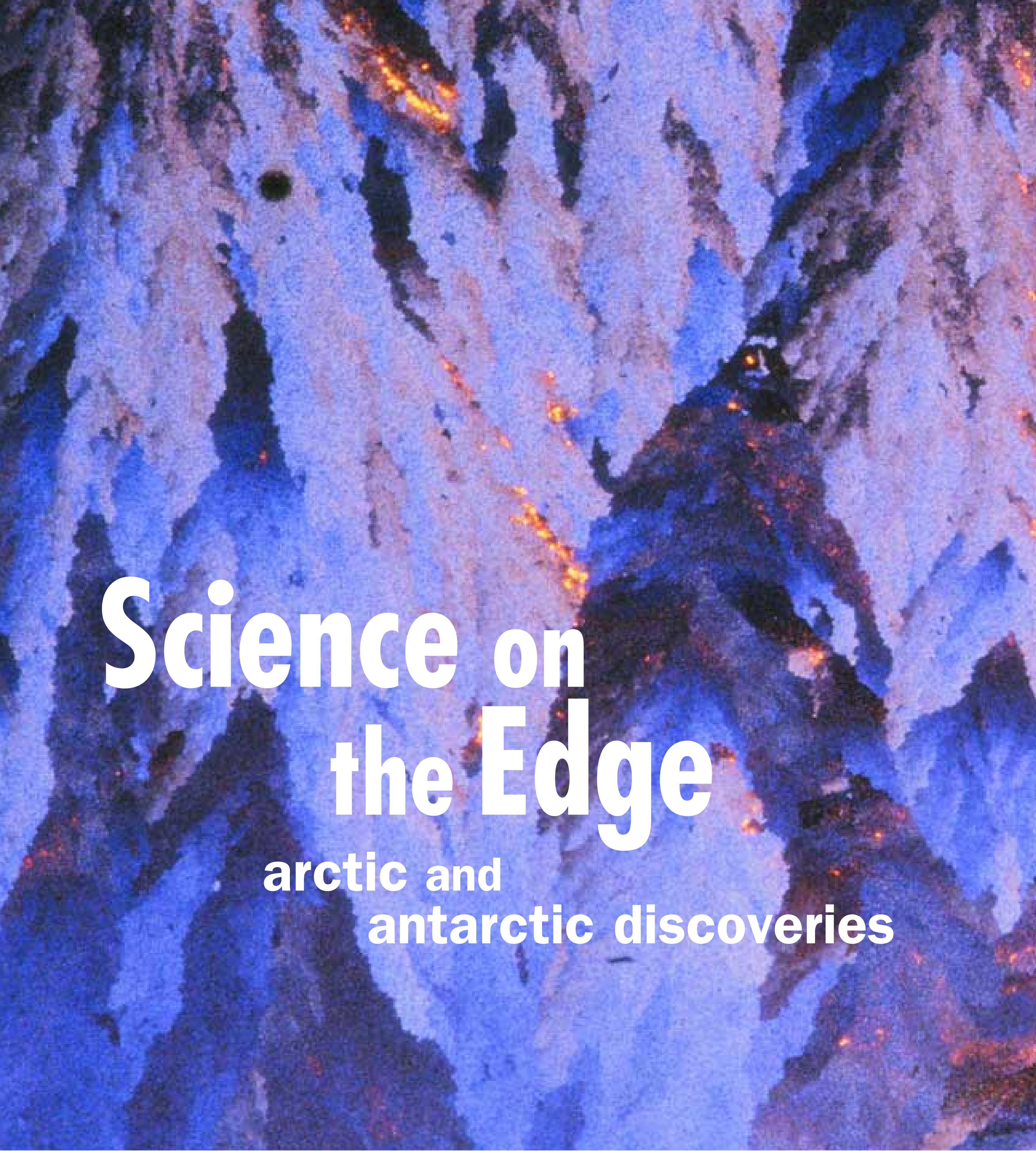
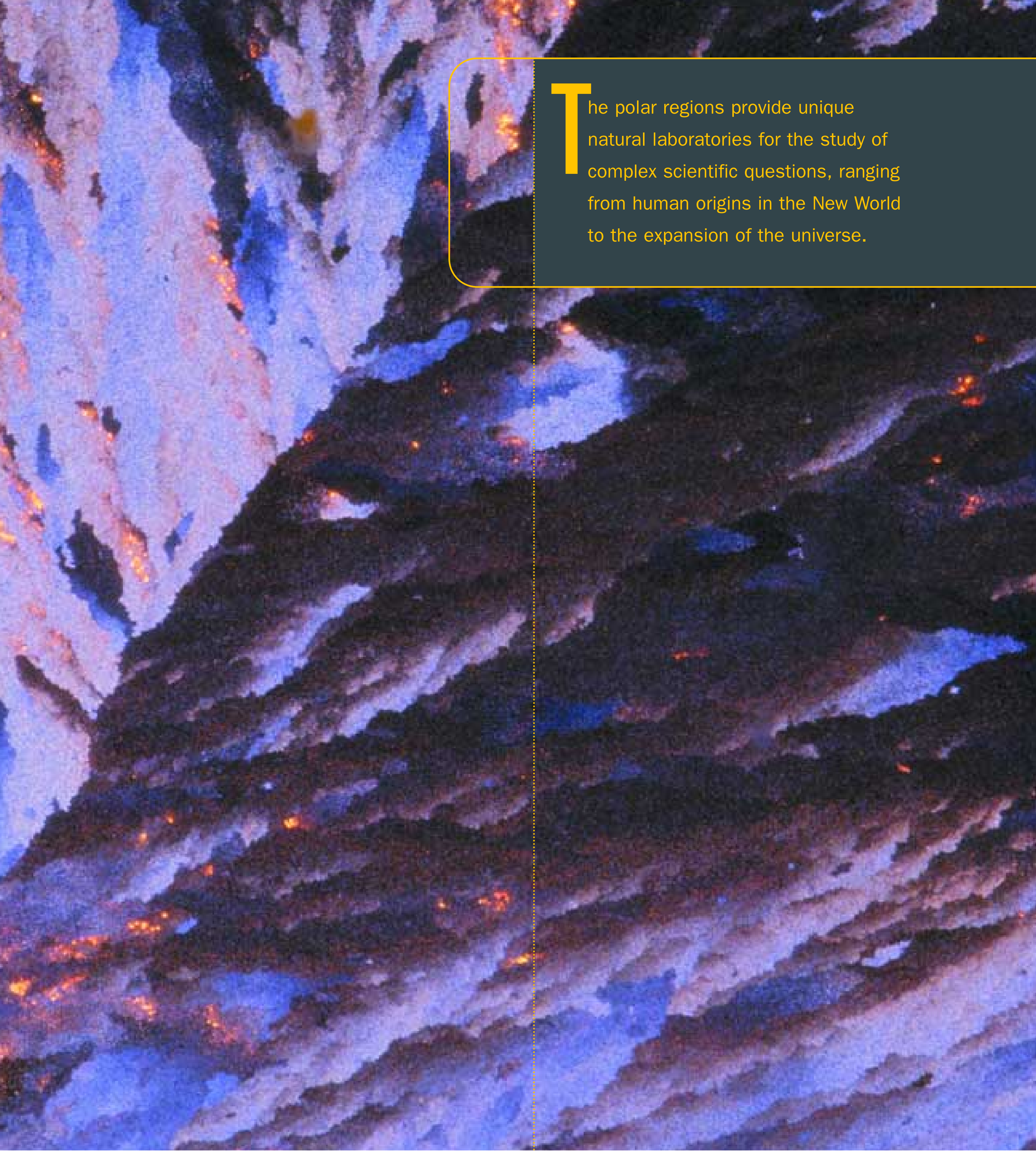
