camp). The study includes research into how deep sunlight penetrates snow. The findings were incorporated into the Swiss computer software SNOWPACK, which measures snow and energy balance.

An expedition to Siberia focused on the physical properties of a late winter snow cover on permafrost, which determine to what extent the ground

freezes. The extremely fragile large crystals known as depth hoar that develop under these climatic conditions can only be measured by combining micro-tomography with numerical simulations.

Understanding of the link between how snow accumulates under windy conditions (sublimation) and topographical features has been shaped by Swiss Alpine research into snowdrifts and avalanche slopes where the wind re-deposits the snow. Even if there is a difference between the topography of Greenland and the Antarctic in comparison to that of the Alps, the processes of sublimation remain similar.

Field studies and computer simulations are used to study how the wind transports snow, including climate and weather models to understand how snowdrifts are formed. Snowfall and drifting snow can be measured very accurately using GPS and lasers. This makes it possible to observe patterns of snow deposits and changes in the surface roughness from which very precise maps can be created. These show in detail where the snow has collected or been transported by the wind.

Snow is also the very substance of the ice cores, the unique climate memory dating over thousands of years. How snow is transformed into solid ice is a process that needs to be understood in order to better interpret the past. Two recent expeditions to the Antarctic have shown that, thanks to Swiss techniques, processes involving how snow is deposited and transformed can be much better understood.

KEY FIGURES

COUNTRY/REGION: Antarctic, Finland, Greenland, Russia
BUDGET: about CHF 5,000,000
SWISS CONTRIBUTION: about CHF 1'000'000
PROJECT PERIOD: 2000–2014
PARTNERSHIP: Alfred Wegener Institute for Polar and Marine Research (Germany), the Finnish Meteorological Institute (Finland), the Laboratoire de Glaciologie et Géophysique de l'Environnement (France), the University of Washington (United States)



Snow measurements near the Samoylov research station in the Lena Delta in north-eastern Siberia. © M. Proksch, WSL



© M. Fitzpatrick

MARTIN SCHNEEBELI
Head of Research Group "Snow Physics", WSL Institute for Snow and Avalanche Research (SLF), Davos



© K. Gavahan

KATHERINE LEONARD
Ph.D, Laboratory of Cryospheric Sciences (CRYOS), EPF Lausanne



Researchers collecting snow and ice samples from young sea ice in the Bellingshausen Sea, West Antarctica. © Katherine Leonard

IMPACT OF SEA ICE ON THE CLIMATE AND WEATHER IN EUROPE

The area of Earth's polar regions covered by sea ice and the dates of the maximum and minimum sea ice areas strongly influence global weather patterns. The freezing process linked with salt rejection and the ice's presence also form a critical component of global ocean circulation – and thus Earth's long-term climate.

Sea ice typically covers about 14 to 16 million km^2 of the Arctic Ocean in late winter and 17 to 20 million km^2 of the Southern Ocean during the Antarctic winter. These numbers are known only for recent decades, since the development of satellite remote-sensing instruments able to "see" the ice during the dark polar winters. While this record is short, climate models have been trained to properly predict sea ice during this period. They are now used to calculate what sea-ice conditions were like in the past and may be like in the future.

A decline in summer Arctic Ocean ice cover has been observed in more than 40 years of satellite records and from climate modelling– even though the area covered by ice in winter has remained fairly stable. The Southern Ocean's ice-covered area has shown slight increases in recent winters, but it is not yet clear if this is a significant change. Learning how a decline in the Arctic's summer ice and an increase in the Antarctic's winter sea ice relate to changing winter weather patterns in Europe and North America has become a recent focus for the world's research community including Switzerland.

Most Swiss sea-ice research to date has focused on the importance of sea ice to global weather and climate systems. Particularly satellite remote-sensing, climate and atmospheric modelling, and field campaigns to evaluate the physical properties of sea ice help understand the modelling and remote-sensing results. Modelling and laboratory research on the mechanical behavior, chemistry,

and micro-structural properties of sea ice has been another area of important Swiss contributions.

Switzerland has also excelled in designing instruments to measure incoming solar radiation and the reflectivity (or "albedo") of different surfaces. Sea ice – particularly when covered with snow – is highly reflective. Thus the area of sea ice available to reflect incoming sunlight and the properties of that ice at times of year when the poles experience sunlight is critical to the amount of heat that can either be reflected back to space or absorbed by the oceans and atmosphere.

A current sea ice research project funded by the Swiss National Science Foundation (SNSF) uses methods described on page 12 to understand how much snow cover there is on Antarctic sea ice. This fieldwork was conducted jointly with projects measuring the thickness and other properties of the ice and underlying ocean. While the area of ice cover can be identified using satellites, (and more recently even the surface topography of the ice), it is impossible to determine the volume of sea ice without knowing how much snow is on it. Also of interest is which fraction of the snowfall lands in the ocean, where the snow comes from, and what role it plays in sea ice formation and growth.

Most Antarctic sea ice melts away during summer and is newly produced each winter. If snowfall increases over several years, the area and volume of sea ice cover could remain the same or even increase while the fraction of that ice formed by freezing ocean water declines. This could impact global ocean circulation, which is strongly influenced by the input of cold salty water during the formation of Antarctic sea ice each fall.

