Understanding Earth's Polar Challenges: International Polar Year 2007–2008

SUMMARY BY THE IPY JOINT COMMITTEE

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Weather • Climate • Water

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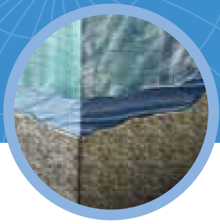

2.6 Subglacial Aquatic Environments

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Recognition as a Focus for Scientific Investigation

In 1996 an article, featured on the cover of *Nature*, reported that a massive subglacial lake containing liquid water was hidden beneath ~4 kilometers of ice in Antarctica (Kapitsa et al., 1996). While the data that suggested the presence of a lake dated to the 1960s and 1970s, this feature had gone largely unnoticed by the broader scientific community until a re-analysis of the data. The article sparked speculation that these environments might be habitats for exotic microbial life long isolated from the open atmosphere. It was speculated that if sediments were preserved at the bottom of the lake they would contain never before seen records of past climate change in the interior of Antarctica. The article demonstrated that the lake (Subglacial Lake Vostok, named after the Russian Antarctic Station famous for its 400,000 year ice core record of climate; Fig. 2.6-1) was an order of magnitude larger than other previously identified subglacial lakes, and was deep (510 m) making it a unique feature on Earth (Kapitsa et al., 1996). Conjecture was that the lake had been entombed for hundreds of thousands, if not millions of years, beneath the East Antarctic ice sheet. A small, but growing, international community of scientists became convinced, based as much on scientific vision as on actual data, that Lake Vostok and other subglacial lakes represented an important new frontier in Antarctic research. The group continued to examine what was already known as well as newly developed information about subglacial environments over the next decade developing the scientific rationale for the study of these environments. The emerging interest in Lake Vostok led to a series of international meetings to develop plans for its exploration. The first, in Cambridge in 1994, established the dimensions and setting of the lake and led to the first published inventory of subglacial lakes (of which 77 were recorded from analysis of radio-echo sounding records, Siegert et al., 1996). In the second half of the 1990s, three scientific workshops entitled "Lake Vostok Study: Scientific Objectives and Technological Requirements" (St. Petersburg, March 1998), "Lake Vostok: A Curiosity or a Focus for Scientific Research?" (Washington DC, U.S.A., November 1998; Bell and Karl, 1998), and "Subglacial Lake Exploration" (SCAR, Cambridge, September 1999) were held. It was recognized early on that that, in order to explore these remote habitats, a major, sustained investment in time, resources and scientific effort would be necessary. The Scientific Committee on Antarctic Research (SCAR) provided a forum for scientists and technologists to gather, exchange ideas and plan for the future; first as a Group of Specialists (2000-2004) and then as a Scientific Research Program (SCAR Subglacial Antarctic Lake Environments [SALE] 2004–2010). The timing of the SALE program conveniently paralleled the development and implementation of IPY, resulting in valuable mutual benefits for both of these iconic polar activities.

The Early Years

From 1998-2006 understanding of subglacial environments incrementally improved based on remote sensing studies and theoretical modeling. Slowly, the belief that the interface between the ice sheets and basement rock was frozen and devoid of environments of interest was changing. As knowledge of subglacial lakes increased, the potential importance

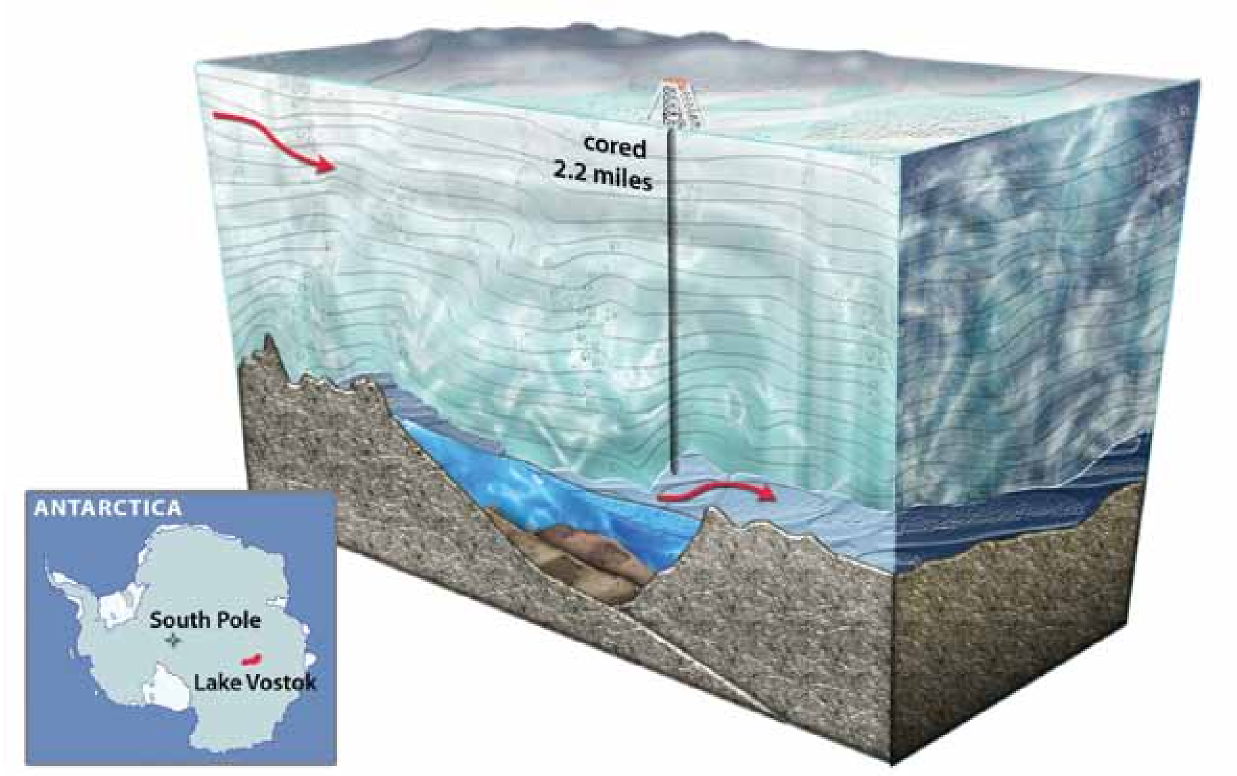

Fig. 2.6-1. An artist's cross-section of Lake Vostok, the largest known subglacial lake in Antarctica. Liquid water is thought to take thousands of years to pass through the lake, which is the size of North America's Lake Ontario
(Credit: Nicolle Rager-Fuller/NSF).

of these environments began to be recognized by a wider community. Early in the discussions, speculation about life existing in lakes beneath the ice dominated people's attention. This speculation was fueled by the detection of microbial cells in the so-called "accreted ice", which was interpreted as ice originating from lake water that had re-frozen on the underside of the ice sheet as it moved across the lake (Karl et al., 1999; Jouzel et al., 1999; Priscu et al., 1999; Bell et al., 2002). Accreted ice had been recovered from the deepest penetrations of the Vostok borehole.

The results of new geophysical surveys, in conjunction with previously collected data, led to the realization that subglacial lakes were not uncommon and in fact were to be expected beneath thick ice sheets (>2 km). Evidence for other lakes indicated that the number of features identified was a function of the coverage of surveys and that in all likelihood the inventory of features would increase as survey coverage increased. Therefore, subglacial lakes were likely to exist in many of the then un-surveyed regions of Antarctica. Lake Vostok continued to dominate discussions as it was the only lake whose shape and size were known. No other lakes had information on water depths or topography and Lake Vostok was the largest known subglacial lake (with an area of about 17,000 km^2 and water depth reaching up to 1200 m). Due to its size and the availability of accreted lake ice recovered by ice coring, it has remained a focus of exploration and research.

The expanding inventory of lakes revealed that subglacial features were not randomly distributed across Antarctica, but that lakes preferentially occurring in certain settings. The idea that different types of lakes might have differing histories, ages, origins and possibly biological residents led to classification systems for lakes. As the inventory of lakes grew, it was evident that some clusters of lakes occurred in regions defined by the dynamics of the overlying ice sheet and the morphology of the underlying basement. "Lake districts" were identified near Dome C (Concordia Station) and other clusters of lakes were located near ice-divides or at the heads of ice streams. Analysis of the distribution of lakes led to the suggestion that at least some lakes might be expected to have hydrological connections analogous to sub-aerial lakes, streams and wetlands. Ideas about hydrological connections between lakes and coupling

Fig. 2.6-2. An artist's representation of the aquatic systems scientists believe are buried beneath the Antarctic ice sheets (Credit: Zina Deretsky/ NSF).

of basal water with the overlying ice sheet dynamics fundamentally advanced our understanding of subglacial environments and how they may evolve and function (Fig. 2.6-2). Geophysical surveys also detected features that did not fit the definition of lakes, but nevertheless appeared to contain liquid water or water-saturated sediments. This led to a broadening of interests from lakes to subglacial aquatic environments in general.

Life under the Ice

As discussed above, in parallel with physical science discoveries, the debate over the existence of life in the lakes continued unabated. This debate engendered public interest in what might be living in the lakes and prompted extensive coverage in the popular press. This discussion proved valuable in maintaining a high profile for subglacial research and assisted in keeping the topic high on the agenda of funding agencies. While many of the physical attributes of subglacial environments (temperature, pressure, salinity, etc.) would not be considered "extreme", the general consensus is that the ultra-oligotrophic conditions (extremely low nutrient levels) that would most likely prevail in these environments would be very challenging, even for microbial life. Extreme nutrition, essential element and energy limitations were expected to be common in these environments due to their relative isolation.

Indirect evidence of biological residents and geochemical conditions in these environments came from the analysis of accreted lake ice (lake water frozen onto the base of the ice sheet) recovered from the Vostok borehole. These samples were not originally recovered for microbiological analyses raising questions about possible contamination of the samples. Partitioning of lake water constituents into ice under subglacial lake conditions is also poorly understood making extrapolation of accreted ice results to lake water compositions difficult at best (Gabrielli et al., 2009). These circumstances have resulted in conflicting and ambiguous evidence about life in the lake, the biogeochemistry of lake water and the possible influence of hydrothermal effluents in Lake Vostok. These discrepancies will not be resolved until water and sediments are collected *in situ* and returned to the laboratory for analysis under clean conditions. The general consensus is that all of these environments almost certainly contain life, based on the current knowledge of the settings, but that life more complex than microbes is highly unlikely. Early speculation that the water in these lakes has been isolated for millions of years is also considered far less likely given the degree of hydrological communication apparent among those lakes examined to date.

A New Frontier Continues to Advance during IPY

The early phases of subglacial aquatic environment research coincided with initial planning for IPY 2007–2008. As a consequence, a group successfully proposed to become an ICSU-WMO IPY project entitled Subglacial Antarctic Lake Environments Unified International Team for Exploration and Discovery (SALE UNITED). As Antarctic science is funded by National Programs, both SCAR SALE and SALE UNITED served primarily as fora to exchange information and network with others interested in subglacial aquatic environments. SALE UNITED participants included scientists and technologists from Belgium, Canada, China, France, Germany, Italy, Russia, the U.K. and the U.S.A. SCAR SALE (and during IPY, SALE UNITED) held meetings in Austria (2005), France (2006), the U.S. (2007), Russia (2008) and Belgium (2009) to further development of strategic plans and sharing of information on progress. In 2006, a large international workshop "Subglacial Antarctic Lake Environment in the IPY 2007–2008: Advanced Science and Technology Planning Workshop" for the broader community was convened in Grenoble, France by M.C. Kennicutt II and J.R. Petit. The workshop brought together 84 participants from 11 countries.

During IPY, significant advances in understanding subglacial environments were achieved. Wingham et al., (2006) detected changes in ice-sheet surface elevations in central East Antarctica using satellite remote sensing and demonstrated that a lake in the Adventure subglacial trench discharged approximately 1.8 km^3 of water over a period of 14 months. The water flowed along the axis of the trench and into at least two other lakes some 200 km away. The flux of water, at around 50 m^3 s^{-1}, was equivalent to the flow of the River Thames in London. This discovery was particularly significant as the observations were from the center of East Antarctica, which was considered to be a stable and ancient ice sheet. The conclusion was that the movement of subglacial water was likely everywhere in Antarctica and indeed the hydrological processes have subsequently been shown to be common-place. This work also suggested that subglacial systems were linked together by a network of hydrological channels defined by the basal topography and surface slopes. Siegert et al., (2007) showed the nature of these channels and suggested how groups of lakes may be associated within discrete systems. Later, Wright et al., (2008) revealed that the directions of several such channels were sensitive to the ice surface slope. They concluded that small changes in surface slope can result in a major alteration to the basal water flow, especially during periods of ice sheet changes such as after the last glacial maximum or even as a consequence of future global warming. These findings also suggested that water would flow along a hydrologic potential which in some instances might be up topographic slopes (up-hill).

Further analysis of satellite remote sensing showed that the process of subglacial discharge and water flow was indeed common-place in Antarctica (Smith et al., 2009). Additionally, many of the newly found lakes and discharge areas were located at the heads of ice streams (Siegert and Bamber, 2000; Bell et al., 2007). Smith et al., (2009) showed, that these lakes actively discharge water to ice stream beds altering basal flow. Satellite investigations of the Byrd Glacier by Stearns et al., (2008) revealed that this was the case and that subglacial lake discharges coincide with 10% anomalies in flow velocity in a major outlet glacier (Byrd) draining East Antarctica. Hence, subglacial lakes can and probably always have influenced the dynamics of overlying ice sheets. Additional satellite imagery analysis has confirmed the widespread existence of lakes and episodic water release events. Evidence has also been found of paleo-outbursts from subglacial lakes, most notably the dramatic outflow features present in the Labyrinth area of the McMurdo Dry Valleys. Vast amounts of lake water were released from large lakes and such events have been speculated to affect ocean thermohaline circulation due to the influx of fresh water possibly interacting with regional climate.

During these years, meetings and international workshops facilitated the development of research questions and plans to enter and sample subglacial environments. Critical issues that surfaced were the cleanliness of these experiments and the need for long-term stewardship of subglacial lakes as sites of scientific and public interest. A U.S. National Academies committee reviewed plans for subglacial lake exploration from the perspective of environmental protection and conservation. This review and subsequent international acceptance of major findings has set standards for conducting future subglacial aquatic environment study and exploration (U.S. National Research Council, 2007).

Studies of Lake Vostok during IPY

Russian exploration at Lake Vostok continued as part of the drilling program within the framework of the long-term Federal Targeted Program "World Ocean", subprogram "Antarctica." It was implemented by a consortium of eight Russian research institutions led by the Arctic and Antarctic Research Institute (AARI) of Roshydromet. In the framework of this program, the Polar Marine Geological Research Expedition (PMGRE) and Russian Antarctic Expedition (RAE) have performed extensive geophysical surveys of the Lake Vostok area and its vicinity by means of ground-based radio-echo sounding (RES) and reflection seismic measurements (Masolov et al., 2006; Popov et al., 2006, 2007; Popov and Masolov, 2007). The overall length of the geophysical traverses completed in February 2009 exceeded 6000 km and included 320 seismic measurements (Fig. 2.6-3). The main output of this large-scale field activity was a series of 1:1,000,000 maps of the Lake Vostok water table limits, the ice and water body thickness, the bedrock relief, its geomorphological zones and the spatial pattern of the internal layers in the overlying ice sheet. While a handful of geophysical transects, involving radio-echo sounding, were acquired over Lake Vostok between 1971-1972 and 1974-1975, it was more than twenty years before the first systematic survey of the lake by Italian geophysicists occurred in 1999. In the Austral season of 1999-2000, twelve new radio-echo sounding transects were collected over the lake, including one continuous flight across the long axis of the lake. From these data, the lake extent was better understood (to be ~260 km by 80 km) and the steady inclination of the ice-water interface was reconfirmed along the entire length of the lake (Kapitsa et al., 1996). The investigation also revealed the relatively high topography on either side of the lake showing that the lake occupies a deep trough.

A year later, U.S. geophysicists undertook what still remains the definitive survey of the lake by airborne measurements (Studinger et al., 2003). More than 20,000 line-km of aerogeophysical data were acquired over an area 160 by 330 km, augmented by 12 regional lines, extending outside of the main grid by between 180 and 440 km. The outcome was the first detailed assessment of the lake and its glaciological locale. Gravity modelling of the lake bathymetry established the existence of two basins (Studinger et al., 2004). The southern basin of the lake is more than 1 km deep. These geophysical investigations supplemented the long-standing geophysical campaigns by Russian scientists from 1995-2008 and resulted in 318 seismic reflection soundings and 5190 km of radio-echo soundings (Masolov et al., 2001, 2006).

During IPY, geophysical, geodetic and glaciological traverse programs carried out by RAE focused on investigating the two ice-flow lines starting at Ridge B, the Vostok flow line (VFL) passing through drilling site 5G at Vostok Station and the North-Vostok flow line (NVFL) crossing the northern part of Lake Vostok (Fig. 2.6-3). These ground traverses were planned and implemented under the IPY TASTE IDEA (Trans-Antarctic Scientific Traverses Expeditions – Ice Divide of East Antarctica) project, as part of the Italian/French/Russian traverse from Talos Dome, via Dome C, Vostok and Dome B to Dome A. The data collected in the field were used to constrain a thermo-mechanical ice-flow line model (Richter et al., 2008; Salamatin et al., 2009; Popov et al., submitted). Coordinated field and modeling efforts yielded an improved glaciological timescale for the 5G ice core and refined the isotope-temperature transfer functions for converting isotope and borehole temperature data from Vostok into a palaeo-temperature record (Salamatin et al., 2009). Other important outputs of the "Vostok ice flow lines" project were more accurate model estimates of the contemporary distribution of the accreted (lake) ice thickness and freezing rates along the Vostok flow line. In addition, ice age-depth and temperature profiles and the basal melt-rate were predicted for

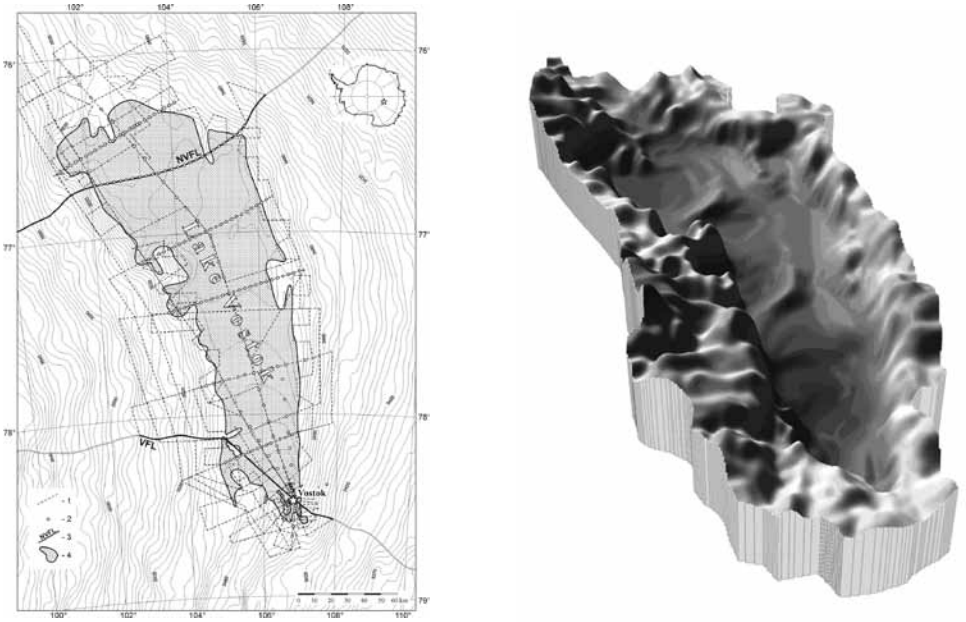

Fig. 2.6-3. Russian scientific traverses in the Lake Vostok area (left) and subglacial landscape of Lake Vostok depression as revealed by RES and seismic measurements (right), courtesy of Sergey Popov (PMGRE). Shown on the map: 1- radio-echo sounding profiles; 2- reflection seismic stations; 3- VFL and NVFL ice-flow lines (the studied segments of the flow lines are highlighted with thicker curves); 4 – the expansions of Lake Vostok water table.

the northern part of Lake Vostok (Fig. 2.6-3). The age and the location of lake accretion ice formation in the Vostok core, as inferred from the ice flow modeling, is illustrated in Fig. 2.6-4 (Salamatin et al., 2009). The upper stratum of lake ice bedded between 3539 and 3609 m beneath the surface comprises scarce mineral inclusions entrapped from the lake bottom sediments in the shallow strait and/or over the small island on the upstream side of Lake Vostok. The underlying clean ice is assumed to be refrozen from the deep water as the ice sheet moved between the "islet" and Vostok Station (Fig. 2.6-4).

Extensive study of mineral inclusions conducted at the Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia) and at the All-Russian Geological Institute (VSEGEI) showed that in most cases they were soft aggregates composed of micro-particles of clay-mica minerals, quartz and a variety of accessory minerals (see inset in Fig. 2.6-4). The larger (up to 4-5 mm) rock clasts found in the inclusions were classified as quartzose siltstone comprised of zircon and monazite grains. The composition of the clasts confirms that the bedrock to the west of Lake Vostok (a potential source of terrigenous material in the ice core) is of sedimentary origin. The ages of zircon and monazite grains cluster between 0.8–1.2 Ga and 1.6–1.8 Ga, which suggests that the provenances of these sedimentary rocks, the Gamburtsev Mountains and Vostok Subglacial Highlands, are mainly Paleoproterozoic and Mesoproterozoic-Neoproterozoic crustal provinces (Leitchenkov et al., 2007).

Resumption of deep drilling at Vostok Station during IPY allowed an extension of the ice core isotopic ($\delta^{18}O$ and δD) profile of accreted ice to 3650 m depth. Analysis of the data set with the aid of an isotopic model of Lake Vostok revealed significant spatial and/or temporal variability in physical conditions during ice formation as well as variability in the isotopic content of freezing lake water (Ekaykin et al., 2010). The data suggested that there was a significant contribution of a hydrothermal source (2.8-5.5 mt of water per year) to the hydrological regime of the lake. Independent evidence (Jean-Baptiste et al., 2001; Bulat et al., 2004; de Angelis et al., 2004) including recent data on the distribution of helium isotopes (Jean-Baptiste, pers. comm., 2009) supports this inference. The extent to which Lake Vostok may be hydraulically connected with other components of the hydrological system beneath the Antarctic ice sheet cannot be assessed from such isotopic data. Precise geodetic GPS observations, from the southern part of Lake Vostok throughout IPY, have demonstrated that, at least on the time scale of five years, the lake and the ice sheet in the vicinity of Vostok Station are in steady-state (Richter et al., 2008) whereas other subglacial lakes show highly dynamic behaviours.

Biological and chemical analyses of the newly obtained accretion ice core and the development of clean procedures for biological sampling continued in collaboration with French scientists from Laboratoire de Glaciologie et Géophysique de l'Environnement, Laboratoire de Ecologie Microbienne and Laboratoire de Microbiologie des Environnements Extrêmes in the bilateral research network "Vostok," established just prior to IPY. A special effort was made by biologists from the Petersburg Nuclear Physics Institute (PNPI) of the Russian Academy of Sciences to accurately assess the cell concentration of microorganisms in the Antarctic ice sheet in the vicinity of Vostok Station. Segments of the Vostok ice core and 10 kg samples of snow collected from layers deposited before the beginning of human activity in the area were collected avoiding contamination (Figs. 2.6-5). The samples were then processed using state-of-the-art decontamination procedures (Bulat et al., 2004, 2007; Alekhina et al., 2007) and concentrated up to 3000-10,000 times. Among methods used for detection and counting of microbial cells (fluorescence, laser confocal and scanning electron microscopy, cytofluorimetry) only the flow cytofluorimetry was successful in assessing the very low quantities of cells typical in the samples studied. The results suggest extremely low biomass in ice strata, both of atmospheric and lake water origins, and emphasize the importance of ultra-clean procedures (and decontamination where necessary) if ice samples are to be used for microbiological analyses (Bulat et al., 2009). Similar pre-IPY studies were undertaken by U.S. and U.K. researchers, confirming low cell numbers and diversity in glacial and accreted ice, though their findings suggested higher cell numbers and diversity in the accreted ice (Christner et al., 2006).

The data obtained for contemporary snow and glacial (meteoric) ice suggest that the Antarctic ice sheet over Lake Vostok serves as a barrier preventing the contact of potential lake biota with the surface rather than being a conveyer of dormant microorganisms inoculating the lake water as assumed in the earliest studies. The purity of accreted lake ice suggest that Lake Vostok water may have a very low microbial content as PCR-based prokaryotic 16S ribosomal RNA gene sequencing has indicated that accretion ice is essentially free of bacterial and archaeal DNA (Bulat et al., 2009). The few bacterial phylotypes recovered from accreted ice cores have all been found in those

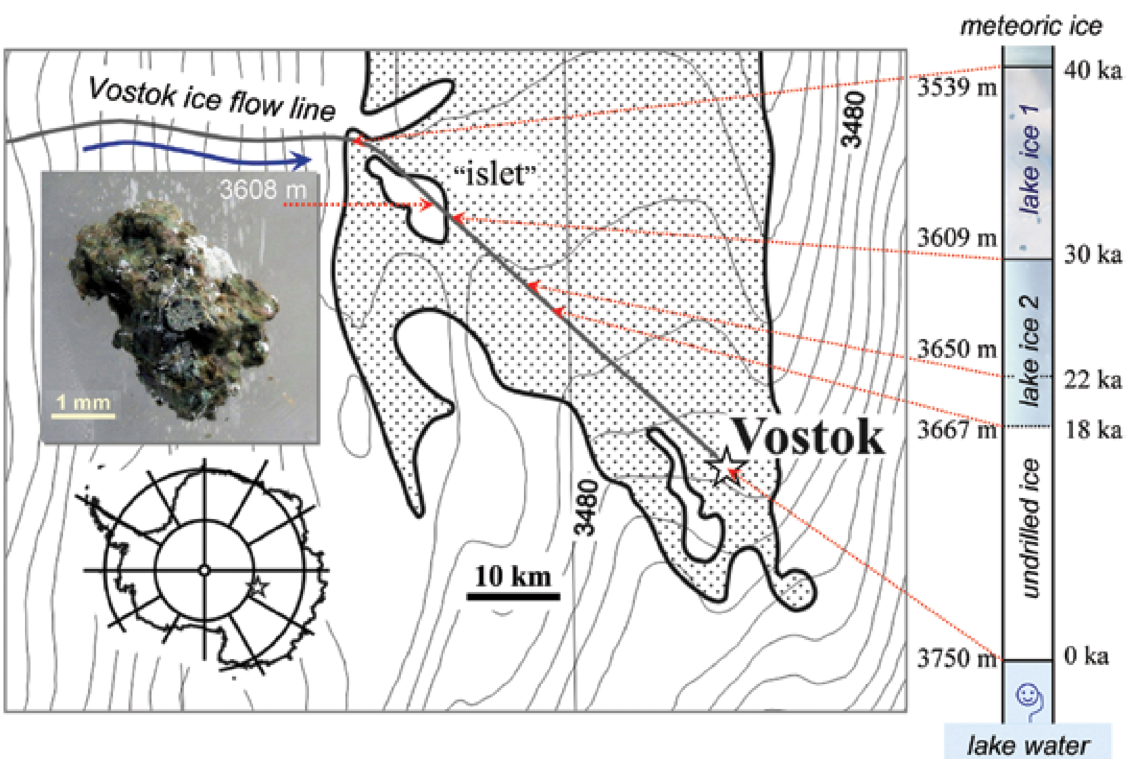

Fig. 2.6-4. Spatial and temporal coverage of the lake ice extracted as a core from the deep borehole at Vostok Station (adapted from Ekaykin et al., 2010). The Inset shows a relatively large inclusion of Lake Vostok bottom sedimentthat was trapped in lake ice 1 as the glacier was crossing the "islet" located 40 km upstream of the borehole.

Fig. 2.6-5a. Collecting snow samples for biological studies at the surface of the Antarctic ice sheet over the subglacial Lake Vostok (Jean Robert Petit from LGGE, France, January 2008), 3 km southwest of Vostok Station.
(Photo: Vladimir Lipenkov)

Fig. 2.6-5b. Russian scientist Sergey Bushmanov collects snow samples on the surface of the Antarctic ice sheet over the subglacial Lake Vostok (January 2010).
(Photo: Vladimir Lipenkov)

ice layers containing mineral inclusions.

Based on current knowledge of the lake conditions inferred from the accretion ice studies and from modeling, the lake may be inhabited by chemoautotrophic psychrophiles that are tolerant of high pressures (and possibly high oxygen concentrations) though no evidence of such microorganisms have yet been found in the accretion ice (Bulat et al., 2007a). Two independent laboratories have confirmed the presence of a thermophilic, chemoautotrophic bacterium *Hydrogenophilus thermoluteolus,* which may be associated with postulated hydrothermal activity in the lake (Bulat et al., 2004; Lavire et al., 2006). It has been speculated that the main water body of Lake Vostok is an extremely dilute, biological solution and this would suggest that life will likely be restricted to bottom sediments. If proven correct, Lake Vostok is an ideal location to develop methods for searching for life beyond our planet (Bulat et al., 2009).

Studies of Other Subglacial Lakes during IPY

The beginning of IPY marked the discovery of a major new set of subglacial lakes at the onset of the Recovery Ice Stream (Bell et al., 2007). Three or possibly four subglacial lakes, predicted by Johnson, are similar in scale to Lake Vostok and are coincident with the onset of rapid ice flow of a major East Antarctic ice stream that drains a surface equivalent to 8% of the ice sheet. These lakes were defined by the distinctive ice surface morphology of subglacial lakes, extensive, relatively flat, featureless regions bounded by upstream troughs and downstream ridges. The Recovery Subglacial Lakes appear to collect water from a large area, effectively concentrating the energy from basal melting and re-releasing it where it can have a significant impact on ice flow through either basal accretion or catastrophic drainage.

Two major programs targeted systematic studies of the Recovery Lakes as part of IPY, the U.S.-Norway traverse conducted surface geophysics and installed GPS stations to monitor ice sheet motions and the AGAP program targeted three flights at these major features. The IPY AGAP program (*Chapter 2.5*) collected gravity magnetics, laser and radar data over the southern two Recovery Lakes (Block et al., 2010). These data will be used to determine the distribution of subglacial water in the lakes and the upstream catchment and to evaluate the geologic setting of these features. The U.S.-Norway Traverse crossed all four of the Recovery Lakes during January 2009 on the return from South Pole Station to the Troll Station. Low frequency radar was used to map the morphology of the subglacial lakes and to image the ice sheet bed of the dynamic lakes identified by Smith et al., (2009). Together these two datasets will provide the first insights into the role subglacial lakes play at the onset of fast ice flow.

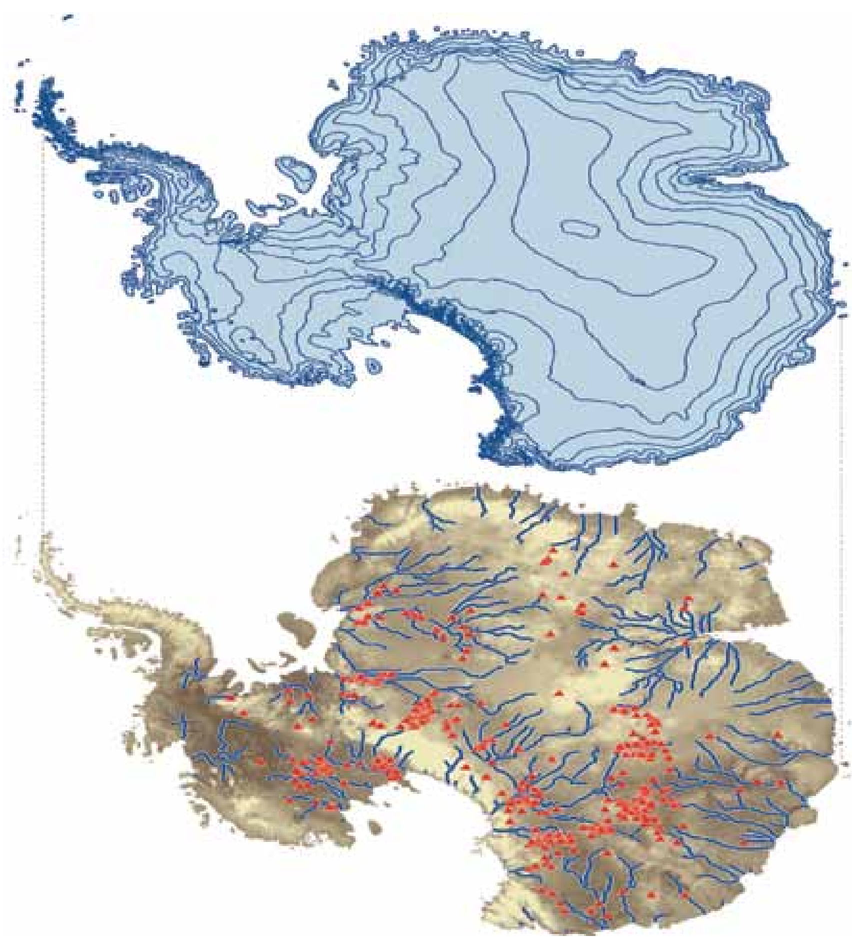

Fig. 2.6-6. The location (red triangles on the lower panel) of 387 subglacial lakes superimposed on the BEDMAP depiction of Antarctic sub-ice topography. The upper panel denotes the ice sheet surface topography.

(Courtesy: Andrew Wright and Martin Siegert)

Emerging Subglacial Exploration Programs

Significant progress has continued on subglacial lake exploration after the IPY period. Almost a decade of planning has led to the funding of major new programs to study various aspects of subglacial aquatic environments. These programs are in addition to continuing efforts at Lake Vostok. An ambitious U.K.-led program will survey and sample Subglacial Lake Ellsworth in West Antarctica in the next few years with lake entry predicted in 2011-2012. The geophysical studies of Lake Ellsworth have shown it to be 10 km long, 2-3 km wide and at least 160 m deep (under 3 km of ice). Surveys confirmed that sedimentary deposits can be expected on the floor of the lake. The surrounding topography revealed that the area is an ancient fjord developed at a time when an ice cap occupied the Ellsworth Mountains prior to the development of the West Antarctic ice sheet. Geophysical surveys confirmed that the lake has likely persisted through glacial cycles. The project will access the lake using clean hot-water drilling and deploy a probe to sample and measure both the water and sediment. Lake penetration and *in situ* sensing and sampling should take place in 2012. On a similar time scale, the U.S. has funded a further program (WISSARD) to enter, instrument and sample an 'actively discharging' subglacial aquatic system beneath Whillans Ice Stream, which is also in West Antarctica. Russian researchers had hoped to penetrate Lake Vostok during IPY, but were beset by technical problems so they are now developing a new strategy for lake penetration and sampling.

A New Frontier in Antarctic Science is Advanced by IPY

The IPY period saw the development of significant new insights into the importance of subglacial aquatic environments including:

- subglacial lakes were common features of ice sheets,
- a spectrum of subglacial environments exists,
- subglacial hydrologic systems and water movement beneath ice sheets on various spatial and temporal scales were common,
- subglacial lakes may be linked with the onset of ice streams influencing ice sheet movement, and
- outbursts of subglacial waters could have feasibly played a role in past climate change.

The exploration and study of subglacial aquatic environments is at its earliest stages and if the major advances realized during IPY are any indication of what is to come, the most exciting discoveries will unfold in the years ahead. In just a decade, findings regarding subglacial aquatic environments have revolutionized how Antarctica is perceived (Fig. 2.6-6). Ice sheets are now seen as exhibiting a highly dynamic behaviour and the environments beneath them may play critical roles in fundamental processes that affect the complex interplay of geology, glaciology, tectonics, ecology and climate over geologic time. On-going and planned projects will ultimately determine if subglacial environments house unique microbiological assemblages, but these programs would not have been possible without the momentum provided by the IPY.

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2.7 Permafrost

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Introduction and Overview

Hans-Wolfgang Hubberten, Jerry Brown, Hanne H. Christiansen and Hugues Lantuit

Permafrost is defined as ground (soil or rock and included ice or organic material) that remains at or below 0°C for at least two consecutive years (van Everdingen, 1998), and exists in approximately 25% of the terrestrial part of the Earth (Fig. 2.7-1). Since permafrost is present on most continents on Earth, in lowlands and in mountains, permafrost research is also undertaken beyond the traditional polar regions (north and south of 60°). During International Polar Year (IPY) 2007–2008, most permafrost research focused on land activities in polar regions. Several coordinated cluster projects had bipolar focus (Fig. 2.7-2). Permafrost research, forming an important part of the cryospheric research, is becoming increasingly multidisciplinary, bringing together geologists, geographers, engineers, biologists, ecologists, and soil and social scientists.

IPY 2007–2008 provided a unique opportunity for permafrost science to focus on regional, bipolar and multidisciplinary activities. Late 20th century observations and compilations of recent data indicated a warming of permafrost in many continental, marine-dominated and mountainous regions with resulting degradation of ice-rich and carbon-rich permafrost (Romanovsky et al., 2007). Major activities during IPY focused on the measurement of ground temperatures to assess the thermal state of permafrost and the thickness of the active layer, on the quantification of carbon pools in permafrost and their potential future remobilization, as well as the quantification of erosion and release of sediment along permafrost coasts, and periglacial process and landform quantification.

To address these and related bipolar questions, four permafrost cluster projects were approved by the IPY Joint Committee:

- The Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost (TSP) [IPY Project 50]
- The Antarctic and sub-Antarctic Permafrost, Periglacial and Soil Environments Project (ANTPAS) [IPY Project 33]
- The Arctic Circum-Polar Coastal Observatory Network (ACCO-Net) [IPY Project 90]
- Carbon Pools in Permafrost (CAPP) [Project 373].