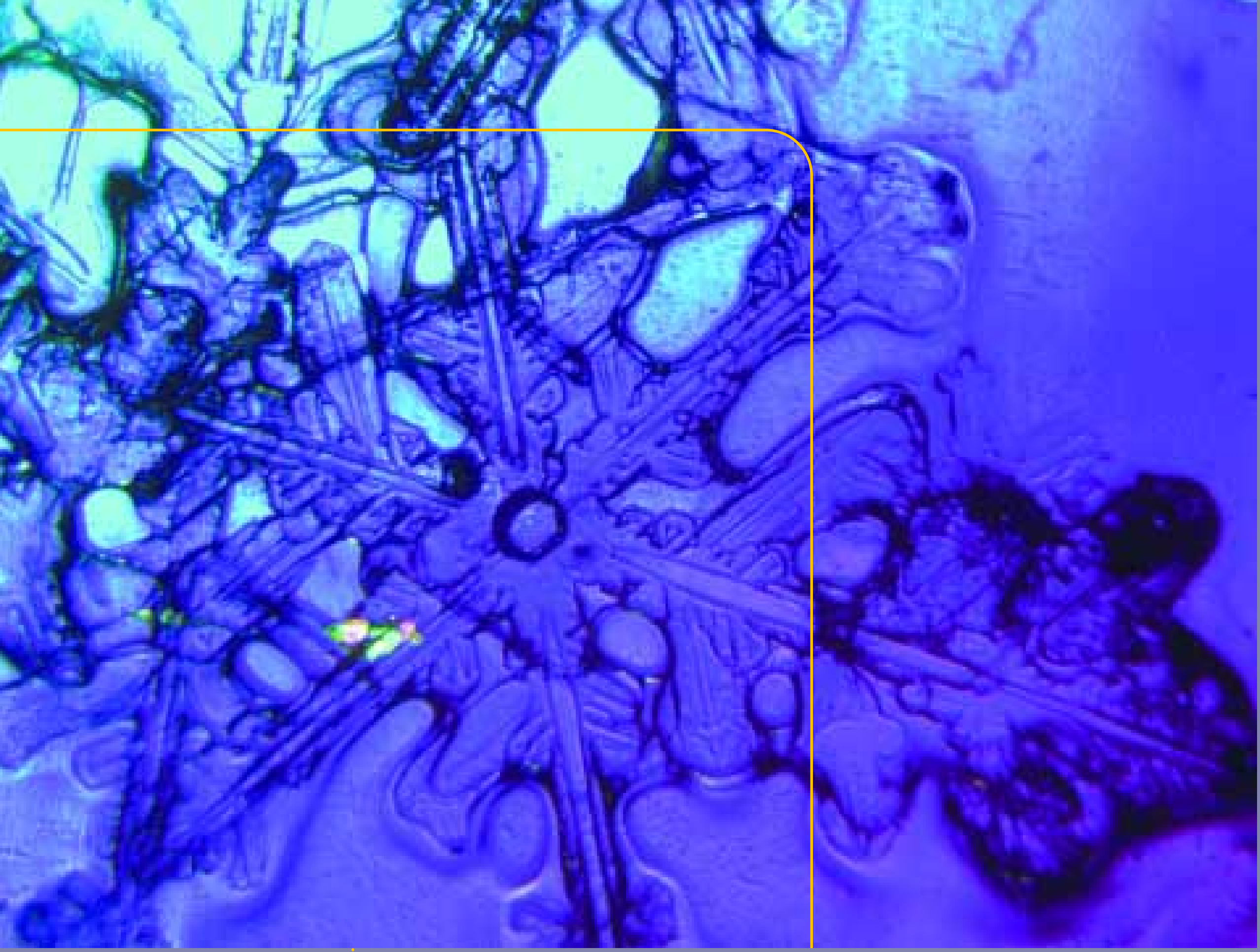