KEY FIGURES

COUNTRY/REGION: Antarctic
VARIOUS PROJECTS, INCLUDING:
Swiss National Science Foundation (SNSF)
Ambizione project "Antarctic precipitation, snow accumulation processes, and ice-ocean interactions"
BUDGET: about CHF 10,000,000
SWISS CONTRIBUTION: CHF 500,000
PROJECT PERIOD: 2012–2016
PARTNERSHIP: Alfred Wegener Institute for Polar and Marine Research (Germany), Australian Antarctic Division, United States Antarctic Program, Woods Hole Oceanographic Institution (United States), University of Colorado, Boulder (United States), University of Tasmania (Australia) , Le Laboratoire de Glaciologie et Géophysique de l'Environnement, CNRS / Université Joseph Fourier (France), British Antarctic Survey (United Kingdom)



Antarctic sea ice; in the back an iceberg, a fracture of a glacier; in front the dazzling white snow cover with greenish sea ice underneath.
© Martin Schneebeli



© K. Gavahan

KATHERINE LEONARD
Ph.D, Laboratory of Cryospheric Sciences (CRYOS), EPF Lausanne, WSL Institute for Snow and Avalanche Research (SLF), Davos, Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder (United States)



King Sejong, Korean Antarctic research station. © Martin Vollmer

FROM THE ARCTIC TO THE ANTARCTIC ON THE TRAIL OF GREENHOUSE GASES

Swiss researchers are on the trail of greenhouse gases from the Arctic to the Antarctic, focusing on hydrocarbons with chlorine, fluorine, or bromine. These compounds are mainly used for cooling, for manufacturing foam materials, in fire extinguishers, or as solvents. They cause the hole in the Antarctic ozone layer and contribute to global warming.

Every year, a total of about 1 million tonnes of greenhouse gases enter the atmosphere, the equivalent to roughly 25,000 full train carriages. The atmospheric lifetime (residence time) varies from gas to gas ranging from one year up to 50,000 years. These gases include chlorofluorocarbons, hydrochlorofluorocarbons, halons (bromine compounds), fluorocarbons, and perfluorocarbons. However, they are not equally distributed in the Earth's atmosphere. The concentrations of these gases are far higher in the northern hemisphere, because this is where their largest sources are found. As the gases from our latitude only reach the southern hemisphere or Antarctica one to two years later, there is a clear north-south divide in terms of concentration.

In the Arctic, the Norwegian Institute for Air Research NILU measures gases at the Zeppelin measuring station (Ny Ålesund) in Spitzbergen. The Swiss Federal Laboratories for Materials Science and Technology (Empa) built a special measuring device for this purpose. The station is one of eight measuring points worldwide as part of the international Advanced Global Atmospheric Gases Experiment or AGAGE project in which Empa and the NILU are working together closely. This includes a detailed comparison of how measurements are carried out at all stations to ensure consistent results. In the Antarctic, Empa works with the Korea Polar Research Institute (KOPRI) at the King Sejong station on the South Shetland Islands. Instead of measuring gases on-site, air samples have been taken every week since 2007. The bottled samples are later measured at Empa.

Empa's results help global emissions and the distribution of gases to be characterised and quantified.

These measurements can be used for independent verification of international agreements such as the Montreal Protocol or the Kyoto Protocol. For example, the measured decrease in chlorofluorocarbons and hydrochlorofluorocarbons in the atmosphere directly confirms the success of the Montreal Protocol. The measurements also support news that the hole in the Antarctic ozone layer has not expanded further in recent years and is likely to repair itself over the next few decades.

At the same time, the sharp increase in fluorocarbons and perfluorocarbons highlights problems in implementing the Kyoto Protocol, that sets binding targets for greenhouse gas emissions in the industrialised countries. New man-made greenhouse gases are constantly being discovered. These include modern fluorinated inhalation anaesthetics which are used for operations. They accumulate in the atmosphere and traces can be found in the Antarctic.

Empa also measures the halogenated trace gases at the alpine Jungfraujoch station, 3,580 metres above the sea, to calculate Switzerland's emissions among other things. This requires very precise measurements and elaborate computer simulations which describe the spread in the atmosphere. Results from polar and other stations are also incorporated into these calculations. Swiss emission data verify the figures declared by industry and the authorities based on consumption and emission estimates.

KEY FIGURES

COUNTRY/REGION: Arctic, Antarctic
PROJECT: "Global atmospheric distribution and emissions of halogenated trace gases using measurements in polar and other remote areas"
PROJECT START: 2007
PARTNERSHIP: Korea Polar Research Institute (KOPRI), Norwegian Institute for Air Research (NILU), Advanced Global Atmospheric Gases Experiment (AGAGE)



King Sejong, Korean Antarctic research station. © Martin Vollmer



MARTIN K. VOLLMER
Research associate, Laboratory for Air Pollution/Environmental Technology, Empa



STEFAN REIMANN
Head of group for climate gases, Laboratory for Air Pollution/ Environmental Technology, Empa



LUKAS EMMENEGGER
Head of Laboratory for Air Pollution/ Environmental Technology, Empa



EPICA science camp at Dome C, Antarctica. The actual drilling takes place in the large tent on the right. The container on the left accommodates the ice core processing line. © EPICA

A WINDOW TO PAST CLIMATE CHANGE AND A BENCHMARK FOR THE FUTURE

Ice core research is a relatively young field that started in 1966 with the first successful deep ice core drilling in Greenland. Only two years later, the first deep ice core drilling was completed in Antarctica at Byrd Station, and samples from this ice core still exist at the University of Bern. Since then ice core science has redefined our understanding of the climate system and its variability.

The unique role of ice cores in climate science stems from the fact that they not only provide information on past temperatures in very high resolution but also on past atmospheric composition. In particular, small air bubbles in the ice represent the only existing direct archive of the past atmosphere and allow us to reconstruct the concentration of three greenhouse gases – CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide) – back in time. In fact, everything we know about these greenhouse gases prior to direct atmospheric measurements stems from ice core research, and a large part of these measurements were taken at the Division for Climate and Environmental Physics (CEP), founded by Hans Oeschger at the Physics Institute of the University of Bern.

Since the 1960s several deep ice cores have been drilled in Greenland and Antarctica by international consortia with Swiss participation. The most important outcome of the Greenland records was the finding of very rapid warming events during the last ice age (10–15°C in Greenland in only a few decades), which are also imprinted in rapid increases in methane concentration. Another important result of recent ice core research was the discovery that the last interglacial was at least 4°C warmer in Greenland than it is now.

