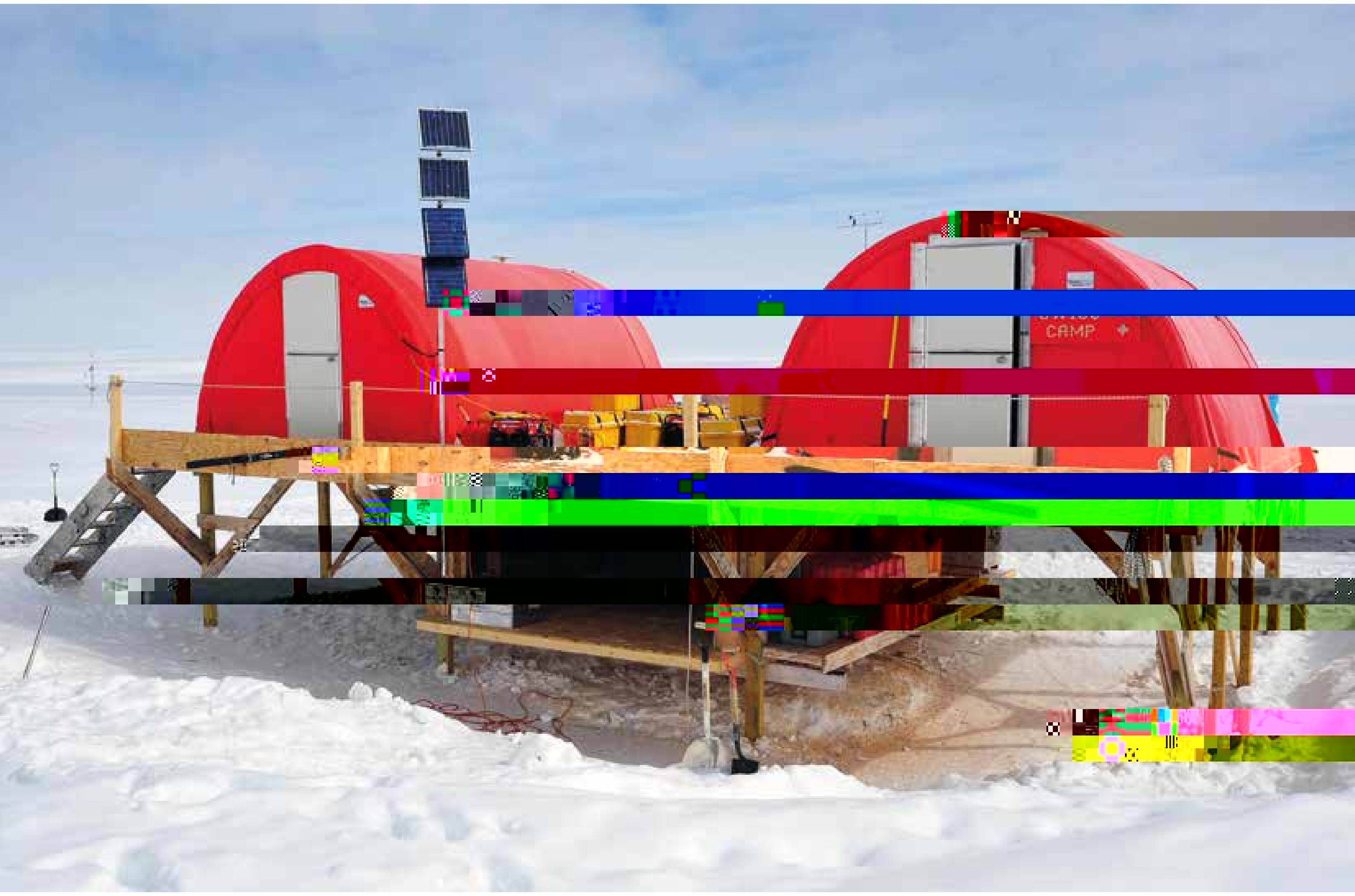
Swiss polar research



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