These four cluster projects focused on research and observations in the permafrost and periglacial environments of the Planet Earth. They together represented more than 50 individual IPY Expression of Intent (EoI) proposals with participants from more than 25 countries representing both polar regions, as well as mid- and low-latitude, permafrost-dominated mountainous regions. They were coordinated by the International Permafrost Association (IPA) and its Secretariat, then based at the University Centre in Svalbard (UNIS). An overall objective of these coordinated projects was to produce a "snapshot" of permafrost conditions during the IPY period, with emphasis on the thermal state of the permafrost (TSP). This includes active layer thickness measurements as part of the Circumpolar Active Layer Monitoring (CALM) program established in the 1990s (Nelson et al., 2008).

The history and accomplishments of the IPA and its related IPY activities are well-documented in semi-annual reports in the journal *Permafrost and Periglacial Processes* (Brown and Christiansen, 2006; Brown and Walker, 2007; Brown and Romanovsky, 2008; Brown et al., 2008 a,b; Christiansen et al., 2007; Kuhry et al., 2009). Permafrost research during the Fourth IPY was highlighted in the Ninth International Conference on Permafrost (NICOP). From 29 June to 3 July 2008, approximately 700 participants representing 31 countries convened at the University of Alaska Fairbanks for the NICOP. Early results of IPY activities were published in the two-volume NICOP proceedings (Kane and Hinkel, 2008), with papers related to borehole temperatures (46), active layer (50) and a number of reports on periglacial, coastal and carbon processes. NICOP also marked the 25th anniversary of the formation of the International Permafrost Association and the Fourth International Conference on Permafrost in 1983, also held in Fairbanks, Alaska. Permafrost activities were also well represented at the official IPY Conferences in St. Petersburg, Russia July 2008 and at the International Geological Congress, Oslo, August 2008.

Traditionally, permafrost research has been mostly undertaken in Northern Hemisphere polar regions by Canada, Russia (formerly the Soviet Union) and the U.S.A. (Alaska). These three countries contributed

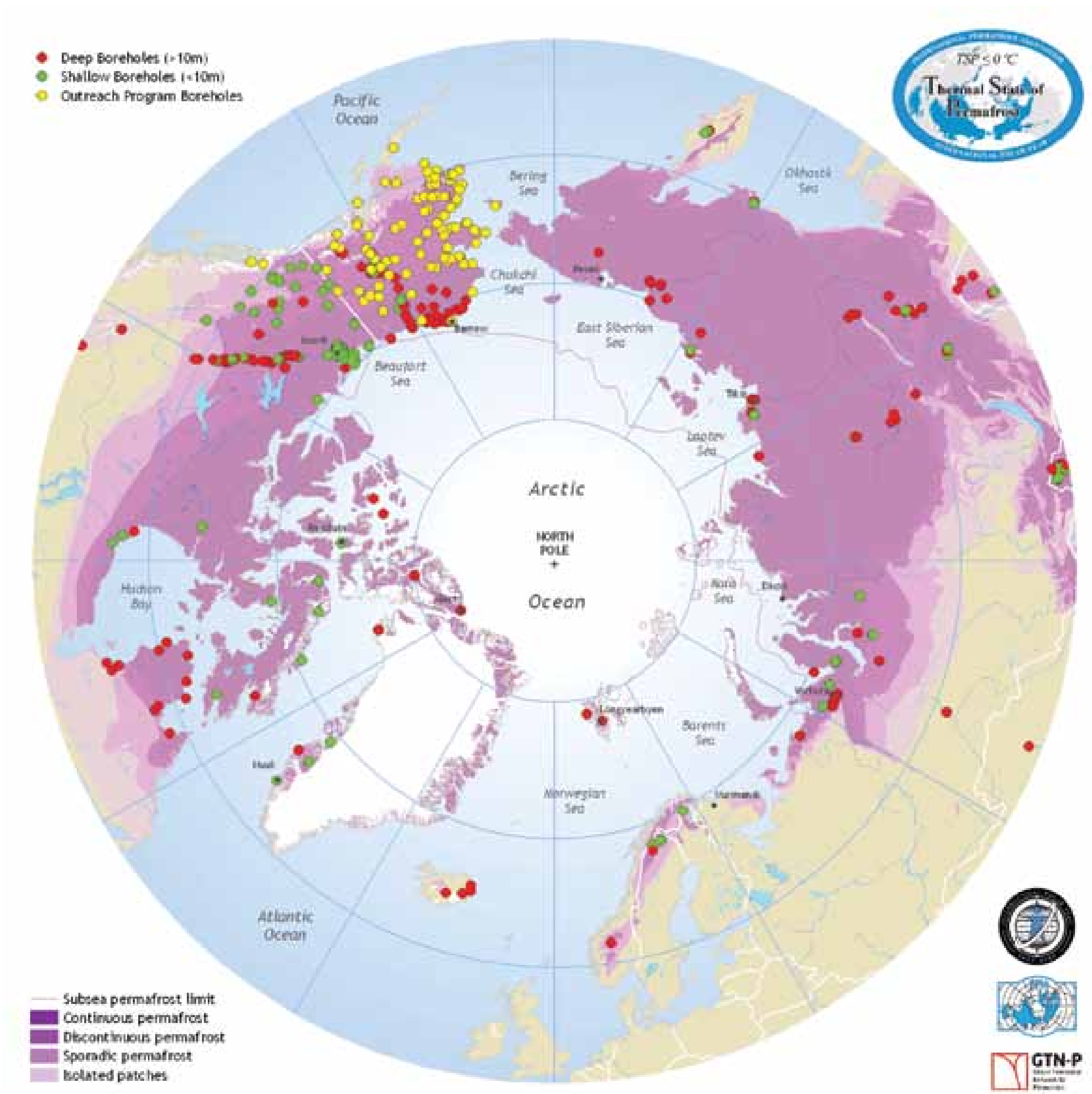

Fig. 2.7-1. Permafrost extent in the northern hemisphere and boreholes drilled during IPY.
(Map: H. Lantuit after Brown, 1998)

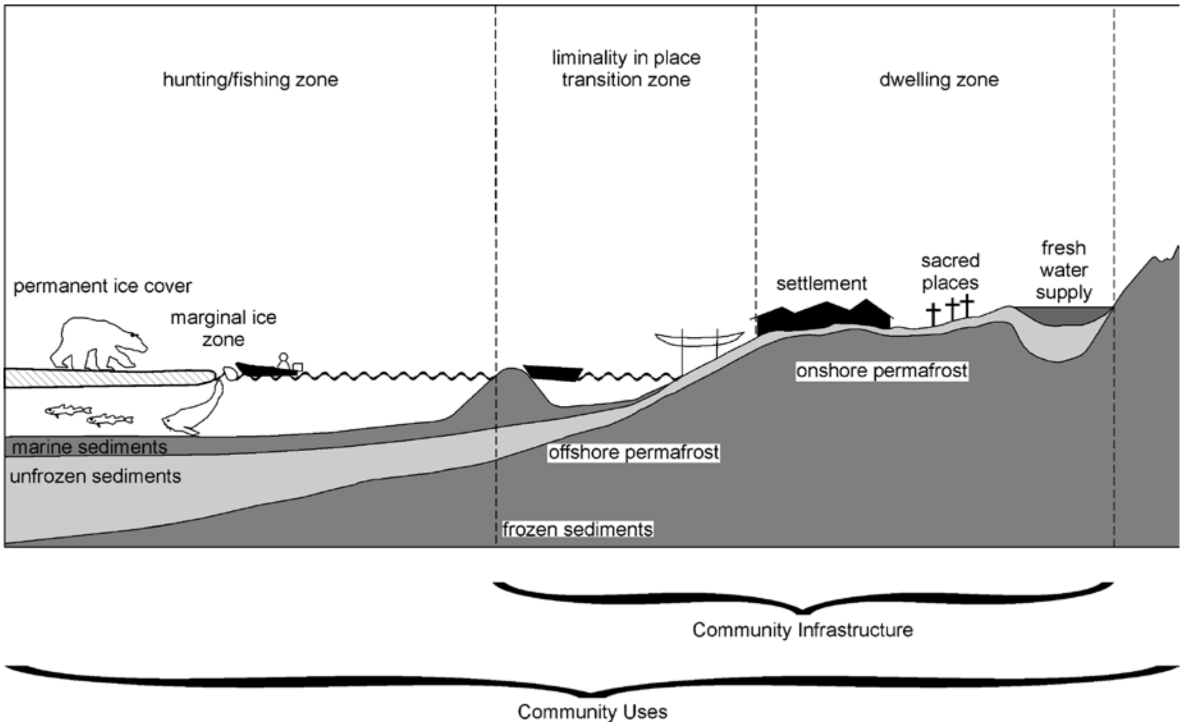

Fig. 2.7-2. The Arctic coastal zone depicted as the climate-sensitive region of the Arctic in which human activity and current rapid change intersect. Observatories in the coastal zone offer the potential for combined multidisciplinary work in a socio-economically relevant milieu.
(Graphic courtesy of the Arctic Centre, University of Groningen, Netherlands)

the majority of the observations performed during IPY. For the Northern Hemisphere, U.S.A., Canadian, Norwegian, Swedish, Russian and European agencies made substantial funding contributions. Several nations took on leadership in several of the IPY permafrost cluster projects. Norway took on a prominent role in temperature and periglacial observations and national database development in Norway, Svalbard and Iceland. Germany coordinated coastal permafrost observations and the drilling of several deep holes in Russia. Sweden played an important role in coordinating research on permafrost carbon pools. Portugal and Spain contributed with great enthusiasm to permafrost research with their projects in Antarctica and their outreach efforts strengthened the overall polar research of those two nations.

IPY provided a unique opportunity to build on existing permafrost and periglacial research in the Antarctic, with development of new sites and mapping efforts. Argentina, Brazil, Bulgaria, Italy, New Zealand, Portugal, Russia, South Africa, Spain, Sweden, U.K. and U.S.A. continued or expanded their activities. The 10-year European PACE project data were reviewed (Harris et al., 2009). In non-polar regions European countries continued the PERMOS (Vonder Mühll et al., 2008) network in Switzerland. In Asia, China, Mongolia, Kazakhstan and Japan continued on-going and developed new permafrost observations (see below). Most participating countries provided funding through national projects.

The establishment of the permafrost thermal snapshot in the TSP project primarily confirms large differences between marine and continental regions, and between bedrock and sedimentary sites, lowlands and mountains mainly in the Northern Hemisphere (Smith et al., 2010; Romanovsky et al., 2010 a,b; and Christiansen et al., 2010). Temperature trends from pre-IPY existing boreholes allow us to conclude that the evolution of the permafrost temperatures is spatially variable and that the warming of the upper permafrost differs in magnitude from region to region, as well as between bedrock and sedimentary regions according to the Northern Hemisphere TSP research. This highlights the need for continued acquisition of a baseline dataset such as the one developed by the TSP, but also for integration with climate monitoring and for sustained observations over many decades.

The Carbon Pools in Permafrost (CAPP) project contributed to our ability to better estimate the amount of carbon stored in permafrost soils, incorporating the upper three meters of the ground and deeper in some cases. Substantial numbers of new soil pedons from Russia were added to the database. This led to the publication of a revised estimate of the amount of carbon stored in the northern circumpolar permafrost region, amounting to approximately 50% of the estimated global below-ground organic carbon pool (Tarnocai et al., 2009). The increasing awareness that carbon pools in permafrost regions are much larger than previously estimated and the potential importance for the global carbon balance has prompted additional scientific questions.

A long-term framework aimed at maintaining both the new operational networks stemming from IPY, as well as the management and capacity-building efforts needed to sustain the level of observation are required. Our overriding goal has been the establishment of the International Networks of Permafrost Observatories including active layer, periglacial, coastal and carbon key study sites, and the development of a sustainable data management system and associated archives. The role of remote sensing in permafrost research has only been touched upon during the IPY and its specific role in detecting key processes relevant to permafrost dynamics as well as its input to modeling will be a future key permafrost technological development in both the Arctic and the Antarctic.

IPY made it clear that international research projects need strong coordinated management, data and information platforms. These needs and approaches were well-recognized by the IPA as early as 1988, when it held its first data session in Trondheim, Norway. This was followed by several workshops that led to the implementation of the Global Geocryological Database; a metadata based information service. Successful future integration with other international programs and compliance with data standards will maximize permafrost cross-disciplinary usability. Data management is often overlooked, but a fundamental component of modern research and often the most challenging for developing financial support. Yet, data management ensures the long-term viability and usability of the results of a large research effort such as IPY and for the IPA, this is of course especially so for permafrost observations and research.

An IPY permafrost initiative included also to continue the IPA support and patronage of the development of the Permafrost Young Researchers Network, PYRN (Bonnaventure et al., 2009). PYRN was started in 2005 to establish a network among students and young permafrost researchers in order to promote future generations of permafrost researchers. During IPY, PYRN grew to a web-connected organization of more than 720 students and researchers in 43 different countries. PYRN activities included training in permafrost methodology, development of the PYRN-TSP Nordic boreholes, participation in conferences, development of a database on dissertations and a list of 160 senior researchers in 16 countries to serve as mentors. Another outreach activity focused on education and was the compilation by the IPA Secretariat of a web-based map and associated searchable catalogue of International University Courses on Permafrost (IUCP) containing 136 courses in 17 countries during IPY. Both PYRN and IUCP are still active after IPY and thus are important IPA IPY legacies.

The four IPY permafrost cluster projects all were integrated into international research or observing programs. The TSP is part of the Global Terrestrial Network for Permafrost (GTN-P), which is a network of both the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS). Links to the Climate and Cryosphere (CliC) project of the WCRP, SCAR and IASC, and more broadly to the World Meteorological Organization (WMO) and the Global Carbon Project of the ESSP facilitated organizing and supporting the CAPP project. The long-term IPA connections with the Scientific Committee for Antarctic Research (SCAR) further facilitated the development of ANTPAS. The ACCONet activities, including new information on carbon fluxes from the erosion of permafrost coasts are a direct contribution to the Land-Ocean Interaction in the Coastal Zone (LOICZ) project, and its assessment of global coastal biogeochemical fluxes. It is also envisioned that the networks created and/or strengthened during IPY will form an integrated component of the upcoming observing networks of the Arctic (Sustaining Arctic Observing Networkds - SAON) and the Antarctic (Pan-Antarctic Observing System - PanTOS), thereby contributing to the overarching Global Earth Observation System of Systems (GEOSS). The international permafrost community also contributed during IPY to the Integrated Global Observing Strategy Theme on Cryosphere, which will serve as a strategic document for the elaboration of polar observing networks.

The June 2010 IPY Oslo Science Conference (*Chapter 5.6*), followed by the Third European Conference on Permafrost (EUCOP III) on Svalbard, provided opportunities for permafrost researchers and scientists from both hemispheres from related research fields to discuss IPY results in context with regional and global changes, and related environmental and social consequences. A special issue of the journal *Permafrost and Periglacial Processes* was presented at the June 2010 conferences, with regional papers for North America (Smith et al., 2010), the Nordic Region (Christiansen et al., 2010), Russia (Romanovsky et al., 2010a) and Antarctica (Vieira et al., 2010), and reports on Central Asia (Zhao et al., 2010), and carbon-rich permafrost (Kuhry et al., 2010), including a Northern Hemisphere synthesis paper on the snapshot of the permafrost thermal state during the IPY period (Romanovsky et al., 2010b; Fig. 2.7-1). The following sections provide more details on our four IPY permafrost cluster project accomplishments.

Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost (TSP, IPY no. 50)

Jerry Brown and Hanne H. Christiansen

Formal planning of the IPY Project 50, Thermal State of Permafrost (TSP) commenced in late summer 2003 following the IPA Zürich Council recommendations on permafrost monitoring and data management. TSP is a focused extension of the Global Terrestrial Network for Permafrost (GTN-P) program (Smith et al., 2009). In 2003, the GTN-P involved 15 countries in both hemispheres and consisted of 287 candidate boreholes and an additional 125 sites in the Circumpolar Active Layer Network (CALM) network. Inventories of these sites and metadata are found on websites maintained by the Geological Survey of Canada (GTN-P) and the CALM project (Shiklomanov et al., 2008).

A TSP planning document, co-authored by Romanovsky et al., (unpubl. 2003), was prepared in fall 2003 with the goal to produce a data set as a standard against which to evaluate future changes and reanalyze past histories of permafrost development and degradation. Initial results of the TSP project were reported and published in the proceedings of the Ninth International Conference on Permafrost (NICOP) in Fairbanks, Alaska and presented at the 33rd International Geological Congress in Oslo, Norway, in summer 2008.

The TSP plans were submitted to the ICSU IPY Planning Group, which assigned TSP to its Theme *"To determine the present environmental status of the polar regions by quantifying their spatial and temporal variability"*. A more formal TSP plan was prepared in July 2004 focusing on an intensive research campaign, with the overall goals:

- obtain standardized temperature measurements in all permafrost regions of Planet Earth (thermal snapshot);
- produce a global data set and make it available through the GTN-P;
- develop maps of contemporary permafrost temperatures;
- include periglacial process monitoring; and
- develop and verify models and reanalysis approaches for past, present and future permafrost and active layer temperatures and scenarios.

Detailed TSP planning took place at meetings and conferences leading up to the November 2005 Second International Conference on Arctic Research Planning (ICARP II) in Copenhagen where an IPA permafrost planning workshop was supported by the International Union of Geological Sciences (Brown, 2006). The TSP project was formally acknowledged by the IPY Joint Committee in November 2005 and subsequently was assigned as project no. 50. Formally, 26 individual Expression of Intent (EoI) proposals were assigned to Project 50. An international TSP meeting was held in October 2009 in Ottawa to summarize and coordinate the international synthesis of the TSP results including both the permafrost snapshot and analyzing permafrost temperature trends including the conditions during IPY. The TSP snapshot comprises measurements in over 850 boreholes and almost 200 current and pre-IPY CALM active layer sites in both hemispheres with over 25 participating and reporting countries (Table 2.7-1). Globally, nearly 350 new boreholes were drilled and instrumented during IPY. The total number of ground temperature sites

Table 2.7-1. Inventory of Northern Hemisphere TSP boreholes and CALM sites.

	Total # of boreholes	Established during IPY	Surface <10m	Shallow 10-<25m	Inter-mediate 25-<125m	Deep >125m	CALM sites*
Austria	3	-	-	3	-	-	-
Canada	192	119	39	122	20	6	28
China	39	6	5	14	15	1	11
Greenland	11	8	7	2	-	2	3
Finland	1	1	1			-	-
Germany (others in Russia/ Svalbard)	2	2	-	-	-	2	-
Iceland	4	-	-	4	-	-	-
Italy	8	0	-	4	4		
Japan (others in Svalbard/ Mongolia/Switzerland)*	10	9	9	1	-	-	-
Kazakhstan	4	2	3		1	-	3
Mongolia	75	27	31	33	8	3	44
Norway/Svalbard	61	48	14	29	13	4	3
Poland/Svalbard	-	-	-	-	-		4
Russia	151	12	39	82	25	4	45
Spain	2	0	1	-	1	-	-
Sweden	12	10	8	3	-	1	1
Switzerland (PERMOS)	30	8	1	15	14	-	2
U.S.A.	185	91	111	16	37	23	48
Total	**790**	**343**	**269**	**328**	**138**	**46**	**192**

** see CALM sites for details < www.udel.edu/Geography/>*

in the Antarctic and South America is 77, including 10 boreholes deeper than 10m in the Antarctic. Fifteen countries are participating in the Southern Hemisphere TSP projects.

Several protocols have been developed for obtaining and reporting data. These were based in part on the PACE project (Harris et al., 2009), the Permafrost in Switzerland (PERMOS) program (Vonder Mühll et al., 2008) and the NORPERM (Juliussen et al., in prep) and a joint U.S.-Russian manual (www.gi.alaska.edu/snowice/Permafrost-lab/literature/TSP_manual.pdf). An online, master borehole inventory containing selective site metadata and the 2007-2009 snapshot data of all boreholes sites was presented at the Oslo, June 2010 IPY Polar Science – Global Impact Conference. Detailed regional TSP results were presented at the Third European Conference on Permafrost (EUCOP III) focusing on the thermal state of frozen ground in a changing climate during IPY. Updates of annual CALM data are maintained on its website.

Early results of the TSP and related activities were published in the two-volume NICOP proceedings (Kane and Hinkel, 2008) with 46 papers related to borehole temperatures and 50 papers related to active layer observations. The establishment of the permafrost thermal snapshot in the TSP project primarily confirms large differences between marine and continental, between bedrock and sedimentary sites, and between lowlands and mountains mainly in the Northern Hemisphere. Temperature trends from pre-IPY existing boreholes allow us to see that the evolution of the permafrost temperatures is spatially variable and that the indications of warming of the upper permafrost differ in magnitude from region to region and between bedrock and sedimentary regions; these trends are mainly based on the Northern Hemisphere TSP research (Romanovsky et al., 2010b; Smith et al., 2010). Regional TSP results for North America (Smith et al., 2010), the Nordic Region (Christiansen et al., 2010), Russia (Romanovsky et al., 2010a), the Antarctic (Vieira et al., 2010), and Central Asia (Zhao et al., 2010) are presented in the June 2010 issue of *Permafrost and Periglacial Processes,* where the Northern Hemisphere polar permafrost thermal state synthesis was also presented (Romanovsky et al., 2010b).

Education and outreach is an important component of the present and future TSP. The Permafrost Young Researchers Network (PYRN) serves to involve students and early career researchers and to develop ownership of individual boreholes (Bonnaventure et al., 2009). The International University Courses on Permafrost (IUCP) was developed as an online searchable database for students when planning permafrost courses as part of their bachelor's, master's or Ph.D. degrees (Christiansen et al., 2007). Several field courses have enabled undergraduates, graduate student and teachers to become directly involved in permafrost measurements. At the pre-university level, a program to install boreholes and active layer measurement sites in the communities, primarily at schools, was expanded from Alaska to Canada and other countries (Yoshikawa, 2008). More than 100 such sites are included in the TSP.

To be successful, TSP required additional sites, instrumentation and funding to provide representative geographic coverage. Most participating countries provided funding to national projects. For the Northern Hemisphere, U.S.A., Canadian, Norwegian, Swedish, Russian and European agencies made substantial contributions. To further encourage broad participation of Russian institutions and sites, a U.S. bilateral project with Russia was funded. IPY provided a unique opportunity to coordinate and expand observations in both hemispheres with development of new boreholes and CALM sites. For the Antarctic, Argentina, Brazil, Bulgaria, Italy, New Zealand, Norway, Portugal, Russia, South Africa, Spain, Sweden, Switzerland, U.K. and U.S.A. started, continued or expanded their monitoring activities (see the following section). Specific national and multi-national projects were funded and these sponsors are identified in the June 2010 *Permafrost and Periglacial Processes* regional paper on the Antarctic (Vieira et al., 2010).

The ultimate legacy of TSP will be the establishment of a permanent international network of permafrost observatories including boreholes and periglacial process monitoring in addition to standard meteorological observations and as appropriate coastal and carbon observations. A sustainable data activity, building on the GTN-P, involvement of the PYRN researchers and outreach activities are critical components of the future TSP.

TSP related websites:

TSP Alaska-Russia: www.permafrostwatch.org
TSP Outreach: www.uaf.edu/permafrost
TSP Norway: www.tspnorway.com
NORPERM: www.ngu.no/norperm
Canada: canpfnetwork.com, GTN-P: www.gtnp.org
CALM: www.udel.edu/Geography/calm/
FGDC: nsidc.org/fgdc/
IPA: www.ipa-permafrost.org/
Pre-university outreach: ww.uaf.edu/permafrost/
PERMOS: www.permos.ch
International University Courses on Permafrost (IUCP): http://ipa.arcticportal.org/index.php/Courses-IUCP/
PYRN: http://pyrn.ways.org

Antarctic and sub-Antarctic Permafrost, Periglacial and Soil Environments (ANTPAS, IPY no. 33)

Gonçalo Vieira

Antarctic and sub-Antarctic Permafrost, Periglacial and Soil Environments (ANTPAS - no. 33) is an interdisciplinary IPY-core project of the IPA Working Group on Antarctic Permafrost and Periglacial Environments and of the SCAR Expert Group on Permafrost and Periglacial Environments. The project includes the Antarctic region as defined by the Antarctic Treaty, as well as South American permafrost regions. Significant advances in the framework of ANTPAS were obtained on: a) developing the Antarctic permafrost monitoring network; b) extending the Circumpolar Active Layer Monitoring Network – Southern Hemisphere (CALM-S); c) soil characterization and mapping, and d) mapping,

Table 2.7-2. Inventory of Antarctic and South American TSP boreholes and CALM sites.

Countries	Total # of boreholes	Established during IPY	<2m	Surface 2 - <10m	Shallow 10 - <25m	Inter-mediate 25 - <125m	Deep > 125m	CALM sites
South America (>1 m)								
Argentina	2	-	-	2	-	-	-	
Argentina (Spain)	2		2					
Antarctica								
Argentina / Japan	1	-	-	1	-	-	-	-
Brazil	15	15	15	-	-	-	-	-
Italy	5	-	1	3	-	1	-	4
Italy / Argentina / Japan	1	-	-	1	-	-	-	-
Italy / New Zealand	2	-	-	-	-	2	-	-
Italy / United Kingdom	2	1	-	1	-	1	-	1
New Zealand	1	-	1	-	-	-	-	1
New Zealand / United States	7	-	7	-	-	-	-	7
Portugal / Bulgaria / Spain	3	3	-	3	-	-	-	1
Portugal / Spain / Argentina	2	2	2	-	-	-	-	1
Russia	6	6	2	4	-	-	-	3
South Africa / Sweden	5	2	5	-	-	-	-	-
South Africa / Sweden / Norway	1	1	-	1	-	-	-	-
Spain / Portugal	11	9	8	1	1	1	-	3
Spain / Portugal / Russia	3	3	-	3	-	-	-	1
United States	6	5	2	1	1	1	1	
United States / Russia	2	-	1	-	1	-	-	2
Total (Antarctica)	**73**	**47**	**44**	**19**	**3**	**6**	**1**	**24**

monitoring and modelling periglacial environment processes and dynamics.

a) Antarctic permafrost monitoring network

(see Table 2.7-2)

The installation of a network of boreholes for monitoring permafrost temperatures in the Antarctic started in the late 1990s in the Transantarctic Mountains (McMurdo Dry Valleys and Victoria Land). It developed into other Antarctic regions in the early 2000s (i.e. South Shetlands – Ramos et al., 2007, 2008; Queen Maud Land), but it was only with ANTPAS that a systematic and coordinated approach took place in order to expand the network to the whole Antarctic region (e.g. Guglielmin, 2006; Adlam, 2009; Adlam et al., 2009; Ramos et al., 2009). Bockheim (2004) reported 21 permafrost boreholes in the Antarctic. Nine of the sites are located in the McMurdo Dry Valleys, five in North Victoria Land, four along the Antarctic Peninsula and three in Queen Maud Land. In late 2009, following ANTPAS activities, the network consists of 73 boreholes, including a more extensive coverage in the Antarctic Peninsula region, Transantarctic Mountains and Queen Maud Land, as well as important sites in Enderby Land, Marie Byrd Land, Vestfold Hills and Wilkes Land. This growth in the number of boreholes is highly significant since it will allow for the first time a continental-scale overview of permafrost temperatures in the Antarctic and an important increase on the knowledge of permafrost characteristics. A synthesis paper (Vieira et al., 2010) was prepared and contains initial data prior to the availability of data from the Antarctic season of 2009-2010.

b) Circumpolar Active Layer Monitoring Network – Southern Hemisphere (CALM-S)

The Antarctic monitoring network of CALM-S sites includes the active layer thickness and temperatures, as well as measurements of controlling environmental variables. Due to the coarse texture and rocky nature of the terrain in the Antarctic, it is generally impossible to measure active layer depth using mechanical probing thus the protocol focuses on ground temperatures. This also limits the application of the CALM grid concept and several sites consist essentially of a shallow borehole with data being collected at closely-spaced depths in the active layer. ANTPAS provided the framework for the application of a common CALM-S protocol to the Antarctic (Guglielmin, 2006) and the expansion of the network from 18 sites in 2004 to 24 sites in 2009. This will be extremely valuable for monitoring the influence of climate change on active layer temperatures and processes as these are central for understanding the ecology of the terrestrial environment.

c) Soil characterization and mapping

One of the main goals of ANTPAS is to produce a soil map of Antarctica. Because of the size of the continent and the low proportion of ice-free areas, activities concentrate on producing permafrost maps of the eight key ice-free regions: Queen Maud Land, Enderby Land, Vestfold Hills, Wilkes Land, Transantarctic Mountains, Marie Byrd Land, Ellsworth Mountains and Antarctic Peninsula. A soil description and sampling protocol manual and keys for classifying soils has been prepared and is available at http://erth.waikato.ac.nz/antpas/publications.shtml.

Field investigations have been conducted all over Antarctica. In Victoria Land reconnaissance and detailed soil maps, as well as soil studies have been produced (Bockheim, 2007, 2008, 2009; Bockheim et al., 2007, 2008a; McLeod et al., 2007, 2008a,b,c; Balks et al., 2008a; Bockheim and McLeod, 2008; O'Neill and Balks, 2008). In the Antarctic Peninsula region, Schaefer and others (Simas et al., 2006, 2007, 2008; Navas et al., 2008; Schaefer et al., 2008) conducted mapping and soil survey, while activities have also taken place in the vicinity of the Russian stations in Queen Maud Land, Enderby Land, Vestfold Hills, Wilkes Land, Marie Byrd Land, the Oakes Coast and King George Island.

d) Mapping, monitoring and modelling periglacial environments processes and dynamics.

Multi- and interdisciplinarity are one of the main characteristics of ANTPAS and that has become especially evident in the investigations on the dynamics of the periglacial environment. Several studies have taken place, especially in the Transantarctic Mountains, Queen Maud Land, Antarctic Peninsula, Marion Island and also in South America with a focus on a diversity of disciplines. Main themes were permafrost and geomorphological mapping (e.g. Vieira et al., 2007, 2008; Bockheim et al., 2008a,b; Guglielmin et al., 2008a; Serrano et al., 2008, Melo, 2009), dynamics (e.g. Hall et al., 2007a,b; Hauck et al., 2007; Raffi et al., 2007; Boelhouwers et al., 2008; De Ponte et al., 2008, 2009; Strini et al., 2008; Trombotto and Borzotta, 2008; Valcárcel-Díaz et al., 2008; Guglielmin et al., 2008b) and landscape evolution (e.g. Bockheim and Ackert, 2007; Bockheim and McLeod, 2008b; Bockheim et al., 2008c,d, 2009), climate analysis (e.g. Berg, 2009; Trindade, 2009; Nel et al., in press), ground-atmosphere modelling (e.g. Ramos and Vieira, 2009; Rocha, 2009), remote sensing of snow (e.g. Mora, 2009), interactions between vegetation, geomorphological dynamics and climate (e.g. Boelhouwers et al., 2007; Cannone and Guglielmin, 2008; Cannone et al., 2008, 2009; Guglielmin et al., 2008b; Haussmann et al., 2009) and microbial communities.

ANTPAS is an important project for Antarctic permafrost research. In its framework, international investigations have been fostered, funding was obtained in several countries and new regions of the Antarctic are now being monitored in the medium to long timescale, providing a legacy of field instrumentation and data. The main results of the project are still to come as the data is still to be collected. ANTPAS will have an impact on Antarctic permafrost research in the next decades. The activities and objectives will continue being promoted within IPA and SCAR, but it is vital that funding continues so that the monitoring sites can be maintained beyond the typical short-term periods of science project funding.

Arctic Circum-Polar Coastal Observatory Network (ACCO-Net, IPY no. 90)

Paul Overduin

Within the Arctic coastal dynamics community, the IPY was seen as a chance to act on the recommendations of the 3rd Working Group of the Second International Conference on Arctic Research Planning (ICARP II), which laid out a series of six key recommendations centered around the establishment of supersites for the interdisciplinary study of Arctic coastal science (Cogan et al., 2005) (Fig. 2.7-3). IPY Project no. 90, entitled Arctic Circumpolar Coastal Observatory Network (ACCONet), arose from the Arctic Coastal Dynamics Project (ACD) of the International Arctic Science Committee (IASC) and the International Permafrost Association (IPA). ACD also has been identified as an affiliated project of the Land-Oceans Interactions in the Coastal Zone (LOICZ) project of the IHDP/IGBP. In its second science plan, created at a workshop at the Arctic Centre in Groningen, Netherlands in November 2006, plans were laid for a template of observables and the creation and/or adoption of standard operating procedures for all sites (Overduin and Couture, 2008). The IPY JC tasked ACCONet to coordinate the group of IPY projects collectively identified with monitoring of the arctic coastal zone, grouping 21 IPY expressions of intent together with a further six projects that submitted national level IPY project proposals, but were not listed in the international IPY database.

IPY has generated sustained international interest in coordinated circumpolar arctic monitoring efforts. As a transitional environment, the Arctic coastal zone is an ideal location for monitoring change. Such systems generally show the greatest sensitivity to climatic or environmental shifts (Committee on Designing an Arctic Observing Network, National Research Council, 2006). The coastal zone is the site of human habitation, industry and transport in the Arctic. A monitoring network here is socio-economically relevant and provides a two-way opportunity to involve residents in monitoring activities and to inform local communities about science. ACCONet's goal is to provide the infrastructure and networking to establish an observatory network in the arctic coastal zone.

ACCONet sites were selected at the national level by national level coastal observatory IPY proposals and by adoption of ACD Key Sites with existing coastal monitoring records. Criteria for selection included site access and the existence of historical records. At the international level, major classifications of coastal typology were included and sites were selected to include the range of arctic coastal environments as described above. Some sites are solely coastal observatories, while others use permanent infrastructure associated with settlements or science stations.

Site selection was further coordinated at an ACCONet meeting in Tromsø, Norway in October 2007 (Flöser et al., 2008) and initial remote sensing data were distributed. Interim results from ACCONet projects were presented at the Ninth International Conference on Permafrost in Fairbanks, U.S.A. in 2008 in a session on subsea permafrost, sea level changes and coastal dynamics (Kane and Hinkel, 2008).

To provide a standardized basis for classification and change detection across all network sites, the European Space Agency granted ACCONet access to third party remote sensing data products for all sites currently being sampled. Both archived data and acquisitions of high spatial resolution optical data during and after IPY have been granted so that change detection up to, during and following IPY is possible for all sites. A critical baseline of remotely sensed data is the cornerstone of the network, permitting comparison of observatory sites in terms of many parameters relevant to coastal processes in the human, biological and physical sciences. Current coastline position is a key observable at each site and will be compared to archival data to provide a baseline for past decadal and current and future annual-scale coastal flux assessments based on two and three dimensional change detection.

In the absence of an international agency for coordinating and apportioning support for circumpolar projects, the IPY process depended on projects funded piece-wise by national-level funding agencies. Not all of the goals of the ACCONet IPY project were completed during IPY 2007–2008 highlighting the continuing need for international support for monitoring activities, analogous to activities around the Antarctic. Remaining major goals are the provision and expansion of observatory on-site infrastructure and resources for sustained networking between observatories. Two major initiatives are currently underway to address both gaps as a post-IPY activity. An initiative arising as a network of terrestrial stations originally based in Scandinavia, SCANNET has grown to include stations in North America and Siberia. This effort provides a basis for observatory coordination and networking, an overlap with ACCONet exists at two stations. The Sustaining Arctic Observatory Network (SAON), an initiative arising out of an Arctic Council directive, aims to create an Arctic network of networks. ACCONet is the coastal network identified in the AON report (Committee on Designing an Arctic Observing Network, 2006) and participates in the SAON process. SAON is working towards presentation of a science plan at the 2011 Arctic Council meeting.

Carbon Pools in Permafrost Regions (CAPP, IPY no. 373)

Peter Kuhry

The CAPP (Carbon Pools in Permafrost Regions) Project is an initiative of IPA and was a full cluster project under IPY. The IPA Project was launched in 2005 with endorsement of the Earth System Science Partnership (ESSP) Global Carbon Project and the WCRP Climate and Cryosphere Project. Its principal objective is to address the increased concern and awareness both within the international scientific community and the general public about the effects of global warming on frozen grounds in the Northern Circumpolar region. Thawing permafrost would result in remobilization of the previously frozen soil organic carbon pools and release large amounts of greenhouse gases. This is a so-called positive feedback within the Earth System as climate warming results in permafrost thawing, which causes a further increase of greenhouse gases in the Earth's atmosphere resulting in even more warming. This effect is not yet considered in climate model projections of future global warming.

Recent findings were discussed during the 2nd CAPP workshop held in Stockholm 3-5 June 2009, which was planned to summarize progress at the end of the IPY years. Research on 'permafrost carbon' has dramatically increased in the last few years. A cooperative effort of the Global Carbon Project and IPA CAPP and CWG (Cryosol Working Group) prepared an important update of the Northern Circumpolar Soil Carbon Database. The new estimate on soil carbon in permafrost regions provided by Tarnocai et al. (2009) more than doubles the previous value and indicates that total below-ground carbon pool in permafrost regions (ca. 1672 PgC) is two times larger than the present atmospheric pool (ca. 750 PgC) and three times larger than the total global forest biomass (ca. 450 PgC). This paper was selected to be included in *Nature* Research Highlights (Ciais, 2009). The new estimate was also mentioned by Nobel Laureate Al Gore in his speech at COP 15 in Copenhagen (December 2009).

Nevertheless, uncertainties remain with regard to the High Arctic, the Eurasian sector and the deeper cryoturbated soil organic matter (SOM) because of relatively few available pedon data. More CAPP-related field studies are, therefore, important and currently underway in Alaska, Canada, Greenland, Scandinavia and Russia. Another uncertainty is associated with the large polygon size (hundreds to ten of thousands of square kilometers) in the soil maps that are being used for upscaling pedon data. A future objective of CAPP, identified at the Stockholm meeting, is to assess if land cover classifications, which have much higher resolution, can be reliably used to estimate soil organic carbon pools.

Permafrost degradation has already been observed in parts of the northern circumpolar region and a significant portion of permafrost is expected to thaw in this century (ACIA, 2005). A unique aspect of permafrost degradation is that gradual thawing of the ground with depth over time will be accompanied by more dramatic events, such as ground subsidence due to melting of buried ice bodies and lateral erosion along the edges of thaw lakes and arctic coastlines, further accelerating the release of greenhouse gases. It is, therefore, of paramount importance to better understand and quantify the physical landscape processes which will lead to carbon remobilization, such as talik formation and thermokarst erosion.

