PART THREE

IPY Observing Systems, Their Legacy and Data Management

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Introduction

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IPY "Expressions of Intent" collected by the IPY Programme Office (IPO) in January 2005 (*Chapter 1.5*) contained specific sections that listed observing facilities to be established within each IPY project to ensure its implementation and meet its scientific requirements and objectives. The JC at its first meeting (JC-1, March 2005) after reviewing the submissions for future IPY projects agreed that it would be useful to have a special Subcommittee on Observations (SCOBS) similar to the Subcommittees on Data Management, and on Education, Outreach and Communications, to help ensure that appropriate links were made between the various projects and the space-based and *in situ* observations communities. An Observing Systems ad hoc group (T. Mohr, E. Sarukhanian, K. Alverson and C. Summerhayes) was formed within the JC to develop a draft Terms of Reference (ToR) and propose a preliminary composition for this subcommittee. At the second session of the JC (JC-2, November, 2005) the SCOBS was established as a special body under the JC supervision, and its ToR and composition were approved by the JC (the composition of SCOBS is given in *Appendix 5*).

According to the ToR, the main tasks of the SCOBS were to evaluate the observational requirements contained in the full proposals for IPY, assess which requirements could be met by existing observing systems, and, after a gap analysis, identify special observing systems and special data and products that needed to be established to meet the requirements of IPY projects. The JC asked the SCOBS to ensure that space-based and *in situ* observing systems, including those set by polar residents and based upon indigenous monitoring systems, would be optimized for IPY purposes. At the first SCOBS session (Potsdam, March 2006) the members submitted assessments of the observing systems requirements contained in 166 IPY-endorsed scientific projects within the domains Atmosphere, Ocean, Ice, Land, People, and Earth and Space (the latter assessment was done after the session in Potsdam).

The assessment results were informative, in particular with respect to observational data requirements, data sources, technological/institutional gaps, data management requirements, and the potential legacy of observing systems planned to be established during IPY 2007–2008. For example, in the case of requirements for satellite data, products and services, the assessment showed that it was crucial to establish an immediate dialog between IPY scientists and the Space Agencies to define the concrete requirements to be met by satellite operators. The appropriate actions were taken by ICSU and WMO, and a special IPY Space Task Group was formed at the end of 2006, as part of the SCOBS under the Joint Committee supervision (*Chapter 3.1*).

Another important task of SCOBS was to establish through the JC and the IPO a dialog with the Arctic Council, Antarctic Treaty Parties, IASC, SCAR and other international organizations and/or programmes, so as to secure the provision for the legacy of observing systems developed during IPY 2007–2008. The results of the SCOBS assessment, in particular those related to a legacy of IPY observing systems, were of potential use by the international organisations responsible for implementing and managing global and regional observing systems. In view of the importance of this issue, the JC at its sixth session (JC-6, October 2007) asked the SCOBS to develop a roadmap to provide a consolidated vision of the IPY observing systems legacy, and to identify a mechanism for early assessment of benefits acquired from IPY 2007–2008 observations, in order to prepare for obtaining support for the long-term reinforcement and maintenance of the observational networks in polar regions.

The SCOBS presented the roadmap to the IPY observing systems legacy to the seventh meeting of the JC (JC-7, July 2008) as a discussion paper. The roadmap was developed to provide a way forward to creating a basic vision of an IPY observing systems legacy that could then be used by decision-makers to identify funding in support of IPY observing networks in the post-IPY era. Some of the emerging initiatives listed below were described in the document. The SCOBS submitted a review of the results of the latest developments of these initiatives to the eighth session of the JC (JC-8, February 2009). That overview paper, *IPY Observing System Emerging Legacy* (JC8/Doc.3), covered the progress in five major observational initiatives established during the IPY 2007–2008 years:

- Sustaining Arctic Observing Networks (SAON) with an Integrated Arctic Ocean Observing System (iAOOS);
- Pan-Antarctic Observing System (PAntOS) with a Southern Ocean Observing System (SOOS);
- The Global Cryosphere Watch (GCW),
- Polar Satellites Constellation (PSC),
- Polar Climate Outlook Forum (PCOF).

The chapters in this section of the IPY Summary provide far more detailed and updated information on most of the listed initiatives, in addition covering several other observational networks developed during IPY 2007–2008. They include:

- Satellite Observations Program *(Chapter 3.1)*,
- Towards an integrated Arctic Ocean Observing System *(Chapter 3.2),*
- Southern Ocean Observing System (SOOS) *(Chapter 3.3),*
- International Arctic System for Observing of Atmosphere (IASOA) *(Chapter 3.4)*
- Meteorological Observations in the Antarctic