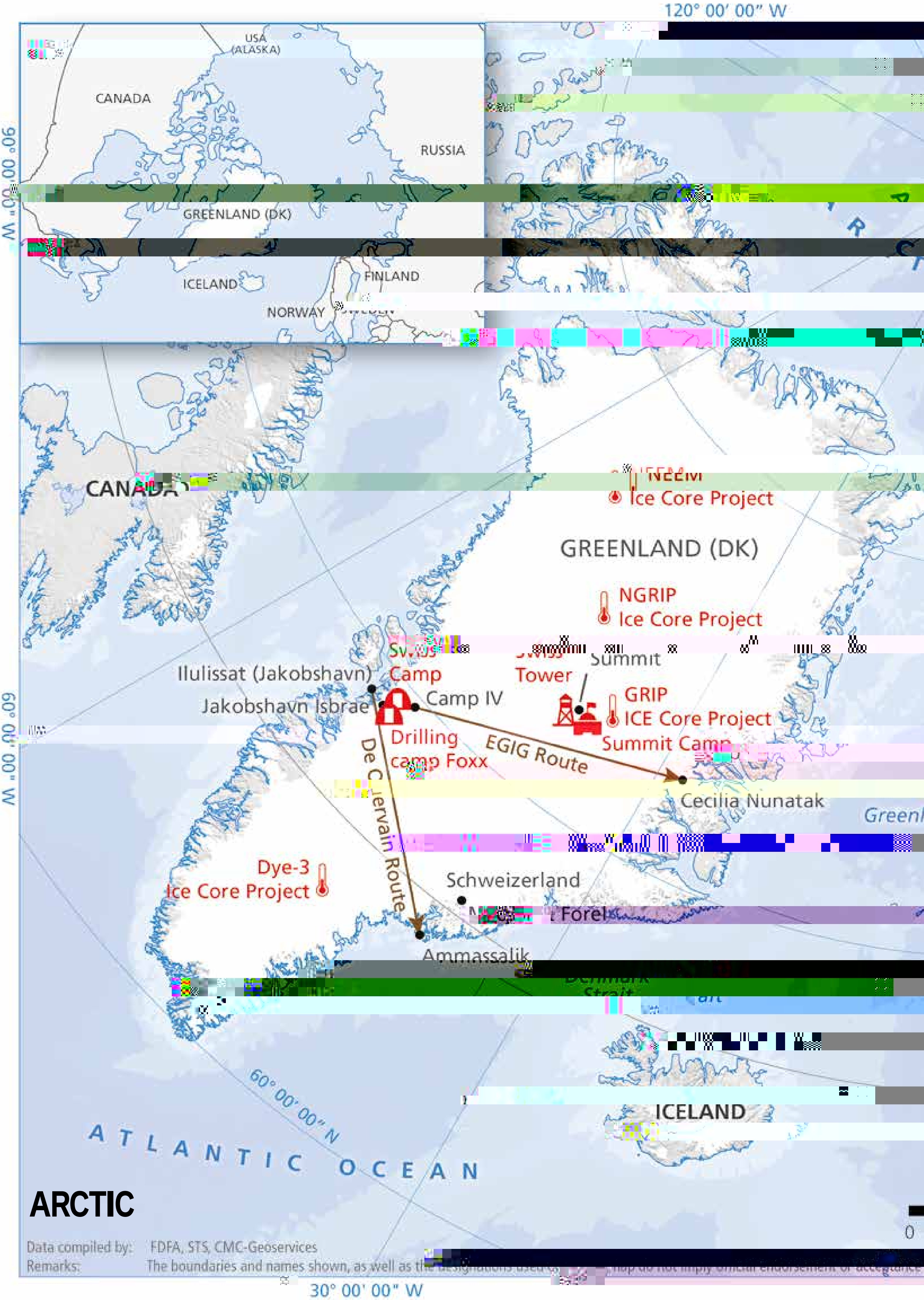
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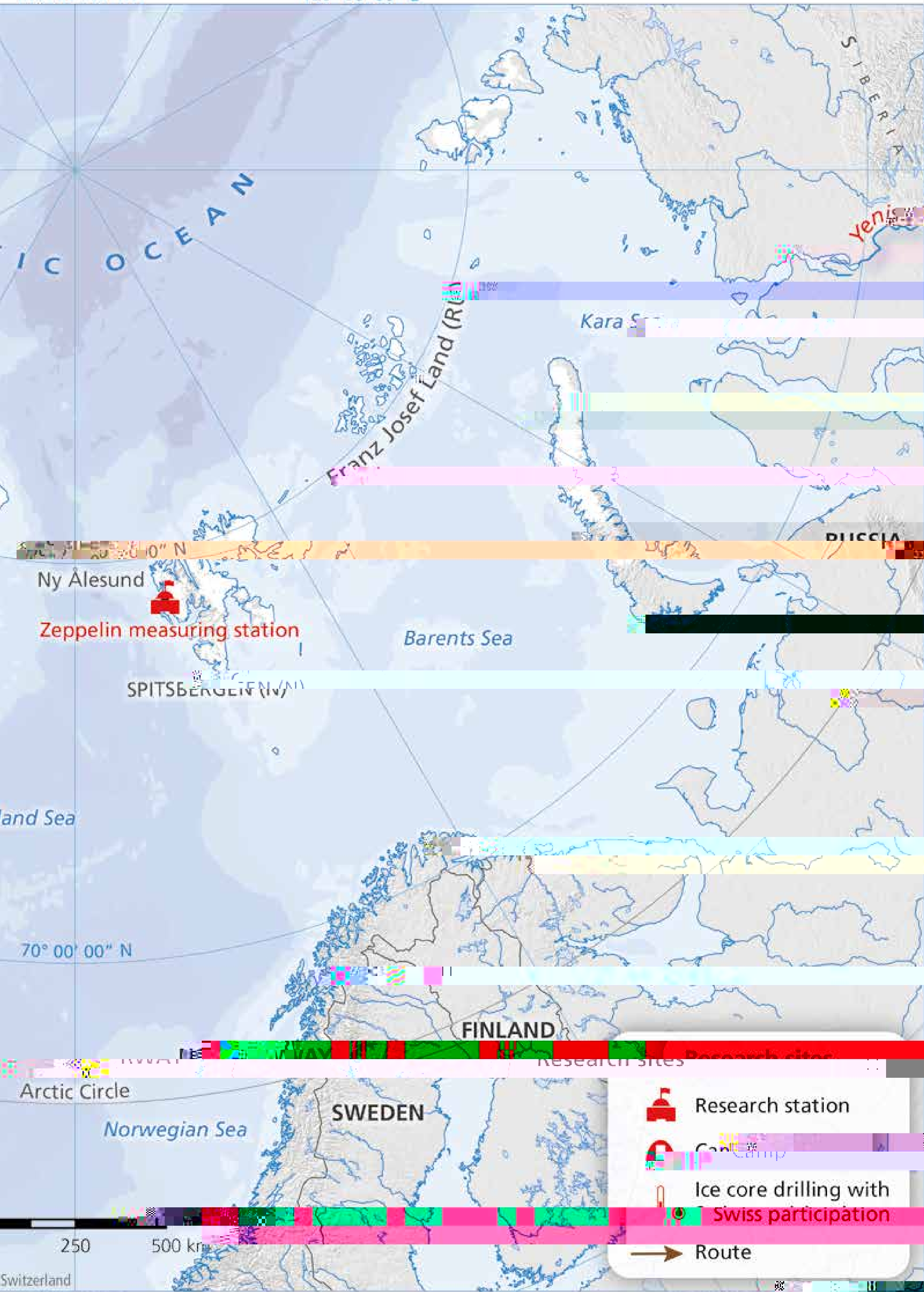