The future permafrost carbon feedback not only depends on the rate at which the soil carbon pools will remobilize (thaw), but also on how quickly the material will start to decompose. Recent findings in Alaska and northern Sweden provide strong evidence that the deeper soil organic matter in permafrost terrain is starting to be released (Dorrepaal et al., 2009; Schuur et al., 2009). Nevertheless, no attempt has been made to define or map SOM lability at the

Northern Circumpolar scale.

CAPP aims for a constant dialogue with the climate and ecosystem modeling communities. Recent research has highlighted the role of SOM in the ground thermal regime of the Northern Circumpolar region, with implications for climate and atmospheric circulation at large (Rinke et al., 2008). An important objective is to define, in consultation with the modeling community, typical pedons appropriate for model setups, with vertical distribution of soil C quantity and quality (mean and range), for all of the land cover and/or soil classes differentiated according to permafrost zone. The thawing permafrost carbon feedback needs to be included in model projections of future climate change.

IPY provided an important incentive for coordination of permafrost carbon research. An important milestone was the new and much higher estimate for soil organic carbon in the northern circumpolar permafrost region (Tarnocai et al., 2009), which highlights the potential role of permafrost carbon in the Earth System. Evidence for remobilization of this deeper and older carbon has already been found. Nevertheless, significant gaps were also recognized at the 2nd CAPP workshop (Stockholm, 2009), which was held to summarize progress at the end of the IPY period and for which continued field research, data synthesis and modeling efforts are needed.

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Planning of the IPY permafrost research was largely accomplished under the coordination of the IPA and its working groups, and with initial financial support from the International Union of Geological Sciences that enabled a final planning session in November 2007 in Copenhagen following the ICARP II Conference. This Copenhagen workshop was attended by some 60 participants representing the four IPY permafrost projects. The coastal planning had a heritage of workshop support for the Arctic Coastal Dynamics (ACD) project from the International Arctic Science Committee (IASC) (Overduin and Couture, 2007). Other support for the IPA-IPY activities were provided by the Norwegian Research Council's three-year grant to the University Centre in Svalbard (UNIS) in support of the IPA Secretariat operation and its coordinating role for IPY (in particular the contribution of Angélique Prick). Details of the many individual national project sponsors are provided in synthesis papers presented in the Special June 2010 IPY issue of *Permafrost and Periglacial Processes*.

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2.8 Earth Structure and Geodynamics at the Poles

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The study of Earth structure and geodynamics in polar regions contributes to an improved understanding of processes of global relevance, due to the role of the Arctic and Antarctic in fields such as geology, oceanography and glaciology, among others. For a better understanding of how global tectonics and sedimentation interact with the Earth system and its changes, it is necessary to have information about the current and past state and relationships of tectonic plates located at high latitudes. Geodynamic, tectonic and sedimentary processes drive the topographic formation and the location of ocean basins and corridors between emergent masses of land. Currents in the polar oceans move along pathways – that have changed through Earth history – with a significant effect on global climate. Subglacial relief features and processes are also connected to the Earth's structure and geodynamics. Such elements may have impacts on the stability and evolution of the ice sheets and must be considered in climate models.

A series of IPY projects have been conducted on this topic, incorporating many research groups and forming examples of multi-national and multi-disciplinary efforts as promoted by IPY. The networks of polar Earth and geodynamics observatories have been significantly improved during IPY; technical advances have occurred and valuable experience of conducting research and collecting data in remote areas and in extreme conditions has been acquired. Scientific results are starting to emerge, as noted below, and more results will appear after processing the great quantity of new data collected during the IPY period of observations. The scope of scientific results will grow thanks to future continuity of measurements in the observing networks, data sharing and international cooperation. Following the IPY spirit, projects in this field have incorporated new and young researchers and have made a significant effort on education and outreach activities.

Geodynamic studies, subglacial environments and evolution of ice sheets

Geodynamic processes act at the base of polar ice sheets, in some cases affecting ice flow and subglacial drainage. The knowledge of such processes, jointly with features at the base of the polar ice sheets, is needed for a better understanding of the status and changes of the polar ice masses. Geodynamic observations using seismic, magnetic, gravity and ice-penetrating radar data, together with satellite imagery and geological observations, were conducted before and during IPY in several locations.

The West Antarctic Rift System was studied as an example of a tectonic system that may be connected to the subglacial drainage and especially to the fast-flowing glaciers that drain the West Antarctic Ice Sheet, with implications for ice sheet stability (Fricker et al., 2007).

The IPY project Antarctica's Gamburtsev Province (AGAP) explored the more than 1200 km long and 3000 m high subglacial Gamburtsev Mountains, located in East Antarctica and discovered by the Russians in 1957 during the International Geophysical Year. This project includes seven nations - U.S.A., U.K., Germany, China, Canada, Australia and Japan - and is a good example of the IPY spirit of promoting international cooperation to carry out multi-disciplinary research in a remote area needing very complex logistics (Fig. 2.8-1).

AGAP field work during the IPY observational period included the deployment of a network of seismometers at 26 different sites, operating instruments over the Antarctic winter at very low temperatures, and a series of survey flights, covering a total of 120,000 square kilometers, using two aircraft equipped with ice-penetrating radar, gravimeters and magnetic sensors (Fig. 2.8-2).

As part of the AGAP survey a seismic experiment was designed to image details of the crust and upper mantle structure across the subglacial range. It consists of the following elements: a) a 900 km linear array of 12 broadband seismic stations; b) an intersecting 550 km linear array of seven broadband seismic stations crossing the Gamburtsev Mountains at an angle of aproximately 115 degrees to the larger line; and c) 8 broadband stations deployed to improve 3-D resolution of the Gamburtsev Mountains survey.

More information about the Gamburtsev Antarctic Mountains Seismic Experiment (GAMSEIS) can be obtained on the Web site at Washington University in St. Louis: http://epsc.wustl.edu/seismology/GAMSEIS/index.html.

The new observations have confirmed the existence of a mountain range with a rugged landscape that it is suspected to have been essential in formation of the East Antarctic Ice Sheet. The data confirm earlier findings about the presence of subglacial peaks, valleys, lakes and rivers in a complex water system connected to the ice sheet flow (Bell et al., 2007).

AGAP research allows study of the lithosphere structure and uplift history of the Gamburtsev Mountains, located within an intraplate setting, and the role it played in the formation of the East Antarctic Ice Sheet. It has provided inputs into ice sheet, subglacial flow and climate models, and could help to locate the oldest ice core record in the Antarctic Ice Sheet which would be useful for future ice and bedrock drilling. Information about the AGAP project is available at www.ldeo.columbia.edu/agap.

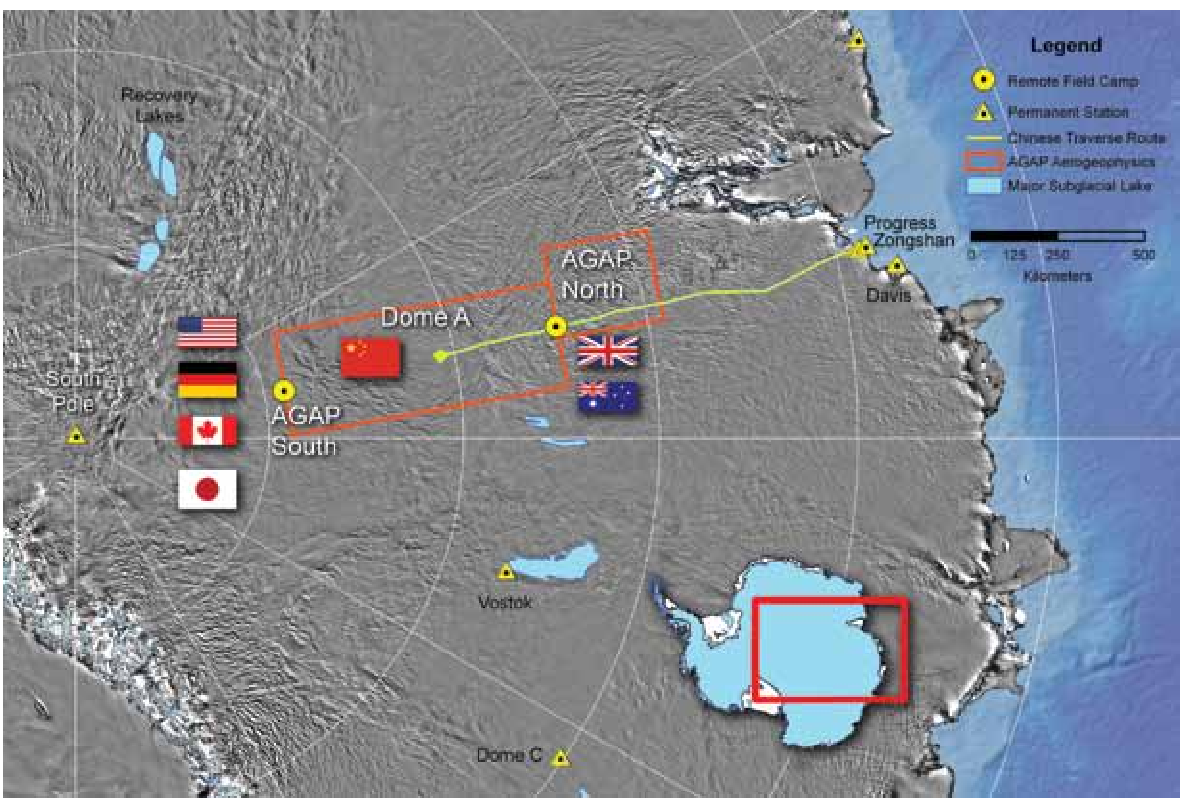


Fig. 2.8-1. Antarctica's Gamburtsev Province (AGAP) IPY project camp locations and aerophysical survey area in East Antarctica.
(Image: M. Studinger)

Plate tectonics and polar gateways in the Earth System

The thermohaline ocean circulation is an important component in the global climate system. The ocean currents transport heat and matter around the globe and are thus likely to cause global environmental changes. At large geological timescales, the global circulation is affected by geodynamic processes which control the motions of the lithospheric plates as well as crustal uplift and subsidence. Plate tectonic motions have constantly altered the shapes and geometries of the ocean basins and the distribution of land masses. In particular, the geometries of so-called oceanic gateways act as continental bottlenecks in the exchange of water masses between ocean basins and are, therefore, key parameters in simulating palaeo-ocean current systems and palaeoclimate scenarios. The reconstruction of the geometries of ocean gateways, basins and their continental margins feeds into numerical models studying the tectonic effect on climate changes. The IPY lead project PLATES & GATES (no. 77) focuses on tectonic reconstructions and sedimentary processes in Mesozoic and Cenozoic times and, in particular, on the transition from climatic greenhouse to icehouse conditions.

For the reconstruction of the oceanographic conditions at times of climate changes, tectonic-magmatic, geodynamic, sedimentary and biostratigraphic processes have been studied in the polar and sub-polar regions. Scientists of 16 nations have been involved in geophysical surveying techniques, tectonic measurements and sedimentary

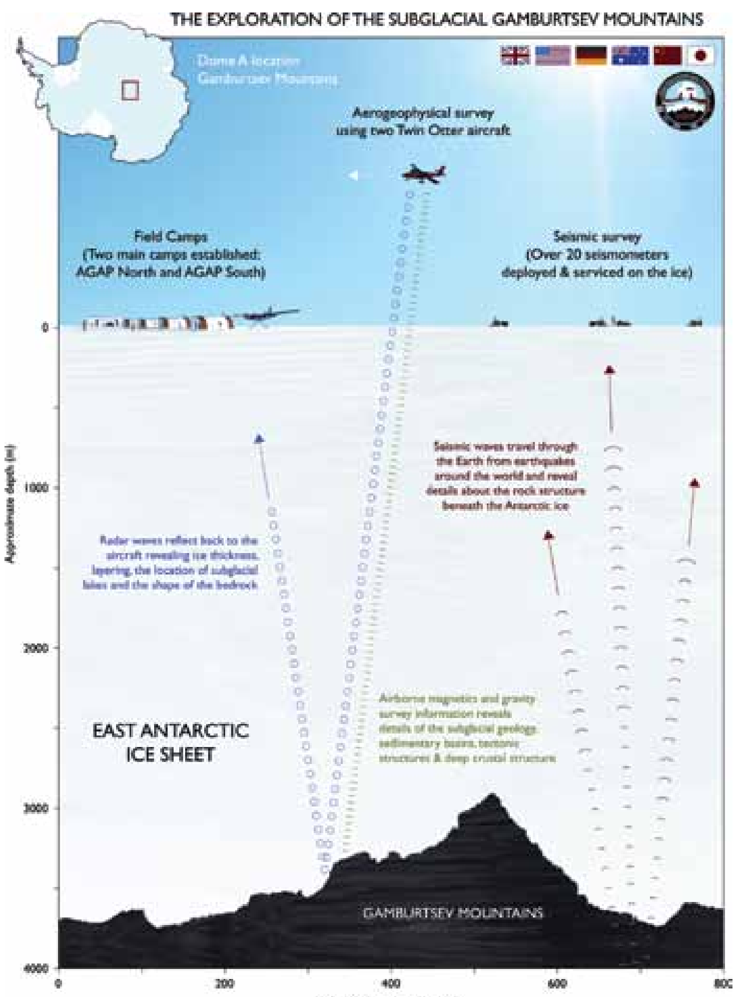


Fig. 2.8-2. Methods in the exploration of the subglacial Gamburtsev Mountains.

(Image: British Antarctic Survey)

sampling at relevant oceanic and terrestrial sites in the Arctic, sub-Arctic, Antarctic and the Southern Ocean in order to address specific objectives such as (1) seismic, magnetic and gravimetric surveying of crust and lithosphere of ocean basin, gateways and their continental margins for constraining past and present plate motions, mantle processes and vertical crustal motion, (2) reconstructing the distribution and variation of palaeo-current systems in the ocean basins by seismic imaging of sedimentary sequences in combination with analyses of palaeoceanographic proxies for decoding signals of past deep-water circulation patterns, (3) reconstructing the palaeobathymetric geometries of polar ocean gateways for shallow and deep water passages between basins at particular times, (4) reconstructing the long timescale palaeoclimatic evolution from the greenhouse conditions of the Mesozoic and Paleogene to icehouse conditions in the Neogene to Quaternary, and (5) numerical modelling of palaeo-current scenarios at varying gateway and basin geometries with regard to the global carbon cycle, the biological evolution and the development of ice sheets.

Studies in the Arctic

In the three Arctic field seasons of 2007, 2008 and 2009, palaeomagnetic, stratigraphic and petrological data from Franz Josef Land, Axel Heiberg Island, Ellesmere Island, the New Siberian Islands and Northern Greenland were collected and are being analyzed. Geoscientific studies including bathymetric mapping, seismic and magnetic surveying, sub-bottom profiling and sediment coring were carried out in the Amundsen Basin on transects across the Alpha-Mendeleev Ridge, over the Lomonosov Ridge and from the North Greenland Shelf. Geological and neotectonic studies were conducted for North and East Greenland, Svalbard, Bear Island, Mohns Ridge, Knipovich Ridge and the Barents Sea. The gateways between the Arctic Ocean and the other world oceans

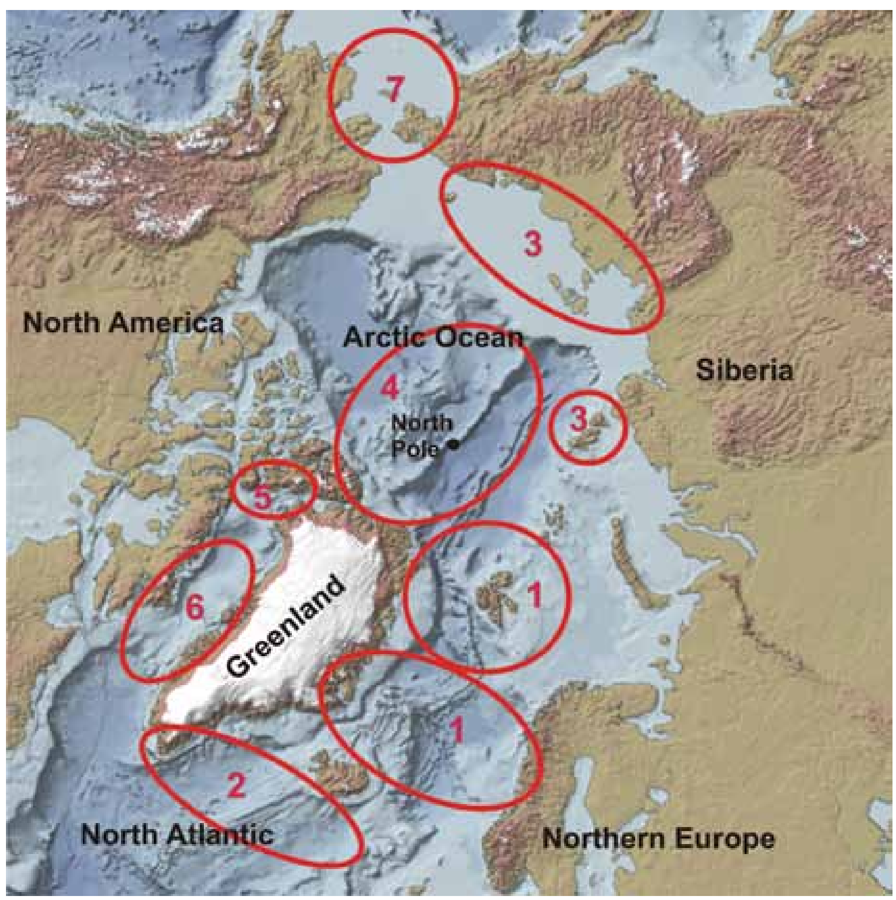


Fig. 2.8-3. PLATES & GATES research areas in the Arctic. 1, Fram Strait, Svalbard and Barents Sea. 2, Greenland Sea and North Atlantic. 3, Laptev Sea / E Siberian Sea. 4, Central Arctic and Alpha-Mendeleev Ridge. 5, Ellesmere Is., Axel Heiberg Is. and Nares Strait. 6, Davis Strait and Baffin Bay. 7, Bering Strait.

(Credit: ETOPO2 database, NOAA, National Geophysical Data Center, www.ngdc.noaa.gov/mgg/global/etopo2.html)

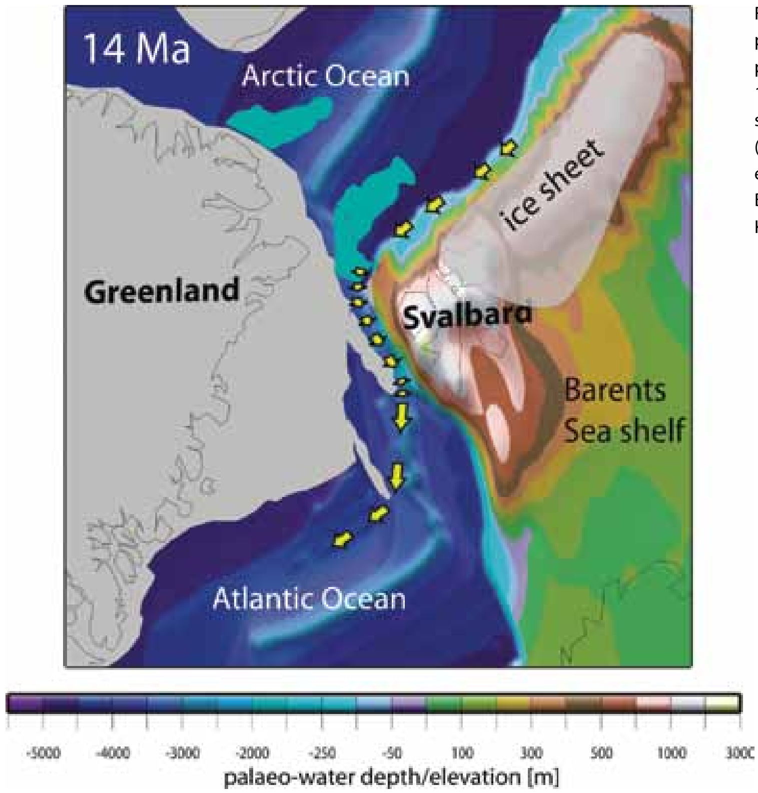


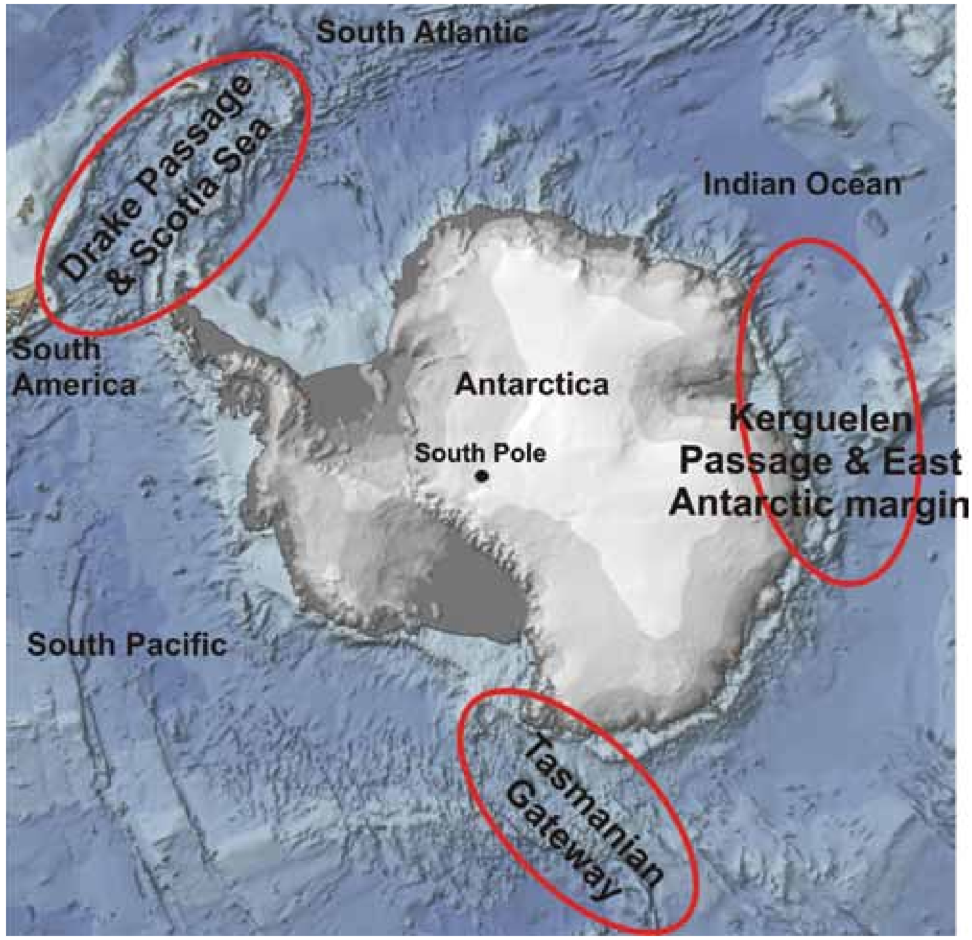
Fig. 2.8-4. Reconstructed palaeobathymetry and palaeotopography at about 14 million years ago with suggested path for icebergs (yellow arrows) and the extent of the northern Barents Sea ice sheet (after Knies and Gaina, 2008).

– the Fram Strait, Davis Strait/Baffin Bay with the Canadian archipelago as well as the Bering Strait – were investigated by a wide spectrum of geophysical and geological approaches to understand the timing and palaeoclimatic consequences of water mass exchange (e.g. Jakobsson et al., 2007) (Fig. 2.8-3). Recent work indicates that early Barents Shelf glaciation correlates with the initial deep water opening of the Fram Strait in the middle Miocene at about 15-14 million years ago (Knies and Gaina, 2008) (Fig. 2.8-4). A particular highlight was the multi-national, multi-expedition effort over several IPY seasons to obtain geophysical and geological data from the Barents Sea shelf, Svalbard and the adjacent Atlantic oceanic crust from the lithospheric mantle to shallow sediments (e.g. Wilde-Piórko et al., 2009) in order to improve understanding of the geodynamic, tectonic and sedimentary processes leading to and accompanying the initiation of major Arctic glaciation phases.

Antarctic studies

In the three Antarctic field seasons 2006/2007, 2007/2008 and 2008/2009, geophysical and bathymetric surveying as well as geological and biological sampling have been conducted in critical regions of the Southern Ocean that formed since the break-up of Gondwana (Fig. 2.8-5). A thorough revision of the break-up processes was performed in parallel with acquisition of new data, compilation and integration of existing data sets. The early stages of development of the Drake Passage/Scotia Sea gateway (e.g. Livermore et al., 2007; Maldonado et al., 2007) are now better constrained by studies of the tectonic and sedimentary evolution of the basins and the origin of bathymetric highs, the structure and history of relevant plate boundaries, and deformation of neighbouring land areas. In a multi-institutional effort, the areas of the southern to central Scotia Sea and northernmost Antarctic Peninsula have been surveyed and sampled thoroughly by a number of Spanish, Italian, U.K., Polish, Argentine, Chilean and U.S. led ship- and land-based expeditions during the IPY which will help solve the puzzle of plate kinematics and sedimentary basin evolution (e.g. Bohoyo et al., 2007; Maestro et al., 2008; Alfaro et al., 2010). From geophysical data of the Tasmanian Gateway, the

Fig. 2.8-5. PLATES & GATES research areas in Antarctica and the Southern Ocean.
(Credit: ETOPO2 database, NOAA, National Geophysical Data Center, www.ngdc.noaa.gov/mgg/global/etopo2.html)



timing of shallow- and deep-water opening between the Indian and Pacific Oceans as well as the motion between East and West Antarctica can be better constrained, which is critical to the determination of the timing of the uplift of the Transantarctic Mountains and the evolution of the West Antarctic Rift System. This large-scale continental rift may have played a role as an additional Pacific-Atlantic gateway at times when the submarine-based West Antarctic ice sheet did not exist or retreated entirely.

As global and regional bottom-water currents are strongly affected by seafloor morphology, the dynamics of outstanding oceanic plateaus, ridges and fracture zones as well as the varying morphology along continental margins and rises (e.g. development of sedimentary drift deposits) was an additional subject of the PLATES & GATES investigation. The Antarctic Circumpolar Current, for instance, is deviated by the elongated and up to three-kilometer-high basement ridges of the Udintsev and Eltanin Fracture Zone systems in the southern Pacific as well as the Kerguelen Plateau in the southern Indian Ocean. Investigating the crustal and sedimentary transition of the deep water Princess Elizabeth Trough between the shallower southern Kerguelen Plateau and the Antarctic continent was the aim of a specially designed Russian-German two-ship seismic experiment with RV *Polarstern* and RV *Akademic Karpinsky* in early 2007. This is just one example of several experiments in the true IPY spirit: a coordinated, multi-national, multi-ship effort with a large science added-value compared to individual experiments. The Russians conducted further extensive geophysical surveys along the continental margin of East Antarctica, which has already resulted in compiled stratigraphic models of the area from the Riiser-Larsen Sea to the eastern Wilkes Land margin (e.g. Leitchenkov et al., 2007). This mapping and interpretation effort contributes significantly to the *New Tectonic Map of Antarctica* (Grikurov and Leitchenkov, in press) as part of the IPY PLATES & GATES project. The information on this map, the characterisation of the Antarctic continent-ocean transitions (e.g. Gohl, 2008) and recent regional stratigraphic grids will be compiled in two follow-up, post-IPY projects *Circum-Antarctic Stratigraphy and Paleobathymetry* (CASP) and *Antarctic Paleotopographic Maps* (ANTScape). The generation of higher-resolution palaeobathymetric and palaeotopographic grids is a key condition for realistic simulations of palaeo-ocean currents.

Within the PLATES & GATES project, Cenozoic and Mesozoic climate reconstructions are performed using a variety of Earth system models designed to evaluate the effect of ocean gateways and basins on palaeo-circulation patterns, the global carbon cycle and nature of polar ice-sheet development. These experiments include sensitivity runs incorporating new palaeobathymetric reconstructions arising from the new data acquisition described above. The results from these experiments are compared with other model simulations, which include different forcing factors such as atmospheric greenhouse gases and mountain uplift to determine the relative importance of palaeogeography on the evolution of polar and global climates over long geological timescales.

An international effort

PLATES & GATES was set up as a closely knit network project, consisting of 33 individual projects with 46 expeditions, of which 26 expeditions were land-based, 27 were ship-based and 7 were conducted as combined marine-land expeditions. The split between Arctic/sub-Arctic and Antarctic/Southern Ocean expeditions is almost even. The following 16 nations with a total of about 60 scientists, technicians and students were active in funded polar expeditions for this project: Argentina, Chile, Denmark, Germany, Finland, Italy, Japan, New Zealand, Norway, Poland, Russia, Spain, Sweden, U.K., Ukraine and U.S.A.. At least two expeditions were conducted by Chile, Germany, Italy, Norway, Poland, Russia, Spain, Sweden and U.S.A. A summary of all funded PLATES & GATES projects and expeditions can be accessed at www.international-polar-year.de/Plates-and-Gates.28.0.html.

Although the tectonic evolution of the polar ocean basins and their continental margins has been investigated over the last 40 years in various individual projects, PLATES & GATES is the first coordinated effort to bring together the relevant geoscientific disciplines with the ultimate objective to understand the tectonic and sedimentary processes leading to ocean gateway developments. Also new is the approach to involve the numerical palaeoclimate modelling community, as they are the ones which translate the resulting basin and margin bathymetries and topographies into their dynamic model geometries. The challenge will be to compile this vast amount of data and results from the individual PLATES & GATES projects for more realistic dynamic palaeobathymetric and palaeotopographic grids of geological epochs which were relevant for major events in the Earth's climate history.

At this stage, most collected data and samples are still being analyzed, models are being built and first publications are being written. First initial results were presented at the IPY Open Science Conference 2010 in Oslo. With the abundance of the large variety of data and samples, it will take several years to unify models and describe the processes of polar gateway and basin formation and their effects on long-term climate change.

Polar Earth Observing Networks in International Polar Year

A dearth of geophysical observations in the polar regions has long been recognized, particularly from sites remote from permanent research stations or inhabited sites. Given the intensive global attention and accelerating research efforts focused on understanding ice sheet behaviour in response to climate change, the establishment of geophysical observing networks during IPY was particularly timely. Fundamental objectives of many of the projects involved in the IPY **Pol**ar **E**arth Observing **Net**work (POLENET) program are focused on measuring solid-earth phenomena that provide information on ice mass change and on controls on ice sheet evolution and dynamics. Predictions of the response of the ice sheets to changing global climate, including how ice mass will change, their modes of collapse and the rapidity of resultant sea-level rise, are crucial to planning for our changing environment. Robust predictions require systems-scale observations over the polar ice sheets. The new observational data from the POLENET deployments is providing such synoptic data for the first time.

Deployments of polar geophysical observatories in the IPY period

The label 'geophysical observatories' can be applied to large multi-instrument or single-sensor sites, consisting of a variety of instrumentation suites designed to probe the terrestrial and space environments. Here we focus on the IPY POLENET programme, which coordinated observations at permanent stations with remote site deployments of sensors at small stations designed to operate autonomously and record continuously (Fig. 2.8-6). GPS and seismic stations constitute the dominant sensor types in new deployments carried out as part of POLENET during the IPY period. Nevertheless, the POLENET umbrella also includes data acquired at magnetic observatories for earth applications (Cafarella et al., 2008), gravity and absolute gravity stations, tide-gauge sites and other types of geodetic observations.

Prior to IPY, continuously-recording GPS and seismic instruments were located at permanent research stations (Antarctica) or inhabited sites (Greenland) (Figs. 2.8-7a and 2.8-7c), relying on the local power grid for operation. Many did not have real-time communications and data were retrieved on a yearly basis. Several SCAR initiatives promoted deployment of remote geophysical observatories in Antarctica. In the time period immediately preceding IPY, many nations deployed GPS and/or seismic stations and arrays at seasonally-occupied stations and at remote sites away from permanent stations, experimenting with alternative energy sources (Fig. 2.8-6). Many of these stations operated continuously through the summer months and some succeeded with full-year recording. These pioneering efforts led the way for the IPY network deployments. IPY provided the opportunity to bring the Antarctic planning forward and forge international collaborative plans for network deployments. Similar IPY efforts were stimulated in the Arctic region, particularly in Greenland.

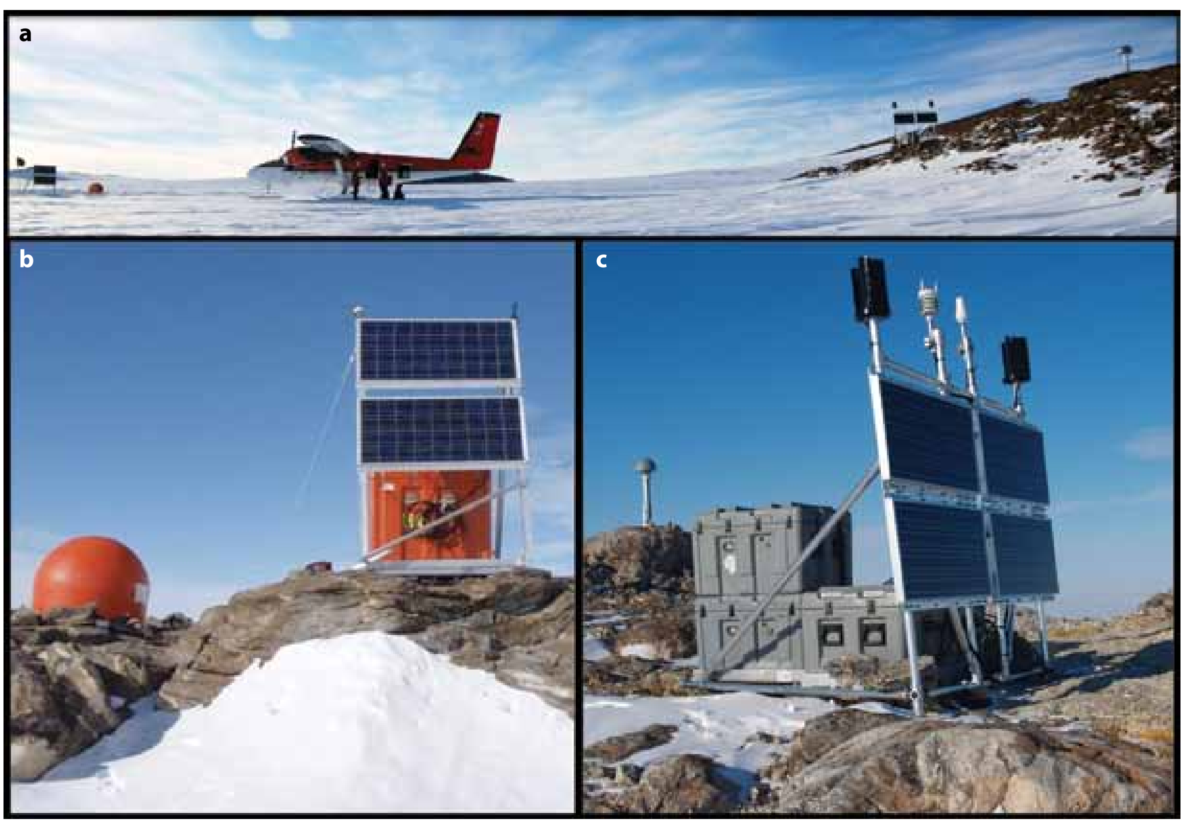


Fig. 2.8-6. POLENET autonomous, co-located continuously-recording seismic and GPS stations at Wilson Nunatak in Antarctica (a, upper panel). Seismic stations may be installed on snow, whereas GPS require bedrock, a major control on distribution of stations in polar regions. Remote sites are commonly hundreds of kilometers from logistic hubs, requiring long-range aircraft for deployment. Configurations of seismic (b, lower left panel) and GPS (c, lower right panel), show power system components (solar panels, wind turbines and extensive battery banks [in boxes]), Iridium antenna for remote communications with sensors. The GPS site has an ancillary meteorological package installed.
(Photos: Antarctic POLENET field team)

Spatially extensive new observatory networks scientifically, targeted new local stations, and upgrades and ongoing maintenance of pre-IPY instrumentation all contributed to the data collection during IPY. The most spectacular advances in network coverage occurred in Greenland and in Antarctica (Fig. 2.8-7) where extensive deployments of autonomous stations at remote sites have been completed. In these regions alone, over 175 remote observatories were installed during the IPY years and 28 nations contributed to the Antarctic and Arctic POLENET effort. More detailed information on the range of activities and national contributions to the program is provided on the POLENET web site (www.polenet.org).

In Greenland (Fig. 2.8-7d), a U.S.-led effort carried out in collaboration with Denmark and Luxembourg installed 46 new continuous GPS sites in a network called GNET (***Gre****enland GPS* ***Net****work*) that completely surrounds the bedrock margins of Greenland (Bevis et al., 2009b). Seismic efforts, led by Denmark, continued in Greenland through the IPY and a new internationally-coordinated seismic network, called GLISN (**G***reen***l***and* I*ce* ***S****heet Monitoring Network*), will deploy new, co-located, autonomous seismic and GPS stations in the coming years (Anderson et al., 2009).

In Fennoscandia, the LAPNET (***Lap****land* ***Net****work*) project deployed ~35 broadband seismometers, complementing existing continuous GPS stations and permanent seismic stations, led by Finland in collaboration with several European nations and Russia (Kozlovskaya and Poutanen, 2006). The HuBLE (**Hu**dson **B**ay **L**ithospheric **E**xperiment) overlapped with IPY activities and seismic data from an array of 35 broadband seismometers is providing a data set across part of arctic Canada, with science objectives highly complementary to the POLENET IPY programme (www1.gly.bris.ac.uk/~jmk/HuBLE/home.html). Elsewhere across the Arctic, geodetic and seismic infrastructure maintained by Canada, Denmark, Finland, Norway, Sweden, Russia and the U.S.A. form an important backbone network providing data from regions surrounding the new, embedded network deployments.