The most prominent example of Antarctic ice core research is the European Project for Ice Coring in Antarctica (EPICA), which was carried out by 10 European nations including Switzerland and which was awarded the EU Descartes Prize for Transna-

tional Collaboration in 2007. EPICA drilled two deep ice cores on the East Antarctic Plateau, one in Dronning Maud Land in the Atlantic sector, which provided unique information on the climate coupling of the northern and southern hemispheres, and one at Dome C in the Indian Ocean sector. The latter provided the longest ice core record ever, covering the last 800,000 years. The greenhouse gas studies on this core, jointly carried out by CEP and colleagues in Grenoble, France, showed that the pre-industrial concentration of CO_2 was always at least 25% lower than current levels, which have been elevated by fossil fuel burning and deforestation.

In recent years the studies at CEP have moved forward with investigations into the isotopic composition of greenhouse gases, providing information on sources and exchange processes that control greenhouse gas concentrations. Moreover, CEP analysed changes in aerosol chemical tracers in high resolution, which provide information on environmental conditions (sea ice extent, atmospheric circulation, aridity in desert areas) far away from the actual drill site. Such ice core results also serve as benchmarks for climate and biogeochemical models used at CEP and lead to a better representation of climate processes in these models and thus more robust predictions of the future.

Much more can be learned from polar ice cores, and the international ice core community has exciting plans, with Swiss climate scientists playing a leading role in their implementation. The most important goal is an Antarctic ice core covering the last 1.5 million years and, thus, the change from studying a world where ice ages and warm periods alternated every 40,000 years to the world of the last 800,000 years, when warm ages appeared only every 100,000 years.

Major target areas for such an "Oldest Ice" ice core drilling have been identified to carry out geophysical reconnaissance studies before the drilling can commence at the end of this decade. Such a core should cast new light on fundamental questions regarding the functioning of the Earth system and its dynamic response to perturbations in the past. This is of immediate relevance to the possible responses of the Earth system to the ongoing perturbation produced by humans.

KEY FIGURES

COUNTRY/REGION: Greenland, Antarctica
VARIOUS PROJECTS, INCLUDING:
"European Project for Ice Coring in Antarctica" (EPICA)
BUDGET: ca. EUR 35,000,000
SWISS CONTRIBUTION: CHF 3,300,000
PROJECT PERIOD: 1995–2008
PARTNERSHIP: Université Libre de Bruxelles (Belgium), Københavns Universitet (Denmark), LGGE Grenoble/LSCE Saclay/Institut Polaire Paul Emile Victor (France), Alfred Wegener Institute for Polar and Marine Research (Germany), ENEA-Progetto Antardide/ Università degli Studi di Milano Bicocca (Italy), Utrecht Universiteit (Netherlands), Norsk Polarinstitutt (Norway), Stockholm Universitet (Sweden), British Antarctic Survey (UK)



Drill head of the EPICA drill used at Dome C (Antarctic) containing a 10 cm diameter ice core
© Jakob Schwander, University of Bern



HUBERTUS FISCHER
Professor, Climate and Environmental Physics, Physics Institute, University of Bern, president of the Swiss Committee for Polar and High Altitude Research, Swiss Academies of Arts and Sciences



THOMAS STOCKER
Professor, Climate and Environmental Physics, Physics Institute, University of Bern, co-chair of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report



Retrieval of a box corer on board the French research vessel Marion Dufresene south of Kerguelen Island, Indian sector of the Southern Ocean. © Alain Mazaud, CEA, Gif-sur-Yvette F

INVESTIGATING PAST CHANGES IN OCEAN CIRCULATION AND GLOBAL CLIMATE – A KEY TO BETTER PREDICTING FUTURE CLIMATE CHANGE

The Swiss paleoceanography community uses climate archives to reconstruct temporal changes in ocean circulation and to investigate its interaction with the climate system on timescales ranging from years to millions of years. The goal is to improve understanding of the climate system and ocean circulation in order to better predict future climate change.

Air bubbles trapped in Antarctic ice reveal that atmospheric carbon dioxide (CO_2) concentrations have oscillated cyclically during the past 800,000 years, with CO_2 concentrations approximately 30% lower during ice ages (see page 18). Because more than 90% of the combined oceanic, atmospheric, and terrestrial carbon resides in the deep ocean, it seems likely that changes in the marine carbon cycle have played an instrumental role in driving past variations of atmospheric CO_2. This in turn has amplified climate fluctuations over the last million years.

While multiple, synergistic processes may have operated to reduce atmospheric CO_2 during glacial periods, the data indicates that the amount of water and carbon exchanged between the deep ocean and the atmosphere in particular was reduced. Dense subsurface water masses reach the surface in the Southern Ocean before sinking back to the ocean interior in a process called convection, providing a communication channel between the voluminous deep ocean and the atmosphere. Put another way, the Southern Ocean is a large window by which the atmosphere connects to the ocean interior below.

Swiss researchers from the Federal Institute of Technology Zurich (ETHZ) and the University of Bern are addressing the Southern Ocean window (see also page 26) and many other important polar oceanographic processes. They focus on reconstructing

past changes in nutrient supply to marine ecosystems, the availability of oxygen in the ocean interior, and feedbacks these processes have on climate variability through trace gas emissions. For this purpose they use a combination of observations based on marine and terrestrial sediments and climate models of various complexities.

Ocean sediment records suggest that as the world transitioned into ice ages less carbon was exported overall from the surface ecosystem to sediments of the polar oceans, coinciding with declining CO_2 concentrations. The areas affected include the subarctic Pacific and its marginal seas. During past ice ages, increased sea ice cover and less vigorous convection in the Antarctic zone of the Southern Ocean contributed to keeping gases trapped in the ocean interior. Yet the drier, dustier conditions on land supplied much-needed iron to phytoplankton in the sub-Antarctic part of the Southern Ocean (located north of the Antarctic polar front), transferring carbon dioxide from the atmosphere into the deep ocean. The combination of these two processes served to remove carbon from the atmosphere, maintaining the planet in a cold, dry climate state.