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Camp
Ice core drilling with
Swiss participation
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Switzerland

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 Arctic Council was established in 1996 to balance the interests of the Arctic states and the indigenous peoples of the Arctic region. It coordi-

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, thDe was carrmp was aoseessential part of climatological and glaciological studies.

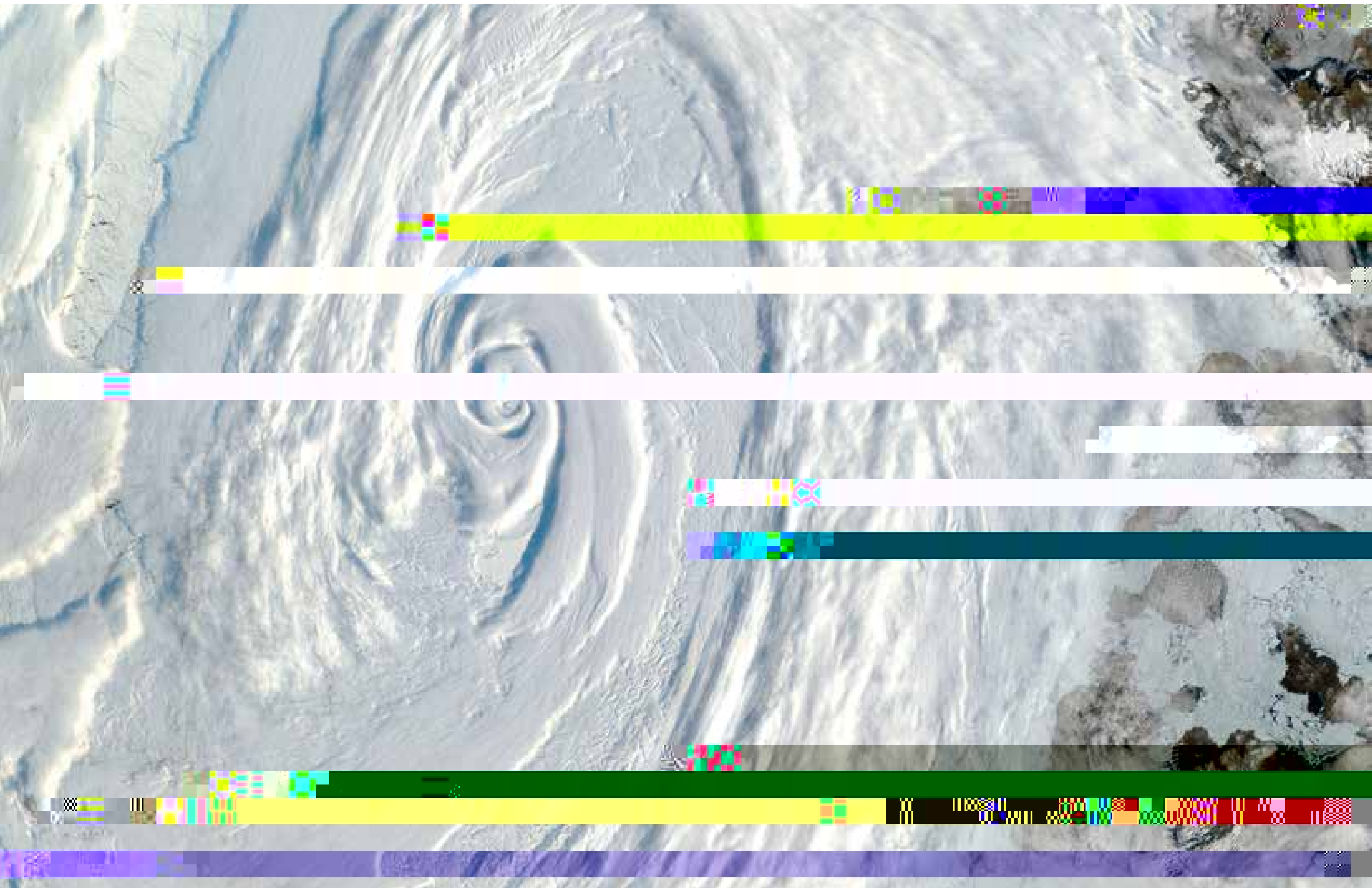
Swiss polar research traditionally focused on polar glaciology and climate. But over recent decades it has greatly expanded its spectrum, and Swiss scientists now also investigate the biology and biogeochemistry in the Southern Ocean or the coupling of climate, permafrost, and vegetation in tundra regions. 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