Science on the Edge

arctic and antarctic discoveries

The polar regions provide unique natural laboratories for the study of complex scientific questions, ranging from human origins in the New World to the expansion of the universe.





People have studied the polar regions for centuries. The extreme cold and stark beauty of the Arctic and Antarctic capture the imaginations of explorers, naturalists, and armchair travelers. In the latter half of the twentieth century, NSF-funded scientists discovered that the Arctic and the Antarctic have much to teach us about our Earth and its atmosphere, oceans, and climate. For example, cores drilled from the great ice sheets of Greenland and Antarctica tell a story of global climate changes throughout history. During NSF's lifetime, the extreme environments of the Arctic and Antarctic have become learning environments.

A Surprising Abundance of Life

Both the Arctic and Antarctic seem beyond life: icy, treeless, hostile places. Yet these polar regions host a surprising abundance of life, ranging from the microbial to the awe-inspiring, from bacteria to bowhead whales.

Important differences mark North and South. The North Pole lies in the middle of an ocean surrounded by land, while the South Pole rises from the center of a continent surrounded by an ocean. In the Arctic, human habitation stretches back for thousands of years. The Inuit and other indigenous peoples in the Arctic continue to carry out age-old traditions while adopting modern technology for subsistence hunting and fishing. The Antarctic has no "native" human populations but hosts a visiting population of scientists and support personnel every year. Human migration and methods of interacting with the environment form important research topics for NSF-supported social scientists who work in the Arctic, while the human scientists in the Antarctic focus on the effects of isolated and confined environments.

The poles were still poorly understood places when scientists the world over organized a special effort called the International Geophysical Year (IGY) to study the Earth and Sun on an unprecedented scale. The IGY, which ran from July 1957 to December 1958, was modeled on two previous International Polar Years and brought NSF firmly into the realm of polar science.

During the First Polar Year (1882–83), scientists and explorers journeyed to the icy margins of the Earth to collect data on weather patterns, the Earth's magnetic force, and other polar phenomena that affected navigation and shipping in the era of expanding commerce and industrial development. In all, the First Polar Year inspired fifteen expeditions (twelve to the Arctic and three to the Antarctic) by eleven nations. Along the way, researchers established twelve research stations.

By the Second Polar Year (1932–33), new fields of science had evolved, such as ionospheric physics, which peers into the outer layer of Earth's atmosphere. Scientists at the time turned to the polar regions to study the aurora phenomena—known in the Northern Hemisphere as the "northern lights"—and their relation to magnetic variations, cosmic radiation, and radio wave disturbances. How did the sun, the atmosphere, and the Earth's interior interact at the poles? Could scientists learn how to anticipate the magnetic storms that sometimes disrupt radio-based communications? Data collected during the Second Polar Year contributed to new meteorological maps for the Northern Hemisphere and verified the effects of magnetic storms on radio waves.

The United States has supported research at the Amundsen-Scott South Pole Station continuously since 1956. The current station, completed in 1975, is being redeveloped to meet the changing needs of the U.S. science community. Today's research at the South Pole includes astronomy, astrophysics, and atmospheric monitoring—e.g. ozone depletion and greenhouse gas concentrations. To the left in the picture is the geodesic dome that currently houses the main station buildings. On the right, a ski-equipped Hercules airplane waits on the South Pole skiway.

Still, scientists lacked a complete picture of how ice, atmosphere, land, and oceans worked together at the poles as a system of cause and effect.

Technological advancements in rockets, satellites, and instrumentation during the 1940s and 1950s allowed more and better measurements in the remote Arctic and Antarctic. By the time of the 1957–58 IGY, researchers were free to explore the ocean floor as well as the upper atmosphere: they could use nuclear-powered submarines to plunge under the ice cap and discover new ocean ridges, and launch rocket-powered satellites to make remote geophysical measurements. For the first time, the polar regions became year-round research platforms available for widespread international cooperation. Furthermore, everyday citizens became involved in scientific observations. People in the far north and the far south recorded their own aurora sightings and temperature readings, information that was funneled to scientists. Sixty-seven countries participated in the IGY, including the United States and the Soviet Union. Despite Cold War tensions between east and west, the world was engaged in cooperative, coordinated science at the poles and in other parts of the world.

Near Antarctica's coast lie the McMurdo Dry Valleys, a long-term ecological research site funded by the NSF. The bizarre rock formation shown here, called a "ventifact," was sculpted by wind-blown particles of ice and stone. Ventifacts are common to dry, windy places like Antarctica, the high deserts, and Mars. In fact, the Dry Valleys served as practice terrain prior to NASA's launch of the Viking probe to Mars.