In West Antarctica (Fig. 2.8-7c), the ANET (***A****ntarctic GPS and seismic* ***Net****work*) project led by the U.S. in collaboration with Canada, Chile, Germany, Italy, Ukraine and the U.K. has installed a network of 29 new continuous GPS and 34 new continuous seismic stations, 18 of which are co-located. Three additional co-located stations and five additional continuous GPS stations will be installed (Fig. 2.8-7c). Additional components of this network on the Antarctic Peninsula include nine new continuous GPS on bedrock from the U.K. CAPGIA (***C****onstraints on* ***A****ntarctic* ***P****eninsula* ***G****lacial* ***I****sostatic* ***A****djustment*) project, six new continuous GPS on bedrock from the U.S.-led LARISSA (***La****rsen* ***I****ce* ***S****helf* ***S****ystem,* ***A****ntarctica*) project and new seismic installations by LARISSA and Spain. Other new continuous GPS stations were installed by Germany/Russia and by Italy to expand the network (Fig. 2.8-7c).

In East Antarctica, the GAMSEIS network (***G****amburtsev* ***A****ntarctic* ***M****ountains* ***Seis****mic Experiment*), also a component of the AGAP (*Antarctica's Gamburtsev Province*) IPY program, led by the U.S. in collaboration with Australia, Canada, China, , Italy, Japan and U.K. (Kanao et al., 2007a,b; Heeszel et al., 2009; Leveque et al., 2010), installed a network of ~40 broadband seismometers on the East Antarctic Ice Sheet (Fig. 2.8-7c). Additional seismic and geodetic installations also took place at inland stations (Leveque et al., 2008; Lombardi et al., 2009).

In addition to these new installations, an essential component of the POLENET programme includes continuously-recording geodetic and seismic stations that existed prior to the IPY period (Figs. 2.8-7a and 2.8-7b). These stations contribute data in sectors of the Arctic and Antarctic that are essential to achieve systems-scale polar data coverage. Some stations, for example Japan's Syowa Station, maintain a critical infrastructure of geodetic measurement systems that supplement GPS. Repeat measurements at absolute gravity stations and related gravity studies are another important POLENET IPY effort in Antarctica (Makinen et al., 2007, 2008; Rogister et al., 2007; Doi et al., 2008). The network of tide gauges in the Antarctica and Arctic provides important data for global sea-level estimates (Craymer et al., 2006; Watson et al., 2008).

Research outcomes

Seismic and geodetic data must be acquired over a substantial time span for robust analysis to be possible. Data collected during the IPY years is currently undergoing initial analysis; results will be forthcoming over the next few years. Here, selected

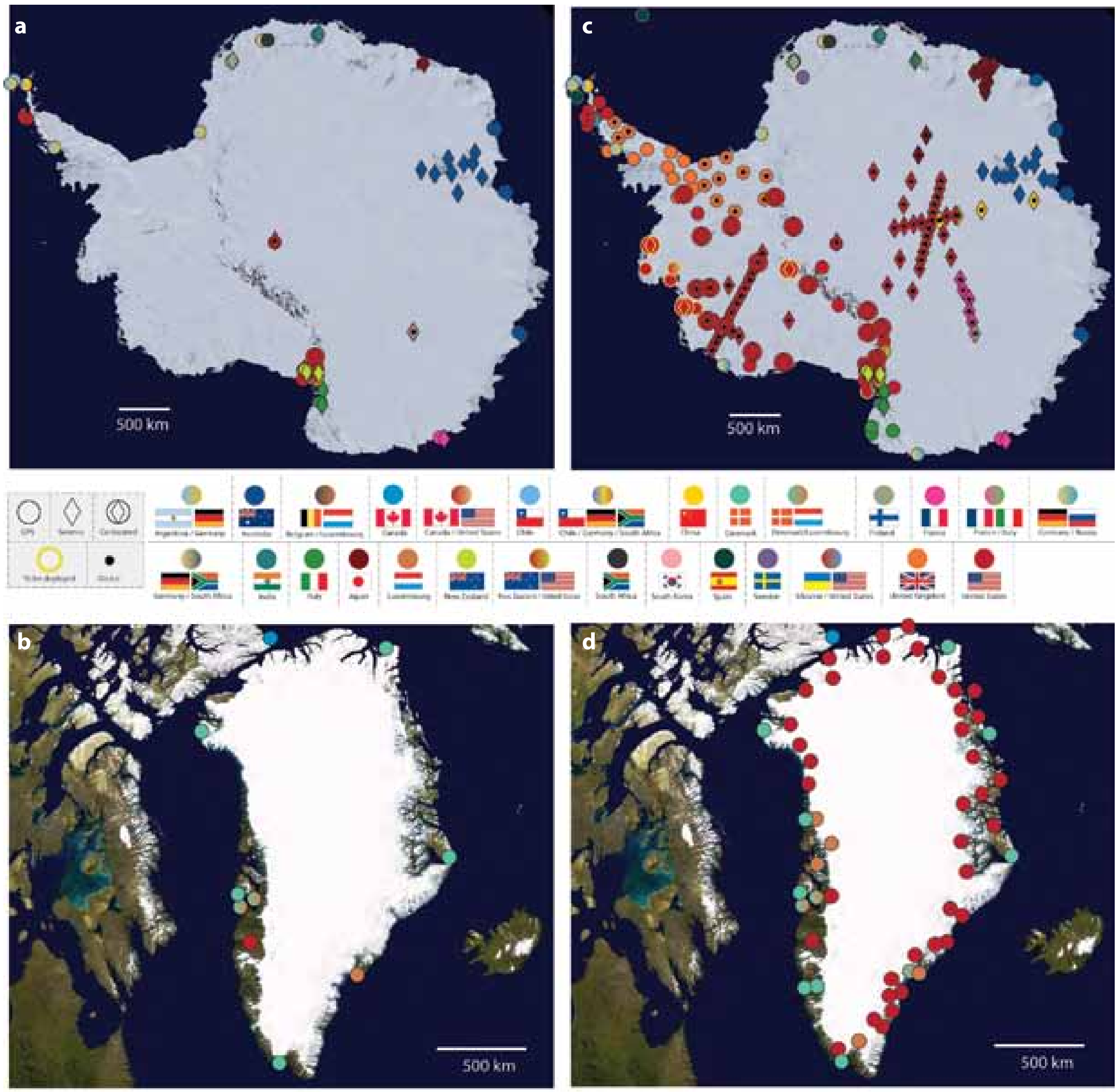


Fig. 2.8-7. Continuously-recording GPS and seismic stations prior to IPY (a, b) and deployed during the extended IPY period from 2006 to early 2010 (c, d).
(Credit: POLENET database, maintained by T.J. Wilson; maps drafted by M. Berg and S. Konfal)

science objectives of projects under the POLENET umbrella are highlighted to indicate the breadth of the scientific results that can be expected from the geophysical observations. Examples are provided of results from relevant studies incorporating pre-IPY and/or initial POLENET IPY data.

Glacial isostatic adjustment and ice mass balance

Measurements of vertical and horizontal solid-earth deformation at mm/yr accuracy are being attained by GPS measurements, providing the first comprehensive view of bedrock motions across polar regions. Viscoelastic rebound (referred to as post-glacial rebound – 'PGR', or glacial isostatic adjustment – 'GIA') is the time-dependent response of the solid Earth to glacial unloading over longer time scales, typically since the Last Glacial Maximum (LGM). Rebound-related crustal motions measured by GPS can provide a unique proxy record of ice mass change. Crustal motions predicted from GIA models depend on several factors, including the ice model (magnitude and position of ice loads, and the history of ice mass loss/gain) and the rheological structure of the Earth. The patterns of uplift documented by GPS measurements can document the positions of major ice loads (Sella et al., 2007). Mantle viscosity and the thickness and elastic rigidity of the lithosphere, control the magnitudes and time scales for isostatic response to glacial loading and unloading. These earth properties, and their variation, can be inferred from studies of seismic velocity and attenuation. Hence, by simultaneously measuring crustal motions using GPS and by gaining higher-resolution data on the thickness and rheology of the crust and mantle from seismological studies, the POLENET observational programme will make an unprecedented leap in our ability to model GIA in Antarctica and Greenland. The first tests of glacial isostatic adjustment models for Antarctica and Greenland based on GPS-derived vertical crustal motions mainly show that GIA model predictions do not match measured rates (Ohzono et al., 2006; Mancini et al., 2007; Khan et al., 2008; Willis et al., 2008c; Bevis et al., 2009a). This emphasizes the need for improved ice and earth models, and for 'GPS-tuned' GIA modeling.

Satellite-based monitoring provides one means of obtaining data on modern ice mass balance for entire ice sheets, and ongoing analyses of both altimetry and time-variable gravity data indicate mass loss from the Greenland and Antarctic ice sheets that appears to be accelerating (Rignot et al., 2008; Chen et al., 2009; Velicogna, 2009). Uncertainties in both types of measurements, however, are mainly due to 'contamination' by vertical displacement of the bedrock beneath the ice sheets due to 'rebound', and a poorly constrained 'correction' must be applied to remove this component in order to derive ice mass change (Alley et al., 2007). POLENET observing networks were designed to directly measure solid earth phenomena, including 'rebound', and provide the first synoptic ground-based observations across the Greenland and Antarctic ice sheets. The new observations will thus greatly reduce the sources of uncertainties in satellite-derived measurements. For example, GPS data from Enderby Land, Antarctica, has shown that an apparent region of positive ice mass change, which could be interpreted as increasing ice mass, cannot be ascribed to incorrectly modeled vertical crustal motion due to GIA (Tregoning et al., 2009). POLENET GPS measurements will thus complement the orbital data sets to measure ice mass change to an unprecedented level of detail and accuracy.

Earth's response to any very recent changes in ice mass, including rapidly accelerating ice loss over decades, will be largely elastic. Outlet glaciers in southeast Greenland showing accelerated flow speeds and rapid ice discharge in the current decade produced a detectable increase in uplift in the time series of a nearby continuous GPS station, recording a rapid elastic response of the crust (Khan et al., 2007). The new array of continuous GPS stations in both Greenland and Antarctica ensure that any such elastic signals will be recorded and, using seismological constraints on regional elastic structure and any independent data on ice mass change, we will be able to calibrate the relationship between ice mass change and crustal deflection. This geodetic measurement of earth's elastic response will provide a new way to recognize and measure periodic or accelerating ice mass loss.

Ice dynamics

An understanding of the 'solid Earth' processes that influence ice sheet dynamics is essential for predicting the future behavior and stability of the polar ice sheets. Coupled ice-sheet climate models require estimates of heat flow and sediment thickness at the base of the ice sheet, which can 'lubricate' the ice-rock interface. Since these parameters cannot be measured directly in Antarctica, seismic images provide a 'remote sensing' method to obtain information that is vital to understanding ice sheet stability. Scientists will use seismological investigations, integrated with results from the geodetic studies, to provide first-order constraints on geological/tectonic parameters important for understanding ice sheet dynamics.

New seismic data will be used to develop high-resolution seismic images that will constrain lithospheric viscosity and thermal structure as well as basal heat flow. High heat flow could produce sub-ice water, lowering bed friction, and may lead to the formation of subglacial lakes. Tomographic images of West Antarctica show the entire region is characterized by slow upper mantle velocities suggestive of high heat flow and thin lithosphere, but resolution is too poor for detailed correlation of low velocity regions with tectonic and glacial features.

Seismic imaging can also be used to map the presence of sedimentary substrate, bedrock topography and structure, all of which can significantly influence ice flow. A variety of evidence suggests that thick sedimentary deposits may be critical to the formation of fast-moving ice streams, yet the distribution and thickness of sediments beneath the ice sheets is poorly known.

Important constraints on ice sheet dynamics can be obtained from glacier seismicity, including insight into the flow of glaciers (e.g. Danesi et al., 2007). Glacial earthquakes of longer period provide critical information about processes associated with calving at ice margins and at the base of glacial systems (Wiens et al., 2008; Nettles and Ekstrom, 2010).

Deep Earth structure and evolution

The resolution of deep seismic structure using data from pre-IPY permanent seismic stations was on the order of 500-1000 km across most of Antarctica, but the new array of seismic sensors will improve this resolution by orders of magnitude, to produce seismic images at scales of interest to tectonic studies. For example, mantle structure associated with rifting, mountain uplift and with potential rising mantle plumes can now be resolved (e.g. Lawrence et al., 2006; Watson et al., 2006; Reusch et al., 2008; Gupta et al., 2009). In addition to improving detail of deep seismic structure beneath Antarctica, Greenland and other Arctic regions, the new seismic data will contribute significantly to global tomographic models of the Earth's interior, which suffer from undersampling around the poles, particularly in the southern hemisphere.

The polar regions provide a unique vantage point for studying the structure and improving understanding of the evolution of the Earth's inner core. Only seismic phases traveling along polar paths can map seismic anisotropy in the core, generally aligned parallel to Earth's rotation axis, which may be due to convection patterns in the core (Leykam et al., 2010). New studies will provide insights into core dynamics with implications for the earth's magnetic field.

Plate tectonics, intraplate deformation and magmatism, and tectonic evolution

GPS and seismology are primary tools for resolving neotectonic deformation between and within plates. The pattern of steady horizontal motion of the bedrock of the continents will be better resolved by the spatially distributed continuous GPS measurements and this information, combined with new knowledge of the location and magnitude of earthquakes from the deployment of seismic stations, will show any active deformation and elucidate the relationships between ice mass loads, GIA, crustal stresses and seismicity (e.g. Chung, 2002; Reading, 2007).

GPS studies using pre- and early-IPY continuous, quasi-continuous and campaign data have indicated rigid behaviour of the Antarctic plate (e.g. Ohzono et al., 2006; Casula et al., 2007; Capra et al., 2008; Jiang et al., 2009). In contrast, tectonic crustal motion is clearly resolved by GPS in the Bransfield Strait and Scotia Arc from GPS results (Dietrich et al., 2004; Smalley et al., 2007). Very small residual horizontal motions remain after rigid plate motion is removed in the Transantarctic Mountains region, suggesting rifting processes may be inactive (Casula et al., 2007; Capra et al., 2008) and/or that horizontal motions may be largely driven by glacial isostatic adjustment (Willis, 2008b).

Available data from long-term, continuously-recording seismic stations indicate that continental Greenland and Antarctica are characterized by a low level of seismicity (Gregersen, 1989; Kaminuma, 2000; Reading, 2007), with the exception of the tectonically active Scotia Arc region, (Fig. 2.8-8). Temporary seismic arrays have shown that regional seismicity is present in the continental interior and around the continental margins in Antarctica, and can be attributed to active structures and plates mobility (e.g. Reading, 2007). Earthquakes go undetected in Antarctica and improved seismic station distribution will reveal seismicity patterns in increasing detail. Deployment of hydroacoustic arrays on the ocean floor is improving monitoring of seismicity associated with Bransfield Strait and Scotia Arc neotectonics (Dziak et al., 2007, 2010). Seismic methods also provide a way to map ancient orogenic fabrics developed during assembly of supercontinents, including the Antarctic core of the Gondwana supercontinent (e.g. Reading, 2006b; Barklage et al., 2009) and the Laurentian and Fennoscandian shields (e.g. Eaton and Darbyshire, 2010), as well as active-margin crustal structure (Majdanski et al., 2008). Mapping of seismic anisotropy can reveal fabric associated with Precambrian and Paleozoic orogenic belts, with rifting processes and with mantle flow and plate motions (e.g. Müller et al., 2008; Reading and Heintz, 2008; Barklage et al., 2009; Salimbeni et al., 2009).

Interdisciplinary outcomes

In addition to the multidisciplinary science investigations and outcomes outlined in the preceding sections, GPS data from the POLENET network will be useful for other disciplines. Two prominent examples are GPS-derived observations of the ionospheric total electron content (TEC) and the amount of water vapor in the troposphere. Studies have shown that GPS data will provide unique and valuable constraints in the undersampled polar regions on TEC and electron density profiles (De Francheschi et al., 2006; Rashid et al., 2006; Yang et al., 2008) and on integrated water vapor estimates for weather and climate models (Sarti et al., 2008; Vey and Dietrich, 2008).

Many of the POLENET stations in West Antarctica have been augmented by simple meteorological instrument packages. Given the near-absence of *in situ* weather data from this region, these data will provide important new information for weather modeling and prediction as well as logistic operations. The new network of continuous GPS bedrock stations will both improve the global and continental reference frames for geodetic measurements (e.g. Dietrich and Rülke, 2008) and provide an important reference network for other experiments, including airborne surveys, meteorite sample locations and measuring glacier motions. The new data will significantly improve ocean tide loading models (King and Padman, 2005; King et al., 2005; Scheinert et al., 2007, 2008, 2010) and improve understanding of other global signals in the atmosphere and hydrosphere.

POLENET Programme – contributions and challenges

Observational data

The data provided by new arrays of sensors spatially distributed around Greenland, across the interior and along the margins of Antarctica, and in targeted regions of the Arctic represent an invaluable trove of new information, commensurate with the

Fig 2.8-8. Seismic station in the Wright Valley, McMurdo Dry Valleys, Antarctica. (Photo: Jerónimo López-Martínez, 2009)

expectations of a 'step function in activity' during an IPY period. For the first time, geophysical observations of a much greater density and a much larger spatial scale are available across the polar regions. This increased observational capacity is the foremost achievement of the Polar Earth Observing Network during IPY.

Many of the new data are being provided to the global science community either in near-real-time via remote communication systems, or shortly after data is retrieved from remote sites, and is available through established archiving facilities. As some data sets remain sequestered, a challenge remains in meeting IPY data goals. A broader data-sharing agreement ,and compiling project metadata and data access, are continuing program goals.

Multidisciplinary and interdisciplinary scientific research

As outlined in previous sections, scientific investigations on a broad range of topics utilizing the new polar geophysical observations are underway. Initial results are beginning to emerge as evidenced by the large number of studies cited here. Results of particular societal relevance will include prediction of mass fluxes of polar ice sheets, improved models of glacial isostatic adjustment, and better modeling and prediction of sea-level change. Improved understanding of continental evolution, plate and intraplate deformation processes, and feedback processes between ice sheets and the solid earth, will provide fundamental new insights into the workings of the polar and global earth systems. Opportunities for interdisciplinary studies between communities studying geophysical, climate, atmospheric and space weather phenomena are provided by new data sets from sectors of the polar regions where few measurements have previously been made. The synoptic scale and scope of the new observational data will surely lead to serendipitous scientific discoveries that we have not yet imagined.

Essential to reaching the full potential for scientific outcomes of the new observational data are integrated, multidisciplinary analyses. Examples include integration of geodetic observations with complementary seismic imaging studies to place new and robust constraints on solid-earth 'rebound', ice mass change and the contribution of polar ice sheets to sea level change, and the integration of geodetic and seismic investigations of glacial earthquakes to understand what their signals tell us about ice dynamics and response of ice sheets to climate change. Geographical integration, combining results and insights obtained from both poles, is also vital. Enhanced modeling capabilities must be developed to integrate data sets, assimilate the improved data sets and boundary conditions effectively, and improve model predictions. Providing a framework for collaborative, interdisciplinary, international research is a key future challenge for the POLENET programme.

Technical advances

The major challenges of remote deployments in polar regions are to provide year-round power, including through the several months of darkness at polar latitudes, to minimize logistical requirements to reach and maintain stations at very remote locations, and to operate the instruments in extreme environmental conditions. Major advances have been made in these areas during the IPY period. The U.S. National Science Foundation invested in technical development for this type of instrumentation. Detailed information from this effort on engineering developments for GPS deployments are found in Willis (2008a,b), Johns (2008), and online from the UNAVCO facility (http://facility.unavco.org/project_support/polar/remote/remote.html). Detailed information on new seismic engineering developments are provided on line by the PASSCAL Instrument Center (www.passcal.nmt.edu/content/polar-programs). Best practices information for autonomous systems construction, power supplies and satellite communications are provided via these websites to the polar science community. Additional development efforts from many nations and disciplines are described in abstracts from sessions on instrumentation development in polar regions that have been held at international meetings, such as European Geosciences Union annual assemblies, throughout the IPY period.

Polar outreach and new polar scientists

The POLENET programme has convened a range of international workshops and thematic sessions at international geoscience meetings to encourage dissemination of science outcomes and promote international collaboration. A significant thematic volume entitled *Geodetic and Geophysical Observations in Antarctica – An Overview in the IPY Perspective,* edited by A. Capra and R. Dietrich (2008), stemmed from these thematic sessions. A section of the journal *Physics Education* featuring IPY (Volume 43, Number 4, July 2008) included a contribution by A. Reading entitled *Bouncing continents: insights into the physics of the polar regions of the Earth from the POLENET project in the International Polar Year.* A variety of education and outreach media have been produced and are under development, and blogs, podcasts and project information are provided on the website *www.polenet.org*. A unique game produced by UNAVCO (http://facility.unavco.org/project_support/polar/remote/POLENET-engineering-game/POLENET-engineering-game.html) is designed to introduce students of all ages to the technical challenges of deploying polar networks and will be a centerpiece of an interactive touch-screen kiosk on polar science. Undergraduate students have worked on polar geophysical research as POLENET interns and a large cohort of graduate students is participating in the program, gaining experience in polar and global collaborative science. These outreach efforts will continue to be developed, hopefully within a broader international framework.

Infrastructure for geophysical observations

The POLENET programme has established a framework for ongoing international geophysical observation networks. Given funding, a subset of the stations deployed during IPY can remain in place as a pan-polar monitoring network. Additional types of sensors can be installed at the same locations to maximize disciplinary and interdisciplinary science outcomes and to minimize logistic efforts that distributed networks in the polar regions demand. Realization of ongoing and expanded polar networks will require new planning and coordination by the polar science community.

Acknowledgements

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2.9 Polar Terrestrial Ecology and Biodiversity

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Introduction

The land masses beyond the polar circles are vast; they are often remote, uninhabited and experience harsh climatic and physical environments. Because of these characteristics, polar ecological and biological research and observation are generally under-represented compared with such research and observation in more populated and benign environments. Past international campaigns have sought to document the biodiversity and ecological processes of terrestrial ecosystems and the previous polar years together with the International Biological Programme of 1967–1974 (Bliss et al., 1981) provided major advances in our understanding and a significant legacy in new generations of researchers and international collaborations. However, the Polar Region research has remained rather esoteric and relatively unconnected with global issues.

Within the past 20 years, this has changed: the Polar Regions have attracted world-wide attention because impacts of UV-B radiation, contaminants and particularly climate change are profound there. The comprehensive Arctic Climate Impact Assessment (ACIA, 2005) documented the major ecological changes occurring in the Arctic and showed how some of these changes, the biospheric feedbacks, were likely to influence the global climate system. Since then, a similar assessment for the Antarctic has also provided compelling evidence of major climate impacts on the Antarctic terrestrial biota (Turner et al., 2009; *Chapter 5.2*).

It is now clear that the Arctic and the Antarctic Peninsula are warming at approximately twice the general planetary rate and that many impacts are already affecting biodiversity and ecosystem processes, some of which are likely to have global consequences. International Polar Year 2007–2008 was therefore, organised at a critical time. The international science community mobilised during this period to document changes, understand its causes, provide baselines against which future changes can be measured, predict future changes and assess prospective global influence of some of these changes.

Altogether, 30 international project consortia on polar biology and ecology were formally endorsed by the IPY Joint Committee. Each project is described in Table 2.9-1, which gives information on title, status, geographic area studied, number of nations, partners and participants involved. For this chapter we contacted all team leaders in order to receive updated information on their activities. Seven projects operated both in the Arctic and the Antarctic; 19 projects operated only in the Arctic and most of these had a circumpolar perspective; three projects operated only in the Antarctic (one project did not receive funding). All projects were international (ranging from three to 27 participating nations), which means that the activities involved several nations with a short history in polar research. Some of the larger consortia had up to 150 participants, but some projects used only a handful of scientists. Many IPY projects were multidisciplinary and engaged climatologists, molecular biologists, soil biologists, plant and animal ecologists, modellers and experts on GIS and remote sensing. Some of the projects had socio-economic aspects as well. A common denominator for most of the research under IPY terrestrial projects was the impact of climate change.

At this time, many of the projects are still processing their data following fieldwork, so that results and publications are likely to continue for the foreseeable

Table 2.9-1. Terrestrial Projects under the International Polar Year 2007–2008

Status: O=operational; U=unknown; Nf=not funded;
Type of output, as of June 2010: B=books; P=papers; W=web site

Short title or acronym	IPY no.	Full title	Status	Region	# nations	# partners and participants	Type of output
ABACUS	246	Arctic Biosphere-Atmosphere Coupling across multiple Scales	O	Arctic: Fennoscandia	3	40 participants	P W
ABC-net	300	Arctic Biodiversity of Chars	U	Arctic			
ACCO-Net	90	Arctic Circum-Polar Coastal Observatory Network	O	Arctic			
Aliens	170	Aliens in Antarctica	O	Antarctic	11	22 partners / 40 participants	P W
ARCDIV NET	72	Network for ARCtic Climate and Biological DIVersity Studies	U	Arctic			
Arctic Hydra	104	The Arctic Hydrological Cycle Monitoring, Modelling and Assessment Program	U	Arctic			
Arctic WOLVES	11	Arctic Wildlife Observatories Linking Vulnerable EcoSystems	O	Arctic: Canada; Norway; Sweden; Greenland; Svalbard; Russia	7	32 partners / 142 participants	P W
B-CILCAS	390	Biodiversity and Climate Induced Lifecycle Changes in Arctic Spiders	U	Arctic			
BIRDHEALTH	172	Health of Arctic and Antarctic bird populations	O	Arctic, Antarctic	3	7 partners / 24 participants	P W
BTF	214	Retrospective and prospective vegetation change in the polar regions: Back to the future	O	Arctic, Antarctic	6	40	P W
CARMA	162	CircumArctic Rangifer Monitoring and Assessment Network	O	Arctic	7	60+ participants	B F W
CARP	329	The Canadian Antarctic Research Program	U	Antarctic			
CBMP	133	Circumpolar Biodiversity Monitoring Program	O	Arctic: circumpolar	7	24 partners	B P W
Cold Land Processes	138	Cold land processes in the northern hemisphere: regional and global climate and societal-ecosystem linkages and interactions	O	Arctic: circumpolar			
Complex monitoring and elaboration of IAS on polar PAS	284	Development of a system of Complex monitoring and elaboration of information and analytical systems on Protected Areas of the Polar zone	U	Arctic			
EBA	137	Evolution and biodiversity in the Antarctic: the response of life to change	O	Antarctic	22	40+ partners	P W

EBESA	452	Internationally coordinated studies on Antarctic environmental status, biodiversity and ecosystems	U	Antarctic	3	6+ participants	P
ENVISNAR	213	Environmental baselines, processes, changes and impacts on people in the Nordic Arctic Regions	0	Arctic	20	100	P
Freshwater Biodiversity Network	202	Arctic Freshwater Biodiversity Monitoring and Research Network		Arctic			
Greening of the Arctic	139	Greening of the Arctic: circumpolar biomass	0	Arctic: circumpolar	5	35 participants	P W
ITEX	188	International Tundra Experiment:	0	Arctic; Subarctic; Antarctic	9	>150 participants	P W
MERGE	55	Microbial and ecological responses to global environmental changes in polar regions	0	Arctic: Canada, Greenland, Svalbard; Antarctic	24	150 participants	B P W
NOMAD	408	Social science migrating field station: monitoring the Human-Rangifer link by following herd migration	0	Arctic: Kola Peninsula	6	7 participants	P W
NORLAKES 4 future	169	Network for present and future circumpolar freshwater lake research and data management	Nf				
PHOENIX	432	Exploring Antarctic dry valleys in preparation for Mars landings	0	Antarctic	6	7 participants	P
PPS	151	Biotic, abiotic and socio-environmental conditions and resource components along and across the Arctic delimitation zone	0	Arctic: circumpolar	9	150 participants	P W
RASCHER	262	Response of Arctic and Subarctic soils in changing Earth: dynamic and frontier studies	0	Arctic; Subarctic	4	22	
TARANTELLA	59	Terrestrial ecosystems: effects of UV light, liquefying ice and ascending temperatures	0	Arctic, Antarctic	14	24	P W
USGS Integrated Research	86	U.S. Geological Survey Participation in the International Polar Year	U	Arctic, Antarctic			
USNP Environmental Change	21	USNP Environmental Change	U	Arctic: Alaska, Chukotka, Yukon			

future. For this reason, the present chapter serves to document activities and early results rather than attempting a full synthesis of the data collected. Further, we are aware that the recent recognition of the global significance of the Arctic biota and ecological processes has stimulated a surge in research and observation activities that are not affiliated with IPY; we do not attempt to review these studies, some of which have been recently summarized (Post et al., 2009).

As most of the IPY projects focus on a certain aspect of change in ecosystem structure and/or function, we structure our paper along a timeline, that is, establishing current baselines against which future changes can be measured, documenting past changes, recent changes, and assessing the likely future changes and the impacts they may have within and outside the polar regions. Finally, we address some critical gaps in our understanding and discuss how the legacy of IPY may help reduce these uncertainties.

Establishing current baselines

Several IPY terrestrial projects sought to monitor biodiversity in terrestrial, freshwater and marine ecosystems across the circumpolar Arctic. For example, the Circumpolar Biodiversity Monitoring Program (CBMP, IPY no. 133; *Chapter 3.9*) is a part of the Arctic Council's CAFF (Conservation of Arctic Flora and Fauna) Working Group. Its aim is to coordinate pan-Arctic biodiversity monitoring, data management and reporting through the development of integrated, ecosystem-based monitoring plans, coordinated, Web-based data management products and targeted reporting tools (e.g. development of biodiversity indicators and indices). CBMP activities within IPY have developed, in coordination with other partners, monitoring frameworks for marine mammals and seabirds and contributed to the development of ecosystem-based, pan-Arctic biodiversity monitoring plans (marine and freshwater) bringing together a multitude of monitoring networks into a coordinated, pan-arctic monitoring effort. It has also contributed to an application for funding by SCANNET (Circum-Arctic Network of Terrestrial Field Bases) to extend the biodiversity monitoring plans to terrestrial ecosystems. A distributed, interoperable Web-based system for accessing and displaying current arctic biodiversity information has already been developed and a range of products is available.

One aspect of biodiversity documentation that has been notoriously difficult is that of microbial diversity and our baseline information has been poor compared with other taxa. MERGE (Microbial and Ecological Responses to Global Environmental Changes in Polar Regions, no. 55) is a large IPY consortium that has used recently developed technology to make major advances in understanding microbial diversity and function in both Polar Regions. MERGE discovered Polar microorganisms with surprising diversity, essential ecological functions and environmental roles as global warming sentinels.

MERGE has resulted in a major leap forward in our understanding of the microbial diversity of polar ecosystems and has contributed fundamental insights into Arctic habitats, their communities and climate impacts. Some of the most striking microbial communities were found in the perennial cold springs in the Canadian High Arctic. Grey-coloured microbial streamers form during winter in snow-covered regions but disappear during the Arctic summer. The streamers were uniquely dominated by sulfur-oxidizing species of the genus *Thiomicrospira* (Fig. 2.9-1). This finding broadens our knowledge of the physico-chemical limits for life on Earth.

The IPY project "The Phoenix Mars Polar Lander and Antarctic Analog Studies" (no. 432) had a component focused on the Antarctic Dry Valley Soil/Ice History and Habitability. It investigated life in an extreme environment by deploying an interdisciplinary team and using recently developed technologies including those used on the Phoenix Mars Lander. This effort not only produced new findings about Antarctica, but also provided a unique opportunity to do comparative planetology. For the first time high- and low- elevation valleys (University Valley and Taylor Valley, respectively) were sampled in depth with samples acquired and analyzed for soil mineralogy, soil solution chemistry, soil pedogenic processes, and total and live biomass, with complementary analyses performed for soil water availability and local environmental conditions. Due to the discovery of perchlorate (ClO_4) on Mars by the Phoenix spacecraft, this chemical was searched for in the Dry Valley samples and unexpectedly high levels were found. These were correlated to nitrate,

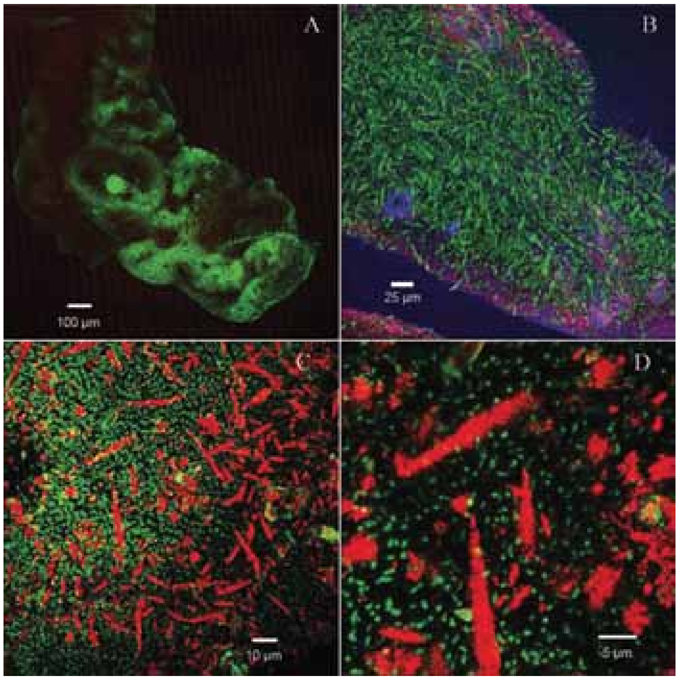

Fig. 2.9-1. Sulfur-oxidizing species of the genus *Thiomicrospira* (confocal micrographs of microbial consortia). (Photo courtesy Warwick Vincent)

supporting an atmospheric source and the hypothesis that ClO_4- is globally formed, but can accumulate only in hyper-arid environments. Also, a new ecosystem was found in the University Valley. The soil temperatures are below zero throughout the entire year, preventing free flowing bulk liquid water. Nonetheless, this valley, the best Mars analog location on Earth, shows soil pedogenesis, salt distribution, diurnal variations in dielectric permittivity, and living microbes, each requiring water, only available from surface snow and humidity or as vapor through sublimation of ground ice. The results from this study move us one step closer to understanding the potential habitats on Mars.

In contrast to the study in the Dry Valleys, IPY MERGE investigated Antarctic lakes and ponds that provided much information relevant to global warming and associated ecological responses. For example, Holocene climate changes were reconstructed from lake sediment cores and palaeo-nests of penguins. Viruses were shown to be responsible for controlling microbial food webs and community structures of the lake ecosystems. Catchment hydrogeology was shown to influence vegetation of terrestrial vascular plants and aquatic mosses. Unique aquatic "moss pillars" are maintained by synergetic biogeochemical processes of a microbial community, and its species diversity and functions have been dissected by metagenomic DNA analyses. In addition, human impacts, specifically the effect of trampling on soil characteristics and biota were first evaluated.

MERGE also compared the genetic characteristics of microbes from the Arctic and Antarctica, such as the 16S rRNA gene sequences of cold-dwelling cyanobacteria from lakes, streams and ice communities. Several High Arctic taxa were >99% similar to Antarctic and alpine sequences, including to the ones previously considered to be endemic to Antarctica. One High Arctic sequence was 99.8% similar to *Leptolyngbya antarctica* sequenced from the Larsemann Hills, Antarctica, and many of the Arctic taxa were highly dissimilar to those from warmer environments. These results imply the global distribution of low-temperature cyanobacterial ecotypes, or cold-adaptive *endemic* species, throughout the cold terrestrial biosphere.

In addition to "endemic" species, global-wide distribution of "cosmopolite" species, or cosmopolitans, has been strongly suggested. Eco-physiological and molecular characterizations of such cosmopolitans will compliment our understanding of distribution and colonization of cold-adaptive endemic species, and thus help prediction of microbial "sentinel" responses to Global Warming.

Fig. 2.9-2. A small moving drill was used to make holes to measure permafrost temperature for the BTF and PYRN-TSP projects near Abisko, northern Sweden. (Photo: Frida Keuper)

In the Arctic, two contrasting studies set up baselines of current biodiversity and population dynamics as well as ecosystem processes for organisms in higher taxa than microbes. ArcticWOLVES (Arctic Wildlife Observatories Linking Vulnerable EcoSystems, no. 11) project initiated comparable observations, mainly on animals, and experiments at a range of sites in Arctic Canada, Norway, including Svalbard, and Russia. The ENVISNAR (Environmental Baselines, Processes, Changes and Impacts on People in the Nordic Arctic Regions, no. 213) project focused national Swedish and international efforts, mainly on the physical environment and vegetation, in one geographic area, Swedish Lapland. ENVISNAR facilitated the analysis of unique long-term (up to 97 years) data on temperature trends, precipitation extremes, snow depth, snow pack structure, lake ice formation and melt timing, permafrost temperatures and active layer depth changes: most showed an accelerating change since the late 1980s (Callaghan et al., submitted: Johansson et al., 2008). ENVISNAR facilitated the research at Abisko by many projects and other IPY consortia such as ABACUS and BTF (see below). It provided logistics including helicopter support (courtesy of the Swedish Polar Secretariat – Fig. 2.9-2) and funding through the EU project ATANS for representatives of over 50 projects to set up baseline information.

To better understand small-scale changes in vegetation, and create a model baseline for future projections, one ENVISNAR sub-project has downscaled past and current climate to the 50 m scale (Yang et al., in press; Fig. 2.9-3). This model is currently being used to downscale regional climate model projections as a driver for ecosystems and permafrost models.

Past Decadal Changes

IPY Project "Greening of the Arctic: Circumpolar Biomass" (GOA, no. 139) used a hierarchical analysis of vegetation change based on a multi-scale set of GIS data bases, and ground information at several sites along two long, north-south transects across the full Arctic climate gradient.