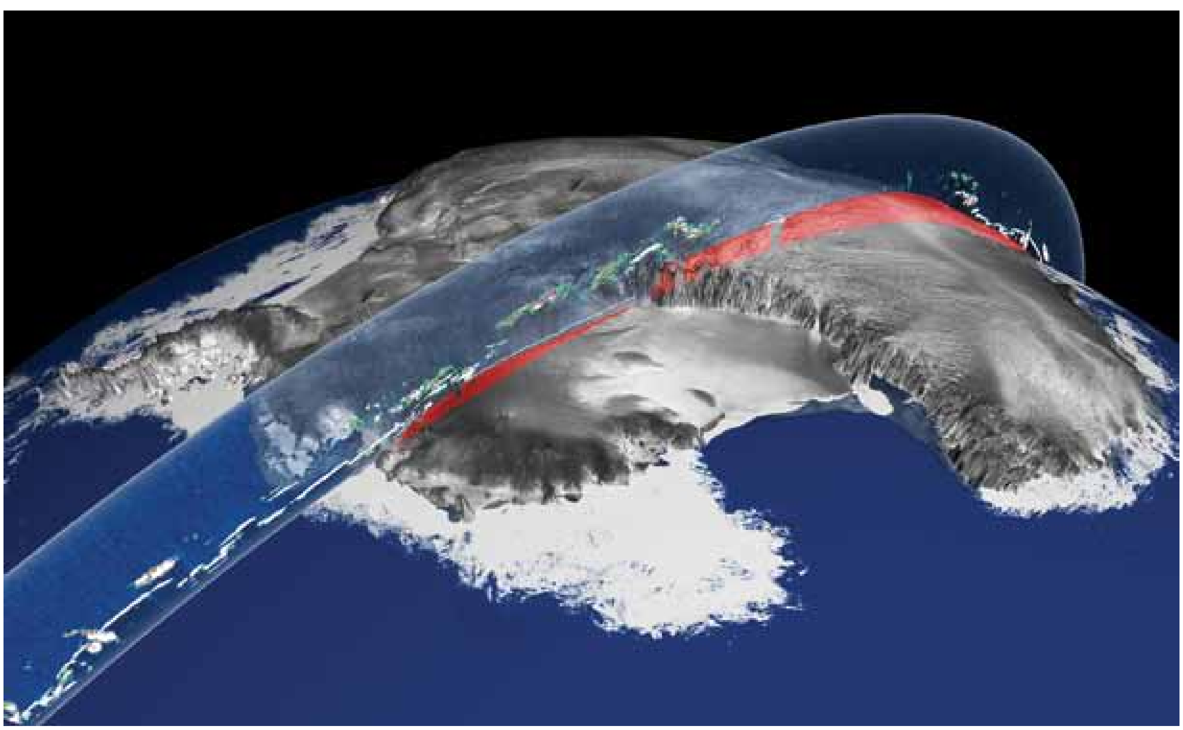


Fig. 3.0-1. NASA Ice, Cloud and Land Elevation Satellite (ICESat) data collection over the Antarctic. ICESat laser altimeters measured ice sheet mass balance, cloud, and aerosol heights during IPY.

(NASA/Goddard Space Flight Center Scientific Visualization Studio, RADARSAT mosaic of Antarctica. Canadian Space Agency) during IPY *(Chapter 3.5)*

- Arctic Sea Ice Outlook *(Chapter 3.6)*
- Global Cryosphere Watch (GCW) *(Chapter 3.7)*
- Sustaining Arctic Observing Networks (SAON) *(Chapter 3.8)*
- Circumpolar Biodiversity Monitoring Program *(Chapter 3.9)*
- Human-based observational activities and indigenous monitoring *(Chapter 3.10)*

In most cases the description covers the process of initial establishment of each of the above-mentioned IPY 2007–2008 observational programmes and their implementation during the IPY period, and offers perspectives of their development as IPY 'legacy initiatives' (e.g. *Chapters 3.1, 3.4, 3.5* and *3.6*). Other chapters provide a scientific guidance and/or recommendations to determine a transition to a sustainable observing system in the post-IPY era (e.g. *Chapters 3.2, 3.3, 3.7, 3.8* and *3.10*).

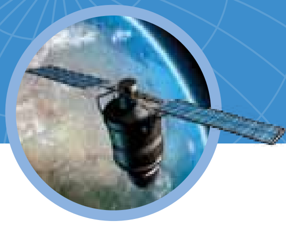
The last chapter in this section (*Chapter 3.11*) addresses the issues of the IPY 2007–2008 data management. From the very beginning of IPY 2007–2008, the IPY planners saw data as a vital legacy of the process, notably stating in *"A Framework for the International Polar Year 2007–2008"* that *"In fifty years time the data resulting from IPY 2007–2008 may be seen as the most important single outcome of the programme."* (Rapley et al., 2004). On behalf of the JC, the Subcommittee on Data Management developed a Data Policy and Data Strategy and worked closely with the various IPY project leaders to ensure *to the extent possible* that data gathered during IPY was appropriately archived and readily available. *Chapter 3.11* reviews the success of the data strategy and policy, and makes a number of key recommendations for the way forward that - if implemented by national programmes - will greatly aid the dissemination, sharing and wider use of IPY 2007–2008 data.

Recommendations offered in *Chapter 3.11* could form the basis for a more strategic approach to data and information management in the polar regions, especially in the Arctic. The Scientific Committee on Antarctic Research (SCAR) used the opportunity of IPY 2007–2008 to develop its own comprehensive data and information management strategy for the Antarctic, (see http://scadm.scar.org/scadm/scar_dis.html). ICSU has followed up the recommendations of the IPY Data Subcommittee by creating its own committee to develop the notion of a 'Polar Information Commons' to enable widespread access to data and information in the polar regions. Successful development and application of these various aspects of the IPY data legacy will bring widespread benefits to scientists, national operators, indigenous peoples, and intergovernmental groups (such as Arctic Council and Antarctic Treaty Parties).

In concluding this introductory section to eleven thematic chapters to follow, we note that it deliberately focuses rather on the processes used during the IPY 2007–2008 period to upgrade, expand or establish observing and/or data management systems that could be expected to form the basis for an IPY legacy of improved observing networks and data management. The chapters thus do not stand alone, but should be read in conjunction with complementary chapters describing the science and the outcomes of project work. Publications produced during the IPY period, or about to be produced as a result of IPY, provide detailed descriptions of design plans, like those for SOOS (see www.scar.org/soos), and CryOS (see www.scar.org/researchgroups/physicalscience/ for The Cryosphere Observing Plan), and readers seeking that level of detail are encouraged to search elsewhere. It was not our intention to duplicate those descriptions. Instead we thought it important for those planning future IPYs to set down here the process by which the present constellation of observing systems and data management plans was designed.

References

Rapley, C., R. Bell, I. Allison, P. Bindschadler, G. Casassa, S. Chown, G. Duhaime, V. Kotlyakov, M. Kuhn, O. Orheim, P. Ch. Pandey, H. Petersen, H. Schalke, W. Janoschek, E. Sarukhanian and Zh. Zhang, 2004. *A Framework for the International Polar Year 2007–2008. Produced by the ICSU IPY 2007–2008 Planning Group.* ICSU: Paris, 57 pp. http://classic.ipy.org/development/framework/framework.pdf



3.1 IPY Satellite Observation Program

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Reviewers:
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The importance of satellite observations to IPY scientific objectives was recognized by the Joint Committee (JC) and its Scientific Committee on Observations (SCOBS) during early IPY planning and preparations. In 2006 SCOBS evaluated all IPY scientific projects that emphasized requirements for satellite data, products and services. The evaluation showed that these requirements were not consistent among projects and not always sufficiently detailed to establish immediate dialog between IPY projects and Space Agencies. Bearing this in mind, the SCOBS approached the Global Interagency IPY Polar Snapshot Year (GIIPSY) project (number 91, co-leaders K. Jezek, Byrd Polar Research Center and M. Drinkwater, European Space Agency) which was selected by JC in November 2005 as an IPY flagship project in order to realize the benefit of the growing constellation of international satellites to the scientific objectives of the IPY. The goal of GIIPSY was to develop consensus polar science requirements and objectives that could best, and perhaps only, be met using the international constellation of Earth observing satellites (Jezek and Drinkwater, 2006; 2008). Requirements focused mainly on all aspects of the cryosphere and ranged from sea ice and permafrost to snow cover and ice sheets. Individual topics included the development of high resolution digital elevation models of outlet glaciers using stereo optical systems, measurements of ice surface velocity using interferometric synthetic aperture radar (SAR/InSAR) and frequently repeated measurements of sea ice motion using medium resolution optical and microwave imaging instruments. Later, the requirements for satellite data, products and services were extended to cover composition, dynamics and chemistry of the polar atmosphere.