The IGY set the stage for polar research at NSF in two ways. First, scientists came to think of the poles as natural laboratories in which to capture and integrate diverse data about "the heavens and the earth." Second, polar research became a cooperative international undertaking. Following the IGY, the twelve countries that had established some sixty research stations in Antarctica concluded a treaty to use Antarctica for peaceful purposes only, to freely exchange scientific information, to prohibit nuclear explosions and disposal of radioactive wastes, and to maintain free access to any area on the continent. By 1999, the Antarctic Treaty had forty-four parties, representing two-thirds of the world's human population; other agreements were made, too, including a protocol for improved environmental protection of Antarctica.

The 1990s also saw cooperation blossom up north. In 1996, the eight Arctic nation-states established the Arctic Council—the result of a process of negotiations aimed at protecting the Arctic environment while also allowing for vital research.

Ice Cores Hold Earth's Climate

As ice forms, gasses and other materials are trapped in the layers that build up over time. This makes the polar regions time machines. With more than 500,000 years of snow and ice accumulation, the ice sheets are ideal places for paleoclimatologists to set up their tubular drills and extract cores—long cylinders of sediment and rock—in order to read the history captured therein.

Working in the center of Antarctica's ice sheet, near the Russian research base of Vostok, a group of researchers from the United States, Russia, and France have extracted the world's deepest core. As a result, the scientists have differentiated more than four ice ages, or about 400,000 years of history.

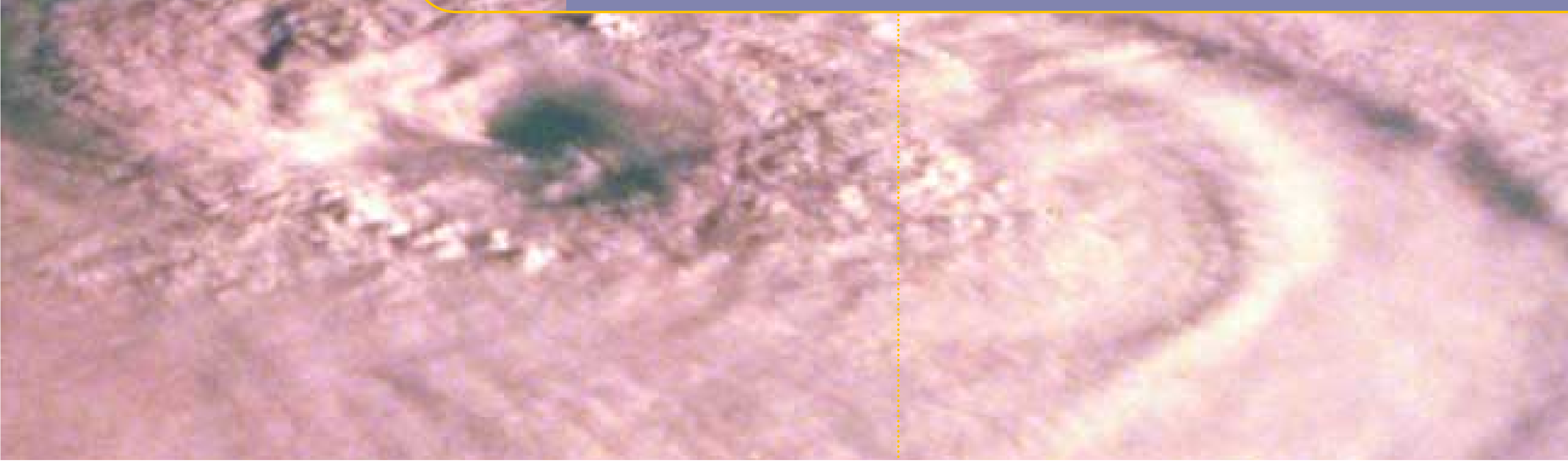
What researchers are discovering is that Earth's climate is not stable, and never has been. Ice ages are punctuated by interglacial periods of relative warmth, such as the one marking the close of the twentieth century. The interglacial periods have been marked by sudden shifts in temperature, wind patterns, and sea levels.

"Some of these rapid changes occur in two decades," says Paul Mayewski, a glaciologist from the University of New Hampshire and a thirty-year veteran of NSF-funded research in Antarctica. "Some [of the pattern changes] actually start in less than two years." While he finds these dramatic shifts surprising, he also notes that Antarctic cores are in sync with the climate data found in the ice cores from Greenland.

Mayewski and his colleagues learn about these changes by examining the chemical indicators, such as sea salt, within the extracted ice cores. High sea salt levels signal increased storminess and stronger winds. In addition, measurements of oxygen isotopes in the ice reveal cooling during periods of increased sea salt. Other tests probe for indicators of wind patterns, volcanic activity, and sea level.

However, the researchers still don't know what caused the rapid climate pattern changes evidenced in the ice cores.

"We need to understand how these changes work in order to make a better assessment of natural climatic change," Mayewski says, "and a better assessment of the human impact on the future climate."



Inupiat whalers wait by the sea ice edge near Barrow, Alaska. When a bowhead approaches, they will slip their seal skin umiaq into the water, anticipating where the whale will surface. According to the Principles for the Conduct of Research in the Arctic, a set of interagency guidelines adopted under the leadership of NSF, Arctic peoples are partners in research. As experts of survival in the North, indigenous elders have already helped scientists understand, for example, how the beaver population can affect whale migration patterns.