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 environ-



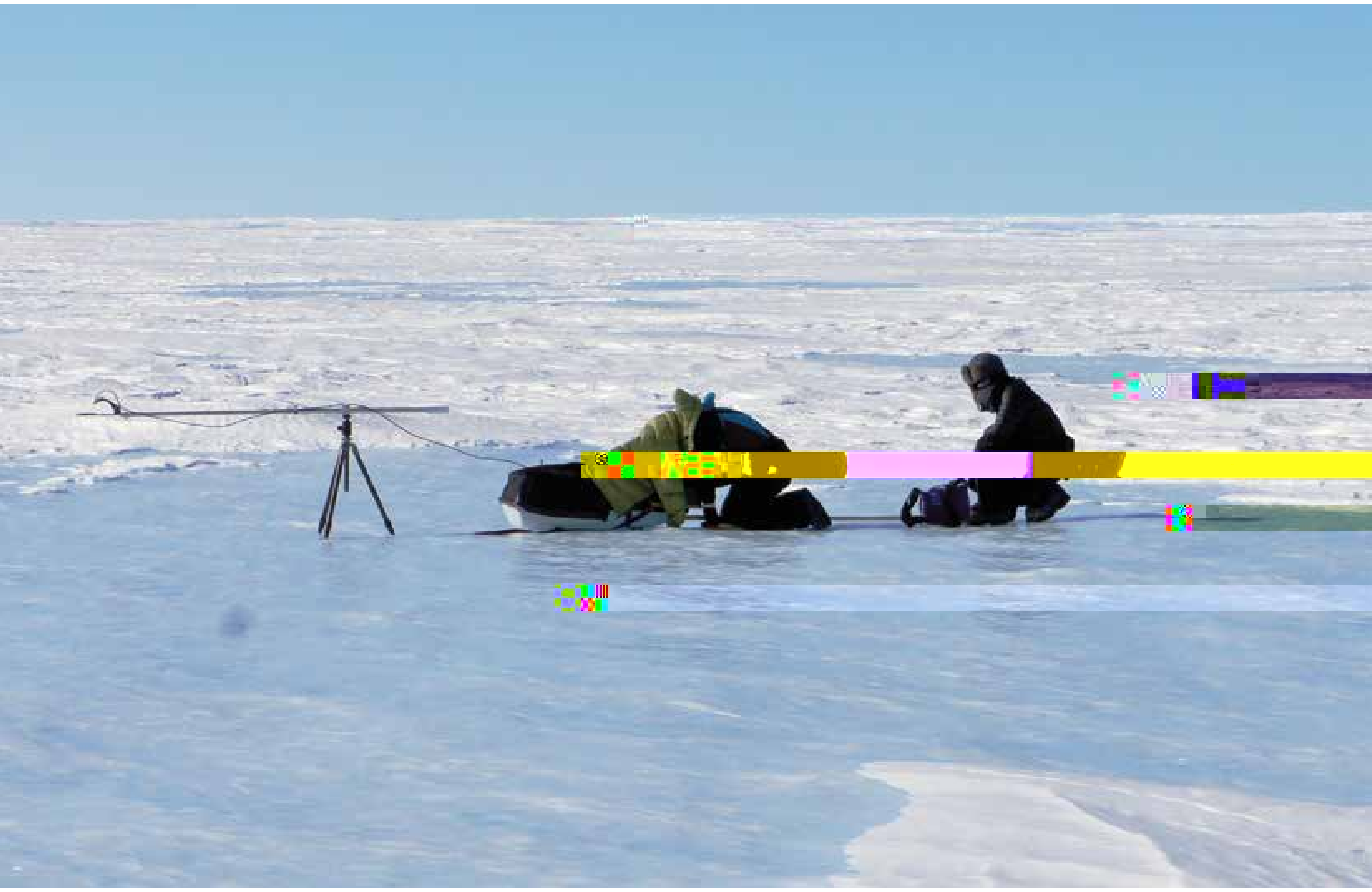
Polar weather and climates are characterised by intense interactions between the ocean, ice, and the atmosphere in a topographically complex environment. A prominent example is the large-scale melting of ice induced by pole-ward excursions of warm air from mid-latitudes, as happened in Greenland during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



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.