What happened when the world transitioned into a warm, interglacial period is less certain. So far, research shows that the upward supply of nutrients to the surface, a process termed upwelling, increased in the Southern Ocean as ice ages waned, correlating with a rapid rise in CO_2. As the Southern Hemisphere warmed, the prevailing westerly winds shifted southward. The pole-ward displacement of the westerly wind belt would have impacted on ocean circulation, possibly allowing previously sequestered nutrients and carbon to be transported to the surface, fuelling productivity. However, climate models suggest that this process alone can only explain a negligible fraction of the CO_2 increase characterising the end of the ice age. Rather, changes in deep ocean convection in the vicinity of the Antarctic margin, possibly related to the retreat of sea ice, played a dominant role in transferring carbon from the ocean interior to the atmosphere.

Lake sediment archives retrieved from remote sub-Antarctic islands, located within the main westerly wind belt, provide a unique opportunity to investigate past changes in wind patterns. They allow the shift of the westerly wind belt to be tracked and geographically restricted. Changes in salinity, whose traces can be detected in freshwater diatoms, provide important information on how the speed and direction of the wind have changed over time.

KEY FIGURES

COUNTRY/REGION: Antarctic
VARIOUS PROJECTS, INCLUDING:
Swiss National Science Foundation (SNSF)
"SeaO2 – Past changes in Southern Ocean overturning circulation – implications for the partitioning of carbon and oxygen between the ocean and the atmosphere"
"MICLIM – High resolution reconstructions of climate variability in the sub-Antarctic during the last two millennia"
BUDGET: about CHF 2,000,000
SWISS CONTRIBUTION: about CHF 2'000'000
PROJECT PERIOD: 2012–2016
PARTNERSHIP: Princeton University (United States), McGill University (Canada), British Antarctic Survey (UK), LSCE Paris (France), University of Ghent (Belgium)



The Marion Dufresne research vessel at anchor in the Crozet Archipelago in the southern Indian Ocean. © Alain Mazaud, CEA, Gif-sur-Yvette F

SAMUEL JACCARD
Professor, Oeschger Centre for Climate Change Research and Institute of Geological Sciences, University of Bern

NICOLAS GRUBER
Professor, Environmental Physics, Institute for Biogeochemistry and Pollutant Dynamics, ETH Zurich

KRYSTYNA SAUNDERS
Ph.D, Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern

FORTUNAT JOOS
Professor, Oeschger Centre for Climate Change Research and Physics Institute, University of Bern



Uruguayan research station Artigas on King George Island with Swiss participation in an expedition in January 2014. © Christian Schlüchter

THE HISTORY OF THE ANTARCTIC ICE SHEET IS IMPORTANT FOR THE FUTURE

Antarctica is a unique natural laboratory for the study of geological processes at high latitudes. Because the size and flow of the enormous Antarctic ice sheet depend on the sea level, ocean circulation and global climate, Antarctica is an archive of climate change data covering the past 10 million years and providing information on conditions during the ice ages and interglacial periods. The establishment of an ice age chronology is a major contribution by Antarctic science to understanding the evolution of the global climate.

Understanding the Antarctic ice sheet requires maps. The mapping of the Antarctic ice sheet is based on aerial photographs complemented by extensive and detailed testing of soil composition in ice-free regions known as Antarctic oases. These include, for example, the dry valleys in Northern Victoria Land which were once covered by glaciers and are now free of snow and ice because they receive almost no precipitation, the Antarctic Peninsula which juts out north of the Antarctic Circle opposite South America, and the Transantarctic Mountains which stretch across the length of Antarctica and whose peaks are to some extent also free of ice. Extensive mapping of glacial moraine systems and alpine glacier systems in Antarctica has been conducted in these key areas.

The maximum ice thickness of glacier ice – *i.e.,* in the Transantarctic Mountains – over millions of years is currently being investigated by the Institute of Geological Sciences of the University of Bern in collaboration with polar research institutes in Italy, New Zealand, the United States, and Uruguay. To this end, "trim lines" are being mapped and recorded. Trim lines are markings that can be used to determine the highest level of the ice during a glaciation event, as glaciers left such lines on both sides of a valley. Trim lines are clearly visible because the composition and colour of the rock surface differs above and below the line. The maps created in this way show variations in the Antarctic mass over millions of years.

Understanding the origins and paleoglacial history of the Antarctic ice sheet also requires quantitative age dating. Surface exposure dating is therefore included in field studies to determine the age of previous glacier movements. This method is used to determine how long the rock surface was exposed to cosmic radiation after the glacier receded and the rock surface was exposed.

Specifically, the method is used to determine the concentration in the rock surface of cosmogenic radioactive nuclides, which are produced by nuclear reactions between cosmic radiation and matter. The energy levels in these particles are so high that they can penetrate the topmost few metres of rock on the Earth's surface and thereby produce new elements and isotopes which are otherwise very rare in rocks. The older the surface and the longer it was exposed to cosmic radiation, the higher the concentration of cosmogenic nuclides in the rock.

Cosmogenic nuclides in Antarctic rock samples are analysed in the Accelerator Mass Spectrometry Laboratory and in the Noble Gas Laboratory of the Swiss Federal Institute of Technology in Zurich (ETHZ) in close collaboration with the Institute of Geological Sciences of the University of Bern as well as with other researchers in Switzerland and abroad. These studies have revealed that parts of the ice-free areas of Antarctica are more than 10 million years old and that the moraine landscape was formed by the multiphase flow of cold-based (temperature of the ice below freezing) glaciers. Surface exposure dating by means of radioactive nuclides is the key – and only available method – to understanding the evolution of the Antarctic ice sheet over the past several million years. Other methods can only be used for shorter time periods.