Human Migration and Local Knowledge

Scientists are only the most recent human arrivals to the poles—people have lived in the Arctic for thousands of years and the region offered the first migratory route for humans moving into North America. At least twelve thousand years ago, and possibly earlier, newcomers to North America are thought to have crossed to present-day Alaska from northeast Asia via Beringia, a vast plain—now submerged—that once connected the two land masses. Until recently, scientists believed that the newcomers entered the present-day Yukon Territory after crossing the land bridge, then headed south through an inland route. But recently, a science team funded by NSF offered evidence in support of another theory, which suggests that rather than going inland, the newcomers used watercraft along the southern margin of Beringia and southward along the northwest coast of North America. This may have enabled humans to enter the southern areas of the Americas prior to the melting of the continental glaciers. In 1997, NSF-funded researchers excavated a cave on Prince of Wales Island, Alaska, and found parts of a human jaw and pelvis dating to between 9,200 and 9,800 years ago, the oldest human bones ever found in Alaska. Isotope analysis of the bones showed that the person had subsisted on a marine diet. These first peoples would have had plenty of fish and other marine resources to eat as they moved in skin-covered boats along the Pacific Coast south to Peru and Chile during the last ice age.

While the story of the first people to arrive in North America continues to unfold, another side of the story tells of the close collaboration between scientists and contemporary indigenous communities in the Arctic. During their excavations of the cave on Prince of Wales Island, the archaeologists sought and attained the approval and collaboration of the tribal governments in Alaska. Alaska Native interns work on the site and present research papers at archaeology meetings. Tribal councils discuss news of scientific discoveries. This relationship of mutual trust and learning exemplifies the *Principles for the Conduct of Research in the Arctic,* a set of guidelines based on the ethical responsibility of researchers working in the North to consult, listen to, and involve the people of the North.

The *Principles*, adopted in 1990 by the NSF-chaired Interagency Arctic Research Policy Committee, echo the wish of Arctic peoples that science involve them as partners. After all, science consists in part of good, systematic observation, a critical element in the long-term survival of indigenous peoples who have for generations carved out economies and cultures in a challenging environment. What's more, indigenous peoples have developed time-tested technologies, such as toggle harpoons and skin boats, well suited for the North. NSF-supported research teams, including Native elders and social scientists, have tapped into this locally held knowledge of the Arctic environment to enrich ecological models and to document oral traditions.

For example, from 1995 to 1997 researchers conducting an NSF-funded study of beluga whale ecology in the Bering Sea asked Native whalers and elders to analyze patterns of whale migration. Surprisingly, the elders began to talk not only about belugas—the white whales with the "smirk"—but also about beavers. As the beaver population rises, more streams leading to the bay are dammed, spawning habitat for the salmon disappears, and fewer fish are available as prey for the belugas. Thus, the belugas may start to bypass the river mouth during their migrations.

The Importance of Sea Ice

Another important topic for researchers is sea ice. Polar sea ice undergoes tremendous changes every year. During the winter, the Arctic ice pack grows to the size of the United States; in the summer, half of the ice disappears. On the other side of the globe, ice at the South Pole covers nearly 98 percent of the Antarctic continent and averages one mile thick. The sea ice surrounding Antarctica changes in size depending on the season, ranging from roughly 4 million square miles in February (the Antarctic summer) to 19 million in August. So huge is the Antarctic ice pack that it accounts for 90 percent of the world's ice and 70 percent of its fresh water.

Like Doing Research on the Moon

NSF began managing the entire U.S. Antarctic Program (USAP) in 1970, providing not only research facilitation but also overall logistics management. The program maintains three year-round research stations and two research vessels capable of navigating through ice, as well as laboratories, telescopes, and other major instruments positioned across the continent. Besides developing the U.S. scientific agenda in cooperation with researchers, NSF provides for the health, safety, and overall well-being of 3,500 American scientists and support personnel, most of whom arrive and depart between October and February, when the continent is readily accessible by plane or ship.

Due to the continent's remote location and the fact that all provisions, building materials, fuel, equipment, and instruments must be brought in by ship or cargo plane, scientists say the experience of working in Antarctica is "like doing research on the moon." Each year, NSF improves the connections between the USAP and the rest of the world, making the region a little less isolated. All of the research stations now have Internet connections, and NSF hopes to extend the program's telecommunications capabilities so that one day scientists can operate equipment remotely and view real-time displays of data from their home institutions.

Given the amount of water that sea ice alternately puts into or pulls out of the ocean and the atmosphere, sea ice variability plays a major role in global climate change. During the International Geophysical Year scientists from the United States and the Soviet Union spent entire winters on ice islands in the Arctic, measuring depth, salinity, temperature, and other factors to model the extreme variability of sea ice. Forty years later, NSF-funded researchers repeated much of the work done in the IGY but this time with modern means, greatly improving our understanding of sea ice variability and the connections to climate change.

Two researchers walk from the ice-breaker Des Groseillers toward their lab, one of more than a dozen huts and tents on the ice where scientists conducted their work. The ship served as a floating field camp for the NSF-funded SHEBA experiment, an international study of heat flow in the Arctic. Frozen into the ice in the Beaufort Sea on October 2, 1997, the ship and its researchers drifted with the Arctic ice for a full year, travelling nearly 2,700 miles.