The functional link between the GIIPSY science community and the international space agencies was established through the IPY Space Task Group (STG) as part of SCOBS. International space agency participation in the STG was solicited through a letter sent in November 2006 on behalf of the WMO Secretary-General and the Executive Director of ICSU to the heads of space agencies. As result, STG membership consisted of representatives from the national space agencies of Brazil (INPE – A. Setzer), Canada (CSA – Y. Crevier), China (CMA – L. Zhao), France (CNES – E. Thouvenot), Germany (DLR – M. Gottwald), Italy (ASI – F. Battazza), Japan (JAXA – M. Shimada), Russian Federation (ROSHYDROMET – V. Asmus), U.K. (BSNC– D. Williams), U.S.A. (NASA – C. Dobson, NOAA– J. Key and P. Clemente-Colon, USGS – J. Mullins), the European Space Agency (ESA – M. Drinkwater, ESA/ESRIN – H. Laur) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT – K. Holmlund). To provide a link between the STG and IPY data management activities, the JC nominated IPY operational data coordinator O. Godoy (Norwegian Meteorological Institute) as STG member.

The IPY STG was established for the purpose of space agency planning, processing and archiving of the IPY Earth Observation legacy dataset. STG, chaired by M. Drinkwater, reported to SCOBS whose responsibility was to ensure that space-based and *in situ* observing systems were optimized for IPY purposes. SCOBS provided the guidelines for a scientific framework and consolidated science and data requirements to the STG, through the coordination of scientific groups such as the GIIPSY IPY project, the WCRP Climate and Cryosphere (CliC) project and the IGOS-P Cryosphere Theme team. STG recommendations were approved by the WMO Consultative Meetings on High-level Policy on Satellite Matters on an annual basis. The operating strategy for STG was to satisfy IPY science requirements in a fashion that distributes the acquisition burden across the space agencies while recognizing the operational mandates that guide the activities of each agency. Thus far, the space agencies have worked to develop IPY data 'portfolios' that, in total, aim to satisfy a significant number of scientific requirements. The primary objectives of STG meetings have been to review science requirements, to provide agency reports on progress in support of developing the IPY data legacy, and to identify and solicit new members. GIIPSY science requirements were presented at the first STG meeting.

STG has met in full session six times. Along with representatives of the space agencies mentioned above, members of GIIPSY (K. Jezek and others), the IPY Joint Committee (T. Mohr and E. Sarukhanian), WCRP (G. Asrar, V. Ryabinin, B. Goodison) and the WMO Secretariat, which provided administrative support, also attended STG meetings. The first meeting was held in January 2007 at the WMO headquarters in Geneva. Since then, the STG has met at EUMETSAT in Darmstadt, Germany in November 2007, at the ESA/ESRIN located in Frascati, Italy in May 2008, WMO Headquarters in Geneva in February and in December 2009 and in Oslo in June 2010. The STG also convened a SAR Working Group chaired by Y. Crevier (Canadian Space Agency). The purpose of the SAR-WG was to address fulfillment, on a best effort basis, of GIIPSY science requirements uniquely related to SAR/InSAR. The SAR-WG first met in March 2008 at the Canadian Space Agency in Montreal. Subsequent meetings were held in October 2008 at the German Aerospace Center in Oberpfaffenhofen and in June 2009 at ESA in Frascati. A full description of GIIPSY science requirements, agency data portfolios and meeting summaries can be found on the GIIPSY web page: http://bprc.osu.edu/rsl/GIIPSY (Drinkwater et al., 2008).

Based on GIIPSY recommendations, the STG adopted four primary data acquisition objectives for its contribution to IPY. The fifth objective was added at STG3. These are:

- Pole-to-coast multi-frequency InSAR measurements of ice-sheet surface velocity.
- Repeat fine-resolution SAR mapping of the entire Southern Ocean sea ice cover for sea ice motion.
- One complete high resolution visible and thermal

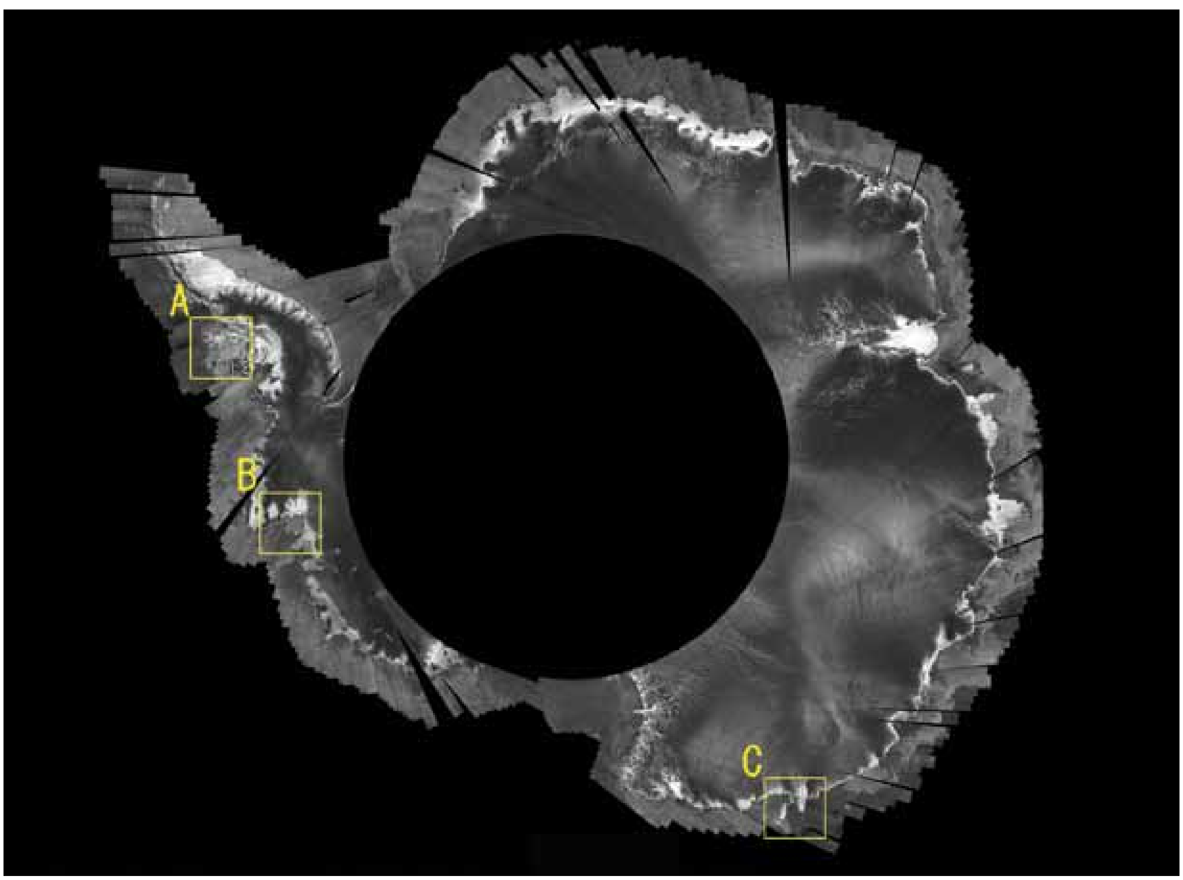


Fig. 3.1-1. Antarctica mosaic image covers the time between 8 December 2007 and 22 January 2008. Yellow square areas show fast glaciers and the location of retreating ice shelves in the Antarctic Peninsula.
(Courtesy: JAXA)

infrared snapshot of circumpolar permafrost.