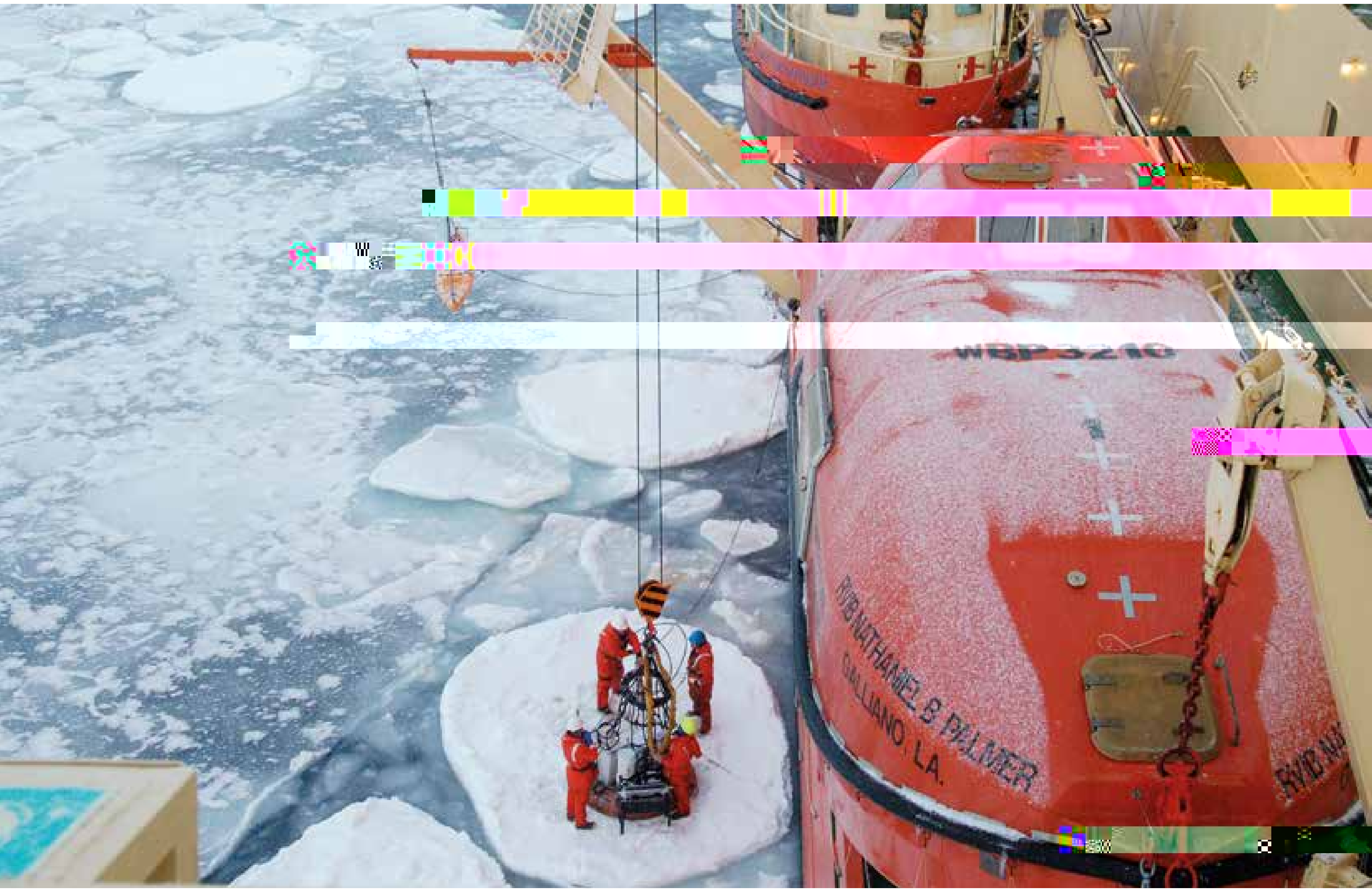
Snow is formed when water vapour and tiny water droplets in the atmosphere crystallise. When it falls to the ground in winter or throughout the year, it forms a snow cover that completely re-crystallises many times – as demonstrated by recent research at the WSL Institute for Snow and Avalanche Research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



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.