GOA studied 1982-2008 trends in sea-ice concentrations, summer warmth index and the annual Maximum Normalized Difference Vegetation Index (MaxNDVI, an index of the photosynthetic capacity of the vegetation). Sea-ice concentrations have declined and summer land temperatures have increased in all Arctic coastal areas. The changes in MaxNDVI have been much greater in North America (+14%) than in Eurasia (+3%). The greatest increases of MaxNDVI occurred along the 50-km coastal strip of the Beaufort Sea (+17%), Canadian Archipelago (+17%), Laptev Sea (+8%) and Greenland Sea (+6%). Declines occurred in the Western Chukchi (-8%) and Eastern Bering (-4%) Seas. The changes in NDVI are strongly correlated to changes in early summer coastal sea-ice concentrations and summer ground temperatures (Bhatt et al., 2010 in revision; Goetz et al., 2010 in press).

Examples from north-south Arctic transects in Russia and North America studied within GOA, and examples from other locations from the sub-Arctic to high Arctic studied within the IPY "Back to the Future" (BTF, no. 214) project, provide insights to where the changes in productivity are occurring most rapidly. In polar desert landscapes near the Barnes Ice Cap, Baffin Island, Canada, recent repeat photographs 46 years after the initial studies and under the auspices of the IPY "Back to the Future" project show dramatic changes on most land surfaces. The vegetation is increasing

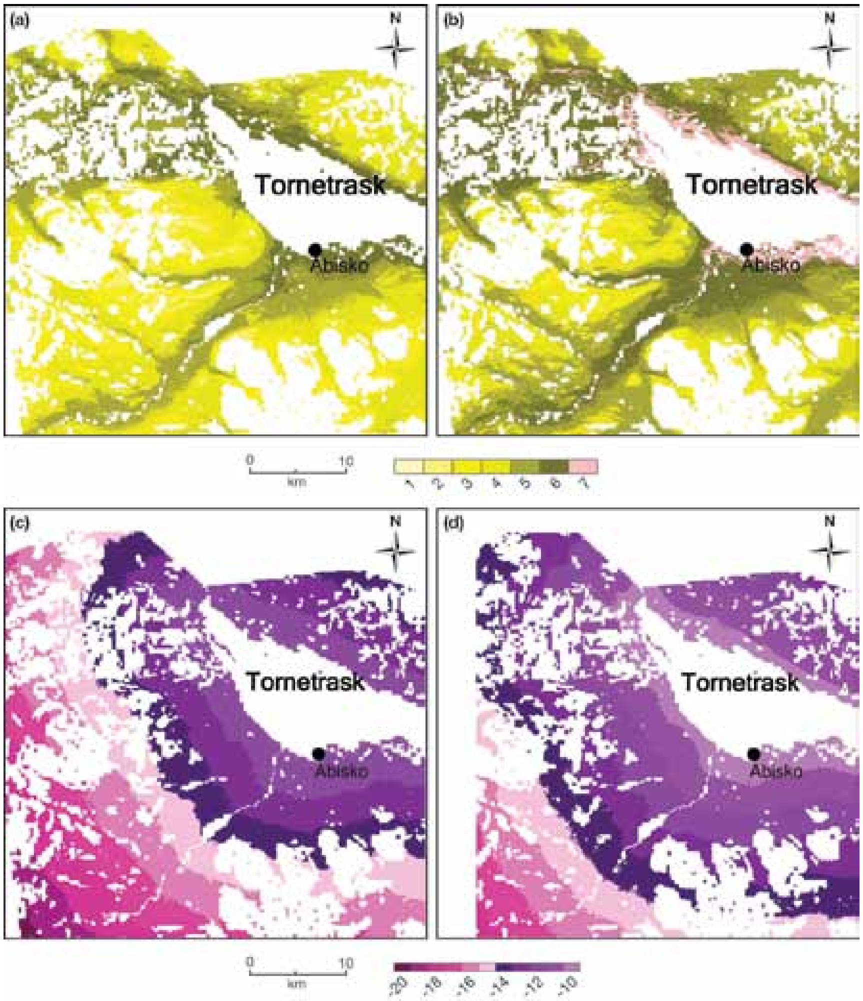

Fig. 2.9-3. Mean monthly surface-air-temperature pattern for the Abisko region for different periods: (a) August 1913-2008, (b) August 2000-2008, (c) January 1913-2008, (d) January 2000-2008. For the August data, growth days above 5°C (GDD5) are used because of their importance for climate-impacts research.
(From Yang et al., in press)

most strongly along ponds and streams and areas with abundant moisture and nutrients. Similar changes have been observed by the BTF researchers in wetland vegetation of East Greenland, but changes in productive habitats in West Greenland over the past 42 years were not so dramatic. Changes in more barren rocky landscapes are less obvious in Canada, although there is strong increase in lichen cover that cause increased NDVI on these surfaces as well. A new satellite-derived data set (AVHRR GIMMS NDVI data) has permitted IPY-GOA to make the first analysis of NDVI trends in the High Arctic (north of 72°). Dry, unproductive sites in West Greenland and Svalbard re-visited after 70 years (Prach, 2010; Fig. 2.9-5) were also much smaller than those in the more productive habitats.

In the Low Arctic, several GOA studies indicate that change is occurring most rapidly in areas where disturbance is most frequent. In the central Yamal Peninsula in West Siberia, Russia greening is concentrated in riparian areas and upland landslides associated with degrading massive ground ice, where low-willow shrublands replace the zonal sedge, dwarf-shrub tundra growing on nutrient-poor sands (Walker et al., 2009; Walker et al., 2010 in press). Analysis of annual growth rings in the Varendei tundra of the Nenets Autonomous Okrug, Russia shows that willow growth is closely linked to the temperature record and increasing NDVI, demonstrating a clear relationship between deciduous shrub growth and Arctic warming (Forbes et al., 2009).

In sub-Arctic Sweden, site re-visits under the BTF project over the past three decades showed dramatic changes in birch tree growth by a factor of six (Rundqvist et al., in press), recent invasion of

2.9-4. Field sites established in 1967 on Disko Island, West Greenland, were re-visited in 2009 as part of the BTF project to repeat measurements of plant performance and plant community composition in order to detect changes over four decades. (Photo: T.V. Callaghan)

aspen trees (Van Bogaett et al., 2010a; Rundqvist et al., in press) and increases in the growth of some shrub species. Repeated photography over 100 years has been used to document changes in tree line location, birch forest growth and aspen stand growth. Also, dendrochronology has been used to identify disturbances to the birch forest caused by periodic outbreaks of geometrid moths that are currently expanding their northern ranges (Post et al., 2009) and herbivory of aspen by moose. A picture emerges in which disturbance to birch caused by its invertebrate herbivore facilitates invasion by aspen that is subsequently controlled by moose browsing (Van Bogaert et al., 2010a, 2010b). Thus the effects of climate on vegetation growth in this region are complex and at least partly result form indirect effects via the population dynamics of herbivores. At tree line near Kharp in northwest Siberia, IPY-GOA studies have shown that alder shrubs are expanding vigorously in fire-disturbed areas and seedling establishment is occurring primarily in areas with disturbed mineral soils, particularly non-sorted circles. Analysis of NDVI trends using three Landsat images (1985, 1995 and 1999) near Toolik Lake in Alaska shows that the higher spatial-resolution Landsat-derived greenness trends match those derived from the AVHRR GIMMS data and that increased greenness is strongest in disturbed areas, such as road-side tracks, and sites with warmer soils and abundant moisture such as south-facing water tracks, wetlands and areas with warmer soils, such as moist non-acid tundras (Munger, 2007).

At the most detailed level of observation, the GOA team used methods developed for the International Tundra Experiment (ITEX) to monitor changes between 1990 and 2008 in the species composition and structure of the vegetation in 150 plots near Toolik Lake, Alaska (Gould and Mercado, 2008). Average plant canopy height at each point has increased by a factor of three; shrub cover and graminoid cover also increased, whereas moss cover has decreased. These observations are concomitant with direct warming manipulations carried out within ITEX. At the same level of detail, observations on the species composition of fellfield and herb slope sites in West Greenland under the PTF project over a period of 42 years showed general reductions in biodiversity although some new species were recorded. Phenology of flowering increased by up to six weeks (as recorded for Zackenberg, North-east Greenland; Høya et al., 2008) although the performance (size, reproductive capacity and population density) of the targeted grass species remained identical after 42 years (Callaghan et al., in prep). Detailed inventories of species over a 30-year period in sub-Arctic Sweden showed changes in floristic composition of some meadows (Hedenås et al., in prep). On Bylot Island, Nunavut, Canada, analysis of a long-term dataset of annual plant biomass by the ArcticWOLVES project revealed that primary production of graminoids doubled between 1990 and 2008 in wetlands (Cadieux et al., 2008).

The general trend at the landscape level across the Arctic is that the most rapid decadal changes have occurred where there are fine-grained soils, strong natural and anthropogenic disturbance regimes, and relatively high supply of water and nutrients. However, where changes have occurred, they were not necessarily caused by climate shifts. For example, some of the vegetation changes documented for Barrow, Alaska, could have been caused by local people changing the hydrology of the system and some of the changes in the wetlands could have been caused by increased goose populations and their effect on eutrophication (Madsen et al., 2010). Similarly, changes in shrub and tree abundance could be related to changes in herbivory in some areas (Olofsson et al., 2009). In general, changes in ecosystems are relatively easy to document but attribution to particular causes is often difficult.

Recent Changes

At the circum-Arctic scale, the latitudinal and northern alpine tree lines are expected to be sensitive indicators of climate change since their shifting locations have responded to changes in climate since the last de-glaciation. Further, changes in the location of tree lines and in the structure of the forest (tree density, growth, species) have many profound consequences, such as regulating biospheric feedbacks to the climate system, biodiversity and ecosystem services to people. Current vegetation models predict that warming will lead to the northward and upward range extension of tree lines but the controls on tree line location are in practice far more complex than temperature alone. Further, there is little evidence of recent tree line advances responding to recent warming and there are only few studies addressing the topic.

IPY PPS Arctic project (Present day processes, Past changes, and Spatiotemporal variability, no. 151) developed an international team to assess the tree line movement in a circum-arctic perspective. The project also seeks to identify the controls on the tree line and the consequences of changes in its position. Recent results show that the influence of climate is seen strongly at all sites even if this is complicated by differences in regional land use pattern. However, responses differ across different climate regions; between coastal and continental regions of the circumpolar north; and according to the dominant tree species. Further, rather than seeing the expected northward tree line shift, due to climate warming, examples of advancing, retreating and stationary tree

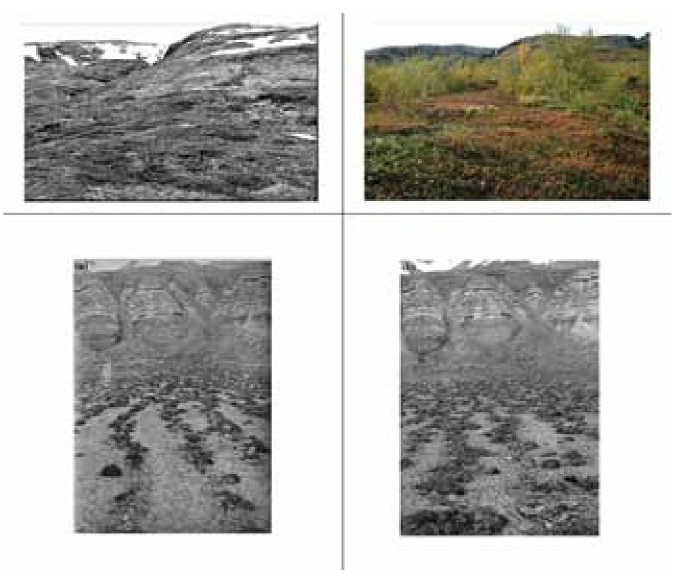

Fig. 2.9-5. Decadal vegetation change and lack of decadal vegetation change. Top left, dwarf shrub and birch woodland vegetation near treeline at Abisko, sub-Arctic Sweden, in 1977 (Photo: Nils Åke Andersson); top right, same location in 2009 (Photo: H. Hedenås). Trees and shrubs increased up to six-fold and a new species colonised the site (Rundqvist et al., submitted.). Bottom left: Vegetation on Svalbard dominated by *Dryas octopetala* in 1936 and bottom right, same location in 2008 (Prash et al., 2009). Note the vegetation and snow beds have not changed substantially in 70+ years.

line zones have been documented across the PPS study sites; still, the advancing zones are dominant.

Several IPY projects showed major changes in ecosystems within particular environments. In the Yukon North Slope, one of the northern regions of Canada where climate warming has been most rapid, ArcticWOLVES project studies detected changes in the abundance of many species. Abundance of savannah sparrows and peregrine falcons has increased, but abundance of Baird's sandpipers and gyrfalcons has decreased. Many rough-legged hawk and peregrine falcon nests are now failing as mud cliffs collapse due to increased rates of permafrost melt. The new northern occurrences of at least five species of butterflies were confirmed. Advancement in the onset of laying for many avian species was also detected. These observations add significantly to the recent review of species range and ecosystem process changes (Post et al., 2009). In sub-Arctic Sweden, the BTF team recorded changes in the location of the tree line and also changes in the structure of the tree line in that aspen trees had recently replaced mountain birch in many areas (Van Bogaert et al., 2010b).

Both ArcticWOLVES and "Back to the Future" projects found that climate change acted as a driver of change directly and indirectly through complex interactions among species. ArcticWOLVES studies demonstrated conclusively that predation played a dominant role in the structuring and function of arctic ecosystems and that many animal populations are strongly impacted, and sometimes driven, by predator-prey interactions. In parallel, "Back to the Future" studies showed that the interaction between two sub-Arctic tree species (mountain birch and aspen) was driven largely by an invertebrate herbivore of one that responded to climate, and the moose herbivore of the other species (Van Bogaert et al., 2010). Similar conclusions have been reached in a recent review of changes in arctic ecosystems (Post et al., 2009).

It has been known for some time that changes in ecosystems can be sudden, even catastrophic, in contrast to ongoing gradual changes. Examples are forest fires and rain on snow events that have decimated ungulate populations. During extreme winter warming events, temperatures increase rapidly to well above freezing (e.g. a change from -20°C to +5/+10°C in 24 hours) and may remain so for a week-long period. Such warming events can result in near complete snow thaw across large regions. Return of freezing temperatures can also be rapid, leaving ecosystems, unprotected due to a lack of snow cover, exposed to extreme cold. Exposure to extreme cold can damage vegetation either directly (through freezing or winter desiccation) or indirectly through ice encasement by re-freezing of melted snow. These events are of considerable concern for indigenous reindeer herders in the sub-Arctic as winter warming events may cause harsh grazing conditions, limit food supply and, consequently, incur large economic costs through the necessity for additional feeding. However, ecosystem response to extreme winter warming events has received little attention.

Simulation of such events within the IPY project ENVISNAR at the Abisko Scientific Research Station using infrared heating lamps and soil warming cables has revealed that (especially) evergreen dwarf shrubs show large delays in phenology, reproduction and even extensive shoot mortality in response to extreme winter warming (Bokhorst et al., 2008). Physiological measurements taken during the simulations have demonstrated that plants will initiate spring-like development after only three to four days of exposure to ~5°C. This breaks winter dormancy/winter hardening and leaves the plants vulnerable to the returning cold following the warming event. Such findings from the simulation study have recently been supported by consistent evidence from a naturally occurring extreme winter warming event that occurred in northwestern Scandinavia in December 2007 (Bokhorst et al., 2009). During the following summer extensive shrub mortality was observed. Vegetation "health", assessed through remote sensing, showed a 26% reduction in NDVI across 1400 km^2 compared to the previous year (Fig. 2.9-6). This reduction indicates a significant decline in either leaf area or photosynthetic capacity at the landscape scale (as illustrated by the IPY GOA and ABACUS projects). These impacts of extreme winter warming are in sharp contrast to the observed greening of the Arctic through shrub expansion considered to be caused by summer warming in other regions.

Overall, the full potential impacts of increased frequency of extreme winter warming events on Arctic ecosystems could be considerable in terms of ecosystem carbon sequestration and floristic composition together with herbivore and predator population numbers.

In the Canadian High Arctic, IPY 2007–2008 was a time of extreme warming at the northern coastline. MERGE researchers recorded that many of the ice-dependent microbial ecosystems in this region experienced substantial change, including extinction of some ecosystem types (Vincent et al., 2009).

Projecting future changes

In the Arctic, projections of changes in ecosystems can be made from the relationships between changes in the environment and changes in vegetation derived from the IPY GOA project. If the summer sea ice vanishes as predicted, the fastest changes will be seen in High Arctic areas that are presently surrounded by perennial sea ice (subzone A of the Circumpolar Arctic Vegetation Map; CAVM Team, 2003). Mean July temperature increase by 3-4°C degrees will cause these areas to change toward the vegetation of the Low Arctic with increased diversity of plants, greater ground cover of mosses, sedges, prostrate shrubs and dwarf shrubs — but also the elimination of the characteristic ecosystems that occur in these coldest regions of the Arctic. Measurements and models resulting from the IPY ABACUS project (Arctic Biosphere-Atmosphere Coupling across multiple Scales, no. 246) will also lead to projections of the future ecosystems and the consequences of the forthcoming changes. Already, it is projected that if global warming results in the tree line continuing to move north (see above sections), then the process of priming (release of organic compounds by plant roots that accelerate decomposition of dead matter in the soil) recorded by ABACUS may result in a loss of carbon from tundra soils.

Projections of impacts of future environmental changes on biota can also be deduced from manipulation experiments that simulate some aspect of a future climate or environment. Passive warming devices have been used extensively for the past ca. 20 years in the International Tundra Experiment (ITEX) (Henry and Molau, 1997; Arft et al., 1999; Walker et al., 2009) and before that in "pre-ITEX" experiments (Havström et al., 1993; Press et al., 1998; Robinson et al., 1998). The IPY project TARANTELLA deployed standard passive warming experiments in the Antarctic and on sub-Antarctic Islands that were comparable to the ITEX experiments in the Arctic. One outcome was the realisation that changes in temperature are more complex than changes in means as they operate through extremes and minima and maxima. Also, many other factors are important, such as the effect of the warming devices (open top chambers) on snow and moisture. Overall, it was concluded that the change in moisture availability brought about as a result of climate change is very likely to be more important for the Antarctic terrestrial ecosystem than change in temperature alone (Fig. 2.9-7).

In contrast to the projections above that imply continuous, gradual greening of the Arctic, the winter warming experiment under the ENVISNAR project suggests that, as temperatures continue to rise in colder regions of the Arctic, it may be that the damage events observed in warmer sub-Arctic communities are indicative of the impacts expected in a warmer higher Arctic. Given these winter events result in opposite effects to spring and summer warming, and

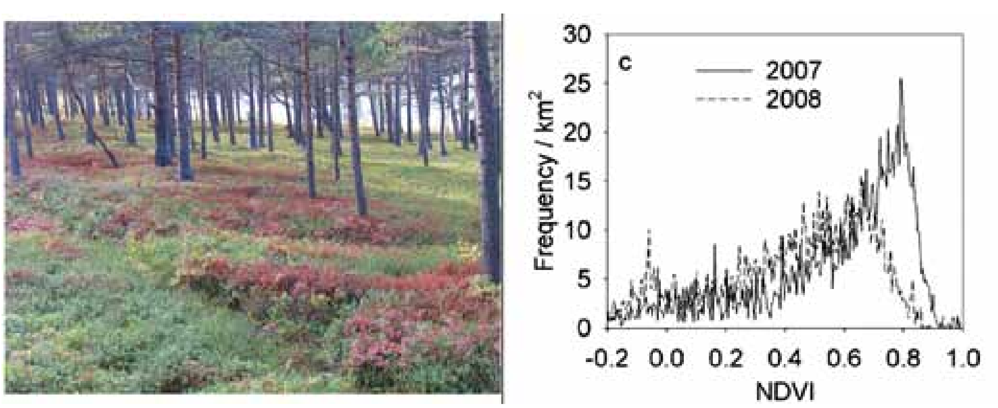

Fig. 2.9-6. Damaged vegetation after a natural extreme winter warming event in northern Scandinavia. During the winter 2007–2008, a week-long period of warm ambient air temperatures melted snow across > 1000 km^2. During the following summer extensive damage to dwarf shrub vegetation was observed. (a - Photo: Terry Callaghan) The extent of damage was validated by NDVI reduction across 1400 km^2 of the winter warming affected area (b): Bokhorst *et al.,* 2009.

that the Arctic is anticipated to warm more in winter than in summer, they provide a considerable challenge and uncertainty to predicting the future of Arctic and sub-Arctic ecosystems in a warmer world.

Projecting changes in animal population numbers and ranges is complex. A surprising projection emerging from the ArcticWOLVES project is that Arctic foxes are vulnerable to changes in sea ice projected in the Gore and Støre report (2009). Observations of predator behaviour and movement showed that Arctic foxes sometimes travelled vast distances over sea ice (Tarroux et al., in press). Satellite-tracking of snowy owls in North America, another predator of the tundra, revealed that many individuals overwinter on the sea ice, a new and unexpected result. This suggests that many top predators of the tundra may be threatened by the rapid melting of Arctic sea ice, and this may have far-reaching consequences to the tundra ecosystem.

Wider consequences of polar ecological processes and changes

Regulation of Climate

Arctic ecosystems have generally acted as a negative feedback to climate in the past by sequestering the greenhouse gas CO_2 and storing large quantities of organic carbon in cold soils as well as reflecting solar thermal radiation away from the Arctic land surface that is covered by snow in late winter-spring. A major reason for current concern about changes in Arctic ecosystems is that climate warming is expected to enhance positive feedbacks to the climate thereby stimulating further warming in the Arctic and further south.

The IPY project ABACUS (Arctic Biosphere Atmosphere Coupling at Multiple Scales. no. 246) has used multiple scales of observations, from leaf to satellite, and has significantly advanced the measurement and understanding of carbon stocks and fluxes in landscapes of sub-Arctic Sweden and Finland. It has used innovative research strategies including using small chambers, flux towers, and aircraft sensors and has developed methodology to enable small-scale processes to be identified from remote sensing. For example, although roots can constitute the majority of plant biomass in Arctic ecosystems, root length and carbon are difficult to quantify. Measurements of root carbon, root length and leaf area in a diversity of Arctic vegetation types has revealed a linear relationship of leaf area with root carbon and length up to a leaf area index of 1. This suggests quantification of root carbon and length measurements at landscape scales may be possible from remotely sensed leaf area data. ABACUS researchers also identified methods to reduce bias in multi-scale estimates of carbon fluxes in Arctic ecosystems by preserving the information content of high spatial and spectral resolution aircraft and satellite imagery.

Studies of carbon cycling in sub-Arctic Sweden and Finland indicated that soil organic matter content was highly variable on a range of scales, but there was a clear pattern of greater total organic matter in tundra (~6.5 kg C m^{-2}) compared to birch woodlands (~3.5 kg C m^{-2}). Plants can increase rates of decomposition (i.e. carbon release to the atmosphere) by supplying labile organic compounds below ground. This process is called 'priming.' Using $^{14}CO_2$ measurements we demonstrated that the decomposition of older soil organic matter was stimulated by plant activity during mid summer in a subarctic birch forest.

The partitioning of fixed carbon into biomass or autotrophic respiration is a critical determinant of ecosystem C balance, often assumed ~50% but rarely measured. ^{13}C pulse labelling in a range of moss communities provided a means to quantify the fate of fixed C. Measurements of $^{13}CO_2$ gaseous return from *Sphagnum* confirmed the expected 50% partitioning over a period of ~14 days. However, in *Polytrichum*, a more productive moss, autotrophic respiration was ~80% of fixed photosynthetic C. These results indicate very different patterns of C dynamics among moss species, with implications for total ecosystem budgets.

Chamber and eddy covariance measurements of CO_2 exchange recorded similar seasonal timing over a range of vegetation types, with a range of magnitudes that corresponded closely to differences in LAI (leaf area index). Chamber measurements of CO_2 exchange identified early-season environmental and physiological factors driving seasonality in branch level CO_2 fluxes while cold season data were successfully collected to facilitate calculation of source/sink status of the landscapes. Aircraft flux measurements during the peak growing season provided an estimate of landscape variability alongside the temporal sampling from fixed tower systems, and a means to constrain upscaling via models.

ABACUS researchers have built the first 3D models of a sub-arctic tree and shrub environment (Fig. 2.9-8) covering areas of many square km in Sweden and Finland. These models were developed based on detailed field measurements, and are now helping the understanding and use of satellite and aircraft data over these regions, to estimate biomass and to improve the use of such data in ecosystem models. Such a process-based mass balance model was parameterised from ABACUS data on tundra and birch woodland and tested against CO_2 eddy flux data and observed time series of stock changes. The initial results closely matched observed fluxes.

In addition to the research by ABACUS on the CO_2 fluxes, methane (a more potent greenhouse gas than CO_2) exchanges were measured with chambers over a range of vegetation types in Finland. These measurements indicated that mires were strong summer sources, while birch woodland was a weak sink. Eddy covariance measurements of mire exchanges were consistent with chamber estimates.

Carbon cycling in sub-Arctic Sweden is also a focus of the IPY projects BTF and ENVISNAR. Within BTF, comparisons are being made of former measurements of fluxes of methane and CO_2 (Christensen et al., 2004; 2008) and a particular focus is being placed on the interannual dynamics of C balance of the birch ecosystem that can be dramatic. Outbreaks of the insect pest of birch (the autumn moth) can result in defoliation of the birch forest and this can convert the birch forest from being a sink for carbon into being a source (Johansson et al., submitted). As birch woodland occupies a large area of the Torneträsk catchment in northern Sweden, such damage can affect the carbon balance of the entire ecosystem (Christensen et al., 2008). Current analyses are in progress to determine the duration of the insect outbreak impacts on the birch forest (Heliasz et al., 2011).

Socio-economic linkages of some of the IPY terrestrial projects

GOA project is presently assessing the relevance of climate and disturbance-related changes to people living in the Arctic — most notably the Nenets reindeer herders on the Yamal Peninsula, Russia, who are faced with rapid changes to their rangelands through both climate change and a rapidly developing infrastructure of roads and pipelines associated with gas and oil exploration and development. Similarly, IPY ENVISNAR is contributing to a multidisciplinary project that includes numerous stakeholders such as Sami reindeer herders to develop adaptation strategies to climate change. These strategies will be based on detailed, high resolution projections (50 m) of climate and snow, derived using the downscaled model to dive the ecosystem model LPJ GUESS (Sitch et al., 2003).

ENVISNAR also includes the sub-project "Snow and Ice" - Sami Traditional Ecological Knowledge and Science in Concert for Understanding Climate Change Effects on Reindeer Pasturing. This joint Nordic study sought an exchange of knowledge between Sami reindeer herders and a multidisciplinary team of scholars with a basis in the humanities, natural and social sciences and in Sami language. The collaboration between reindeer herders and experts in economics, snow physics, ecology, remote sensing, meteorology and linguistics aims to enrich the understanding of the past, present and future changes in snow and ice conditions across northern Sweden and Norway. Indigenous knowledge and its communication with science play a core role in the project, for example by developing better collaborative monitoring at a range of spatial scales. The study builds on the complementary skills and approaches of all participants. For example, scientific experiments and models were employed to predict future changes and are combined with the in-depth knowledge of the Sami on the landscape-scale patterns of past and present snow conditions and their relevance. To-date, workshops have been held and several expeditions to winter grazing lands have resulted in physical measurements of snow conditions and their correlation with Sami snow classifications. Further, Sami knowledge of extreme weather events in winter, and changes in wind patterns in the late 1980s has led to the deployment of a winter-warming experiment (Bokhorst et al., 2008) and observations of a natural event (Bokhorst et al., 2009; Fig. 2.9-6) as well as a re-analysis of long term climate data (Callaghan et al., submitted).

Legacies

Legacy of understanding. Some of the IPY terrestrial projects have contributed significantly to the

Fig. 2.9-7. Olga Bohuslavova, Ph.D. student from the Czech Republic, conducts site assessment for the IPY project "Multidisciplinary research of the Antarctic terrestrial vegetation". (Photo: Josef Elster)

development of ecological theory. For example, within IPY ArcticWOLVES, standardised observations along a latitudinal gradient together with an experimental approach have contributed significantly to ecological theory by explaining the reason for bird migration northwards to unproductive ecosystems: predation decreases towards the North (McKinnon et al., 2010). Further, the significant development of baseline information, for example on the biodiversity of polar microorganisms (MERGE), is an essential pre-requisite for future assessments of biological change. Also, the development of methodology such as spatial scaling to improve remote sensing analyses (e.g. GOA and ABACUS) will play significant roles in future research.

Legacy of infrastructures. The pulse of activity and funding in IPY 2007–2008 has led to the up-grading of Arctic infrastructures within ArcticNet in Canada and at the Zackenberg Station in Greenland. These improved facilities will continue to facilitate high quality observation and research into the future.

Legacy of collaboration. Many nations and hundreds of researchers in various disciplines have taken part in the terrestrial IPY activities together with some stakeholders. Many legacies of inter-disciplinary research, international research, inter-regional (e.g. bipolar) research and collaborations between scientists and stakeholders such as reindeer herders will endure.

Legacy through input to ongoing international organisations and programmes. Although the IPY projects led to a pulse of activities for a short time span, some of these activities, like CBMP, are planned to continue. Also, data, methods and researchers will play role in several new initiatives such as SAON (Sustained Arctic Observing Network; *Chapter 3.8*) and existing organisations such as AMAP and CAFF.

Conclusions

IPY 2007–2008 had six major, general themes or objectives. The terrestrial IPY activities outlined in this chapter have contributed significantly to all of them.

1. *Status*. Most projects, and particularly CBMP, ENVISNAR, MERGE, Antarctic Dry Valley Soil/Ice History and Habitability, ArcticWOLVES, GOA and ABACUS, have produced new baselines of polar environmental conditions, biodiversity and ecosystem processes.
2. *Change*. Two projects have explicitly addressed past decadal changes (GOA and BTF), while four other have explicitly focused on recent changes (PPS, ArcticWOLVES, ENVISNAR and MERGE). Two of these projects (GOA and ENVISNAR) are developing socially relevant activities such as facilitating the development of adaptation strategies. However, only one project explicitly seeks to project future

changes (TARANTELLA) by simulating future warming. Despite that, inferences can be made from almost all the projects while some have developed methodology such as models (e.g. ABACUS, ENVISNAR) and baselines (almost all the projects) that can be used to project changes or to measure them in the future.

3. *Global linkages.* Although a major incentive for several of the projects (particularly ABACUS and ENVISNAR) was to understand processes that could potentially have global consequences, i.e. biospheric feedbacks from Arctic landscapes to global climate, the link from the findings in the Arctic to the Global/Regional Climate Models remain to be made. However, the characterisation of carbon cycling at multiple scales in ABACUS and the interannual dynamics of carbon cycling measured in ENVISNAR and BTF potentially have global relevance and plans exist to incorporate processes measured in these projects in models of wider scale climate processes.
4. *New frontiers.* IPY terrestrial projects have investigated new frontiers in science by discovering new microbial diversity and polar and global connections between genetic lineages (MERGE); by describing new extreme environments and their biota (MERGE), some of which are analogous to environments on Mars (Antarctic Dry Valley Soil/Ice History and Habitability); contributing to ecological theory and answering long-standing persistent ecological questions (ArcticWOLVES); recording effects of hitherto unrecorded extreme events (MERGE, ENVISNAR); and by developing new methodologies/models (GOA, ABACUS, ENVISNAR).
5. *Vantage point.* Only one project, "The Phoenix Mars Polar Lander and Antarctic Analog Studies" through its focus on the Antarctic Dry Valley soil/ice history and habitability, made the connection between the Earth and beyond. This project used the same technology that was used on the Mars Lander to measure environmental conditions in the Dry Valleys that are the habitat on Earth most similar to that on Mars.
6. *The human dimension.* While most of the projects have relevance to people through changes in ecosystem services, GOA and ENVISNAR are explicitly engaging the Indigenous peoples and other Arctic residents in a dialogue that it intended to help the development of adaptation strategies to alleviate – or opportunistically use – the expected changes in Arctic environments and ecosystem services.

Overall, the IPY projects have made major contributions to the spirit, knowledge generation and legacy of IPY 2007–2008.

Fig. 2.9-8. IPY-ABACUS researchers built the first 3D models of a sub-Arctic tree and shrub environment in sub-Arctic Sweden and Finland including part of the area in Sweden where ENVISNAR modelled the landscape temperature distribution.
(Image: Mathias Disney - Disney et al., 2011)

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2.10 Polar Societies and Social Processes

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Introduction

The introduction of the social sciences and humanities, as well as the inclusion of polar residents, particularly indigenous people in International Polar Year (IPY) 2007–2008, marked a radical shift from the earlier IPY/IGY template. It was a major experiment not only to its planners (*Chapter 1.3*), but also to the social scientists and polar residents themselves. Previous IPYs, especially IPY-2 in 1932–1933 and the International Geophysical Year (IGY) in 1957-1958 excluded research in the socio-economic and humanities field, though some medical and psychological studies were carried out, mostly in Antarctica and focused exclusively on the personnel of the IGY polar stations (*Chapter 1.1;* Krupnik et al., 2005; Aronova et al., 2010). Many advocates and key institutional supporters of IPY 2007–2008, such as the Arctic Council (IASC) and the International Arctic Social Sciences Association (IASSA) argued for the inclusion of social and human studies in the new IPY program, but their role expanded significantly only after a special theme focused on polar people was added to the IPY science plan in fall 2004 (*Chapters 1.3, 1.4;* Rapley et al., 2004; Krupnik, 2008, 2009).

The IPY organizers and institutions involved in the early planning viewed the prime mission of the social sciences in contributing what was then called 'The Human Dimension' to the new IPY program centered on geophysical and natural science research (*Chapter 1.3*). As welcoming as it sounds, the 'human dimension' paradigm assumed the leading role of the physical and natural processes, to which a certain 'human aspect' (or 'dimension') is to be added to produce a more integrative or societal-appropriate view. Nonetheless, the inclusion of a 'human dimension' as a special theme in 2004 is widely viewed among the major achievements of IPY 2007–2008 (Allison et al., 2007, 2009; Stirling, 2007; Elzinga, 2009; Carlson, 2010).

Joining IPY 2007–2008 was also a major challenge to polar social scientists. Never before had they participated in a multi-disciplinary research initiative of such magnitude. Coming late to the IPY planning, lacking the institutional memory and the expertise of physical and natural researchers in running complex big-budget projects, polar social scientists were pressed to experiment and to learn on the fly. Even more so, that applies to many indigenous organizations and institutions that joined IPY 2007–2008, either as partners in social science and humanities projects or by launching their independent research initiatives.

This chapter covers IPY activities in social science disciplines (anthropology, archaeology, economics, linguistics, political science) and the humanities (history, literature, arts) that are featured in the 'People' field of the IPY project chart (Fig. 2.10-1).[1] It includes 35 endorsed international research projects (Table 2.10-1), plus several initiatives in 'Education and Outreach' that are directly related to the social science and humanities themes (nos. 69, 82, 112, 135, 160, 299, 342, 410, 433), as well as a number of projects with a substantial social component in the 'Land' and 'Ocean' fields (nos. 21, 29, 151, 162, 164, 212, to name but a few). Some of these projects are partly covered in other sections (*Chapters 2.9, 5.4*). Activities related to human health and associated issues, such as pollution, contaminants and food security are reviewed in *Chapter 2.11*.

Table 2.10-1. List of active projects in Social Sciences and the Humanities, 2007–2009 (projects that sent reports for this chapter are marked with *).

Research

IPY No.	Full Title	Project Acronym	Participating Nations
6*	Dynamic Social Strategies		Denmark, Norway, Canada
10*	Historical Exploitation of Polar Areas	LASHIPA	The Netherlands, Sweden, Russia, Norway, U.K., U.S.
21	Understanding environmental change in national parks and protected areas of the Beringian Arctic		U.S., Russia, Canada
27*	History of International Polar Years		Germany, Russia
30	Representations of Sami in Nineteenth Century Polar Literature: The Arctic 'Other'		Sweden
46*	Traditional Indigenous Land Use Areas in the Nenets Autonomous Okrug, Northwest Russia	MODIL-NAO	Norway, Russia
82	Linguistic and Cultural Heritage Electronic Network	LICHEN	Finland, Norway, U.K.
100	Polar Field Stations and IPY History: Culture, Heritage, Governance (1882-Present)		U.K., Sweden, Norway Russia, U.S., Denmark
120*	Northern High Latitude Climate variability during the past 2000 years: implications for human settlement.	NORCLIM	The Netherlands, Canada, Greenland, Iceland, Norway, U.S.
123	Glocalization: Language, Literature, and Media		Greenland, Denmark, U.S., Canada
157*	Community Adaptation and Vulnerability in Arctic Regions	CAVIAR	Norway, Canada, U.S., Iceland, Finland, Russia, Greenland
162*	Circum-Arctic Rangifer Monitoring and Assessment	CARMA	Canada, U.S., Russia, Norway, Finland
164*	Inuit, Narwhal, and Tusks: Studies of Narwhal Teeth		U.S., Canada
166*	Sea Ice Knowledge and Use: Assessing Arctic Environmental and Social Change	SIKU	U.S., Canada, Russia, Greenland, France
183	Community Resiliency and Diversity		Canada, Greenland
186*	Engaging communities in the monitoring of zoonoses, country food safety and wildlife health		Canada, Denmark, Greenland, Norway, Poland
187*	Exchange for Local Observations and Knowledge of the Arctic	ELOKA	U.S., Canada, Finland
227	Political Economy of Northern Development		Denmark, Greenland, Finland, Russia
247*	Bering Sea Sub-Network: International Community-Based Observation Alliance for Arctic Observing Network	BSSN	U.S., Russia
276	Initial Human Colonization of Arctic in Changing Palaeoenvironments		Russia, Canada, Norway
310	Gas, Arctic Peoples, and Security	GAPS	Norway, Canada, Russia
335*	Land Rights and Resources	CLUE	Sweden, U.S., Russia
386*	Survey of Living Conditions in the Arctic, Remote Access Analysis System: Inuit, Saami, and the Indigenous Peoples of Chukotka	SliCA-RAAS	Greenland, U.S., Canada, Norway, Finland, Russia
399	Reindeer Herders Vulnerability Network Study	EALAT	Norway, Finland, Denmark, Russia, Sweden
408*	Social-science migrating field station: monitoring the Human-Rangifer link by following herd migration	NOMAD	Germany, Bulgaria, Finland, Norway, Russia
435	Cultural Heritage in Ice		Canada, U.S.
436*	Moved by the State: Perspectives on Relocation and Resettlement in the Circumpolar North	MOVE	U.S., Canada, Denmark, Finland Greenland, Russia
462*	Arctic Social Indicators	ASI	Iceland, Canada, Finland, Denmark, Greenland, Norway, Russia, Sweden, U.S.