- Pan-Arctic high and moderate resolution Vis/IR snapshots of freshwater (lake and river) freeze-up and break-up.
- Atmospheric dynamics and composition.

The STG has made substantial progress towards these acquisition objectives (IPY-STG, 2010). Fig. 3.1-1 shows a JAXA ALOS SAR mosaic image which covers the time between 8 December 2007 and 22 January 2008. Yellow square areas show the location of several fast glaciers and also the location of important ice shelf retreat in the Antarctic Peninsula. Fig. 3.1-2 shows the first measurements of surface velocity along a 250 km long tributary draining into Recovery Glacier, Coates Land, Antarctica (Floricioiu and Jezek, 2009). The tributary was discovered during the Radarsat-1 Antarctic Mapping mission. TerraSAR-X was used to acquire interferometric data along the length of the glacier resulting in the first velocity map of this unusual feature. ASI, CSA, DLR, ESA and JAXA have worked together to acquire the first pole to coast InSAR data sets for measuring surface velocity on both ice sheets. Surface velocity from these campaigns will be used to study the ice flux from the ice sheets into the oceans and to better understand controls on the motion of ice streams and the break-up of ice shelves. Ice shelf studies included an intense, routine-monitoring campaign following the Wilkins Ice Shelf break up, which demonstrated the importance of SAR for satellite daily monitoring of the polar regions (Fig. 3.1-3). COSMO-SkyMed, the Italian X-band SAR constellation, contributed to observations of the Wilkins ice shelf by monitoring the disintegration events and ice movement over large and medium areas (Battazza et. al, 2009a). COSMO-SkyMed data were also used to measure the glacier velocity field of Patagonian glaciers using spotlight high resolution images with time intervals of 8 and 16 days (Fig. 3.1-4), (Battazza et al., 2009b). ESA and CSA have coordinated SAR campaigns to fill gaps in Arctic and Antarctic sea ice cover where either station masks or on-board recorder time have usually precluded routine coverage.

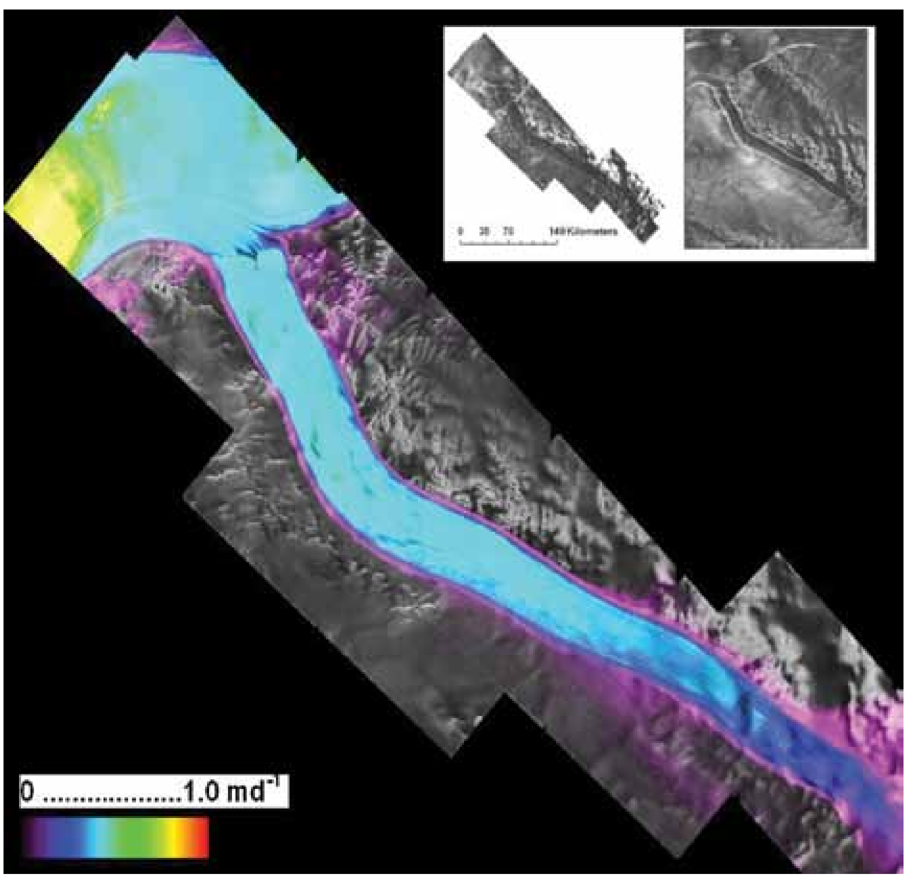
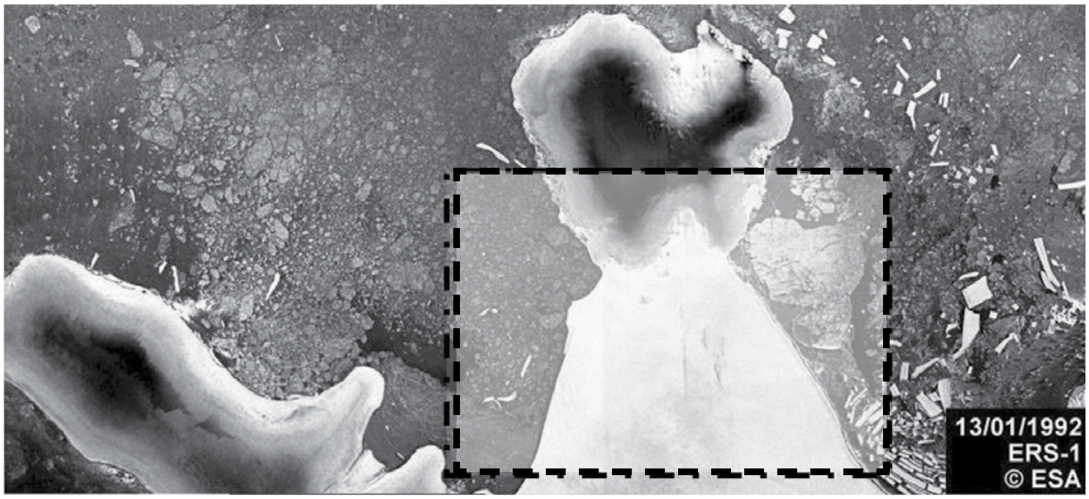