From the fall of 1997 through the fall of 1998, the Canadian ice-breaker ship known as *Des Groseillers* was frozen into the Arctic ice pack for scientific studies related to a multinational project known as SHEBA, or Surface Heat Budget of the Arctic. NSF, the U.S. Office of Naval Research, and the Japanese government cooperated in funding this massive study of heat flow among the water, ice, and air of the northernmost Arctic. For a full year, researchers documented how ice, clouds, snow, and the ocean interact and exchange energy. SHEBA researchers are now off the ice and back in the laboratories to integrate and analyze the vast amount of data they have collected but already they have reported a number of surprises.

One unexpected finding concerned the salinity of the water. When the scientists first arrived at the Arctic ice pack in October 1997, they discovered that the water was much fresher than it had been when the same area was analyzed twenty years earlier. They concluded that the melting of the ice pack during the summer of 1997 caused the water to be proportionally less salty. Such a change can have serious consequences for marine life as well as for how ocean water circulates and interacts with the atmosphere. In addition to altering salinity, melting sea ice also raises worldwide sea levels, with potentially significant effects for coastal cities and towns.

All of which, of course, raises questions about the nature of the warm weather associated with sea ice melting. Over the last one hundred years, overall global climate has warmed, on average, about 0.9˚F with the Arctic leading the way. Temperatures at the North Pole have risen nearly

Why the Ozone Hole? A Writer Explains

Why did the ozone hole develop over Antarctica, and not over Detroit or some other manufacturing center where chlorofluorocarbons, or CFCs, are released prodigiously? The reasons are explained by Rebecca L. Johnson, who participated in NSF's Antarctic Artists and Writers Program in 1991, 1994, and 1997.

In winter, the stratosphere above the Antarctic continent gets colder than it does anywhere else on Earth. Temperatures frequently drop below -112˚F. Antarctica is also one of the windiest places on Earth. In May and June, strong winds in the stratosphere begin to blow clockwise around the continent. These howling stratospheric winds gradually form an enormous ring of moving air, called the Antarctic polar vortex, that swirls around and around, far above the frozen land . . . .

During the winter, temperatures inside the Antarctic polar vortex fall so low that water vapor and several other types of molecules in the stratosphere condense into extremely small icy particles. These icy particles, in turn, make up polar stratospheric clouds (PSCs). When the sun sets in the Antarctic around the end of March each year, its disappearance marks the beginning of a long, dark winter. Once the last rays of sunlight have faded away, temperatures on land and in the air fall very quickly.

In the stratosphere, high-altitude winds that create the polar vortex begin to blow around the continent. Isolated from warmer air outside the vortex, the air inside gets colder and colder. Eventually, it is cold enough for PSCs to form. And that is when the trouble really begins.

Drifting around inside the polar vortex are reservoir molecules that have bonded with chlorine atoms and in so doing prevented them—so far—from attacking ozone. When PSCs form above Antarctica, chlorine reservoir molecules bind to the icy particles that make up the clouds. Once this happens, complex chemical reactions begin to take place that result in molecules of chlorine gas (Cl_2) being released from the reservoirs. In this form, however, chlorine doesn't attack ozone. It just collects inside the vortex. All through the long, dark winter, especially during July and August, the chemical reactions taking place on the surfaces of the PSC particles continue, and more and more Cl_2 builds up inside the vortex. At this point, the stage is set for ozone destruction. All that is needed is a trigger to get the process going.

That trigger comes in late August, when the sun begins to rise. As the first rays of spring sunlight strike the stratosphere high over the frozen continent, conditions change very rapidly. The UV rays coming from the sun strike the Cl_2 molecules inside the vortex. The molecules break apart, releasing billions of chlorine atoms that begin an attack on ozone molecules. The result is massive ozone destruction. Before long, so much ozone is destroyed inside the vortex that an ozone hole is formed.

Ozone destruction continues—and the hole remains—until conditions in the stratosphere above Antarctica change. This change usually begins in early October, when the continent and the air above it finally begin to warm up. Warmer temperatures in the stratosphere melt the icy particles that make up PSCs. The PSCs disappear, and the reservoir molecules that were bound to the icy particles are released. Free at last, the reservoir molecules bind chlorine atoms once again, and ozone destruction stops.

By early November, the strong stratospheric winds circling Antarctica die down, and the polar vortex breaks up. As it does, ozone-rich air from outside the vortex flows in, and much of the ozone that was destroyed is replaced. In a sense, the hole in the ozone layer fills in. Usually by the end of November, the amount of ozone in the stratosphere over Antarctica has almost returned to normal. The next winter, however, the cycle will begin again.

From *Investigating the Ozone Hole* by Rebecca L. Johnson. © 1993 by Lerner Publications Company. Used by permission of the publisher. All rights reserved. Ms. Johnson is also the author of *Science on the Ice: An Antarctic Journal* (1995) and *Braving the Frozen Frontier: Women Working in Antarctica* (1997).

The dim, late-summer sun brightens the Ferrar Glacier in the Transantarctic Mountains of Antarctica. What can still seem like the most remote and forbidding region on Earth has become a model of ongoing international scientific cooperation, with the National Science Foundation playing a lead role.

3.6˚F per decade in the last thirty years, significantly faster than in other regions of the world. The Antarctic is warming up, as well. Ice shelves from the western side of the Antarctic Peninsula have been shrinking; according to some reports, the 502-square-mile Wordie Ice Shelf disappeared completely between 1966 and 1989.