Knowledge Exchange (Conferences, Publications, etc.)

69*	6th International Congress of Arctic Social Sciences	ICASS-6	Greenland, U.S., Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, U.K.
135*	Polar Heritage: Protection and preservation of scientific bases in polar regions – Polar Base Preservation workshop		Norway, U.S., Australia, U.K.
160	Arctic Change: An Interdisciplinary Dialog Between the Academy, Northern Peoples, and Policy Makers		U.S., Canada, Greenland, Iceland
299	Arctic Energy Summit		U.S., Canada, Russia
410*	Inuit Voices Exhibit: Observations of Environmental Change		U.S., Canada

For this overview, standard questionnaires were mailed in November 2009 to the leaders of all international projects in the 'People' field and of several projects in the 'Education and Outreach' field. Altogether, 23 responses were received by April 2010; information on nine other projects was assessed via participating in their meetings or tracking their publications and websites (Table 2.10-1). *Chapters 3.10* and *5.4* introduce additional data on eight projects with a strong community observation/monitoring component (nos. 46, 157, 162, 166, 187, 247, 399, 408).[2]

Basic Features of Social Science and Humanities Research in IPY 2007–2008

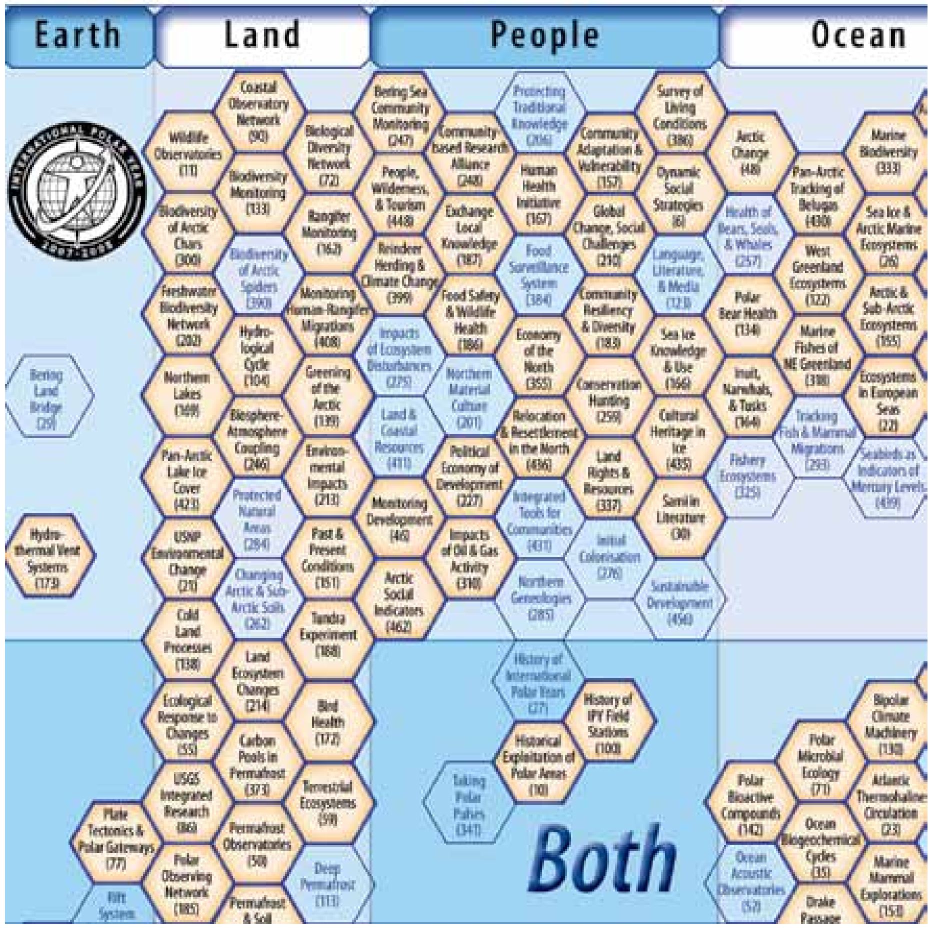
Polar research today is moving rapidly to address global and local urgencies and to seek strong societal justification, as requested by many key stakeholders—the Arctic Council, major science organizations (like ICSU, WMO, IASC and SCAR), local governments, funding agencies, environmental groups, indigenous organizations and polar communities, and the public at large. All of these constituencies have become increasingly vocal about social issues, thanks in part to the massive educational, outreach and communication efforts during IPY 2007–2008. As the public is introduced to and engaged in the issues of polar regions, the stakeholders' interest in societal justification continues to drive the growing portion of polar research and funding, and raises the role of social, economic and cultural issues in the science advancement and planning. We may expect more of these developments continue in the years to come.

The changing nature of polar research and its shift towards more societal-oriented and societal-justified scholarship has been in the making during the past two decades, but was greatly accelerated by IPY 2007–2008 (*Chapter 5.2*). It has been observed at various scales—from national to regional to global. The transition is particularly visible in the Arctic, in Canada, (Griffiths, 2009; www.northernstrategy.ca/index-eng.asp), Iceland, Greenland, but also in the U.S.A. (U.S. ARC, 2010) and other polar nations that are members of the Arctic Council.[3]

Arctic social scientists have previously participated in large interdisciplinary initiatives, starting with the International Biological Programme (IBP) in 1964–1974, although at smaller scale than today. Even the IBP, with its strong 'human component,' had a much narrower disciplinary focus than IPY 2007–2008, and its human studies were primarily in physical adaptation, nutrition, health and small-population demography (Sargent, 1965; Milan, 1980; Worthington, 1965), that is, in the 'human health' domain (*Chapter 2.11*). The social science and humanities field in IPY 2007–2008 was, by far, the largest and the most diverse program of its kind by all measurable criteria, including the number of projects, nations and scientists involved, and the level of funding.[4] In addition, dedicated efforts were made to encourage cross-disciplinary studies linking socio-cultural processes, ecological diversity, community and ecosystem health (*Chapters 5.1, 5.2*). For the first time, physical, biological, social and humanities researchers, and local community-based experts were encouraged to join forces under common multi-disciplinary framework.

To many polar social scientists, the experience of collaborating with a broad spectrum of other disciplinary experts—remote sensing specialists, oceanographers, climate modelers, cryosphere scientists, biologists, data managers—was also eye-opening. Several large multi-disciplinary IPY projects

Fig. 2.10-1. IPY projects in the 'People's' field and adjacent themes as shown in the IPY projects chart (Version 7.3 – September 2008). Projects with limited or no funding are colored in blue (though some eventually contributed to the IPY program).



that included social scientists and Arctic indigenous experts, such as ArcticWOLVES (no. 11), Biodiversity of Arctic Chars (no. 300), the Canadian Circumpolar Flaw Lead System Study, PPS Arctic (no. 151), DAMOCLES (no. 40), Circumpolar Biodiversity Monitoring Programme (no. 133) and others helped expand interdisciplinary partnership beyond the pre-IPY range.

IPY also created the momentum for polar social science and humanities researchers to advance the international collaboration to a new level. All endorsed IPY projects included partners from several nations and/or from indigenous communities and polar residents' organizations. Many social science and humanities studies were, in fact, large, coordinated programs with teams of researchers from several nations working in different areas under a concerted agenda, though with the individual national funding (nos. 6, 10, 100, 120, 123, 157, 162, 166, 399, 436, 462). Such collaborative studies included researchers and agencies from at least 21 countries[5]; scientists from 14 nations acted as project leaders.[6] Several projects generated large international teams of 50-80 people from six to eight nations (nos. 10, 157, 166, 386, 399, 436, 462); the average size of an IPY social science project team, including local partners, was close to 30 people. This new level of institutional complexity achieved in IPY 2007–2008 helped move social studies structurally closer to large interdisciplinary programs that are currently the trademark activities in the polar regions.

For the first time, several initiatives in IPY 2007–2008 have been proposed by polar indigenous organizations (*Chapter 5.4*). All major organizations representing indigenous people in the Arctic—the Inuit Circumpolar Council, Aleut International Association, Arctic Athabaskan Council, Gwich'in Council International, Russian Association of Indigenous Peoples of the North, the Sámi Council—and many of their national and local chapters were actively involved in IPY activities (nos. 30, 46, 69, 162, 164, 166, 183, 187, 247, 399, 410, etc.) as local partners, logistical and public supporters, but also as initiators and lead institutions (nos. 46, 183, 247, 399; Fig. 2.10-2).

Altogether, IPY social science and humanities projects engaged at least 1500 researchers, students, indigenous experts and monitors, and representatives of polar indigenous people's organizations. Compared to an almost 'zero' presence in IPY-2 and in IGY 1957–1958, the social/human studies accounted for more than 20% of active research projects in this IPY (28 out of 136) and for 34% of all research projects in the northern polar regions (24 out of 71)[7].

As of 2010, 28 research projects in the 'People' field and at least seven related projects in other categories had been implemented (Table 2.10-1). The list is most likely incomplete. In addition, more than 20 national IPY projects have been supported by national funding agencies in Canada, U.S., Russia, Sweden and other countries besides the endorsed international initiatives. We may tentatively estimate that social sciences, humanities and community studies constituted the third-largest component of IPY activities, after 'Oceans' and 'Land,' though its share in terms of funding and personnel involved is significantly smaller. Social science project budgets until recently were dwarfed by the funding allocated to natural science research, and to geophysical projects in particular.

Highlights of IPY Social Science and Humanities Research

Principal research areas. Almost 30 implemented international research projects in the social science and humanities field addressed a broad variety of themes: the well-being of polar communities (nos. 157, 183, 386, 462); the use of natural resources and economic development, particularly, the impact of oil and gas industry (nos. 46, 227, 310); local ecological knowledge (nos. 164, 166, 183, 399); preservation of natural, historical and cultural heritage (nos. 27, 100, 135); history of exploration, peopling and the exploitation of polar regions, including Greenland, Svalbard and Antarctica (nos. 6, 10, 27, 276); and many

Fig. 2.10-2. EALÁT herders'meeting in Khralovo
(Photo: Svein Mathiesen).

Box 1. The 'first-ever' achievements in the social and humanities field in IPY 2007–2008
(As reported by Project Lead Investigators, November–December 2009)

In Research

- Comparative study of local community vulnerabilities and adaptation strategy under the impact of modern climate change and non-physical (social, economic, etc.) factors across eight Arctic countries (Canada, Finland, Greenland, Iceland, Norway, Russia, Sweden and U.S./Alaska), with a snapshot of today's challenges and community responses from 30 studied communities (CAVIAR, no. 157)
- Pioneer study in constructing of Arctic 'social indicator' monitoring system of assessing community well-being and tracking human development in the Arctic (ASI, no. 462)
- Analysis of potentials and limitations (restrictions) of Arctic regional economies and their abilities to build a self-reliant (sustainable) development path (POENOR, no. 227)
- First contemporary 'snapshot' of the use and knowledge of sea ice in 30-some communities in four Arctic nations (Canada, Greenland, Russia and U.S.) during the IPY 2007–2008 era, with a new vision on polar sea ice as a critical subsistence area for indigenous people and a highly endangered 'cultural landscape' being sustained by the continuous use and shared community knowledge of ice environment and processes (SIKU, no. 166)
- Analysis of the political and ideological sphere created via conflicting interactions of the local drive for indigenous self-governance and self-determination with modern enlightened environmental discourse and commercial interests of local majority population, extractive industry and regional administrations (CLUE, no. 335)
- Correlation of social, cultural, economic and environmental factors in rapid economic transition (social change), which is commonly (mis)interpreted, often deliberately, as a consequence of catastrophic climate/environmental change (NOMAD, no. 408)
- First pan-Arctic perspective of governmental initiated relocations and resettlements of northern residents and indigenous communities (in Canada, Greenland, Russia/Soviet Union and U.S.) during the 20th century – with the lessons critical for prospective future decisions regarding community relocation due to climate change and resource development (MOVE, no. 436)
- Comparison of the early commercial exploitation of marine and terrestrial resources (whaling, sealing, etc.) in the Arctic and Antarctica over the past 400 years (LASHIPA, no. 10)
- New insights and comparative overviews of the history of the polar research, both in the Arctic and Antarctic, starting from the preparations for the First IPY in the 1870s and up until the IGY era (no. 27)
- Greater awareness of significance of historical/heritage resources in the polar regions, particularly in Antarctica, and of special activities related to polar heritage protection, site preservation, documentation and public use (tourism) (no. 135)
- Synchronous study of ancient Eskimo/Inuit adaptation patterns across Nunavut, Nunavik, Labrador and Northwest Greenland, in relation to sea ice conditions and climate change (GeoArk, no. 6)
- The most diverse international gathering of scholars from Arctic social sciences and the humanities and the largest venue during the IPY 2007–2008 era to present results on the ongoing activities and to get feedback from colleagues, community activists and insights from other disciplines (ICASS-6, no. 69).

In Data Collection, Observation, Monitoring and Data Management

- Building up of a GoogleEarth-based GIS atlas and database for the indigenous Nenets communities in northwestern Arctic Russia to help them deal with degradation of their land use areas through large-scale oil and gas development (MODIL-NAO, no. 46)
- Establishment of a comprehensive dataset (since 1998) containing comparative data on the living conditions among circumpolar indigenous people in six nations (Canada, Greenland, Norway, Russia, Sweden and U.S.) based upon local surveys and broad partnership among social scientists, local statistical services, polar indigenous residents and their organizations (SLICA, no. 386)
- Establishment of an international network of researchers, caribou hunters, co-management boards and government agencies to cooperate in monitoring and research; assessment of vulnerability and resilience to the environmental and human pressure of individual caribou herds across Alaska, Canada, Greenland, Norway and Russia (CARMA, no. 162)
- Engaging northern communities and local organizations in collection and preservation of cultural sensitive mate-

rials (including cultural objects and human remains) that become available through land and environmental change triggered by climate warming in the Arctic (no. 425)

- Engaging northern residents in communicating, monitoring and managing new food safety risks due to climate and economic change by using traditional and modern methods and techniques (no. 186)
- Collaboration of scientists and indigenous knowledge experts in combining data from various science fields (anatomy, genetics, physiology, morphology, acoustics) and traditional ecological knowledge for in-depth study of narwhal (NTR, no. 163)
- First experience of a community-driven regional observational network crossing international boundaries and run by indigenous organizations, with the purpose to document quantitative and qualitative observations by local experts in nomadic and/or remote indigenous communities (BSSN, no.247; EALAT, no. 399)
- First-ever data management and user support service established for local and traditional knowledge data and community based research/monitoring, with the prospect of emerging into a circumpolar network (ELOKA, no. 187)
- Visual, educational and public presentation of the experiences of Inuit communities facing impacts of climate change through the words and stories of the people who live there (Silavut, no. 410).

more.[8] Indigenous participants were particularly active in studies investigating community response and adaptation to rapid environmental and socio-economic changes (nos. 46, 157, 247, 335, 399). Many polar communities joined the IPY monitoring efforts to collect, exchange and document data on changes in sea ice, biota and climate (*Chapter 3.10*). All of these themes were new to the IPY program.

Major achievements (Box 1). As in the case of other IPY fields, the complete picture of research activities in the social science and humanities disciplines may not be available until 2011 or even 2012. Nonetheless, we were able to generate a list of 'first-ever' achievements—in research, observation, data collection, and management—based upon the responses from the leaders of 23 implemented projects. This is, of course, a preliminary inventory of major advances, since many IPY projects were cluster initiatives of several local and national efforts, and the results of several implemented projects are yet to be accounted.

The 'pulse' of social science and humanities research during the IPY years produced a steady stream of tangible products, such as scientific and popular papers and books, observational data, conference and project reports, maps, museum exhibits, websites and other online materials, as well as new explanatory models and research practices. Only a fraction of these results ('products') can be assessed at this early stage. No estimate exists yet of the total number of new papers in the social science and humanities fields, out of the overall number of some 3900 publications reported in the general IPY publication database as of May 2010 (http://nes.biblioline.com/scripts/login.dll - *Chapter 4.4*). A more 'user-friendly' Canadian IPY database (www.aina.ucalgary.ca/ipy/), which lists about 1900 entries related to Canadian IPY research *only*, counts more than 1100 social and human science entries, including 398 on 'indigenous people', 357 on 'government and socio-economic conditions', 141 on 'history', and 192 on 'human health'. The overall list of papers produced by IPY projects in the social sciences and humanities is certain to grow into many thousand. It is worth noting that IPY data were collected and disseminated in several indigenous languages of the Arctic, such as Sámi, Inuit (Inuktitut, Kalaallit, Inupiaq), Yupik/Yup'ik, Chukchi, Nenets, Sakha and others.

The field of the social sciences and humanities generated by far the largest share of the first books produced by the IPY 2007–2008 programs. As of this writing (summer 2010), at least twelve volumes based upon nine IPY projects in the social science and humanities field were already published or are in press (Barr and Chaplin, 2008 – no. 135; Barr and Lüedecke, 2010 – no. 27; Fienup-Riordan and Rearden, 2010 – no. 166; Hovelsrud and Smit, 2010 – no. 157; Krupnik et al., 2009, 2011 – no. 166; Launius et al., 2010 – no. 27; Larsen et al., 2010 – no. 462; Oskal et al., 2009 – no. 399; Shadian and Tennberg, 2009 – no. 100; Stuckenberger, 2007 – no. 160; Winther, 2010 – no. 227). Several more books are in submission and preparation. In addition, several reprints of the early IPY sources, collections on IPY history and polar research heritage were produced (Andreev et al., 2007; Arnestad Foote, 2009; Barr and Chaplin, 2008; Tromholt, 2007; Vairo et al., 2007a,b). By 2012, the publication 'imprint' of IPY social science and humanities research will be even more visible and will include several special journal issues and heritage materials produced for participating polar communities, now in preparation.

From 'local' to 'polar.' During IPY, seven projects (nos. 157, 162, 166, 227, 399, 436, 462) included new coordinated research and data collection in four or more Arctic nations. Four projects, CAVIAR (no. 157), CARMA (no. 162), EALÁT (no. 399) and MOVE (no. 436), aspired to produce pan-Arctic overviews of local community adaptation and vulnerability; subsistence caribou hunting; status of reindeer herders' knowledge; and the role of governmental policies in community resettlement and relocations, respectively. These projects, together with other large initiatives were critical in moving the social science and humanities field from local and regional to the 'circumpolar' level, as a result of IPY.

Two new 'pan-Arctic' IPY projects – Community Adaptation and Vulnerability in the Arctic Region (CAVIAR, no. 157) and Arctic Social Indicators (ASI, no. 462) – were particularly instrumental in this transformation. The CAVIAR project was aimed at testing a new research and modelling approach to assess Arctic populations' vulnerability and adaptability via studies in 26 communities in Canada, U.S. (Alaska), Greenland, Iceland, Norway, Sweden, Finland and Russia (*Chapter 3.10;* Hovelsrud and Smit, 2010). The main outcome was a new vision of the Arctic peoples' resilience to environmental stress as a 'two-way' process that depends as much (or more) on the strength of the community internal networks (social, cultural, institutional, economic, etc.) as on the intensity of the environmental signal (Fig. 2.10-3). As the CAVIAR case studies illustrate (and as social scientists have been arguing for years), the projected impact of change should be first assessed at the local community level rather than from the top-down, large-scale climate change scenarios that simulate certain temperature, ice, or seasonal shifts. In the pre-IPY impact assessment, including the IPCC Reports, the latter approach was viewed as a standard pathway to complex environmental impact modeling (Smit and Wandel, 2006; Krupnik, 2010). The ASI project aspired to develop a set of thoroughly calibrated indicators, via data mining and expert assessment, to evaluate the status of socio-cultural well-being of Arctic population at the community, local and regional level. Here, again, more general national indices used by UNESCO and other major international agencies, such as per capita gross domestic product or the overall level of literacy (http://unstats.un.org/unsd/demographic/products/socind/default.htm) have been successfully substituted by more locally-nuanced tools to assess community well-being, as a result of IPY research (Larsen et al., 2010; Table 2.10-2). It remains to be seen whether a community-based ('bottom-up') approach will become standard in the post-IPY studies.

The Power of Multiple Perspectives. This notion used by one of the IPY socio-cultural teams (Huntington et al., 2010) led to a new way of IPY data collection and will impact the future synthesis of IPY-generated materials. As has been long recognized by researchers, each process or phenomenon should be viewed from several perspectives, coming from different disciplines and/or groups of stakeholders. In physical and natural studies, bringing several disciplines to inter-disciplinary inquiry is most often aimed at grasping more elements and linkages in the complex natural systems. In social science research, this approach is rather associated with the use of radically different types of knowledge that have independent origins and basic principles, like those coming from the science and the

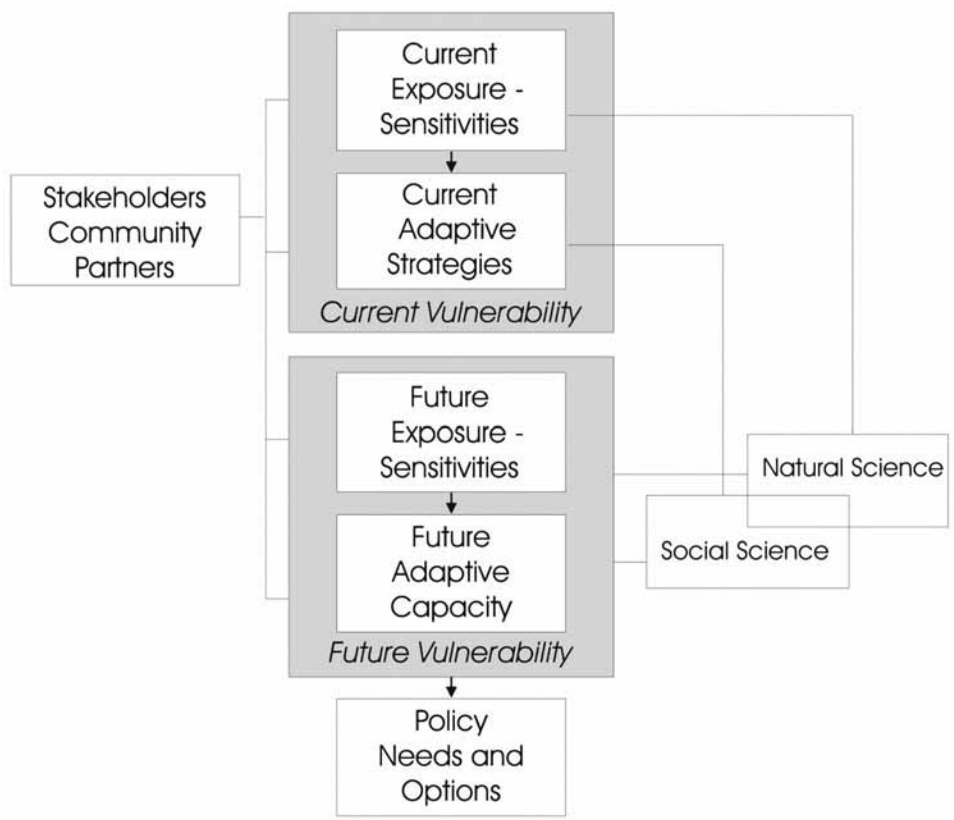


Fig. 2.10-3. CAVIAR interpretative framework for community vulnerability and resilience assessment (Smit et al., 2008).

humanities (arts, history, narratives) or from what is commonly called 'academic research' and indigenous knowledge. IPY 2007–2008 was a great experiment in demonstrating the power of multiple perspectives in many of its multi-disciplinary projects, but also specifically, thanks to the inclusion of social sciences, humanities, arts and indigenous knowledge with their very diverse vision, data collecting and roots.

Bringing together those diverse types of knowing, though not artificially merging ('integrating') them, increases the power of understanding; it also helps illuminate phenomena that are often beyond the radar of scientific research. For example, ice scientists, climate modelers, oceanographers, local subsistence users, anthropologists, mariners and science historians have remarkably different vision of polar sea ice. To various groups of scientists, sea ice is a multi-faceted physical and natural entity: an ocean-atmosphere heat fluxes regulator, a climate trigger and indicator, a habitat (platform) for ice-associated species and/or an ecosystem built around periodically frozen saltwater. To polar explorers and historians, sea ice was first and foremost a formidable obstacle to humanity's advance to the Poles (Bravo, 2010). Polar indigenous people view sea ice primarily as a cultural landscape; an interactive social environment that is created and recreated every year by the power of their cultural knowledge. It incorporates local ice terminologies and classifications, ice-built trails and routes with associated place names, stories, teachings, safety rules, historic narratives, as well as core empirical and spiritual connections that polar people maintain with the natural world (Krupnik et al., 2010). Cultural landscapes created around polar sea ice (icescapes) are remarkably long-term phenomena, often for several hundred years (Aporta, 2009 – Fig. 2.10-4). By adding a socio-cultural perspective and indigenous knowledge, ice scientists broadened the IPY agenda in sea ice research beyond its habitual focus on ice dynamics and coupled ocean-atmosphere-ice modeling (Druckenmiller et al., 2010; Eicken, 2010; Eicken et al., 2009).

The introduction of Arctic peoples' visions on weather, climate, snow and ice patterns is another

Table 2.10-2. Recommended 'Small' Set of Arctic Social Indicators for Tracking Human Development in the Arctic.
(Larsen et al., 2010)

Indicator	Domains
1. Infant Mortality	Health/Population
2. Net-migration	Health/Population and Material Well-being
3. Consumption/harvest of local foods	Closeness to Nature and Material Well-being
4. Per capita household income	Material Well-being
5. Ratio of students successfully completing post-secondary education	Education
6. Language retention	Cultural well-being
7. Fate Control Index	Fate control

example of how scientific understanding may be expanded by indigenous knowledge. The EALÁT project (no. 399, *Chapter 3.10*) was aimed at documenting indigenous herders' interpretations of weather and climate change they observe and at articulating the difference with the scientists' views dominated by the concepts, such as 'regime shift', 'tipping point', 'multiple feedbacks' and the like. As Sámi herders argue, "We have some knowledge about how to live in a changing environment. The term "stability" is a foreign word in our language. Our search for adaptation strategies is therefore not connected to "stability" in any form, but is instead focused on constant adaptation to changing conditions" (Johan Mathis Turi, in: Oskal et al., 2009). Whereas environmental scientists point to the increased vulnerability of polar ecosystems due to the warming climate, to the herders, the key factors in their response to rapid change are the overall range of their used territories and the freedom of movement across its constituent habitats. Therefore, the herders' prime concern continues to be about the diminishing size of Arctic pastures under the pressure of industrial development, government land rights and nature preservation policies, which are now increasingly coupling with the impact of climate change. Anthropologists and biologists working closely with communities had been long aware of this situation, but it took the momentum of IPY to bring this point across to a broader audience.

Field and Institutional growth

New Arctic-Antarctic Connection and the Emergence of Antarctic social sciences. IPY social science studies covered all eight Arctic nations (Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden and U.S.A.) and most of the IPY social and humanities projects focused on the Arctic region. No international proposals were originally submitted in 2004–2006 from the Southern hemisphere nations and only four proposals (nos. 10, 27, 100 and 135) were designed as 'bipolar' initiatives, with two (nos. 10 and 342) centered on Antarctica, albeit with strong participation by Arctic social science and policy experts. Nonetheless, IPY 2007–2008 has given rise to a number of social science and humanities studies in the southern polar regions: history of polar explorations, law and policy, governance and tourism. Eventually, 'Antarctic social sciences' emerged as a new and expanding field thanks to IPY 2007–2008.

A vocal and growing community of Antarctic social science and humanities researchers first anchored at the 'History of Science' Action Group established by the Scientific Committee of Antarctic Research (SCAR) in 2004 (no. 27, www.scar.org/about/history). The group held five workshops in 2005–2009 and produced numerous reports, publications and a summary edited volume (Barr and Lüdecke, 2010). This new level of awareness of societal issues in southern hemisphere research, with a growing number of interdisciplinary projects and system-based approaches stimulated SCAR to support the establishment of a new Social Sciences Action Group in 2009 (www.scar.org/researchgroups/via/). The new group focuses its activities on the topic of "Values in Antarctica: Human Connections to a Continent" and will use the *Social Sciences and Humanities Antarctic Research Exchange (SHARE)* network (www.share-antarctica.org/index.php/about-share) to improve the profile of Antarctic social studies. It also aspires to take on the role that the International Arctic Social Sciences Association (IASSA) plays for the Arctic social sciences. During the Oslo IPY conference, the new SCAR Social Sciences Action group/SHARE team held its first joint meeting with a large group of Arctic social science researchers, which was viewed as a key step in new bipolar cooperation in social science and humanities research. Thus IPY was instrumental in

Fig. 2.10-4 . Inuit polar ice trail network connecting communities across frozen land and water is being recreated every year, since time immemorial (Aporta, 2009).

raising interest to the social issues that are common to both polar regions, such as history of science, early economic exploration, sustainable economies, governance and political regimes, tourism, heritage preservation and engagement of local constituencies, to name but a few.

Funding. Twenty-one projects (out of 23) that reported their funding between 2006 and 2010 had a cumulative budget of $31.2M U.S.. This is, evidently, a low estimate of the level of funding for social science and humanities research in IPY, since it covers neither all endorsed international projects nor projects in other fields with a substantial human component. Also, it does not include national efforts supported by the national IPY programs in Canada, Russia, Sweden, the U.S.A. and other countries. For example, the total budget for 13 Canadian projects in social science and community studies, and human health was $21M (David Hik, pers. comm.); the NSF overall funding for social science research in 2006–2010 is estimated at $19M, of which only half was allocated to the internationally endorsed IPY projects. Other U.S. agencies, like NOAA, the National Park Service and the Smithsonian Institution, also contributed their resources to IPY social science research. In addition, many 'in-kind' expenses, such as researchers' salaries and travel costs, were often covered via their host institutions. It could be reasonably estimated that the overall amount of 'new' money for international IPY projects in the social science and humanities research was close to $40M, plus a yet unknown amount of funding (and in-kind contribution) for the 'national' IPY efforts, including conferences, websites, publications, travel and student support.

IPY highlighted the crucial role of funding for research in the polar social sciences and humanities, which produced additional tangible results. In summer 2005, the European Science Foundation (ESF) initiated a new 'EUROCORES (European Collaborative Research) Programme' called *Histories from the North – Environments, Movements, Narratives* (BOREAS – Vitebsky and Klein, 2005, 2006/2007). It was operational for five years, 2006–2010, with the overall budget of € 6M (about $8.5M) that eventually funded seven international project clusters (Klein et al., 2007; ESF, 2010), including several endorsed IPY projects (nos. 30, 100, 386, 436).[9] Though only a portion of the BOREAS budget was used for the IPY efforts, two corresponding initiatives resulted in an unprecedented rise in polar social science funding during the IPY years.

Technological innovations. IPY generated major advancements in new technologies used in polar social science research and facilitated the transfer of many of these technologies to polar residents and indigenous people. Several IPY social projects were focused on the creation of electronic maps and atlases (cybercartography – nos. 46, 166 – Fig. 2.10-5; Pulsifer et al., 2010) and new datasets and data management services for local communities (nos. 162, 164, 187, 247, 399). They used satellite imagery (nos. 166, 300, 399; Alfthan et al., 2010 – Fig. 2.10-6), Google Earth as a research and outreach tool (no. 436), and new GPS-based technologies (Druckenmiller et al., 2010; Gearheard et al., 2010) to assist in community-based monitoring and data collection. Many of these new technologies that were first tested in IPY will become core features of the research projects, services and legacy initiatives of the post-IPY era (*Chapters 3.8, 3.9, 5.2, 5.4*).

Major events. Four events (in chronological order) were critical in mobilizing the social science and humanities field in IPY. The first public discussion of some future IPY projects developed within the social science disciplines (nos. 6, 123, 157, 210, and 227) took place in April 2005 at the Nordic IPY seminar in Ilulissat, Greenland. It was organized by the Greenland National IPY Committee (Fig. 2.10-7) and included more than 100 researchers and students from the European (primarily Nordic) countries and also from North America, Russia and China. For indigenous participants, the key event was the symbolic launch ceremony for the 'Indigenous People's IPY' in the Norwegian town of Kautokeino/Guovdageaidnu, on 14 February 2007 organized jointly by the Sámi University College/Nordic Sámi Institute, International Centre for Reindeer Husbandry, the Association of World Reindeer Herders and the local municipality (Fig. 2.10-8). It brought together almost 300 representatives of indigenous peoples from all Arctic nations, climate researchers, reindeer herders, Sámi youth, as well as politicians and high-ranking officials from Norway, Russia and other countries. The largest IPY-related event was the 6th International Congress of Arctic Social Sciences (ICASS-VI) in Nuuk, Greenland in August 2008 (Figs. 2.10-9, 2.10-10) organized as an IPY project (no. 69, Poppel, 2009). It brought together 370 participants from 22 nations and featured plenary and thematic sessions on 12 IPY projects (nos. 100, 123, 157, 166, 167, 436, 462, etc.). Lastly, the IPY 'People Day' on 24 September 2008 (www.ipy.org/index.php?/ipy/detail/people/) (*Chapter 4.2*) was most instrumental in raising the profile of social science and human research in IPY and highlighted 41 projects, including associated efforts in education and outreach (Fig. 2.10-11).

Participatory research. IPY has advanced the participation of Arctic residents, including indigenous peoples, in polar research at all levels: project planning, data collection and management, analysis, and outreach. For the first time, Arctic residents and their organizations acted as partners and leaders in several international projects (nos. 30, 46, 157, 166, 183, 187, 247, 335, 399, 410, 425 – *Chapter 5.4*) that involved participants from many nations and disciplines. For the organizations and communities involved, it was an impressive contribution to local capacity building, training and introduction of modern research methods and technologies. The observations and knowledge of Arctic residents was the key factor to the success of IPY studies of sea ice (no. 166), wildlife habitat and distribution (nos. 162, 164), sustainability of local communities (nos. 157, 183) and economic development (nos. 46, 310, 335). Partnerships built

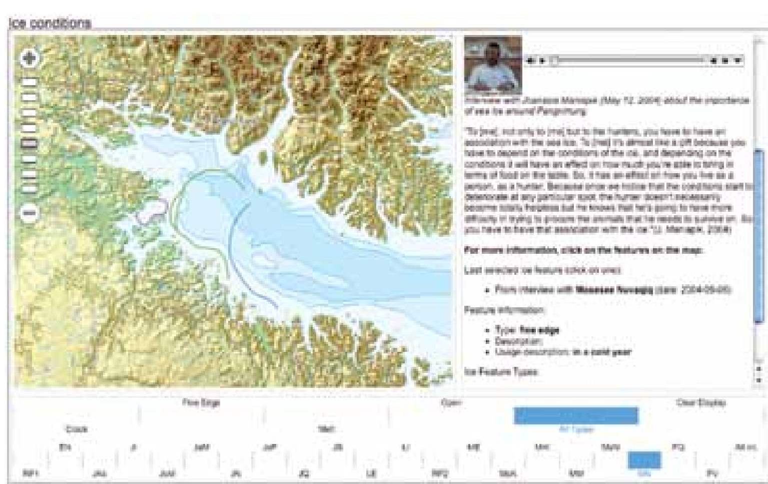


Fig. 2.10-5.
Cybercartographic atlas
(Credit: Peter Pulsifer).

Fig. 2.10-6. Poster "Polar View: Satellite-based monitoring to assist Arctic Indigenous Communities in Adapting to Climate Change" presented at the Oslo Science Conference (Alfthan et al., 2010) illustrates new links between satellite technologies and indigenous stakeholders.

during IPY enabled local communities to benefit from science projects in their home areas (Paci et al., 2008) and ensured that the implemented IPY projects were relevant to the communities and local policy development. That will certainly facilitate bridging research driven by academic institutions, agencies, and indigenous communities and organizations in the years ahead.

Several other footprints of the social science and humanities participation in IPY expand beyond the disciplinary field. Social scientists were the first to argue for the need for established 'ethical guidelines' in conducting IPY research and lobbied successfully for its approval by the Joint Committee in 2007 (www.ipy.org/ipy-blogs/item/796 - Appendix 8).[10] They initiated the collection of narratives, documents and memoirs related to the origination and early planning for IPY 2007–2008 (*Chapter 1.2*), and produced the first historical overviews of IPY 2007–2008 and compared it to the earlier IPY/IGY programs (Barr and Lüdecke, 2010; Elzinga, 2009; Korsmo, 2007, 2009; Launius et al., 2010). They argued for the preservation of IPY-related documentation and memorabilia that eventually helped establish the IPY archives at the Scott Polar Research Institute in Cambridge, U.K. (*Chapter 4.4*).

Social Science and Humanities Contributions to the IPY Science Themes

Snapshot (status). The fundamental goal of IPY 2007–2008 was to determine the baseline status of contemporary natural and human environments and processes in the polar regions (Theme 1 – Rapley et al., 2004). Almost every major IPY project in the social science and humanities field assessed the contemporary status of polar societies and social processes, and generated 'baseline' data on community development (nos. 157, 183, 462), industrial exploitation of polar resources (nos. 10, 46, 227, 310), status of indig-

Fig. 2.10-7. Participants of the 'Nordic IPY Seminar' boarding the ship in Ilulissat, Greenland, April 2005 (Photo: Birger Poppel).

Fig. 2.10-8. Opening of the Indigenous People International Polar Year, 15 February 2007. Left to right: former Sámi University College Rector, Mai-Britt Utsi, Mayor Klement Erland Heatta, former Norwegian Minister for the Environment Helen Bjørnøy, and former President of the Norwegian Sámi Parliament, Aili Keskitalo (http://arcticportal.org/ipy/opening-of-the-indigenous-peoples-international-polar-year-guovdageaidnu-norway-feb-14-2007; www.polararet.no/artikler/2007/IP_IPY).

enous languages and knowledge systems (nos. 82, 123, 164, 166, 183), cultural heritage (nos. 100, 135), community use of local resources (nos. 162, 247, 399, 408) and other themes. Several IPY publications have already connected these data to earlier datasets, thus expanding the value of IPY records by several decades (Heleniak, 2008, 2009; Kruse, 2010; Winther, 2010). The comparative value of IPY datasets is certain to grow in the years to come; it is, nonetheless, contingent upon IPY researchers making their data available to a wider community in accordance with the IPY requirements.