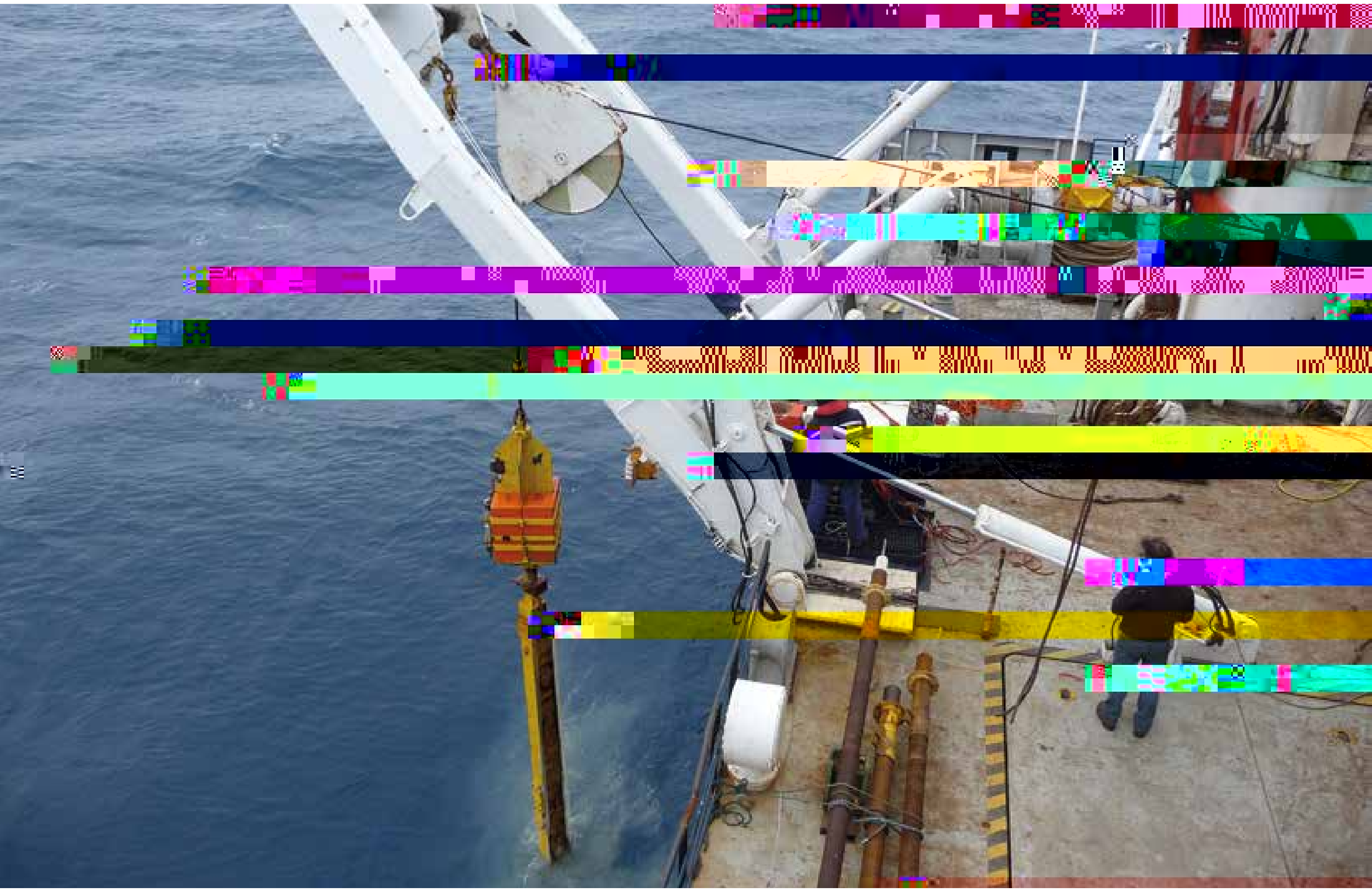
Sea ice typically covers about 14 to 16 million km^2 of the Arctic Ocean in late winter and 17 to 20 million km^2 of the Southern Ocean during the Antarctic winter. These numbers are known only for recent decades, since the development of satellite remote-sensing instruments able to "see" the ice during the dark polar winters. While this record is short, climate models have been trained to properly predict sea ice during this period. They 3.7(b)-11.7(e)-9pis

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

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

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 tional Collaboration in 2007. EPICA drilled two deep ice cores on the East Antarctic Plateau, one in



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
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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.

SAMUEL JACCARD
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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

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.

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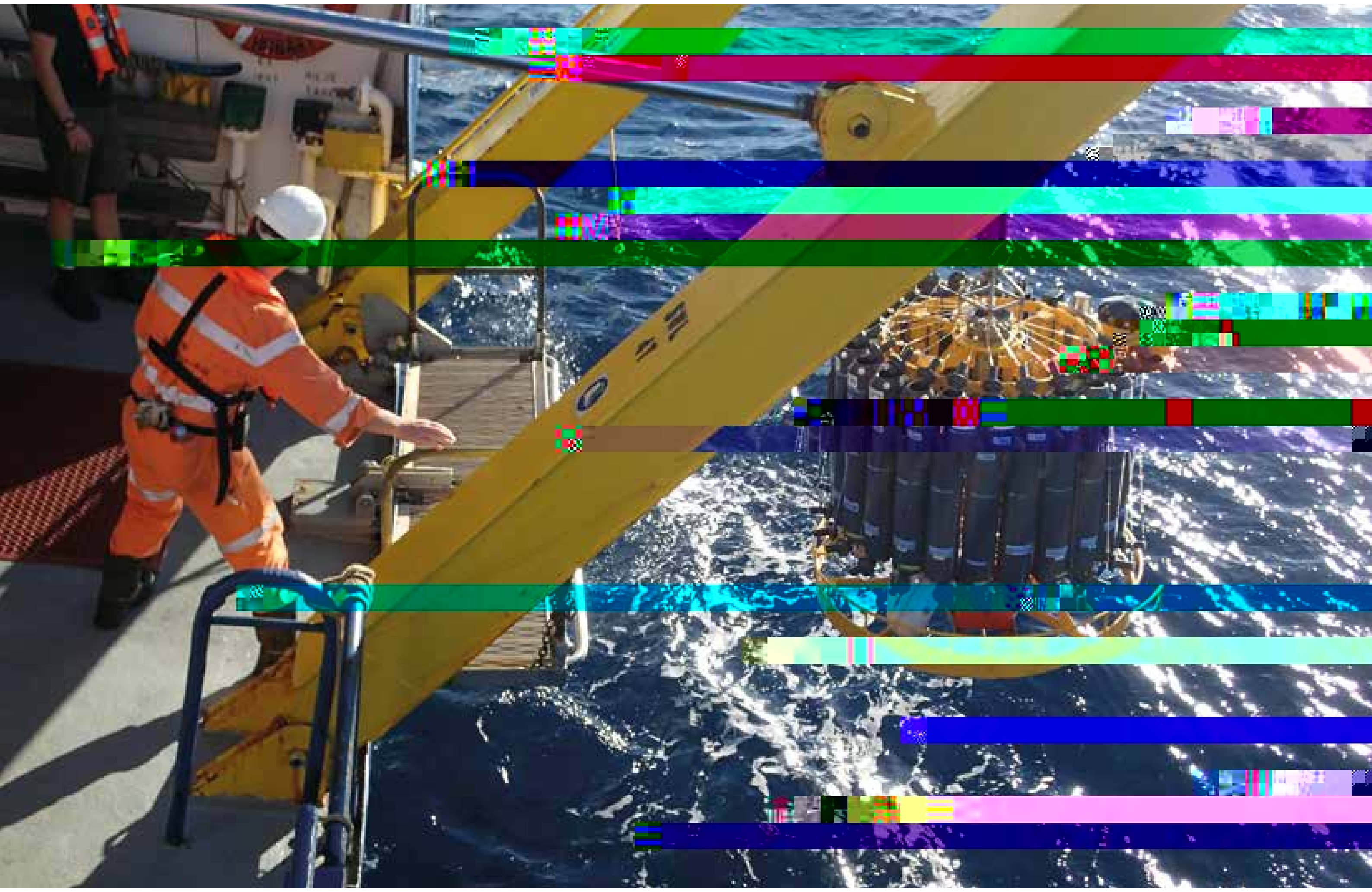
Tree rings are a unique environmental archive. They store information on growing conditions in a certain growing season. Ring analysis of trees in extreme locations allows scientists to reconstruct past climate conditions. The rings, which correspond to an annual growth period, allow accurate dating of 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 prm t73.6(.)0.27 Tw-13.7(s) wod-10.1(d wa2e)-2.9(r u)0.9(n)-1.9, wA bnhan hr u