NSF-funded scientists who participated in the Scientific Ice Expeditions (SCICEX) program have confirmed that there is an acceleration in sea ice shrinkage. The SCICEX program provided the opportunity to use U.S. Navy submarines for Arctic research during the 1990s. Data from the SCICEX cruises demonstrate that the Arctic sea ice cover is showing signs of diminished extent and seasonal duration. What's more, ice observed in the 1990s was more than three feet thinner compared to measurements taken two to four decades earlier. Together, the SHEBA and SCICEX projects have revealed a major climatic factor—shrinking sea ice—that is now being incorporated into forecasts of global climate variability. If the ice pack continues to decrease in coverage and thickness, researchers suggest the possibility of a nearly ice-free Arctic—an area that has been covered by ice for at least three million years—and a vastly changed world.

What is the source of the warming trend? Part of the challenge in answering this question is learning how to separate the effects of human activity (such as the introduction into the atmosphere of "greenhouse" gases like carbon dioxide) from warming and cooling cycles that occur naturally. In the polar regions, average temperatures have fluctuated on various time scales, from the tens of thousands of years to one hundred thousand years. Further study of ice and sediment cores will provide a more detailed picture of ice sheet behavior during warmer intervals of Earth's history. Because Earth was warmer in the distant geologic past, studies of this complex period should shed light on the future effects of global warming.

Studying Extremes Above and Below

Ice is not the only substance of interest at the poles. These extreme environments offer windows into realms yet to be explored. The universe, for example. How did the universe evolve? Will the universe continue to expand? Astronomers use a year-round observatory at the South Pole to answer these questions, taking advantage of the Pole's natural features: the dark, dry, and cold environment makes for easier detection of infrared wavelengths and small particles. Infrared and submillimeter radio telescopes at the South Pole detect wavelengths obscured at most other observing sites. NSF-funded researchers use the Antarctic ice sheet to capture invisible, subatomic particles called neutrinos in order to gain insight into violent astrophysical events such as black hole collapses and supernova explosions.

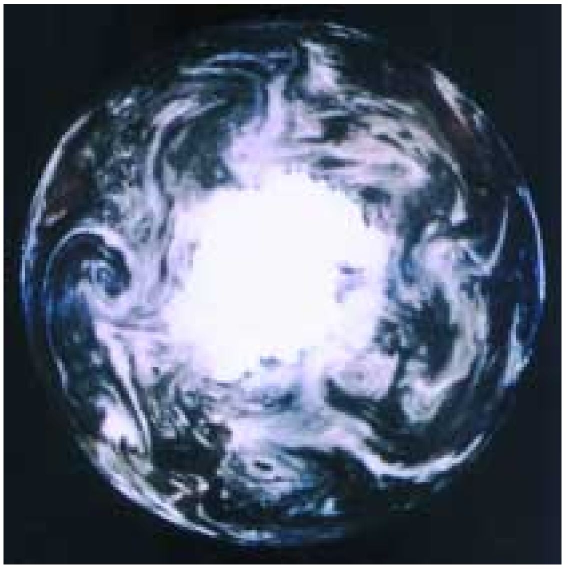
Another territory ripe for exploration can be found deep below the ice. Thousands of feet under the Antarctic surface, below the Russian-run research station known as Vostok, lies Lake Vostok. The subglacial lake, roughly the size of Lake Ontario, has been isolated from Earth's ecosystem for millions of years. Cut off from the rest of the Earth, Lake Vostok may be home to ancient species of microbes that have been able to survive in this extreme environment. As part of a joint U.S., French, and Russian research project, Russian teams have drilled down into the ice covering the lake and extracted the world's longest, deepest ice core. They stopped drilling at about 395 feet above the ice-water interface to prevent possible contamination of the underlying lake by kerosene-based drilling fluid.

The upper 9,800 feet of the ice core provide a continuous paleoclimatic record of the last 400,000 years. The record shows that there have been four complete climatic cycles, including four ice age or glacial periods associated with the development of large ice sheets over the Northern Hemisphere, and four warmer interglacial periods.

In addition, NSF-funded scientists discovered that the core contains bacterial forms, showing that microbes existed under the ice and probably still thrive in the lake. Supporting this theory is a July 2000 report by a separate team of NSF-funded researchers that they have discovered metabolically active bacteria surviving in South Pole snow.

How do such "extremophiles" survive? Where do they get their energy—from geothermal activity? Studying the microbes and their unique and isolated environment will tell scientists more about whether life may be able to exist in harsh conditions elsewhere in the solar system. Indeed, Lake Vostok appears to resemble conditions on Jupiter's frozen moon Europa. Scientists and engineers are now working on methods to sample the subglacial lake while preventing contamination.

In 1999, NSF-funded researchers sailed aboard a U.S. Navy nuclear submarine (the USS Hawkbill, shown here poking through the ice), to map the oceanic ridges and basins beneath the Arctic ice cap and to study ocean currents that may have an effect on global climate. The project, called Scientific Ice Expedition (SCICEX) '99, was the fifth in a series of annual missions, all taking advantage of sophisticated scientific instruments aboard highly maneuverable warships.



Antarctica as pictured by the spacecraft Galileo on its way to Jupiter. The picture was taken in early December, a time of year when the ozone hole over the South Pole is small to nonexistent. During the cold Antarctic winters—April through August—icy stratospheric particles form, which interact with atmospheric chemicals to foster ozone destruction upon the return of sunlight in late August. The ozone hole grows until October, when warmer temperatures begin to melt the icy particles. Because stratospheric ozone protects living things against harmful radiation, NSF-funded researchers at the Pole are working hard to better understand the cause and effects of ozone depletion.