Frontiers (Theme 4) is the code name for the most rapidly developing science areas that the IPY planners viewed as particularly relevant to IPY research. They included social transformation induced by large-scale resource exploitation, industrialization and infrastructure development in polar regions; relations between demographic, economic and social trends and their ultimate impact on the environment as the issues of particular importance (Rapley et al., 2004). Several IPY projects in the social science and humanities field addressed those issues (nos. 10, 46, 157, 227, 310, 335, 399, 462), but other themes emerged as the obvious research 'frontiers' in IPY.

By far, the most important is the inter-relationship between indigenous perspectives developed via generations of shared knowledge and observations, and the data and interpretations generated through thematic scholarly research. The field that compares such perspectives (on climate change, sea ice, sustainability, development, community well-being) did not even exist prior to the late 1990s (Huntington et al., 2004; Krupnik and Jolly, 2002; Oakes and Riewe, 2006; Roncoli et al., 2009). Many projects contributed to its rapid growth during IPY (nos. 27, 46, 157, 162, 164, 166, 186, 187, 247, 399, 408, 410, also nos. 133, 151, 300). A related, though independent, 'frontier' area centers on making polar research culturally and socially relevant by collaborating with the new groups of stakeholders (nos. 46, 157, 162, 164, 186,187, 247, 399; *Chapter 5.4*). As stakeholders become involved in research planning in their home areas, more attention is being paid to local concerns and community observations, so that research goals are set through dialogue with local communities, rather than among scientists and funding agencies.

Another frontier area pioneered in IPY is the comparative study of northern-southern hemisphere processes to understand the development of the so-called 'fringe environments.' In the social sciences and humanities field, it focuses on the history of polar explorations, commercial use of local resources, polar governance, tourism, heritage preservation and advances the 'bipolar' approach (nos. 10, 27, 100, 135 – Avango et al., accepted; Barr and Chaplin, 2008; Broadbent, 2009; Hacquebord, 2009; Hacquebord and Avango, 2009) typical for IPY.

Change in the polar regions (Theme 2 – Rapley et al., 2004). Perhaps the very addition of 'change' as the lead research theme was the hallmark of IPY 2007–2008 compared to its predecessors. It was also a projection of the new societal concerns about global warming, environmental diversity and the industrial exploitation of the lands and the ocean,

Fig. 2.10-9. 6th International Congress of Arctic Social Sciences (ICASS-VI) in Nuuk, Greenland (August 2008) was the largest gathering of IPY social sciences and humanities researchers (Photo: Birger Poppel).

Fig. 2.10-10. IPY Plenary session at the 6th International Congress of Arctic Social Sciences. Left to right: (unidentified technical assistant), Yvon Csonka, Aqqaluk Lynge, Kristjan Kristjanson, Lars Kullerud, Rüdiger Klein, Grete Hovelsrud, Igor Krupnik and Ludger Müller-Wille (Photo: Birger Poppel).

Fig. 2.10-11. IPY 'People Day' webpage, 24 September 2008. www.ipy.org/index.php?/ipy/detail/people

and of the growing focus on 'change' in modern interdisciplinary research. Change, both environmental and social, was addressed in many IPY social science and humanities projects, including the impact of oil and gas development, polar ice, community integration and well-being, and new threats to the continuity of indigenous economies, languages, and cultures (nos. 46, 82, 157, 166, 187, 227, 247, 335, 399, 408, 436, 462). Several IPY projects in history and archaeology explored past changes in the polar regions (nos. 6, 10, 100, 151, 276) and studied early forms of commercial exploitation of polar resources, such as whaling, seal-hunting and mining, as models to the present and future development (Hacquebord, 2009). Significant effort was put into researching Arctic social change via the creation of long-term comparative datasets (nos. 227, 386, 462).

Linkages and global connections (Theme 3). Two major outcomes of broad relevance emerged from the IPY social science and humanities research. The first relates to the multi-level and adaptive nature of governance of the 'international common spaces,' such as Antarctica, the Central Arctic Basin, High Seas and Outer Space (Antarctic Treaty Summit, 2009; Shadian and Tennberg, 2009; *Chapter 5.5*). Though few IPY projects ventured explicitly into the policy and governance field (nos. 27, 100, 342), the overall awareness of such issues has grown substantially during the IPY thanks, in large part, to the historical studies of IGY 1957-1958, the celebration of the 50th anniversary of the Antarctic Treaty in 2009 and the new role of the United Nations Convention on the Law of the Sea (UNCLOS) in the Arctic Policy debate. Significant effort was made to integrate law, economics and governance with more traditional research areas such as resource use, climate science and minority rights issues (nos. 46, 157, 310, 335, 436, 462), and more is to be expected by the Montreal IPY conference in 2012 (*Chapter 5.6*).

Another major input of social science research to IPY is the recognition of complex relationships among various drivers of change and the inclusion of local communities, their voices and perspectives in the interdisciplinary studies of climate change. Several IPY projects have demonstrated that, although climate warming and changing bio-physical conditions have direct consequences to the communities that depend upon local resources, more immediate challenges stem from the many social agents, such as local system of governance, economic development, break-up in community support networks and culture shifts (nos. 46, 157, 166, 247, 335, 399, 408). In certain areas in the Arctic, the purported 'threat' of climate change is being used to mask or distort the impact of more immediate factors, such as the alienation of property rights, appropriation of land, disempowerment of indigenous communities and more restricted resource management regimes (nos. 46, 335, 399, 408; Forbes et al., 2009; Konstantinov, 2010).

A broader implication of this perspective is that environmental change ('global warming') should be considered an *added* stressor to the already challenging local conditions that can be assessed by working with the communities on the ground rather than from general models. This is a very different process than the one used in physical and natural sciences to 'downscale' global or regional scenarios of change and our understanding of the complex interplay of many factors in this process has been markedly enhanced through IPY research. Again, the value and the impact of the new information collected during IPY depend upon the individual project teams making their data widely accessible via post-IPY publication, dissemination and cross-disciplinary teamwork.

Vantage Points. 'Theme 5' of the IPY science program promoted the unique vantage point of the polar regions and was originally tailored to feature geomagnetic, space and atmosphere studies, that is, geophysical research (Rapley et al., 2004). Nonetheless, the very idea of the polar regions offering unique insight in the broader global processes resonates with the current discussions among polar social science and humanities researchers. Polar regions indeed offer a special vantage point due to the long established tradition of community and human-environmental studies, and because of the 'amplification' of many societal phenomena at the local scale, much like in the case of climate and broader environmental change.

During IPY and particularly under the ESF BOREAS program, substantial efforts have been made to place the circumpolar regions into the wider global context, with the goal to 'de-provincialize' ('de-exoticize') Arctic social science studies and to demonstrate how social and environmental research at the poles can provide new insights of, and be linked up with other parts of the world (Heading North, 2008). Such broader insights explored in IPY included the development of policies in managing 'common spaces' (nos. 100, 342); commercial resource exploitation of the economic 'frontier' zones (no.10); population exchange between 'North' and 'South' (no. 436); search for the broadly applicable indicators of community well-being (no. 436); and gaps in our datasets to assess community vulnerability to environmental change.

An internal 'vantage point,' particularly in the Arctic, is the stock of knowledge about the polar environment accumulated by local residents and, especially, by indigenous people. That knowledge has been generated independently of the advancement of scholarly studies and is based upon different sets of data and observations. Many social scientists and indigenous experts believe that both vantage points offered by the two ways of knowing, the academic and the local/indigenous knowledge, are extremely beneficial to our common understanding of the polar regions and processes (nos. 162, 164, 166, 186, 187, 247, 399, etc.).

Conclusion: The Legacy of the Social Sciences and Humanities in IPY 2007–2008

Being true newcomers in IPY 2007–2008, polar social scientists and indigenous organizations mobilized quickly and made substantial contributions to its program. They also emerged much stronger—scientifically, institutionally, and financially—as a result of IPY (*Chapter 5.4*). This is evident from the growing acceptance of indigenous, social science and humanities issues by IPY sponsors, ICSU and WMO, many polar umbrella organizations, such IASC and SCAR, and from across-the-board expansion of funding for social science research during 2005–2010. The implementation of several IPY projects operated primarily by Arctic indigenous organizations, such as EALAT, BSSN and others is another success story (*Chapters 3.10, 5.4*). Overall, all parties should be pleased that they did not miss the IPY boat in 2004.

The IPY years also witnessed the growth of interest among physical and natural scientists in the issues related to polar residents, and in the methods of social and human research. This transition becomes especially apparent through the strong presence of human and social science themes at all major IPY-related events, like the two main IPY science conferences in 2008 and 2010 (Fig. 2.10-12).[11] Many national IPY committees, for the first time, added social scientists and representatives of polar indigenous organizations to their ranks (*Chapter 5.4*). Today, we have many more partners sympathetic to the indigenous, social and humanities topics than at the beginning of the IPY planning in 2002–2003. Several IPY 'legacy initiatives,' such as SAON (*Chapter 3.8*), CBMP (*Chapter 3.9*), SWIPA (*Chapter 5.2*) and the proposed International Polar Decade (*Chapter 5.6*) now view social science's inclusion and indigenous participation as a given. The lines of collaboration

Fig. 2.10-12. Ole Henrik Magga, former President of the Sámediggi (Sami parliament) and one of the leaders of the EALÁT project (no. 399) delivers plenary talk "Arctic peoples and Arctic research - success stories, contradictions and mutual expectations" at the Oslo Science Conference, June 10, 2010 (Photo: Igor Krupnik).

established during IPY produced new alignments with colleagues in the natural and physical sciences that will become instrumental in the years ahead. Last but not least, social science issues are taking much higher profile among the next generation of polar researchers represented by APECS (*Chapter 4.3*), which now has its Law and Policy working group and a social sciences disciplinary coordinator, not to mention that the last and the current APECS President (as of 2010) have been social scientists.

We believe that the IPY 2007–2008 also has broader repercussions beyond the field of polar research, namely as a successful attempt at 'remaking' science (or 're-thinking science – Gibbons et al., 1994; Nowotny et al., 2001) particularly, by building a grassroots trans-disciplinary program via bottom-up and open collaboration among academic scientists and many new stakeholders that had little or no voice in earlier research (*Chapter 5.4*). Another key IPY legacy is the legitimization of the 'two ways of knowing' (cf. Barber and Barber, 2007) or rather, of the many 'ways of knowing' of polar regions and processes, including those advanced by physical and biological scientists, polar residents, social and humanities researchers, but also increasingly by educators, artists and media. The door to those many 'ways of knowing' was, again, opened by the inclusion of the new 'others' to the PY, primarily by the inclusion of social sciences, humanities, and polar residents' agendas into its program, and also by the outstanding success of public and outreach activities in the fourth IPY.

This leads to other crucial legacies of the social sciences' and humanities' participation in IPY 2007–2008, namely, the more complex vision of the polar regions and processes, and the recognition that the 'human dimension' paradigm is too limiting. The latter term was originally coined in the wildlife and natural park management in the 1940s and was propelled to popularity during the 1980s (Manfredo, 1989; Stern et al., 1992). It has been applied broadly in the past two decades in the studies of environmental and climate change, resource management, ecosystem dynamics, wildlife monitoring and even broader areas, such as geoengineering, urban planning or adaptation to natural catastrophes.[12] In most of these applications, it has been viewed primarily as a tool in top-down 'impact assessment' (mitigation) approach, with little relation to local communities and actual socio-cultural development on the ground. The inclusion of social sciences and the humanities to the IPY program introduced the complexity of processes going at the local scale or, at the very least, demonstrated the limitation of the dominant top-down scenarios in complex environmental modelling. It strengthened the value of comparative perspectives, other ways of knowing, and new voices in what may eventually emerge as the new (post)-IPY 'inter-disciplinarity' (*Chapters 5.1, 5.2, 5.4*). The IPY momentum has been extremely helpful in putting it to work, bridging disciplines and fields as so often and long advocated. It will be for future generations to judge whether these approaches will have a lasting impact on polar science.

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Notes

1 The field of the social science and humanities research in IPY has been covered in earlier overviews (Hoveslrud and Krupnik, 2006; Krupnik, 2008, 2009; Hovelsrud and Helgeson, 2006) and at several meetings, particularly at the 6th International Congress of Arctic Social Sciences (ICASS-6) in Nuuk in 2008.

2 Additional information can be found on the websites and in publications generated by individual projects.

3 For example, the newly released U.S. Arctic Research agenda (2010) features 'Indigenous Languages, Cultures, and Identities' (also 'Arctic Human Health') among its five central themes.

4 Unlike their colleagues in physical and natural sciences, polar social researchers and indigenous organizations had little experience in running major international projects that crossed the boundaries of several Arctic nations and covered large sections of the circumpolar zone. The Study of the Living Conditions in the Arctic (SLICA), started in 1998 and completed as IPY project (no. 386), was the only coordinated international social survey in six Arctic nations (Canada, Greenland, Norway, Russia, Sweden and the U.S.) prior to IPY 2007–2008.

5 The nations most active in IPY social research, both in terms of internationally coordinated projects and their participants, were Canada, Norway, U.S.A., Denmark/Greenland, Iceland, Russia and Sweden, with the substantial participation by scientists from Germany, U.K., Finland and the Netherlands. Individual researchers from Bulgaria, Estonia, France, Poland, Australia, Argentina and New Zealand were active in certain projects. Little or no social research was, reportedly, conducted during IPY 2007–2008 in China, Korea, Japan, India, Chile, Belgium, Portugal, Spain, Switzerland and other nations with substantial IPY activities in other fields.

6 Bulgaria, Canada, Denmark/Greenland, Finland, Germany, Iceland, the Netherlands, Norway, Sweden, Russia, United Kingdom, and U.S.A.

7 The overall number of endorsed international projects associated with the social sciences and the humanities at the onset of IPY was around 60 (Hovelsrud and Krupnik, 2006), including 16 projects in 'Education and Outreach.' Overall, those 60 proposals made an amazingly high score of about 28% of the total IPY effort. The 'full proposal' database (http://classic.ipy.org) featured a total of 83 proposals under the listing of 'People,' of which 54 can be reasonably attributed to the social and humanities field.

8 See earlier analysis of a larger sample of endorsed IPY projects in Hovelsrud and Krupnik (2006), Hovelsrud and Helgeson (2006) and Krupnik (2006, 2008, 2009).

9 Funding for BOREAS was coordinated by the European Science Foundation and came as contributions from Canada, Denmark, Estonia, Finland, Iceland, Norway, Poland, Sweden and the U.S.A. Associated project partners were based in Belgium, France, Germany, Russia, Switzerland and the U.K. Though the overall amount of funding may look modest to the natural scientists, it was the biggest program ever funded for humanities research in the Arctic.

10 The discussion about a special statement on 'ethical guidelines' for IPY research to be issued by the Joint Committee was started at the JC-3 meeting in Cambridge in April 2006 and continued at the JC-4 and JC-5 meetings (in September 2006 and 2007, respectively). A draft of the 'Ethical guidelines' for IPY research was prepared by Igor Krupnik in November 2006; it was finally approved by the JC and posted on the main IPY website in May 2007 (Appendix 8).

11 The IPY Conference in St. Petersburg (2008) featured a special theme, "People and Resources at the Poles," with eight sessions on social/human projects in IPY 2007–2008 that included more than 100 oral and poster presentations (www.scar-iasc-ipy2008.org/). The Oslo Science Conference in June 2010, similarly had a special theme titled "Human Dimensions of Change: Health, Society and Resources" with six thematic areas featuring more than 350 presentations (http://ipy-osc.no/theme/4).

12 Recent Google search for 'Human dimensions' generates about 5.5 M references (May 2010)

2.11 Human Health

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Introduction and Overview

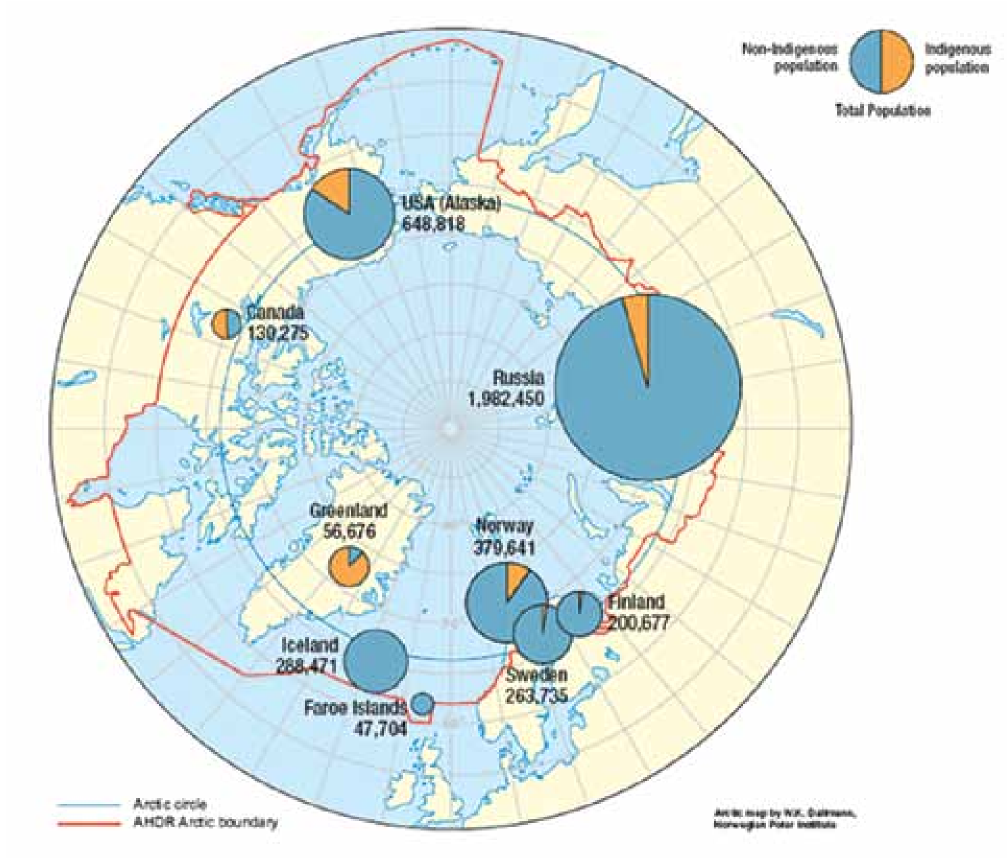
While health research is not new to international collaborations, International Polar Year (IPY) 2007–2008 was the first IPY to include human dimensions as a thematic area of study. The theme for the human dimension was established to "investigate the cultural, historical, and social processes that shape the sustainability of circumpolar human societies, and to identify their unique contributions to global cultural diversity and citizenship" (Rapley et al., 2004).

This chapter will introduce the circumpolar health context, and then provide an overview of the history which informed health research activities during IPY 2007–2008 and highlight the activities which arose as a result of this initiative.

The IPY activities related to human health primarily focused on polar regions with permanent human inhabitants (Fig. 2.11-1). Nevertheless, it should be recognized that locations such as Svalbard and Antarctica are inhabited by transient populations, and have rich histories in science and exploration. The legacy lives on as these populations continue to be primarily made up of scientists, explorers and occupational workers (including passing shipping traffic in Antarctica and coal miners in Svalbard). Both Antarctica and Svalbard have international treaties which support an environment for international activity. Despite the high level of scientific activity in these regions, scientific programs that explore the human health of these populations were underdeveloped during IPY. Human health needs in these populations tend to focus on emergency medicine, telehealth, rescue and expedition medicine and human response to isolation, cold and remote environments. Populations are small, so studies tend to be descriptive or qualitative. In some instances, human health research at the remote polar stations has been used to inform and better understand elements of human behavior in space (http://humanresearch.jsc.nasa.gov/analogs/analog_antarctica.asp). Communities such as Argentinean Esperanza Base in Antarctica and Longyearbyen in Svalbard have family residents, and medical services tend to be based on standards of the nation state: Argentina for the base in Antarctica and Norway in Svalbard. Each of these locations focuses on acute care and utilizes a medivac system to relocate individuals who are no longer able to work for any medical reason. Individuals with chronic conditions tend to self select and do not relocate to these remote locations.

Although substantial progress has occurred in the health of circumpolar peoples over the past 50 years, considerable disparities still exist across different regions and populations; these disparities tend to predominate in Indigenous populations (Young and Bjerregaard, 2008). Indicators such as life expectancy at birth (LE_0) and infant mortality capture these regional differences. In North America, LE_0 for the State of Alaska is the same as that of the rest of the United States. For Alaska Natives, however, there is a gap of about 5 years. In the three northern territories of Canada, the values decline as the proportion of Indigenous people increases, such that there is a difference of 11 years between the territory of Nunavut and the Canadian national value. In Scandinavia, there is essentially no difference between the northern and the national LE_0. Russia as a country is suffering

Fig. 2.11-1. The circumpolar Arctic region, showing total population and proportion of indigenous and non-indigenous populations.
(Map: K.W. Dahlmann, Norwegian Polar Institute)



from an unprecedented health crisis, with the male LE_0 less than 60 years. Among the northern regions, the difference in LE_0 between Iceland and Koryakia, Russia, is 29 years in men and 21 years in women.

A similar pattern is observed for infant mortality rate. The lowest rates (below 5 per 1000 livebirths) are observed in the Nordic countries (with little difference between North and South). There is an intermediate group consisting of northern Canada, Alaska and Greenland, with the Russian regions having the highest rates of infant mortality. There are substantial disparities between the Alaska Native and Alaska all-state rates, and Nunavut rate is almost three times the Canadian national rate. The highest Arctic infant mortality reported from the Evenki Autonomous Region in Russia, is 13 times that of the Faroe Islands (Fig. 2.11-2).

In general, substantial health disparities exist across different circumpolar regions. In terms of disparities between the Indigenous populations and the nation-states to which they belong, two extremes can be identified. In Scandinavia, the northern regions are almost indistinguishable from the country-at-large in terms of most health indicators. At the other extreme are Greenland and the northern territories of Canada, especially Nunavut, where the disparities with Denmark and Canada, respectively, are substantial. Alaska, as a state, tends not to differ much from the all-race U.S.A. rates, but Alaska Natives generally fare much worse than the State average. The health and demographic crisis in Russia is evident – in certain indicators, e.g. tuberculosis incidence, certain northern regions are at particularly high risk, within a country that is itself also at substantially elevated risk relative to other circumpolar countries. Selected health and demographic indicators have been compiled and available as a Circumpolar Health Supplement (Young, 2008) or online at the Circumpolar Health Observatory (www.circhob.circumpolarhealth.org).

History of Circumpolar Health Research

The scientific program of International Geophysical Year (IGY) 1957–1958 did not have a human health component. However, it did provide the catalyst for the beginning of the "Circumpolar Health Movement", a collaborative international effort to focus on human health in the Arctic. In 1957, the Nordic Council appointed a committee for Arctic Medical Research that resulted in the publication of the Nordic Council for Arctic Medical Research Report. Also in 1958, the idea for an International Biological Program (IBP) was conceived and it was implemented in 1967 as a biological analog for IGY, which had served as a successful catalyst for Arctic and Antarctic research in the physical sciences (Milan, 1980).

Although human health is new to IPY activities, there is well established history of cooperation and collaboration in health research between polar nations. The first exploratory conference on Medicine and Public Health in the Arctic and Antarctic, sponsored by the World Health Organization (WHO), was held in Geneva 28 August - 1 September 1962. It concluded that there was a need to stimulate high latitude research especially on health problems (WHO, 1963). As a result of these combined events, the first international circumpolar health symposium was held in Fairbanks, Alaska in 1967, and it was agreed to hold similar symposia every three years (Harvald, 1986). Twenty years later, these meetings resulted in the formation of the International Union for Circumpolar Health (IUCH). The IUCH is a non-governmental organization comprising an association of five circumpolar health organizations: American Society for Circumpolar Health, the Canadian Society for Circumpolar Health, the Nordic Society for Arctic Medicine, the Siberian Branch of the Russian Academy of Medical Sciences

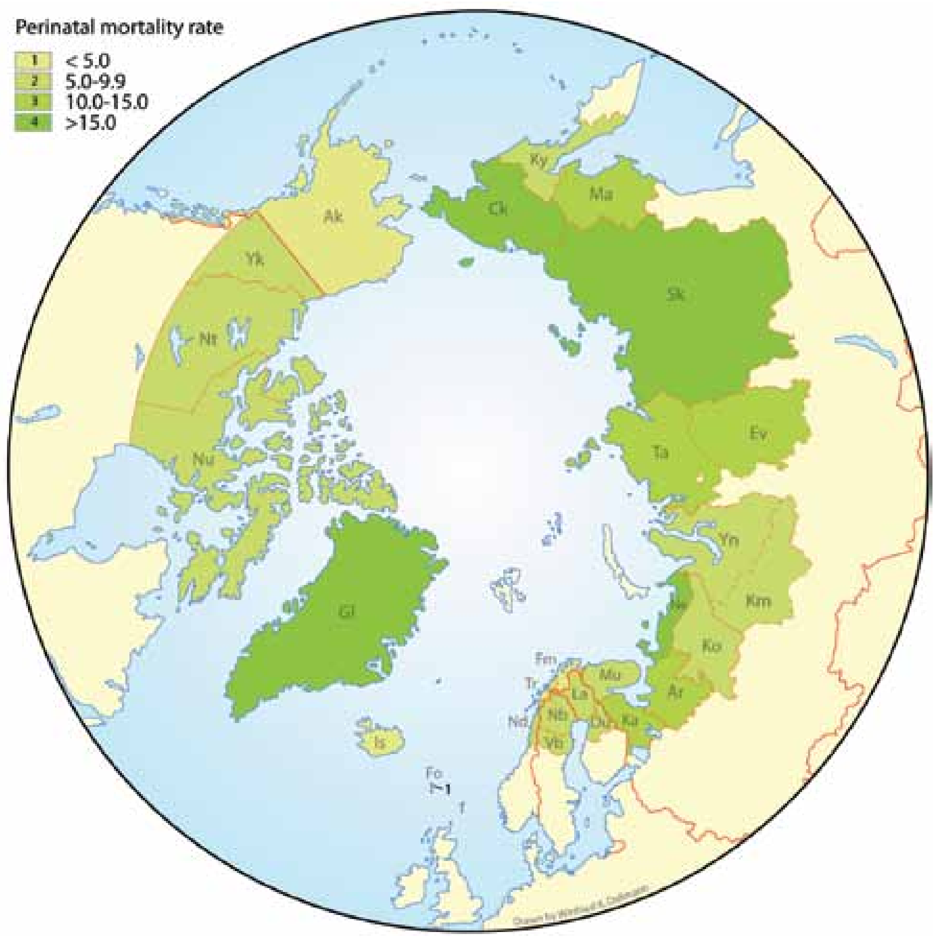


Fig. 2.11-2. Map of perinatal mortality rate (number of late fetal deaths and early neonatal deaths per 1000 total births) in circumpolar regions. (Map: W.K.Dahlman, Norwegian Polar Institute)

and the Danish Greenlandic Society for Circumpolar Health. The IUCH promotes circumpolar collaboration and cooperation through the activities of its working groups in various fields of health and medicine (www.iuch.net). Outreach and communication are provided through the publication of the *International Journal of Circumpolar Health* and the hosting of the triennial International Congress on Circumpolar Health http://icch2009.circumpolarhealth.org/ .

The success of the IPY health activities can be attributed to the development of mechanisms for communication, contributions of existing polar organizations engaged in health research and the dedication of individuals through the circumpolar regions.

IPY and the Arctic Human Health Initiative

Within the Arctic Council, it was recognized that IPY 2007–2008 represented a unique opportunity to further stimulate cooperation and coordination on Arctic health research and increase the awareness and visibility of Arctic regions, and an opportunity to expand cooperation on human health. The Arctic Human Health Initiative (AHHI, IPY no. 167) was a U.S.-led Arctic Council IPY coordinating project that aimed to build and expand on existing Arctic Council and International Union for Circumpolar Health's human health research activities. The project aimed to link researchers with potential international collaborators and to serve as a focal point for human health research, education, outreach, and communication activities during IPY. The overall goal of the AHHI was to increase awareness and visibility of human health concerns of Arctic peoples, foster human health research, and promote health strategies that will improve health and well being of all Arctic residents. Proposed activities to be recognized through the initiative included:

- Expanding research networks that will enhance surveillance and monitoring of health issues of concern to Arctic peoples, and increase collaboration and coordination of human health research;
- Fostering research that will examine the health impact of anthropogenic pollution, rapid modernization and economic development, climate variability, infectious and chronic diseases, intentional and unintentional injuries;
- Promoting education, outreach and communication that will focus public and political attention on Arctic health issues, using a variety of publications, printed and electronic reports from scientific conferences, symposia and workshops targeting researchers, students, communities and policy makers;
- Promoting the translation of research into health policy and community action including implementation of prevention strategies and health promotion; and
- Promoting synergy and strategic direction of Arctic human health research and health promotion.

As of 31 March 2009, the official end of IPY, AHHI represented a total of 38 proposals, including 21 individual Expressions of Intent (EoI), nine full proposals (FP) and ten national initiatives (NI), submitted from lead investigators from the U.S., Canada, Greenland, Norway Finland, Sweden and the Russian Federation (Table 2.11-1).

The AHHI currently monitors the progress of 28 individual active human health projects in the following thematic areas: Health Network expansion (5), Infectious Disease Research (6); Environmental Health Research (7); Behavioral and Mental Health Research (3); and Outreach Education and Communication (5). While some projects have been completed in 2008–2009, others will continue beyond IPY. Individual project details can be viewed at: www.arctichealth.org. The AHHI proved to be an effective exercise in identifying and featuring health research activities during IPY. The information was shared via websites, circumpolar health supplements, congress presentations and within peer reviewed journals. The positioning of the project within the Arctic Council also allowed for information to be shared at the level of the Sustainable Development Working Group. The sharing of activities and projects raised the profile of health research and highlighted the need within Arctic Council for there to be ongoing access to research findings and experts engaged in circumpolar health research. To this end, strengths of the AHHI were identified and formalized through the development of the Arctic Human Health Expert Group, a government appointed advisory to the Sustainable Development Working Group (Parkinson, 2010a,b).

Project Title	Lead Country(s)	EoI/FP no.
Expansion of Networks		
International Circumpolar Surveillance	U.S.A.	1150
International Network for Circumpolar Health Researchers www.inchr.com/	Canada	516
Arctic Health Research Network. www.arctichealth.ca/	Canada	NI
Survey of Living Conditions in the Arctic: Remote Access	Denmark	**386**
The Inuit Diet and Health Study: Inuit Health in Transition	Canada	NI
Integrated Research on Arctic Marine Fat and Lipids	Canada	NI
Inuit Health Survey: Inuit Health in Transition and Resiliency (www.inuithealthsurvey.ca/?nav=home)	Canada	NI
Genetics and Environmental Risk Factors for Complex Diseases: A study of the Saami population	Sweden	1274
Center for Alaska Native Health Research	U.S.A.	NI
Does Exposure to Persistent Organic Pollutants (POPs) increase the risk of breast cancer?	Denmark	1257
An Epidemiological Study of the Cumulative Health Effects of Persistent Organic Pollutants and Mercury in Subsistence Dependent Rural Alaska Natives	U.S.A.	NI
The burden of Infectious Diseases in Greenland-means of evaluation and reduction	Denmark	1107
Hepatitis B in aboriginal Populations in the Arctic: Alaska Natives, Canadian Inuit, First Nations Peoples, Greenland Inuit and Russian Native Populations.	U.S.A.	1109
Addressing Viral Hepatitis in the Canadian North	Canada	NI
Sexual Health and Sexually Transmitted Infections in Northern Frontier Populations.	Canada	1147
Engaging Communities in the Monitoring of Zoonoses, Country Food Safety and Wildlife Health	Canada	**186**
Evaluation of the impact of an immunization program combining pneumococcal conjugated vaccine and inactivated influenza vaccine in Nunavik children, Province of Quebec, Canada	Canada	1119
Prevalence of Human Papillomavirus Infection and Cervical Dysplasia in the North West Territories	Canada	1121
Health and social condition of adoptees in Greenland - a comparative register and population based field study. Creation of an "adoptees-database"	Denmark	1201
Healthy Lifestyle Projects	U.S.A.	1271
Negotiating Pathways to Adulthood: Social Change and Indigenous Culture in Four Circumpolar Communities	U.S.A.	1266
Mental and Behavioral Health Issues in the U.S.A. Arctic	U.S.A.	NI
Outreach, Education, Communication:		
The Circumpolar Health and Wellbeing: Research program for Circumpolar Health and Wellbeing, Graduate School of Circumpolar Wellbeing, Health and Adaptation, and International Joint Master's Program in Circumpolar Health and Wellbeing	Finland	1045
Scientific and professional supplements on human health in polar regions-the International Journal of Circumpolar Health	Finland	1046
Development of a Women's Health and Well-Being Track at the 14th International Congress on Circumpolar Health in Yellowknife, NWT July 2009	U.S.A.	1223
Telemedicine Cooperation Project	U.S.A.	1270
Arctic Monitoring and Assessment Program Human Health Assessment Group Conference.	Canada	**145**
Climate Change and Impacts on Human Health in the Arctic: An International Workshop on Emerging Threats and Response of Arctic Communities to Climate Change	U.S.A.	NI

Table 2.11-1. Major Research, Outreach and Training Proposals in Human Health during IPY 2007–2008. IPY Full Proposals (FP) are denoted in bold.

Canadian training, communications and outreach projects

The Inuit Cohort: A Community of Research Practice Across Canada www.ciet.org/en/documents/projects_cycles/2007102165919.asp	Canada	NI
Healthy Foods North NWT www.hlthss.gov.nt.ca/sites/healthy_foods_north/default.htm	Canada	NI
Pan-Arctic Interactive Communications Health Project www.naho.ca/inuit/wellnessTV/index.php	Canada	NI

Research Infrastructure and the Expansion of Networks

While various networks exist to coordinate circumpolar health researchers, how circumpolar health research is organized varies from country to country. Some countries have established polar institutes and support special polar research programs focused on population health, whereas other regions do not have a central health program and health researchers have to compete with other specialists for program funds (Hanne, 2009). Over the IPY years, as a result of increases in research activities, both networks supporting individual researchers and infrastructure to support circumpolar research programs have been enhanced and developed.

During the preparation and implementation of IPY 2007–2008, circumpolar countries have made substantial progress in expanding health research institutes. In Greenland, the Greenland Institute for Circumpolar Health Research was established in Nuuk in 2008. In Canada, the Institute for Circumpolar Health Research in Yellowknife, NWT and the Arctic Health Research Network – Yukon and Qaujigiartiit/ Arctic Health Research Network NU, in Iqaluit, Nunavut were established. Health research capacity was also built at the Labrador Institute via infrastructure enhancements and the establishment of a faculty position in community health and humanities in partnership with the Memorial University in Newfoundland and Labrador.

The Centre for Arctic Medicine's Thule Institute, University of Oulu, Finland (http://arctichealth.oulu.fi) has a developed research program related to Circumpolar Health and Wellbeing. Activities are focused on environmental health and adaptation; population health and health care; societal and individual wellbeing, and cultural aspects of health and wellbeing. Research projects are supported by the Finnish Academy and the European Union.

In the U.S.A., circumpolar health research infrastructure has been expanded at the University of Alaska, Anchorage through development and support of a new graduate program in public health (MPH) focused on northern and circumpolar health issues (http://health.uaa.alaska.edu/mph/index.htm) and in the reorganization of Alaska's existing Institute for Circumpolar Health Studies (www.ichs.uaa.alaska.edu).

The establishment and development of institutes can be facilitated by northern-based leadership, a vision for health research and the engagement of key partners and stakeholders (Chatwood and Young, 2010). Proximity of these institutes to the peoples and governments allow for efficiencies in public health research including access to policy-makers, partnerships with community-based organizations and opportunities to design research projects of relevance to their regions while considering the circumpolar context.

Connecting people in circumpolar regions

During IPY 2007–2008, the core participants were self-organizing groups of researchers, their parent organizations, existing bodies with a role in polar regions research and monitoring, and consortia of such bodies. Increased activities created synergies and the development of new networks.

The International Union for Circumpolar Health (www.iuch.net) has served as an ongoing network where the numerous circumpolar societies can meet and work on initiatives that support research development, networking and dissemination of health information. To this end the main activity of the IUCH has been the International Congress on Circumpolar Health, which is held in circumpolar regions every three years (see below). The IUCH also has working groups which provide a mechanism for networking in specific thematic areas.

IPY saw the establishment of the International Network for Circumpolar Research (INCHR) (EoI no. 516). This is a voluntary network of individual researchers, research trainees, and supporters of research based in academic research centres, Indigenous people's organizations, regional health authorities, scientific and professional associations and government agencies, who share the goal of improving the health of the residents of the circumpolar regions through international cooperation in scientific research (www.inchr.com).

Another network that facilitated connections among more than 145 researchers in natural, health and social sciences from universities and institutions (or agencies) in Canada, Denmark-Greenland, France, Japan, Norway, Poland, Russia, Spain, Sweden, United Kingdom and U.S.A. was ArcticNet. Through this network, scientists connected with partners from Inuit organizations, communities, federal and territorial agencies to study the impacts of climate change in coastal regions (www.arcticnet.ulaval.ca).

The Arctic Health Research Network (AHRN) was launched as a Canadian contribution to IPY 2007–2008 (EoI no. 449 - www.arctichealth.ca/aboutahrn.html). The AHRN is based in the three northern territories and a provincial region of Canada and has four sites in Yukon, Northwest Territories, Nunavut and Labrador. Each site is independent and is registered under territorial societies act and are governed by a board of directors. The AHRN supports activities which build sustainable health research infrastructure in the north as well as engage northern partners in health research projects.