KEY FIGURES

COUNTRY/REGION: Antarctica
VARIOUS PROJECTS, INCLUDING:
Swiss National Science Foundation (SNSF)
"Glacial chronologies in high and mid latitudes: geological field and cosmogenic multi nuclide analysis"
BUDGET: about CHF 450,000
SWISS CONTRIBUTION: about CHF 300,000
PROJECT START: 2008
PARTNERSHIP: Columbia University, New York (United States), University of Maine, Orono (United States), Università di Pisa, Dipartimento di Scienza de la Terra, Pisa (Italy), Instituto Antarctico Urugayo, Montevideo (Uruguay)


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RAINER WIELER
Professor of isotope geochemistry, ETH Zurich



SUSAN IVY-OCHS
Ph.D in particle/ion beam physics, ETH Zurich



CHRISTIAN SCHLÜCHTER
Professor, Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern



Driftwood washed up on an Icelandic shore.
© Willy Tegel, University of Freiburg (Germany)

ARCTIC DRIFTWOOD: AN ARCHIVE FOR CHANGES IN CLIMATE AND ENVIRONMENTAL CONDITIONS

Tree rings are a unique environmental archive. They store information on growing conditions in a certain growing season. Ring analysis of trees in extreme locations allows scientists to reconstruct past climate conditions. The rings, which correspond to an annual growth period, allow accurate dating of the logs. It is therefore possible to date driftwood, dead wood, extinct tree species, and wood from historical buildings, paintings, and archaeological finds back to a specific year. This occurs by comparing it with samples from already dated growth-rings and reference tree-ring patterns (chronologies).

Arctic driftwood comes from the forests of Siberia and North America. Rivers transport the driftwood to the Arctic Ocean. Enclosed in ice, it is transported by the currents and deposited on the unfrozen coastlines of the Arctic islands (*i.e.,* Greenland, Svalbard, or Iceland). The wood is an exceptional proxy at the interface of marine and terrestrial environments. In the best case, scientists can identify changes in the currents in the Arctic Ocean and the expansion of the ice as well as the exact age and place of origin of the driftwood.

The dendroecology research group at the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL) in Birmensdorf is conducting research on this driftwood. Analyses of the wood structure and growth periods (wood anatomy and dendrochronology) show that the driftwood is mainly from pine (39%), larch (26%), and spruce trees (18%), which dominate forests of the boreal zone, the most northerly vegetation zone in the northern hemisphere.

The pines have been identified as Scots pines (Pinus sylvestris), which conclusively places their origin on the Eurasian continent. Some 90% of the Scots pines are from the catchment of the Yenisei River in Central Siberia, where pine forests dominate. This

was indicated by measuring the growth rings and comparing them with growth curves of the same tree species (reference chronologies) on the Yenisei River. The catchment of the Yenisei, one of the longest rivers in the world, was the centre of the Siberian timber and timber rafting industry. A particularly large quantity of timber was felled in the region from the 1920s to the mid-1970s.

According to the analyses of the driftwood, more than half of the pines had been felled since the driftwood deposited on the beaches had been cut, unlike trees that die naturally, which have root stock. The pine can therefore be considered waste material from the Siberian lumbar industry, which had already begun in the 19th century. Industrialisation boosted demand, and transport and export rose accordingly. The most usual method was to raft the logs on the great rivers, which at the beginning resulted in loss of up to 50% of the logs. By the end of the 1970s, less than 1% of the timber was lost. Since the mid-1980s, timber rafting has all but ceased.

A better understanding of past processes helps scientists to better predict future reactions of the highly sensitive Arctic ecosystem to changing climatic conditions. Therefore, the driftwood research at WSL has three long-term goals:

First, to build up the world's biggest data set of Arctic driftwood samples, including identification of the species based on anatomical features (structure and growth). Scientists all over the world will have online access to the data, which will be added to the International Tree-Ring Data Bank.

Second, the samples will be dated to a specific year and their origin determined by comparative statistical analysis with tree ring chronologies from the boreal forests of Eurasia and North America.

Third, the structure of the driftwood, which varies over time and from region to region, makes it possible to reconstruct long-term fluctuations in the currents and the pack-ice of the Arctic ocean.

A better understanding of past processes helps scientists to better predict future reactions of the highly sensitive Arctic ecosystem to changing climatic conditions.

KEY FIGURES

COUNTRY/REGION: Arctic, Greenland, Siberia
PROJECT: Arctic Driftwood Project
BUDGET: CHF 300,000
SWISS CONTRIBUTION: CHF 200,000
PROJECT PERIOD: 2012–2015
PARTNERSHIP: Institute for Forest Sciences IWW, University of Freiburg, Freiburg (Germany), Sukachev Institute of Forest SB RAS, Krasnoyarsk (Russia), Iceland Forest Service, Reykjavik (Iceland), Johannes Gutenberg University, Mainz (Germany), Institute of Plant and Animal Ecology UD RAS, Yekaterinburg (Russia), North-Eastern Federal University, Yakutsk (Russia), Stolby National Wildlife Nature Reserve, Krasnoyarsk (Russia), Siberian Federal University, Krasnoyarsk (Russia), Department of Plant Pathology, University of Minnesota, St Paul (United States)



Taking driftwood samples with a chain saw in eastern Greenland.
© Willy Tegel, University of Freiburg (Germany)



LENA HELLMANN
Ph.D student with the dendroecology research group at the Swiss Federal Research Institute (WSL), Birmensdorf

ULF BÜNTGEN
Adj. Professor, team leader of the dendroecology research group at the Swiss Federal Research Institute (WSL), Birmensdorf



A rosette frame holding instruments to measure temperature, salt content, pressure, etc. and water sample bottles is hoisted onto the Southern Surveyor from the Southern Ocean.
© Bethany Ellis, July 2013

THE POLAR OCEAN WINDOW IN THE SPOTLIGHT

The polar oceans – and especially the vast expanses of the Southern Ocean – play a disproportionally large role in controlling the global carbon and nutrient cycles, the redistribution of heat, and primary biological production (production of biomass by plants, algae and bacteria by means of sunlight and chemical energy). The polar oceans are also likely to be those most severely impacted by climate change and acidification.