Fig. 3.1-2. 2008-09 TerraSAR-X mosaic (left inset) and 1997 RAMP mosaic (right inset) of Recovery Glacier tributary (Antarctica) The main trunk of Recovery Glacier is located in the upper part of the RAMP and TerraSAR-X mosaics. Scenes are centered on 82.5°S 19°W. Central figure shows surface velocity along the entire 250 km length of the tributary measured using TerraSAR-X data.
(Image: DLR)



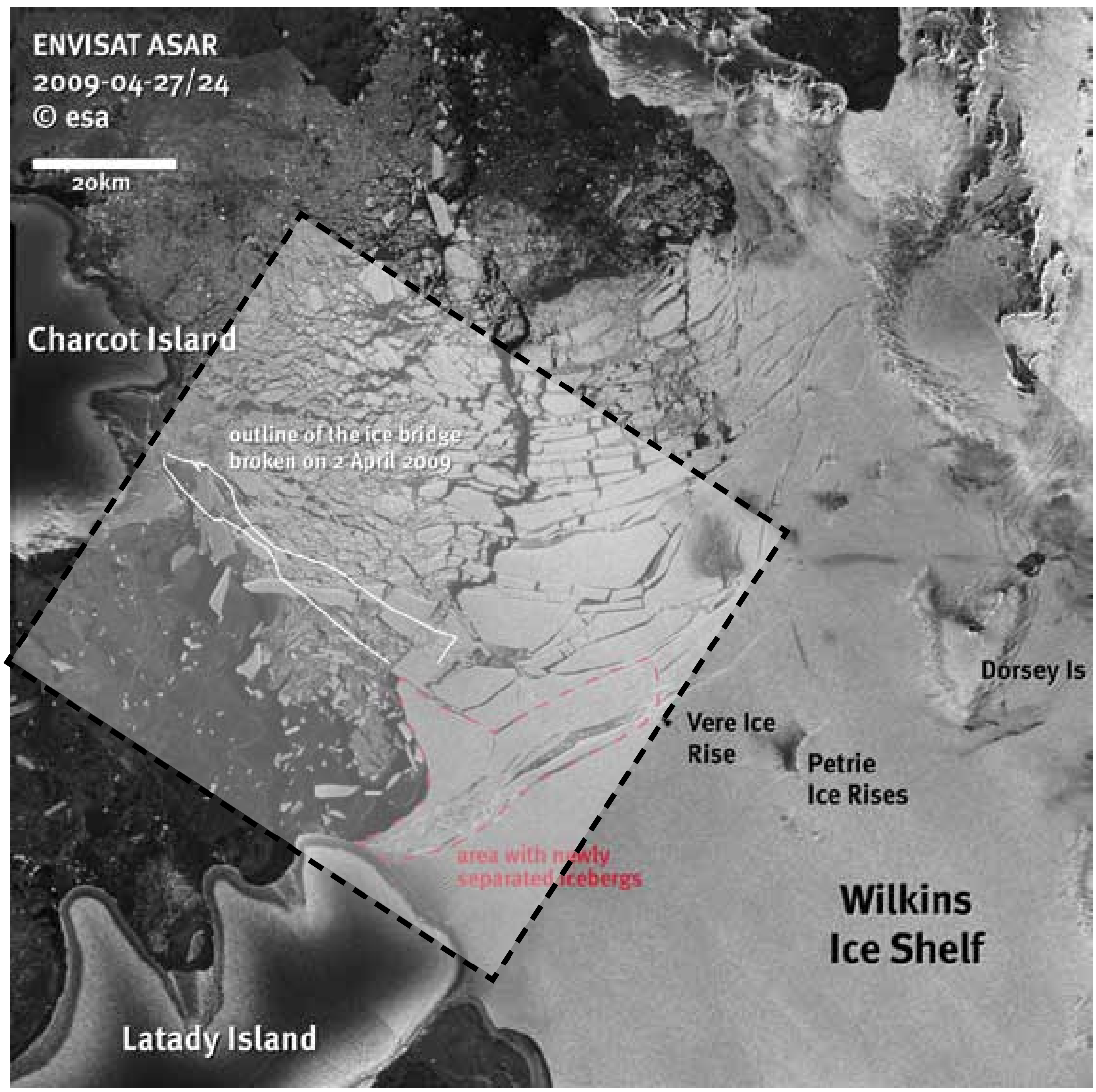
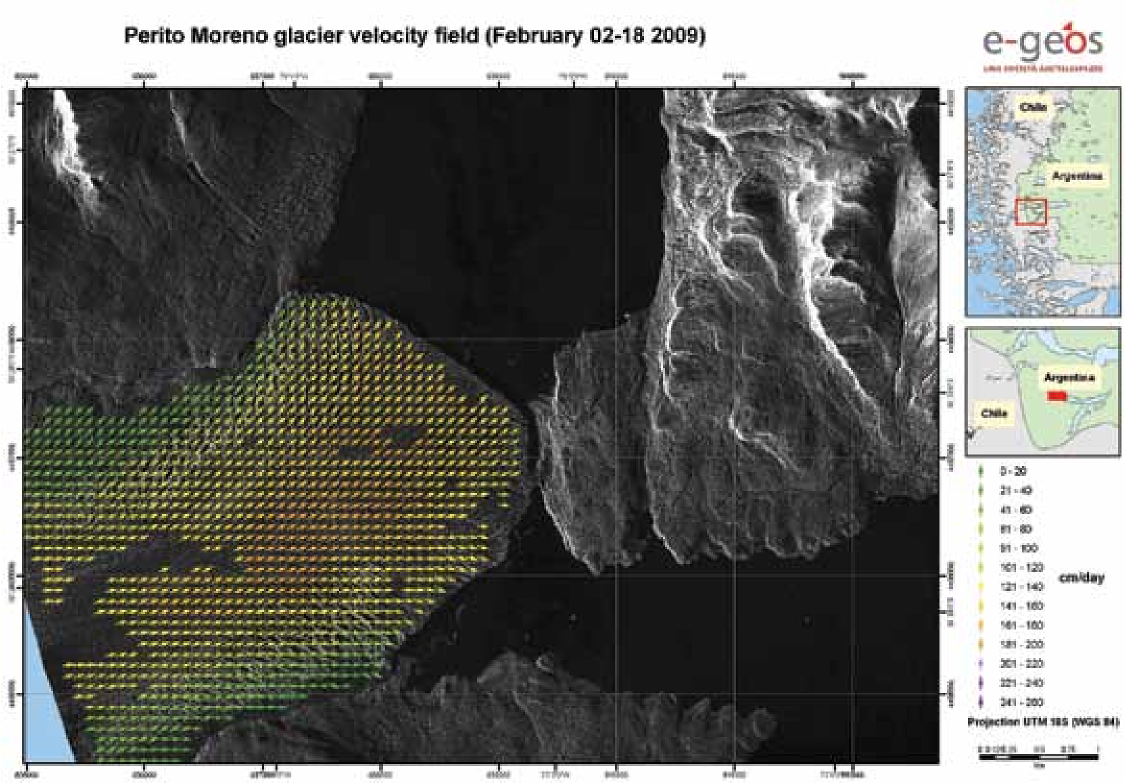