Data Resources

A key focus of International Polar Year was to create a legacy of data resources; thus it was not surprising to see the enhancement and development of networks that focus on data sharing among circumpolar countries. These health data initiatives were featured and contributed to discussions around the establishment of well coordinated and Sustaining Arctic Observing Networks (SAON) (www.arcticobserving.org - *Chapter 3.8*).

It is recognized that several human health monitoring networks already exist and could form the basis for the components of SAON related to human health. The following section highlights health data initiatives which could contribute to the SAON Human Health component. Established in 1999, the International Circumpolar Surveillance (ICS) system is an integrated population-based infectious disease surveillance network system, linking hospital and public health laboratories in the Arctic Circumpolar countries (U.S.A./Alaska, Canada, Iceland, Greenland, Norway and Finland) (Parkinson, 2008, Parkinson et al., 2008) (Fig. 2.11-3). Accomplishments during IPY included an expansion of surveillance to include tuberculosis, an effort to include northern regions of the Russian Federation in this system, and the establishment circumpolar working groups to focus on research aspects of viral hepatitis, diseases caused by *Helicobacter pylori* and sexually transmitted infections (EoI no. 1150). While the International Circumpolar Surveillance network is currently focused on prevention and control of infectious diseases, the network can be adapted to monitor and respond to other non-infectious Arctic human health priorities and, therefore, serves as a model as an Arctic Observing Network for human health (www.arcticobserving.org).

The Arctic Monitoring and Assessment Program (AMAP) of the Arctic Council has been coordinating circumpolar monitoring and assessment of atmospheric pathways, biota impacts, food chain dynamics and human health issues for environmental contaminants since 1991 (www.amap.no/). The contaminants have included persistent organic pollutants (POP's-both historic and emerging compounds), metals and radionuclides of concern in the circumpolar world (Fig. 2.11-4). The AMAP Human Health Assessment Group (HHAG) has members in all eight circumpolar countries and has completed three assessments on the human health impacts of arctic environmental contaminants (AMAP, 1996, 2002, 2009). These assessments include human monitoring data, dietary studies, health effects studies and risk management strategies to mitigate the effects of contaminants.

The Survey of Living Conditions in the Arctic (SliCA, IPY no. 386) itself is an interdisciplinary and international research project, which was founded in 1998 (Kruse et al., 2008; Poppel and Kruse, in press). The project is developed in partnership with the indigenous peoples organizations (*Chapter 2.10*). SLiCA has collected data in Canada, Alaska, Chukotka, Greenland and Sweden (Poppel et al., 2007) and, by the end of

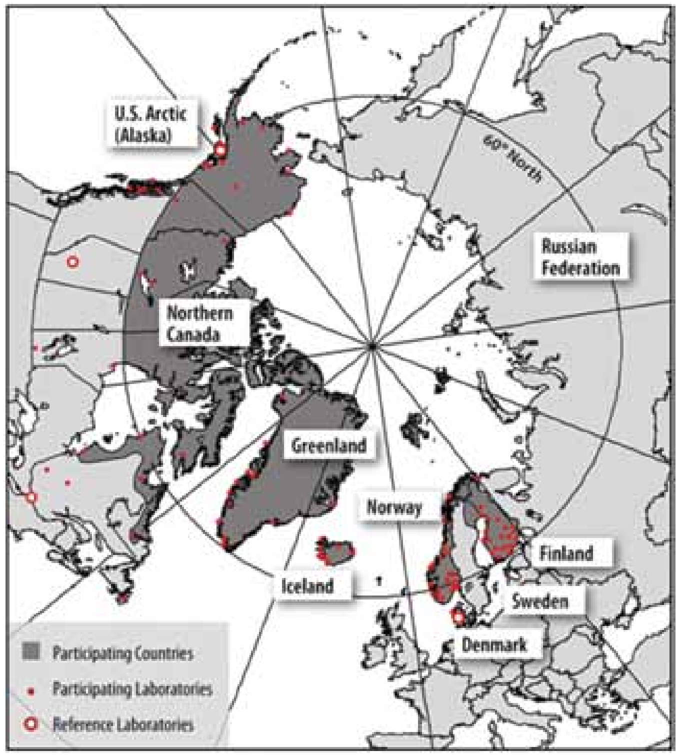


Fig. 2.11-3. The International Circumpolar Surveillance (ICS) network of public health laboratories and institutes linked together for the purpose of sharing standardized information on infectious diseases of concern to Arctic peoples
(Source: Arctic Investigations Program).

2008, interviewing among the Sámi in Norway and the Kola Peninsula was concluded. The data material consists of approximately 8000 personal interviews.

During IPY, SLiCA intended to expand the understanding of Arctic change by extending the concepts of remote access analysis to the SLiCA international database (Hamilton et al., 2009), allowing other researchers to remotely conduct analysis without access to raw data. All interview data (except the Canadian SLiCA data) have been included in a SPSS database and almost 600 tables including survey results based on the interviewing among the Inuit (www.arcticlivingconditions.org).

During IPY, the concept of a Circumpolar Health Observatory (CircHOB) was developed (www.circhob.circumpolarhealth.org). Circumpolar regions have much in common beyond climate and geography. While health priorities are generally similar, health and social policies, service delivery systems, available resources and population characteristics vary considerably across regions. As a consequence, substantial disparities in health outcomes exist among circumpolar countries and regions. Monitoring, documenting and disseminating statistical health data will contribute to improvements in the design of policies, planning of services and evaluation of programs by government agencies, non-governmental organizations, academic institutions and communities across the circumpolar world. The objective of the CircHOB is an international collaborative health information system, involved in systematic, standardized and consistent data collection and analysis. It is population-based and covers all northern regions in all circumpolar countries. CircHOB's purpose is to monitor trends and patterns in health status, health determinants and health care, and provide an on-going knowledge base and analytical support for decision-makers, service providers, academic researchers and consumers.

Several other human health and social indicator networks are operational and will increase our research capacity and to address social realities of the Arctic. They all aim to encourage data sharing and use.

The Arctic Social Indicators (ASI - *Chapter 2.10*) is a follow-up project to the Arctic Human Development Report (Young and Einarsson, 2004). This project, which is currently on-going, will take advantage of existing data to create relevant indicators and will recommend a set of new and relevant indicators (*Chapter 2.10*). ASI developed indicators in six domains: ability to guide one's destiny, cultural integrity, contact with nature, education, health and demography, and material well-being. The Arctic Observation Network Social Indicators Project (AON-SIP, no. 462 - *Chapter 2.10*) is compiling data using a common framework, geography, time and variables. There are five clusters of indicators: community living conditions (organized within the six ASI domains), tourism, fisheries, oil gas and mining, marine transportation and marine mammal hunting (www.search-hd.net). ArcticStat is a portal database that allows the user to select and reach existing tables that cover Arctic countries and regions, some ten socio-economic indicators and more sub-indicators, and years (www.arcticstat.org). Thousands of tables mainly from national agencies are linked to ArcticStat.

Research

IPY human health research focused on some of the issues of most concern to Arctic residents. These concerns include: the health impacts of environmental contaminants, climate change, rapidly changing social and economic parameters within communities, the changing patterns of chronic diseases and the continuing health disparities that exist between indigenous and non-indigenous segments of the Arctic populations. Other issues of importance, such as injuries and maternal and child health, are not captured within the endorsed IPY projects and are thus not commented on in this chapter. Nevertheless, dissemination initiatives during IPY captured the broader spectrum of health research outputs outside of the IPY programs (Young and Bjerregaard, 2008).

The intensity of research activities and networks during IPY has served as a catalyst to integrated programs, which promote communities and researchers working collaboratively. It is hoped research, informed by community perspectives, will enhance the relevancy of findings and improve health policies and programs.

Environmental Contaminants

While socio-economic conditions and lifestyle choices are major determinants of health, contaminants may also have a contributing effect. Toxico-

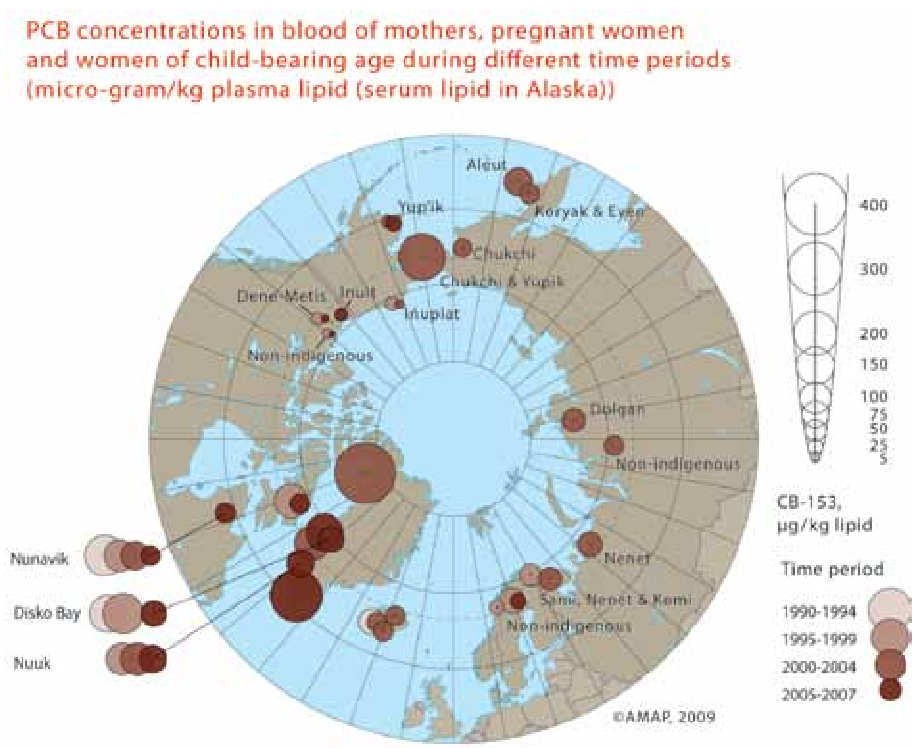


Fig. 2.11-4. PCB (CB 153) concentration in blood (serum/plasma) of mothers, pregnant women and women of child bearing age during different time periods (Source: AMAP, 2009).

logical studies show that contaminant levels found in some parts of the Arctic have the potential for adverse health effects in people. Epidemiological studies looking at Arctic residents directly provide evidence for subtle immunological cardiovascular and reproductive effects due to contaminants in some Arctic populations (AMAP, 2009). If climate change is associated with rising salmon and human levels of POPs and mercury it would provide data to further support reduction of POPs and mercury production and release, and efforts to reduce global warming. Another study led by researchers at the Center for Arctic Environmental Medicine, School of Public Health, University of Aarhus, Denmark examined the risk of the development of breast cancer in Greenlandic Inuit women following exposure to persistent organic pollutants (EoI no. 1257). Blood levels of POPs in women with breast cancer will be compared to controls with respect to age and lifestyle. The bio-effects of POP levels on hormone receptor function will also be examined (Bonefeld-Jorgensen, 2010).

Infectious Diseases

A continuing major health disparity is the increased morbidity and mortality due to infectious diseases seen among indigenous populations when compared to the non-indigenous populations of the Arctic. These disparities can be resolved with greater understanding of their causes through research, focused efforts at treatment and prevention.

Hepatitis B infection occurs at high and endemic rates in Arctic populations. For example research has shown that 3-5% of individuals residing in the Canadian North, 5-14% of Inuit in Greenland and 3-10% of Alaska Native people in Western Alaska are infected with hepatitis B virus (HBV) and likely, if left untreated, 10-25% will develop liver cancer or die of cirrhosis. Researchers from the U.S., Canada, Greenland, Denmark and the Russian Federation have formed a Circumpolar Viral Hepatitis Working Group and are conducting studies to determine the epidemiology of chronic HBV in Aboriginal populations (EoI no. 1109). The study monitors patients to determine disease progression, examine demographic characteristics associated with disease outcome, examine environmental factors associated with disease outcome, including contaminants in the environment and subsistence foods, examine co-factors such as alcohol intake, obesity and metabolic syndrome, and examine viral characteristics, such as genotype and viral loads and mutations that could affect disease outcome. This study allows the identification of barriers to vaccination, the development of registries for research and clinical management, the development of criteria to identify potential treatment candidates, monitoring of treatment outcome, and the examination of the role of factors, such as demographics, viral genotype, and environmental factors in treatment outcome. Already, this research group has identified a new HBV sub-genotype (B6), which is only found in indigenous populations of Alaska, Canada, and Greenland (Sakamoto et al., 2007) and assisted Greenland in the investigation of an outbreak of hepatitis D superinfection in adolescents with chronic HBV in a community in Greenland (Borresen et al., 2010). In addition this working group has been instrumental in encouraging the Greenland government to adopt universal childhood hepatitis B vaccination in Greenland.

Similarly reported rates of sexually transmitted infections (STIs) are disparately high among indigenous populations of the Arctic (Gesink-Law et al., 2008). Research in Canada, U.S.A. and Greenland (EoI no. 1147), aimed at building capacity to examine individual, social and environmental factors that influence perceptions of sexual health and sexually transmitted infections, is being conducted by researchers and communities using participatory methods (Gesink et al., 2010; Rink et al., 2009). The aims include a description of the basic epidemiology of sexual health and STIs and to identify communities at risk and targets for capacity-building and interventions. Preliminary results indicate that *Mycoplasma genitalium* is as prevalent as *Chlamydia trachomatis* in Greenland, and that social and cultural norms around sexual health communication, trust, drinking and sex appear to influence individual sexual behaviours and risk for STIs. Based on this research, the National Science Foundation has granted U.S., Canadian, Greenlandic and Danish researchers new funds to explore community based participatory methods in Greenland and develop a social intervention focusing on sexual health communication with families and relationships.

Canadian researchers are examining the potential for incorporating Human Papillomavirus (HPV) DNA testing into the present screening program (EoI no. 1121). This project examined HPV infection and cervical dysplasia (precancerous cells) in women of the Northwest Territories, Yukon, Nunavut and Labrador to determine general prevalence rates, types of HPV and risks associated with the development of HPV. The aim is to provide scientific evidence for policy-makers and local public health workers to assist in the planning and implementation of cancer control programs.

With their strong hunting traditions and subsistence based on wild game, Arctic indigenous peoples are at increased risk of zoonoses and parasitic infections acquired from infected meat. Zoonoses refer to a group of diseases caused by organisms that are usually present in animals, but are transmitted to and cause disease in humans. As temperatures warm and habitats change, diseases and parasites will move northward with the migration of their wildlife hosts, others will increase their density due to optimal temperatures for replication. These factors together with other environmental changes (water availability, ice and snow cover, ocean currents, extreme weather events, forest fires, etc.) will favor a shift in the distribution of hosts and zoonotic disease threats to the safety of country foods. Food-borne parasites, such as Trichinella, Toxoplasma and Anisakidae nematododes, are significant Arctic zoonoses endemic in some regions and directly related to consumption of country food (Figs. 2.11-5; 2.11-6). In addition, the prevalence of some diseases, such as those caused by *Salmonella sp.* and *E. coli 0157:H7* may increase in warmer weather. A study in Canada has resulted in the development of simplified diagnostic tests for these pathogens (IPY no. 186). The study provided equipment and training for the evaluation of these tests in several northern communities (Gauthier et al., 2010). The prevalence and distribution of each disease studied in Canadian wildlife will be documented and entered into a Canadian web-based data base on wildlife diseases of the Canadian Cooperative Wildlife Health Centre.

Streptococcus pneumoniae is one of the leading causes of pneumonia, meningitis, bacteremia, septic shock and otitis media in Arctic indigenous populations, particularly among children and the elderly (Bruce et al., 2008). For example, the incidence rates of invasive pneumococcal disease in Inuit are approximately four times that of non Inuit. A Canadian study is analyzing medical records of more than 3000 children born in Nunavik between 1994 and 2005 to verify whether vaccination reduces the number of respiratory infections, prescriptions for antibiotics, hospitalizations and hearing disorders (EoI no. 1119). The results of this study could be used to inform vaccine programs for all populations living in the Arctic.

IPY provided the opportunity to strengthen surveillance and research on infectious diseases in Greenland (EoI no. 1107). This project, a cooperation between Greenland and Denmark, addressed the burden of infectious diseases in Greenland by establishing research programs to evaluate long-term consequences of certain infectious diseases, to evaluate the use of routine surveillance data, to initiate intervention trials in order to prevent infectious diseases, to seek implementation of results in the Greenland health system and to establish cooperation with public health and research organizations in other countries. Specific studies under this project included a validation of the Greenlandic inpatient register, the initiation of tuberculosis studies (Nielsen et al., 2009; Soborg et al., 2009), an evaluation of the distribution of bacterial pathogens causing invasive disease (Madsen et al., 2009; Meyer et al., 2008; Bruce et al., 2008), a study of the long-term consequences of hepatitis B (Sakamoto et al., 2007; Borresen et al., 2010), a study of the association between Epstein Barr virus and various cancers (Friborg et al., 2009; Boysen et al., 2009), a study of HIV drug resistance (Madsen et al., 2008; Lohse et al., 2008), and a study of the etiology of viral respiratory pathogens among Greenlandic children. In collaboration with Canadian researchers a nationwide study of viral pathogens in children hospitalized with lower respiratory tract infections in Greenland is on-going. With researchers in Canada and the U.S., the network organization is involved in studies of epidemiological, microbiological, and social aspects of sexually transmitted infections (Gesink et al., 2010).

Life-style, Diet and Nutrition

Considerable life-style changes have occurred over the past decades among the indigenous peoples in the circumpolar region. Parallel to this has been a change

Fig. 2.11-5. Salmon drying on the Yukon River. Indigenious peoples of the Arctic rely on nutrient dense traditional foods such as fish, marine mammals, wild game and plants to provide them with food security and nutrition. (Photo: David Hik)

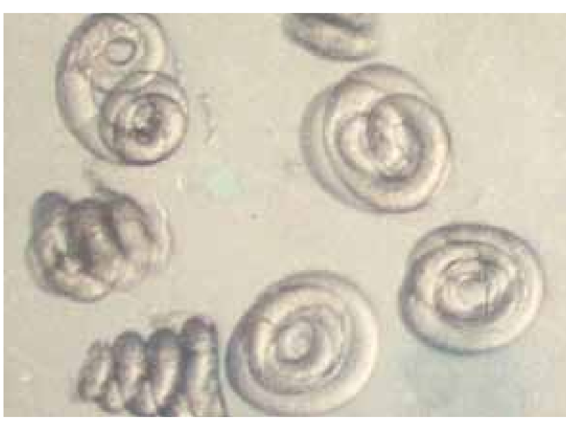


Fig. 2.11-6. Walrus meat may be infected with *Trichinella nativa* which causes Trichinellosis, a disease caused by a roundworm whose larvae encapsulate in the muscle tissue. Illness can occur in humans, who ingest infected undercooked or raw meat, and it can range from mild or inapparent to a fulminating fatal disease depending on the number of larvae ingested. *Trichinella nativa* (shown right, x 100 magnification) can survive in frozen muscle tissue for many years. (Photos: Manon Simard, Makivik Corporation, Canada)

Fig. 2.11-7. The Inuit Health Survey, an IPY-Canada project, involved measuring the health status of Inuit across the Canadian Arctic onboard the science research ship/icebreaker Amundsen. A barge from the ship leaves for shore to pick up survey participants. (Photo: Kue Young)

in disease patterns, with an increase for example in cardiovascular diseases, obesity and diabetes. Among the main causes are alterations to the diet and levels of physical activity as the population changes from their traditional hunting and fishing economy to more Westernized living conditions. Several large IPY activities were initiated to address some of these issues.

A large international study entitled "The Inuit Health in Transition" was proposed to cover a cohort of over 7,000 Inuit adults in Alaska, Canada and Greenland during IPY. The Canadian federal IPY program funded a major component of this international study during 2007–2008 in Nunavut, Northwest Territories and Labrador. Known as the Inuit Health Survey, it covered 1900 households in 33 communities across the Canadian Arctic, which were visited by the Coast Guard icebreaker–science research vessel CCGS Amundsen (Fig. 2.11-7). The study was focused on diet and other lifestyle factors such as smoking, contaminant exposure and physical activity. Baseline data collection was completed in all participating regions during IPY. Cross-sectional analyses are currently underway to investigate the associations between environment, living conditions, lifestyle risk factors and existing chronic and other diseases among these populations. A total of 2600 adults participated. Information was collected by personal interviews, physical examination and laboratory tests. In addition, 388 children aged 3-5 from 16 Nunavut communities took part in a child health survey. The Inuit health survey contained question on household crowding and food security, nutrition, country food and eating habits, mental health and community wellness, and medical history. The survey also contained a number of medical tests including measures for heart health, diabetes risk, body measures, exposure to infection, bone health, nutrient status and exposure to environmental contaminants (Chan, 2009; Dewailly, 2009). Preliminary descriptive findings from the study have been compiled and distributed via community reports. Early studies have found there is a high prevalence of household food insecurity among Inuit households (Egeland et al., 2010) and overweight prevalence is increasing (Galloway et al., 2010).

A Swedish IPY project evaluated a northern Swedish population with known demographic and environmental exposures to identify genetic and environmental factors that contribute to health status (EoI no. 1274). In this study, cross-population comparisons are used to study genetic and environmental risk factors among populations with widely differing origins and environments. The study measures a broad spectrum of environmental (e.g. diet, physical activity and daylight exposure) and genetic (e.g. single-nucleotide polymorphisms) factors with potential relevance for health risk. A comprehensive set of health indicators and diagnoses of cardiovascular, orthopedic and metabolic diseases has been collected. In particular, the state-of-the-art laboratory analysis of blood lipids comprising several hundreds of lipid species will give unique insights into the human metabolism under extreme living conditions. Studies of rural populations can make substantial contributions to basic research to understand environmental and genetic determinants of disease. The European Special Population Network (EUROSPAN) provides a platform combining studies of rural populations from different parts of Europe to leverage these for collaboration with large international consortia (Igl et al., 2010).

In the U.S., the Center for Alaska Native Health Research (CANHR) at the University of Alaska, Fairbanks used the IPY momentum to build a collaborative research presence in Alaska Native communities, focusing on prevention and reduction of health disparities by seeking new knowledge through basic and applied research that can ultimately be applied to understand, prevent and reduce health disparities in indigenous communities (Mohatt et al., 2007) (http://canhr.uaf.edu/). The Center studies behavioral, dietary and genetic risk and protective factors related to obesity diabetes and cardiovascular disease risk in Alaska Natives of Southwestern Alaska. CANHR includes studies related to substance abuse and suicide prevention, the development of novel dietary biomarkers, contaminants and the safety of substance foods, stress and gene by environment interactions, and nutrition research. All CANHR studies employ community-based participatory research approaches.

Behavioural and Mental Health

Behavioural and mental health disorders are common worldwide and circumpolar regions are not exempt from this burden. Contemporary dynamics of rapid social change have dramatically affected the political, cultural and economic systems of circumpolar indigenous people. Depression and suicide have been highlighted as significant issues in northern regions. (Levintova et al., 2010). During IPY, there were a number of research projects which explored behavioral and mental health, and the relationships between outcomes and environmental factors.

The Inuit Health Survey collected information on mental and community wellness. Findings provide information on the burden of mental illness and also evaluate social support and other determinants of resiliency and self-reported health (Egeland, 2009). In Nunavik a cohort study was carried out that focused on exposure to environmental contaminants and child behaviour. The study also explored the impact of lifestyle factors, such as smoking, alcohol and drug abuse during pregnancy, on multiple domains of child development and behaviour (Muckle, 2009).

Two CANHR affiliated studies focus on behavioural health research. This U.S.-led study examined social change and indigenous culture in five circumpolar communities by exploring responses to rapid social transition through the life experiences of circumpolar youth (EoI no. 1266). This study is completing over 100 youth life history interviews from Alaska Inupiat, Alaska Yup'ik, Canadian Inuit and Sámi and Siberian Eveny communities. The project team identified shared and divergent stressors and patterns of resilience in the transition to adulthood across these different circumpolar settings (Fig. 2.11-8).

Elluam Tungiinun -"Toward wellness"- is a culturally-based preventive intervention to reduce suicide risk and co-morbid underage drinking among Alaska Native Yup'ik Eskimo youth. This five-year community based participatory research prevention trial will enroll 239 youth ages 12 through18 in five rural remote Yup'ik communities and test effectiveness post-intervention using a randomized dynamic wait list control design. This study represents the next stage in a 15-year community-based participatory research process with Alaska Native people (Allen et al., 2009).

A Danish study examined the health and social condition of adoptees in Greenland. Greenland has a significant number of adoptees and the number of children placed at institution is large (EoI no. 1201). The study explored how adoption and collective

Fig. 2.11-8. Even, Inupiaq, Inuit, Sámi and Yup'ik youth co-researchers with elders and university co-researchers at the Circumpolar Indigenous Pathways to Adulthood Workshop Meeting, Scott Polar Institute, Cambridge University, England, May 2009.
(Photo: CANHR, 2009)

care have an impact on well being, family health and social conditions. Adoption is closely linked to social organization, identity, cultural openness and collective consciousness. This study identified settings in which adoption was linked to child neglect and lack of care. The study also examined parents' and care givers' control and coping strategies. The study concluded that, contrary to findings related to adoptees in Western societies, being an adoptee in Greenland does not increase the risk for psychiatric admission (Laubjerg and Petersson, 2009).

Health Services Delivery

The circumpolar regions experience unique challenges in the delivery of health services because of widely dispersed populations and geographic obstacles. During IPY 2007–2008, opportunities were created for cross-border partnerships to explore needs related to service delivery. The Northern Forum (NF), a forum of northern regional governments (www.northernforum.org), cooperated with the Alaska Federal Health Care Access Network (AFHCAN) to implement a strategic and innovative solution to address health care needs of two regions in the Arctic. Together, the NF and AFHCAN facilitated cooperation in telemedicine technology expertise between Alaska, the Republic of Sakha and Khanty-Mansyisk region in Russia (EoI no. 1270). The goal of the project was to promote the establishment of a mutually beneficial collaboration in telemedicine, tele-health, mobile medicine and distance learning in remote areas of the Russian north. This project is an important first step in both improving technologies to enhance access to care and utilization of existing forums to promote cross-border partnerships and activities.

Mental health services are also of importance in the north and efforts are required to enhance service delivery. The Northern Forum developed and promoted The Healthy Lifestyle Projects (EoI no. 1271), which provided information exchange and training opportunities to advance care and treatment of Arctic residents with mental health issues.

While the health service delivery research field is underdeveloped in the north, these projects identify key areas of importance and play an important role as we begin to understand and develop best practices to improve services and programs in northern regions.

Outreach Education and Communication

An important aspect of IPY was, and will continue to be, the promotion of education, outreach and communication, which will focus public and political attention on Arctic health issues; increase dialogue between researchers, policy-makers and communities; increase distribution of scientific information to scientists and the public through conferences, symposia, workshops and a variety of electronic and printed media; increase community involvement in research activities; and foster a "new" generation of Arctic health scientists.

Symposia and Workshops

IPY was highlighted by the occurrence of the 13th International Congress on Circumpolar Health held in Novosibirsk, Russian Federation, 12-16 June 2006, the *"Gateway to the International Polar Year"* for the circumpolar health community. This congress was put on by IUCH and brought together circumpolar health care professionals, workers, researchers, policy-makers and indigenous community members. The meeting presented a forum for discussion on their respective visions and priorities for human health activities for IPY and beyond. These discussions resulted in recommendations that emphasized the role of communities in research planning, research activities and the translation of research findings into actions that would benefit the health and wellbeing of Arctic communities (ICCH13, 2007). The Women's Health Working Group of the IUCH was reactivated at that congress in June 2006 (EoI no. 1223). Participants identified at least four areas of mutual interest, including, but not limited to: 1) perinatal health systems and challenges, 2) infectious disease, particularly HPV and new vaccine; 3) interpersonal violence prevention and 4) health communication and health literacy.

At the end of IPY, the 14th International Congress on Circumpolar Health was held in Yellowknife, Northwest Territories, Canada, 12-16 July 2009. The theme of the congress recognized the end of the Polar Year and spoke to *Securing the IPY Legacy: From Research to Action*. While results from much of the research conducted over IPY are still pending, the congress program contained a broad cross section of presenters, sessions and preliminary results from IPY. The sessions allowed for complementary perspectives of researchers, clinicians, community representatives and governments on numerous topics that impact public health, health services delivery, the research process and Indigenous wellness in our circumpolar regions. Presentations demonstrated instances where research findings are applied in numerous settings, with uptake by clinicians, community organizations and governments. Presentations also recognized the contributions of numerous stakeholders through the research process with a particular focus on community engagement and participatory methods (ICCH14, 2010).

IPY also provided the opportunity to conduct a number of workshops that brought together researchers from circumpolar countries on topics such as the human health impacts of climate change, environmental contaminants and developing a prevention research strategy for behavioral and mental health.

The Arctic, like most other parts of the world, has warmed substantially over the last few decades. The impacts of climate change on the health of Arctic residents will vary depending on such factors as age, socioeconomic status, life-style, culture, location and capacity of the local health care infrastructures to adapt. It is likely that the most vulnerable will be those living close to the land in remote communities and those already facing health related challenges (Berner and Furgal, 2005).

Climate change workshops were convened in Anchorage, Alaska as part of the 2008 Alaska Forum on the Environment (www.akforum.com), in Moscow, May 2008 and in Arkhangelsk, June 2009, all organized by UNDP, WHP and UNEP. These meetings recommended that action be taken on the human health recommendations put forward by Chapter 15 of the ACIA Report, and in the report by the United Nations and the Russian Federation "Impact of Global Climate Change on Human Health in the Russian Arctic" (Parkinson and Berner, 2008; Parkinson, 2010c; Revich, 2008, 2010).

A joint AMAP and Northern Contaminants Program (NCP) symposium was held in Iqaluit, Nunavut, Canada 10-12 June 2009 (IPY no. 145). At this meeting, the third NCP and AMAP Human Health Assessments reports on environmental contaminants were released and the results were discussed (AMAP, 2009; CACHAR, 2009). The symposium demonstrated that the overall management of contaminants issue in the Arctic by all partners has been effective in reducing the health risks to northern populations from environmental contaminants. While the results indicate that there are declines in many contaminants in several Arctic Regions, there are still indications that there may be subtle health effects (cardiovascular, immunological) due to contaminants in some Arctic populations. The symposium reemphasized the importance of biomonitoring of persistent organic pollutants and metals to track international protocols, biomonitoring of emerging contaminants, quality control of laboratory methods, health effects research and dietary choice, risk perception and risk communication.

The Fogarty International Center at the National Institutes of Health (NIH), together with the U.S. Arctic Research Commission (USARC) and other NIH institutes and CDC, organized a strategy setting conference on the *Behavioral and Mental Health Research in the Arctic* in Anchorage, AK on 2-3 June 2009. The purpose of this meeting was to develop a U.S. Arctic Human Health Research Strategy that will advise the Interagency Arctic Research Policy Committee (IARPC) on the development of a Arctic Human Health Research Plan. This meeting engaged Arctic health stakeholders including U.S. government, scientific and tribal community leaders and international scientists in behavioural and mental health with discussions of current knowledge and gaps in research, with a particular focus on improving our understanding of the risk factors for and barriers to reduce suicide and other behavioral and mental health ailments among Arctic populations. The conference outcome will be a strategy plan that will include specific goals and methods, as well as discussion of potential future research and research training activities on behavioral and mental health in the Arctic (Levintova et al., 2010).

Electronic and Print Media

Dissemination in Scientific Community

While the activities of the polar years focused on study implementation and data collection, analysis and dissemination of findings will be ongoing for years to come. During IPY, a number of summary and synthesis documents were created. The International Journal of Circumpolar Health (www.ijch.fi) produced a series of Circumpolar Health Supplements on topics of general interest and related to IPY themes (EoI no. 1046). To date, seven supplements have been published as contributions to the IPY: (1) Anthropology and Health of Indigenous Peoples of Northern Russia (Kozlov et al., 2007); (2) Diet and Contaminants in Greenland (Hansen et al., 2008); (3) Circumpolar Health Indicators (Young, 2008); (4) International Circumpolar Surveillance: Prevention and Control of Infectious Diseases (Zulz et al., 2009); (5) Behavioral and Mental Health Research in the Arctic: Strategy Setting Meeting (Levintova et al., 2010); and (6) The Arctic Human health Initiative (Parkinson, 2010b); (7) Proceedings of the 14th International Congress on Circumpolar Health (ICCH14 2010).

The International Network for Circumpolar Health Research produced a book, *Health Transitions in Arctic Populations* (Young and Bjerregaard, 2008) with contributions from 23 scientists and health care practitioners from all the Arctic countries. It synthesized existing knowledge on the health status of all the circumpolar regions and populations, with specific focus on the indigenous Sámi, Dene and Inuit people, their determinants, and strategies for improving their health.

Multi-media and knowledge sharing

The Arctic Human Health Initiative facilitated the development of the Arctic Health website www.arctichealth.org as a central source for information on diverse aspects of the Arctic environment and the health of northern peoples. The site gives access to health information from hundreds of local, state, national and international agencies, as well as from professional societies and universities. In addition, the Arctic Health Publications Database, (currently more than 96,000 records), provides access to Arctic-specific articles, out of print publications and information from special collections held in the Alaska Medical Library.

During IPY, a concept for a circumpolar health portal was developed (www.circumpolarhealth.org). This project is exploring the feasibility of a coordinated venue to capture and promote the activities of circumpolar health organizations and initiatives. The website also incorporates Facebook and Twitter, and has dedicated channels for You Tube iPod casts and Flickr. These mechanisms allow for storage and access of photos, audio files and video. These tools are especially valuable to share information and outputs related to youth driven and participatory research projects.

In addition to web-based media, radio and TV still play an important role in the sharing of information with circumpolar residents. A series of three live TV call-in shows on Inuit wellness was developed under the umbrella of the Pan-Arctic Interactive Communications Health Project. TV programs were produced and focused on the current health issues of importance to Inuit, including: (1) Inuit men's health and wellness, (2) Inuit maternal care, and (3) Inuit youth and coping. Each show was moderated and featured panel discussions about programs and research with community representatives and physicians, video vignettes and interactions with the studio audience, Skype, phone and e-mail participants. The television broadcasts reached a wide audience by airing on networks in Canada and Alaska. This project was an innovative, multi-dimensional, collaborative health communication project that raised both interest and awareness about complex health conditions in the North, and stimulated community dialogue and potential for both local and regional collaborative action. On-going evidence-based resources for health education and community action developed through this program were assembled and archived in digital format (www.naho.ca/inuit/e/TVseries) to increase accessibility for otherwise isolated individuals and remote communities.

Education and Training Initiatives

Education and training in the "discipline" of circumpolar health is as varied and broad as the number of topics related to human health, which are explored in circumpolar regions. Thus education and training activities through the polar years have tended to be cross-cutting and integrated in research programs. Activities have included the support of graduate students and training of community partners. Many health research initiatives now employ community-based participatory methods in which training in research methods, data collection and dissemination practices are integral components of the methodology. Examples of community participation have been demonstrated in programs, such as the Inuit Health Survey, Healthy Foods North project and the Inuit Cohort, an education initiative to promote graduate education for Inuit. All of these initiatives are important as research methods are improved to incorporate academic and community perspectives. The evaluation of the The Pan-Arctic Inuit Wellness TV Series project provides specific lessons to build a strong foundation of community-professional-academic partnership (Johnson et al., 2009).

In addition, the Centre for Arctic Medicine, Thule Institute, University of Oulu, Finland (http://arctichealth.oulu.fi) has a program dedicated to circumpolar health (EoI no. 1045). It is delivered in close collaboration with the University of the Arctic (www.uarctic.org). The program offers both PhD and Master's programs in the field of health and well being in the circumpolar regions. The International Master's program started in autumn 2008 with 14 students from Canada, United Kingdom, Finland, Russia and Australia. Other partners involved in providing courses towards the degree program include, the Center for Health Education (Nuuk, Greenland), Luleå University of Technology (Luleå, Sweden), Northern Medical State University (Arkhangeslsk, Russia), Pomor State University (Arkhangelsk, Russia), NORUT Social Science Research Ltd (Tromso, Norway), University of Lapland (Rovaniemi, Finland), University of Manitoba (Winnipeg, Canada) and University of Southern Denmark, (Esbjerg, Denmark) as well as the Cross Border University of Barents area. The Centre for Arctic Medicine is collaborating with the University of Alaska Anchorage MPH program and others to off the first Summer Institute in Circumpolar Health Research in Copenhagen in May 2010 (http://sichr.circumpolarhealth.org).

Securing the Legacy of IPY 2007-2009

The aim of IPY activities was to harness the resources and intellect across the circumpolar regions and leave a legacy of data, observing sites, facilities and systems to support on-going polar research and monitoring, and to provide value to future generations. (Rapley et al., 2004). During IPY, it was evident that health research productivity increased and many collaborative research projects were started because of national interest and the availability of new funding programs dedicated to human health research. Other projects were possible because agencies and organizations redirected resources and in-kind support to ensure the success of this human health initiative. Through these activities networks grew, infrastructure was built, health research institutes were established, training opportunities were provided, data projects were initiated and mechanisms to improve knowledge dissemination were supported and developed. Unique features of health research included the engagement of community and end user stakeholders in the research process to optimize relevancy and uptake of findings. A number of networks, policies and best practices to enhance research impacts have been developed and leave elements of frameworks for best practices in circumpolar health research.

The legacy for health research lies in the mechanisms and framework, which support the interconnectivity from polar communities to the international forums of decision-makers. It is through these initiatives from community-based networks, to SAON-coordinated projects, to Arctic Council advisories, circumpolar institutes and their affiliated networks of stakeholders and partners that value for future generations will be secured. On-going critical development of and support for these initiatives must be secured throughout the circumpolar regions. A broad informed base will ensure ongoing uptake and analysis of data to the highest standard as well as ensuring dissemination of findings so best practices may inform the development of government policies and clinical guidelines which influence health and well being. It is the networks and institutes, which support these connections, that will combine perspectives and knowledge bases required to address the complexities of the polar environments, the multifaceted nature of health determinants, and will ultimately inform solutions to promote health across the polar regions.

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