The reason why polar oceans are so important is that they act as the "window" to the deep ocean. Polar oceans are the only place where water is exchanged between the warm surface layers, where carbon and nutrients are depleted, and the cold deep ocean, where most of the ocean's carbon and nutrients are stored. This polar ocean window not only provides an explanation for variations in atmospheric carbon dioxide (CO_2) concentrations during ice ages and interglacial periods but also for how man-made CO_2 emissions and excess heat enter the ocean's interior.

The polar window is at the heart of Swiss research into cycles of carbon and other important elements, *i.e.,* biogeochemistry. Swiss researchers – particulary at the Federal Institute of Technology Zurich (ETHZ) and the University of Bern – have made a significant contribution to a better understanding of the polar window. Thanks to their observations and computer models, it is now possible to determine how CO_2 and heat are absorbed by the polar oceans and how marine biology influences the polar window of the Southern Ocean.

They developed high-resolution computer models to simulate the role of winds, eddies, and changes in the freshwater balance on primary biological production of the ocean and how it affects the net air-sea CO_2 balance. They also used computer models and observations to determine levels of ocean acidification in the past and present while making predictions for the future. Research is also being done into how much more CO_2 emissions the planet can tolerate without the polar oceans

becoming too acidic and climate targets still being attainable.

Thanks to new data on oceanic carbon content, the intake and storage of anthropogenic CO_2 in the polar oceans can be estimated. The findings show that the Southern Ocean south of 30°S accounts for nearly half the global ocean intake of anthropogenic CO_2, despite this region covering only 30% of the global ocean's surface. During the past 10 years the intake of CO_2 appears to have increased more than would have been expected based on the increased levels of CO_2 in the atmosphere.

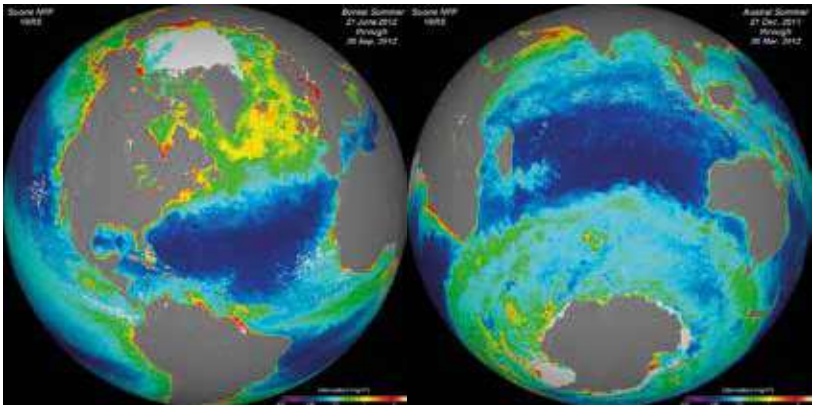
A reason for this could be that the southward shift of the strong westerly wind belt has caused an increase in the ocean circulation of the Southern Ocean. The growing numbers of observations of sea-surface CO_2 also now enable relating carbon changes in the ocean interior to CO_2 fluxes across the air-sea interface. Recent analyses of these observations suggest that CO_2 intake has risen particularly since the year 2000.

While beneficial for the climate, increased intake of CO_2 by the polar oceans also lowers their pH level and their saturation level with regard to calcium carbonate ($CaCO_3$). The process is commonly referred to as ocean acidification. Recent research shows that undersaturation relative to $CaCO_3$ is imminent in the Arctic and will occur within a few decades in the Southern Ocean. Acidification and related undersaturation lead to stress on the marine organisms there and can damage the entire ecosystem.

In contrast, the recent climatic changes in the Antarctic had only a minor effect on primary biological production in the Southern Ocean. This is what analysis of observations and computer models suggests. This contrasts with the Arctic, where the continuing ice retreat has fostered the growth of algae in places where they had not grown before.

KEY FIGURES

COUNTRY/REGION: Arctic/Antarctic
VARIOUS PROJECTS, INCLUDING:
Swiss National Science Foundation (SNSF)
SOGate: "Phytoplankton ecosystem control of the Southern Ocean biogeochemical gate"
Ambizione project: "Anthropogenic carbon and heat intake by the Southern Ocean"
EU framework programme P7
CarboChange, Geocarbon, PAST4FUTURE
BUDGET: about CHF 500,000 per year
SWISS CONTRIBUTION: about CHF 300,000 per year
PROJECT START: 2009
PARTNERSHIP: Princeton University (United States); Alfred Wegener Institute for Polar and Marine Research (Germany), University of East Anglia (UK); University of Bergen (Norway)



Ocean chlorophyll concentrations
The image shows chlorophyll concentrations in the Arctic and Antarctic during the summer months. Blue indicates lower levels; yellow and red indicate higher concentrations.
© NASA/Suomi NPP/Norman Kuring

NICOLAS GRUBER
Professor, Environmental Physics, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich

THOMAS FRÖLICHER
Ph.D, Environmental Physics, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich

FORTUNAT JOOS
Professor, Oeschger Centre for Climate Change Research, University of Bern

SAMUEL JACCARD
Professor, Oeschger Centre for Climate Change Research and Institute of Geological Sciences, University of Bern



Icebergs off northern coast of Antarctic Peninsula.
© KEYSTONE/LAIF/Andre Schumacher/laif

THE BIOLOGY OF THE SOUTHERN OCEAN: UNDERSTANDING ITS BIODIVERSITY AND ECOSYSTEM

Biodiversity at the South Pole is mostly associated with penguins and seals but the real treasures are the microscopic organisms in the water that usually remain invisible to the human eye. These microorganisms are important for climate and biodiversity as well as for reconstructing climate history (paleoenvironmental reconstruction). Researchers at the University of Geneva have made these the focus of their work.