The polar oceans – and especially the vast expanses of the Southern Ocean – play a disproportionally large role in controlling the global carbon and nubecoming 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 comm2(e s)4.7(h)-4.2(e p4 Tc 0.57.5273 3(i)2.8(m504 Tc 0.537 Tw T426(n)3.3(s)-7.o)-5.1(m

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.

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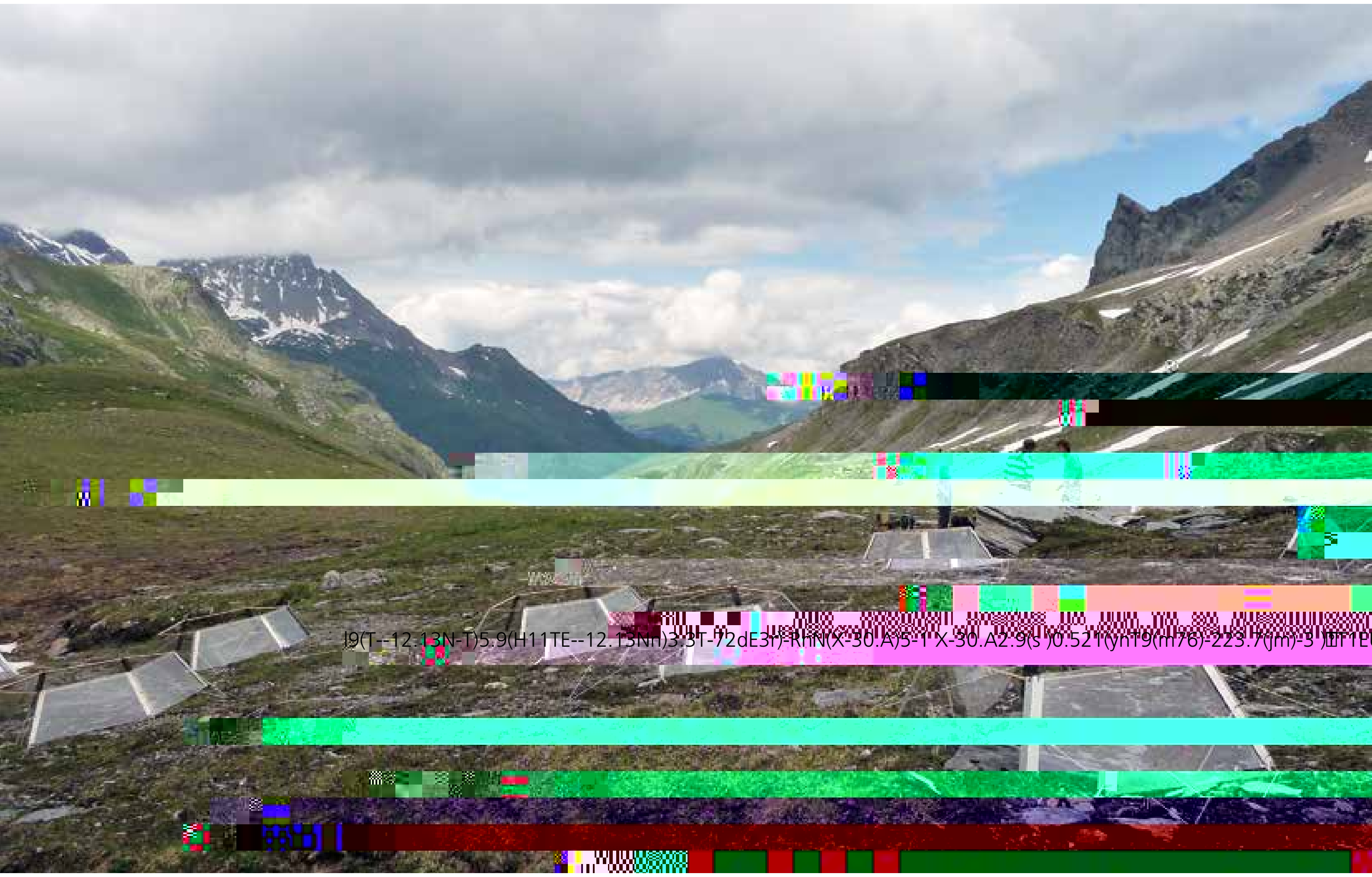
One project deals with phytoplankton, microscopically small algae that drift in the water. Phytoplankton provide the explanation as to why a considerable amount of global carbon emissions is absorbed at the water's surface and ends up in the depths understanding of the ecosystem of the Southern Ocean 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