Fig. 3.1-3. Evolution of the Wilkins Ice Shelf in the past 18 years. Top: SAR image captured by ERS-1, showing the extent of the ice shelf. Bottom: Envisat ASAR following with daily imagery the break-up of the ice shelf giving scientists worldwide the opportunity to understand the dynamics of this event. This intense acquisition campaign has been one of the Envisat contributions to IPY. (Image: ESA)



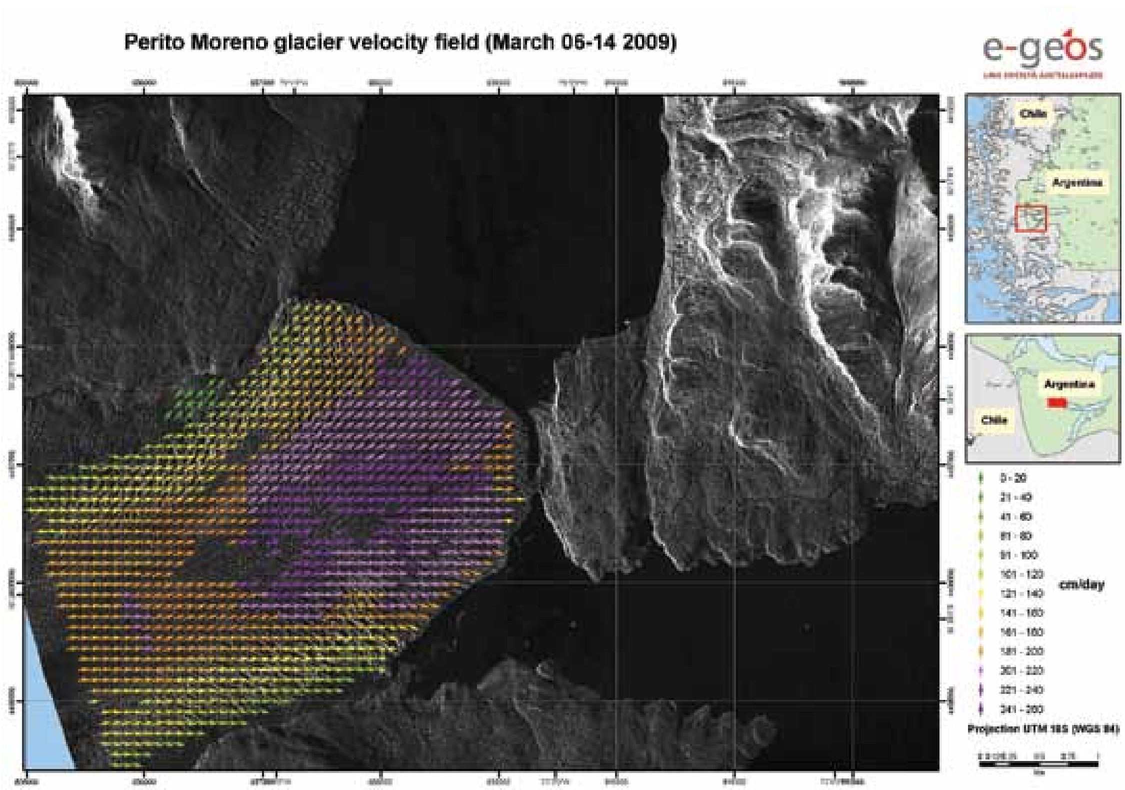


Fig. 3.1-4. Maps of Perito Moreno glacier (Argentina) velocity field using ASI COSMO-SkyMed constellation spotlight images (prepared by Luca Pietranera and Achille Ciappa, e-GEOS). The velocity field has been extracted from spotlight images pairs acquired on 2 and 18 February, 2009 (detected by COSMO-1 with a time interval of 16 days and pixel resolution of 1 meter) (upper) and on 6 and 14 March, 2009 (detected by COSMO-1 and COSMO-2 with a time interval of 8 days, 1 m, resolution) (lower). High speeds occur along the centre slope of the glacier tip while slow speeds are located along the lateral sides. End-of-summer speeds are higher than mid-summer speeds.

(Courtesy: Agenzia Spaziale Italiana, 2009)