One project deals with phytoplankton, microscopically small algae that drift in the water. Phytoplankton provide the explanation as to why a considerable amount of global carbon emissions is absorbed at the water's surface and ends up in the depths of the ocean. They convert the carbon into organic substances and are also important for the functioning of the ecosystem since they are at the start of the food chain.

The Southern Ocean plays a special role in this regard. Phytoplankton need iron to convert carbon and to grow, but iron is only available in limited quantities in the ocean around the Antarctic. The conversion processes are examined in field studies and through laboratory analyses – in particular the relationship between the presence of iron and phytoplankton. To get the full picture of the impact of the iron deficiency, other microorganisms that are also dependent on iron are included in the studies, for example the interaction between bacteria and zooplankton, which is an important source of food for fish and many other forms of life in the sea. Research at the University of Geneva focuses in particular on the role that sugar (polysaccharides) and organic substances excreted by organisms play in the availability of iron for carbon sequestration.

Thanks to this research, we are now learning about the relationship between the iron cycle and the carbon cycle at the surface of the sea – including its impact on the presence of phytoplankton, biodiversity and the sequestration of the greenhouse gas CO_2 by ocean organisms. The research findings, which have contributed to gaining a better

understanding of the ecosystem of the Southern Ocean and to better assessing its vulnerability to climate change, are important for various international programmes, networks and working groups. The results are being used in the modelling of the ecosystem of the Southern Ocean and its further development. This aspect is all the more important since today such models are the only available tool for making projections about the future.

Another field of research at the University of Geneva is being conducted on foraminifera – single-celled, shell-forming organisms. The research group has developed genetic methods to identify and classify foraminifera and through this has discovered many new genera and subordinate ranks. Hundreds of Antarctic foraminifera have been classified according to standardised criteria into classes and sub-classes. The Scientific Committee on Antarctic Research published the results, to which Switzerland contributed, in the *Biogeographic Atlas of the Southern Ocean* which illustrates the current biogeographic distribution, the Earth's historical development, and the environmental relationships of micro- and macroorganisms living in the Antarctic.

The research on foraminifera also helps to assess the impact of tourism on the Antarctic's ecosystem. Swiss scientists are participating in the international observation of the Antarctic coastline which is visited every year by hundreds of tourist boats. Research is being conducted into the migratory movements of foraminifera between southern Patagonia and the Antarctic Peninsula. The studies show that most Antarctic species are indigenous and that they differ genetically from South American species of the same family. However, some species with no genetic differences were also discovered. Whether these were brought to Antarctica on boats or have migrated by natural means remains an open question.

KEY FIGURES

COUNTRY/REGION: Antarctic/Southern Ocean
PROJECTS: "Novel technologies to reveal the impacts of nutrients limitation in aquatic systems: from biodiversity to biogeochemical cycles".
"Molecular diversity and evolution of Antarctic foraminifera"
BUDGET: CHF 1,600,000 and about USD 5,000,000
SWISS CONTRIBUTION: CHF 1,600,000 and about CHF 500'000
FUNDING: Swiss National Science Foundation (SNFS)
PROJECT PERIOD: 2012–2016 and 1998–2015
PARTNERSHIP: US Antarctic Program (United States), Polish Academy of Science (Poland), British Antarctic Survey (UK), Alfred Wegener Institute for Polar and Marine Research (Germany)



Shallow water Antarctic foraminifera (Globocassidulina sp) from McMurdo Sound.
© Jan Pawlowski



CHRISTEL S. HASSLER
Swiss National Science Foundation Professorship, head of the Marine and Lake Biogeochemistry Working Group, Institute F.-A. Forel, University of Geneva



JAN PAWLOWSKI
Associate Professor, Department of Genetics and Evolution, University of Geneva



Swiss ITEX site in Val Bercla, Mulegns, GR
© Christian Rixen

SWITZERLAND IS TAKING PART IN THE INTERNATIONAL TUNDRA EXPERIMENT ITEX

The International Tundra Experiment ITEX is a scientific network of experiments focusing on the impact of climate change on selected plant species in tundra and alpine vegetation. Currently, research teams at more than 40 circumpolar sites carry out similar, multi-year plant manipulation experiments that allow them to compare annual variation in plant performance with respect to climate conditions.

The ITEX research model combines long-term and short-term experimentation with monitoring and has the elegance and simplicity called for to understand ecosystem response and vulnerability to change. The experiment is designed to examine the effects of temperature change on individual plant species on as broad a geographical base as possible and by limiting technical and equipment requirements.

The level of complexity and sophistication at which researchers participate depends on their interest and the funding available. However, each ITEX site does operate some form of warming experiment. Most sites use open-top chambers to warm the tundra. These passive chambers affect plant growth and phenological development, *i.e.,* the timing of flowering, growth of leaves, etc., in a variety of ways.

Each ITEX study site is expected to collect similar data following established protocols. Collectively the ITEX network can pool its data sets to examine vegetation response at varying levels, for example, across space (from habitats to ecosystems) and over time.

In control plots across all study sites, it was found that changes in vegetation height and the abundance of growth forms were largely consistent with predictions based on warming experiments. Comparisons with other sites indicated that shrubs (particularly deciduous shrubs) increased over time, primarily in sites that were warming rapidly over the study period. But this pattern was only apparent in locations already quite warm. In contrast, vegeta-

tion in the coldest tundra sites was relatively insensitive to climate warming.

Switzerland is taking part in the global data analysis and maintains its own site in the country. It also sends researchers to ITEX sites in other countries, such as Alexandra Fjord in the Canadian Arctic. The Swiss ITEX site is located in Val Bercla, Mulegns, in the Graubunden region of Surses (Oberhalbstein) between Tiefencastel and the Julier pass. It was set up in 1994 and has been maintained by the WSL Institute for Snow and Avalanche Research (SLF) in Davos since 2009.