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 -1.9(a)-0.6 4.9(...1(n)7(t)-43(i)-2(t).4(c)-27.2(t)-2.9(n t)3.7(u)0 Tc 0 Tw 21.462

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

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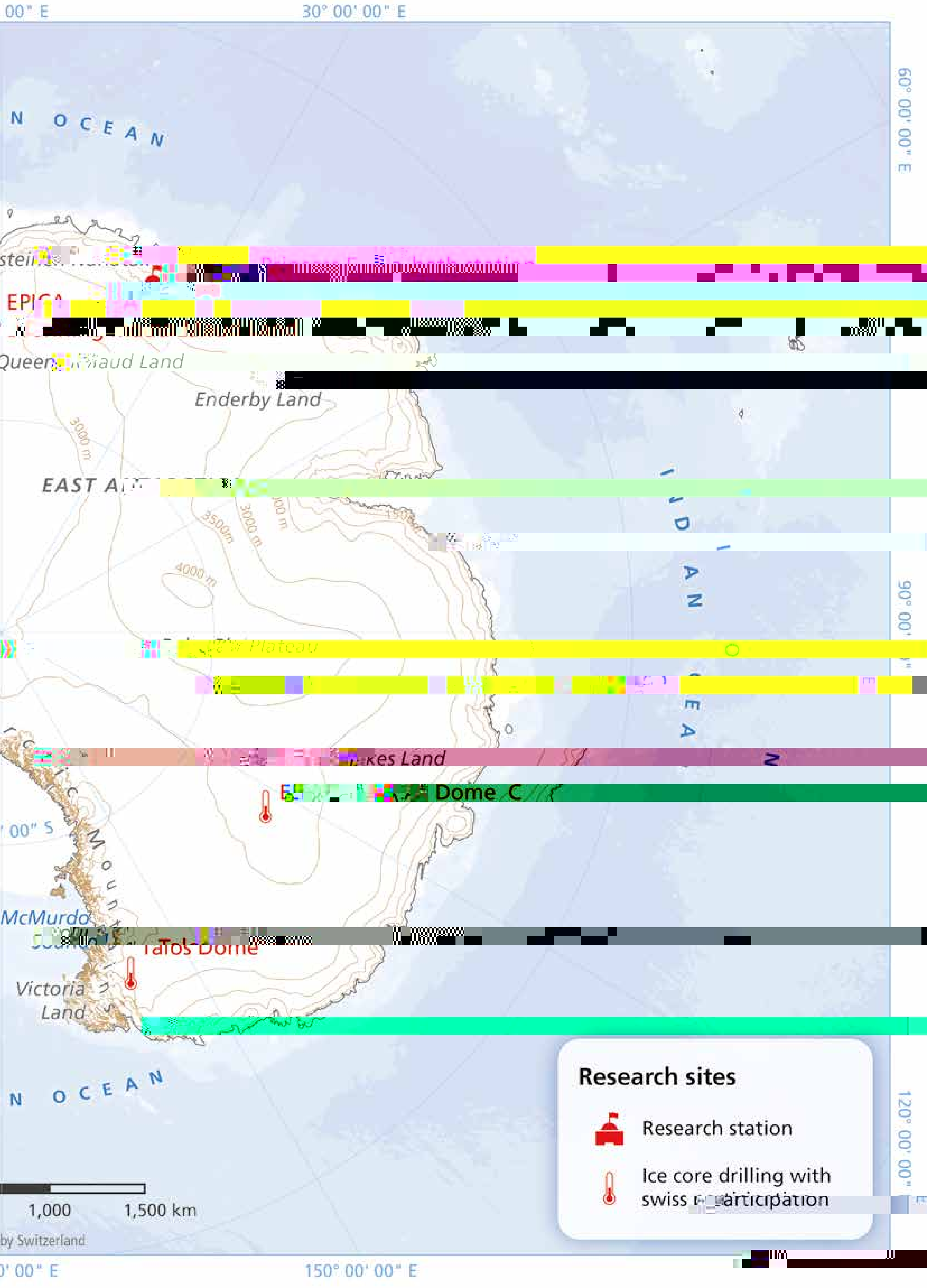
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Research sites
Research station
Ice core drilling with