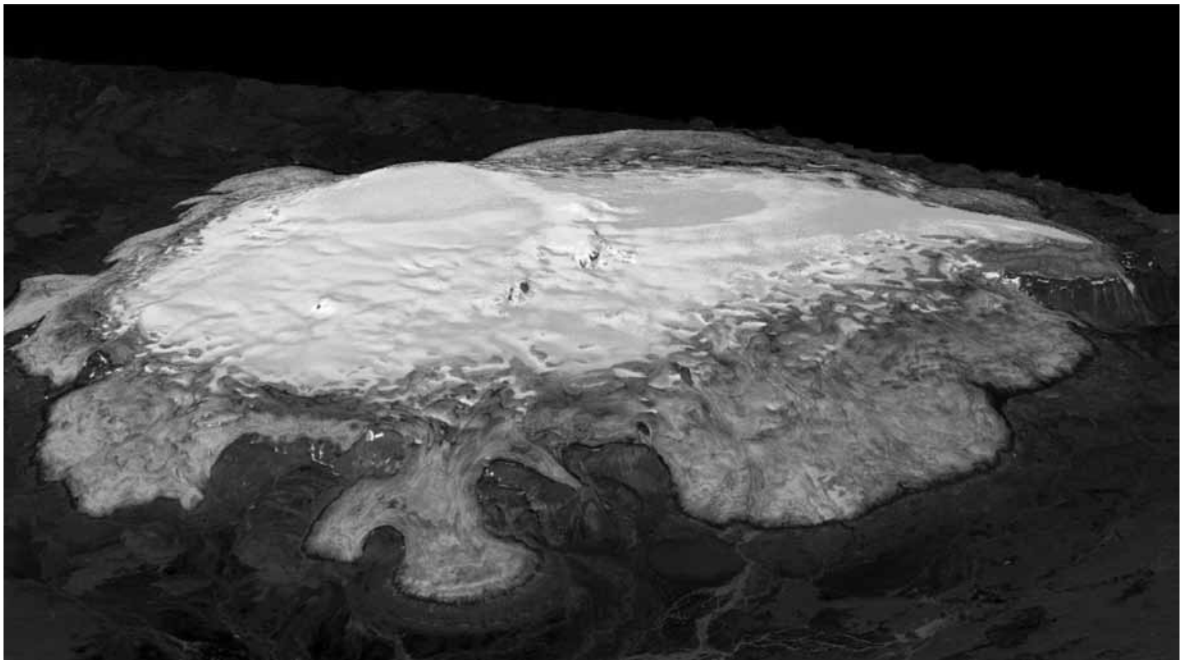


Fig. 3.1-5. Three-dimensional mapping of Hoffsjökull Ice Cap, Iceland completed as part of the CNES SPIRIT project. SPOT optical stereo data were acquired over substantial areas of Arctic ice caps and the Antarctic Ice Sheet (Korona and others, 2008a,b). (Image: CNES)

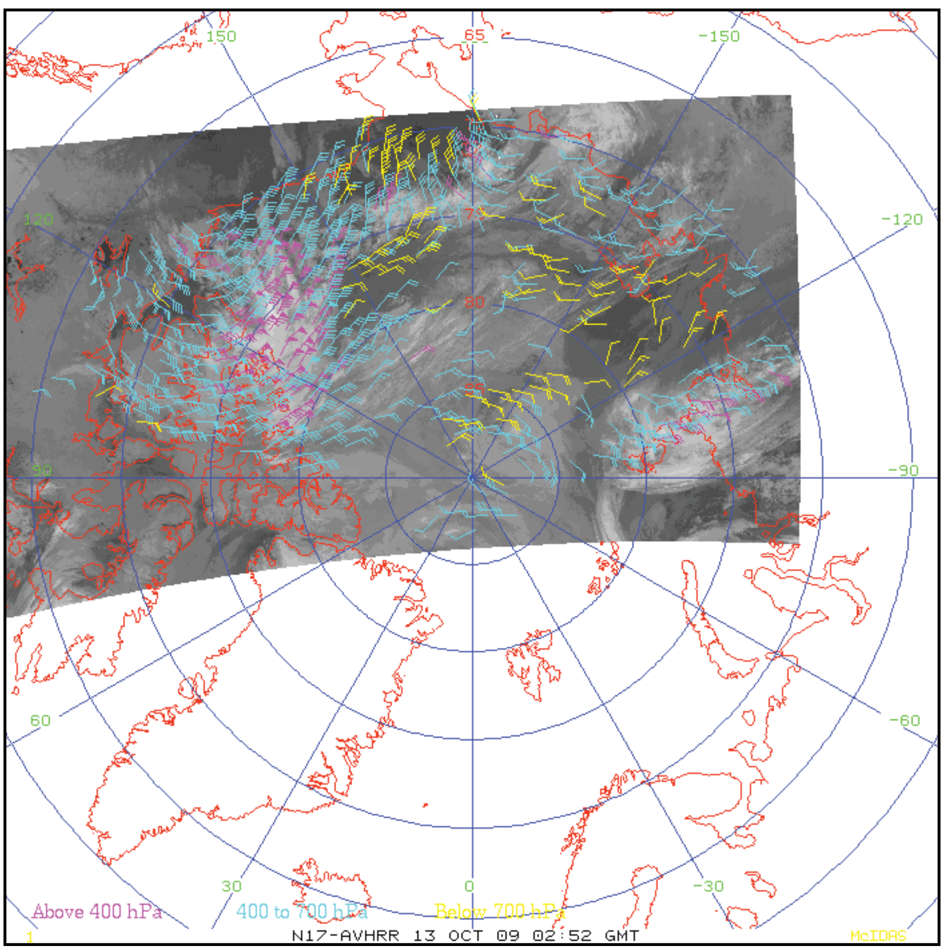


Fig. 3.1-6. Winds are now being generated from Advanced Very High Resolution Radiometer (AVHRR) data collected at the NESDIS High Resolution Picture Transmission (HRPT) receiving station in Barrow, Alaska. The first winds were generated on February 16, 2008. All processing is done at the NESDIS Fairbanks Command and Data Acquisition Station in Fairbanks. Data from NOAA-16, -17, -18, and -19 are processed. The HRPT wind information is an improvement over the AVHRR Global Area Coverage (GAC) winds in that it is available much sooner (e.g., 25 minutes after acquisition rather than 2-3 hours) and at a higher spatial resolution.

Using SPOT Stereo data, the CNES IPY SPIRIT project (Korona et al., 2008a; 2008b) is creating optically derived, high resolution digital elevation models (DEMs) of the perimeter regions of ice caps and ice sheets (Fig. 3.1-5). These highly detailed DEMs are the most extensive, high precision DEMs of polar ice caps and the margins of the polar ice sheets yet acquired. Using routine acquisitions by the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) sensor and the ESA Medium Resolution Imaging Spectrometer (MERIS) instrument, as well as the JAXA Advanced Visible and Near Infrared Radiometer (AVNIR-2) and Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) instruments, there have been extensive acquisitions of optical imagery of permafrost terrain.

Operational satellite data have been used to study, on a continuous basis, the polar atmosphere during the IPY. The acquired data permit retrieving information from all layers of the Earth's atmosphere, from the troposphere up to the mesosphere. For example, real-time systems for polar winds have been implemented at direct readout sites in both polar regions to meet numerical weather prediction needs for timeliness (Fig. 3.1-6). It is, however, equally important to generate long-term (relative to the satellite record) products for studies of recent climate change. In this regard, historical Advanced Very High Resolution Radiometer (AVHRR) data have been reprocessed to generate 25-year wind, cloud and surface properties, and radiation (Dworak and Key, 2009; Liu et al., 2008).