In this experiment, alpine vegetation is warmed with passive warming chambers (OTCs). The vegetation consists of alpine cushion plants, dwarf willows, grasses, and sedges. Researchers at the SLF investigate changes in the vegetation within warmed and control plots over a period of time. As ongoing climate change is expected to affect alpine vegetation, the SLF plans to continue maintaining the Swiss ITEX site.

KEY FIGURES

COUNTRY/REGION: Switzerland, Arctic
PROJECT: Swiss Tundra Experiment
PROJECT START: 1994
PARTNERSHIP: Universities and institutes particularly from Australia, Denmark, Finland, Germany, Iceland, Japan, Korea, the Netherlands, Norway, Russia, Sweden, the United Kingdom and the United States



ITEX site in Alexandra Fjord in the Canadian Arctic. © Anne Bjorkman



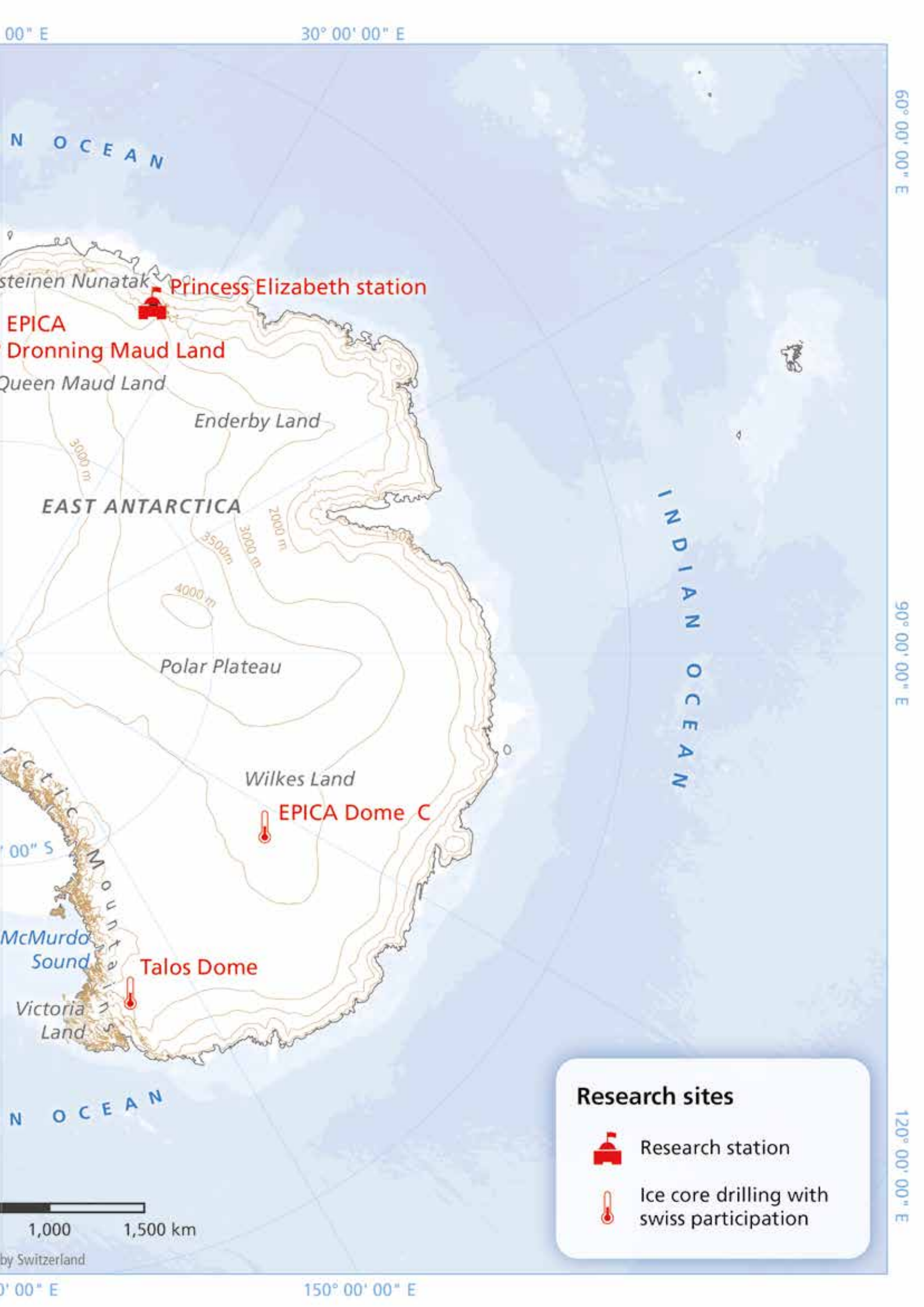
CHRISTIAN RIXEN
Ph.D, WSL Institute for Snow and Avalanche Research (SLF)



ANTARCTICA

Data compiled by: FDFA, STS, CMC-Geoservices

Remarks: The boundaries and names shown, as well as the designations used on this map do not imply official endorsement or acceptance


00" E
30° 00' 00" E
60° 00' 00" E
N O C E A N
steinen Nunatak
Princess Elizabeth station
EPICA
Dronning Maud Land
Queen Maud Land
Enderby Land
3000 m
EAST ANTARCTICA
2000 m
3500m
3000 m
4000 m
Polar Plateau
INDIAN OCEAN
90° 00' 00" E
Wilkes Land
EPICA Dome C
00" S
Mountains
McMurdo Sound
Talos Dome
Victoria Land
N O C E A N
120° 00' 00" E
Research sites
Research station
Ice core drilling with swiss participation
1,000
1,500 km
by Switzerland
0' 00" E
150° 00' 00" E

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Orders:
FDFA Information
Tel.: +41 (0)58 462 31 53
email: publikationen@eda.admin.ch

Specialist contact:
Sectoral Foreign Policies Division
Tel.: +41 (0)58 465 14 26
email: pd-asa@eda.admin.ch

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