Moving up in scale from microbes, biologists continue to discover important adaptations among larger extremophiles. In the late 1960s, physiologist Arthur L. DeVries discovered with the help of NSF funds that Antarctic notothenioid fish are protected from subzero temperatures by antifreeze glycoproteins in their blood. Continuing studies to unravel the workings of fish antifreeze could have profound implications in a number of areas—from human organ transplantation to agriculture and beyond. As it happens, Arctic cod have similar glycoproteins. These proteins bind to ice crystals and keep them from growing. Yet NSF-funded studies in the 1990s revealed that the Arctic cod and Antarctic notothenioid actually belong to two different orders of fish that diverged in evolution some forty million years ago. This is a striking case of convergent evolution in polar environments: the fish took different routes toward the identical solution of how to stay alive in ice water.

Ozone Hole over Antarctica

Life at the margins may be extreme, but it is also fragile. The British Antarctic Survey's first documentation of the Antarctic ozone hole in 1985 and subsequent NSF-funded study of the phenomenon alerted the world to the danger of chlorofluorocarbons, or CFCs. That research team, led by 1999 National Medal of Science winner Susan Solomon, conducted observations that have significantly advanced our understanding of the global ozone layer and changed the direction of ozone research.

Stratospheric ozone protects against ultraviolet radiation. The breakdown of this ozone layer by CFC molecules can have harmful effects on a range of life forms, from bacteria to humans. The long, cold, dark Antarctic winters allow the formation of polar stratospheric clouds, the particles of which form an ideal surface for ozone destruction. The returning sunlight provides energy to start the complex chemical reaction that results in the depletion of ozone. The ozone hole above Antarctica typically lasts about four months, from mid-August to late November.

During this period, increased intensity of ultraviolet radiation has been correlated with extensive DNA damage in the eggs and larvae of Antarctic fish. Embryos of limpets, starfish, and other invertebrates do not grow properly. Other species have developed defenses. The Antarctic pearl wort, a mosslike plant on rocky islands, developed a pigment called flavenoid that makes it more tolerant of ultraviolet radiation.

In the northern polar regions, ozone levels in the early 1990s measured 10 percent lower than those estimated in the late 1970s. The Arctic does experience ozone depletion, but to a lesser degree than the Antarctic. Unlike the Antarctic, large-scale weather systems disturb the wind flow in the Arctic and prevent the temperature in the stratosphere from being as cold. Therefore fewer stratospheric clouds are formed to provide surfaces for the production of ozone-depleting compounds. Some clouds do form, however, and allow the chemical reactions that deplete ozone. Ozone depletion has a direct effect on human inhabitants, but research has only just begun on the effects of increased ultraviolet radiation on terrestrial and aquatic ecosystems and societies and settlements in the Arctic.

The good news is that countries around the world have agreed to ban the manufacture of CFCs through the Montreal Protocol. The contributions of Antarctic researchers led to swift policy action and because of that the ozone layer should recover in the future. In the meantime, however, NSF-funded research continues to monitor the level of the CFCs still lingering in the atmosphere. The polar regions will continue to play an important role as early warning systems for the rest of the globe.

Knowledge of the Whole

Knowledge of life in extreme environments helps us to understand not only how life may have begun on Earth, but also what we may find beyond our own planet. Records from ice and sediment cores reveal past climate patterns, helping scientists to anticipate future scenarios and maybe allowing policymakers to make more informed decisions. Following ethical principles in partnership with Arctic communities brings researchers to a deeper understanding of their own scientific methods while enabling them to listen to local knowledge and oral traditions.

What will happen to the sea ice in the Arctic and the massive glaciers in the Antarctic? How will ecosystems adapt to the rapid changes observed over the last few years? Data captured at the poles show that the Earth is a total system where cause and effect know no north or south. The Arctic and Antarctic both register the effects of, and have their own influence on, global circulation patterns in the ocean and atmosphere.

NSF has enabled science to reach the most remote and seemingly forbidding regions on Earth, only to discover that these regions may hold the key to a global understanding. As scientists make discoveries at the ice's edge, they join earlier generations of hunters, explorers, and navigators in a time-honored quest for knowledge of the extreme, leading to knowledge of the whole.

To Learn More

NSF U.S. Antarctic Program
www.nsf.gov/od/opp/antarct/usap.htm

Antarctic Muon and Neutrino Detector Array (AMANDA)
http://amanda.berkeley.edu

Center for Astrophysical Research in Antarctica
http://astro.uchicago.edu/cara/home.html

McMurdo Dry Valleys Long-Term Ecological Research (LTER)
http://huey.colorado.edu

Scientific Committee on Antarctic Research
www.scar.org

Scientific Committee on Antarctic Research Global Change and the Antarctic
www.antcrc.utas.edu.au/scar/

NSF Arctic Program
www.nsf.gov/od/opp/arctic/

Arctic Research Consortium of the United States
www.arcus.org

International Arctic Environment Data Directory
www.grida.no/prog/polar/add/

Alaska Native Knowledge Network
www.ankn.uaf.edu

Center for Global Change and Arctic System Research
www.cgc.uaf.edu

SHEBA Home Page
http://sheba.apl.washington.edu