IPY satellite data are also being used to study atmospheric chemistry (Fig. 3.1-7 and Fig. 3.1-8). The polar atmosphere is considered to be highly sensitive to anthropogenic impacts on the earth system and thus to climate change. The acquired data permit retrieving atmospheric information, from the troposphere to the mesosphere. For example, reactive halogens are known to be responsible for ozone depletion (Fig. 3.1-7) and mercury deposition in polar regions during springtime. Bromine monoxide (BrO) is a key indicator of reactive halogen chemistry and is a highly efficient catalyst in ozone destruction. Meanwhile, the seasonal to interannual variability in BrO has been documented using high-latitude polar orbiting satellite data, both in the troposphere and stratosphere, where enhanced tropospheric BrO related to a tropospheric 'bromine explosion' is observed over the Arctic sea-ice area in springtime. Using SCIAMACHY limb-viewing observation mode data, a detailed timeseries of polar stratospheric BrO has been acquired spanning the entire IPY period.

The initial goal of the STG was to identify key IPY era science objectives addressable with satellite instruments and then to acquire the necessary data sets. Because a major international campaign of coordinated

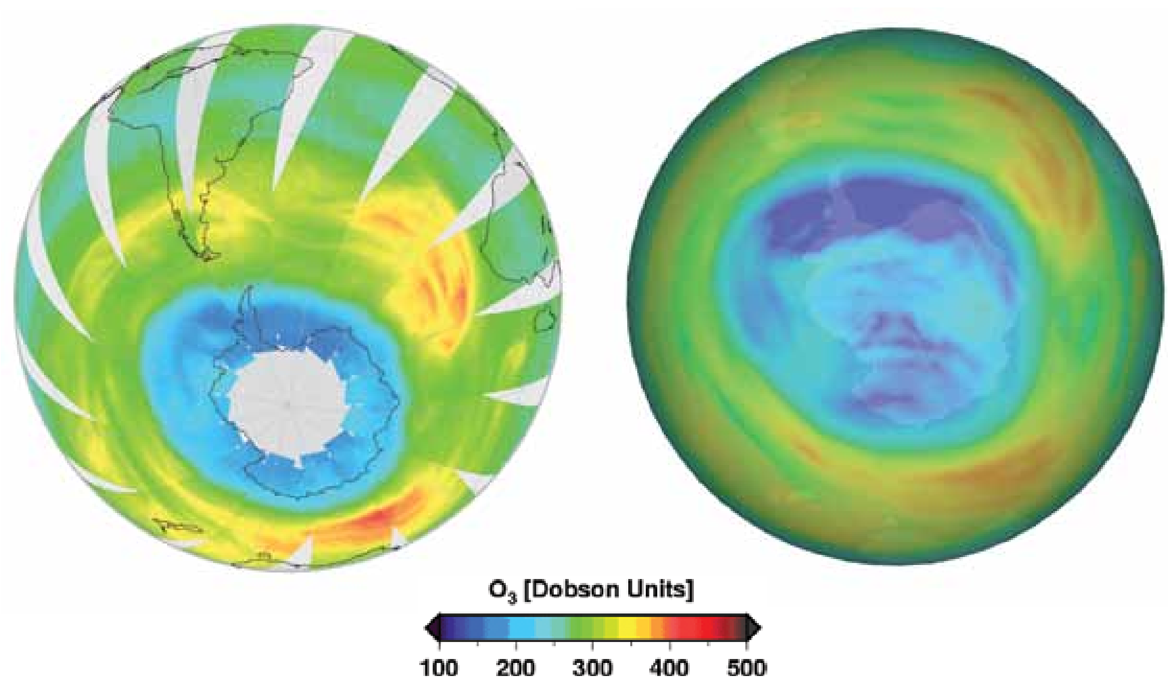
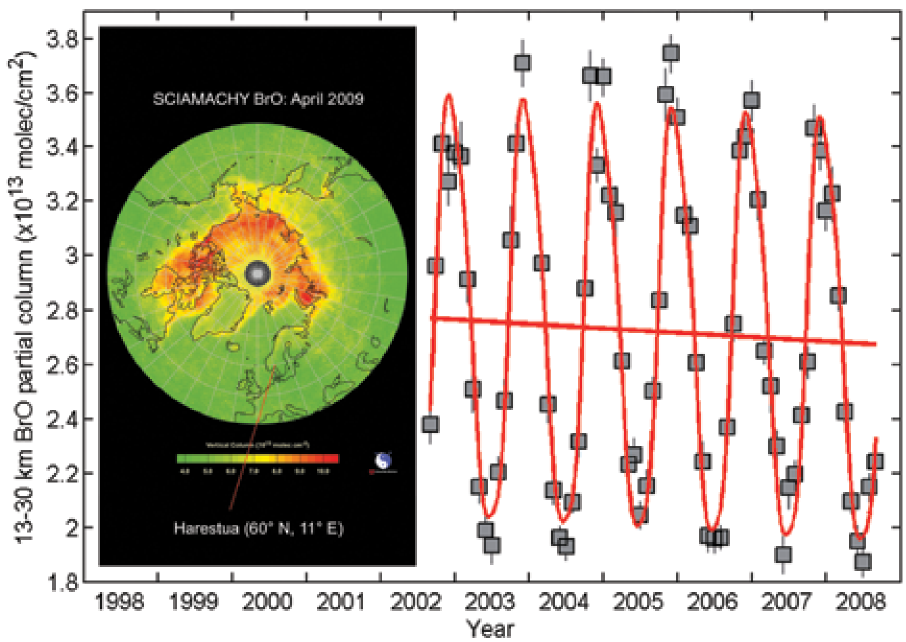


Fig. 3.1-7. Two independent views of the southern hemisphere ozone (O_3) hole on 8th September 2008, characterized using a) measurements of the GOME-2 instrument on-board the MetOp-A satellite (courtesy DLR/EUMETSAT/O3MSAF, available from http://wdc.dlr.de/); and b) total ozone columns from the TEMIS ozone and UV forecast, based on measurements from the SCIAMACHY sensor on-board ENVISAT.
(Courtesy KNMI/ESA, available from www.temis.nl)

Fig. 3.1-8. Time series of monthly averaged stratospheric inorganic bromine (BrO) partial column abundances measured over the Harestua upper air monitoring site by the SCIAMACHY instrument on-board ENVISAT (courtesy Hendrick et al, 2009. The inset shows a monthly composite BrO image over the Arctic in April 2009, again as seen by SCIAMACHY (courtesy IUP-IFE, University of Bremen) together with the location of the Harestua station in Norway. Analysing SCIAMACHY limb measurements over the 2002-2008 period, a trend analysis indicates a decline of -0.6+/-0.3% per year, which is in good agreement with ground-based UV-visible measurements (-0.7+/-0.3%/year).
(Image: F. Hendrick (BIRA/IASB) and A. Rozanov (IUP/IFE-Bremen), 2009)



Earth observations from space had not been attempted previously, participants agreed that developing the mechanisms for coordinated acquisitions and then executing those plans was a substantial challenge. As a result, enhanced international coordination and cooperation among space agencies have produced an extraordinary quantity and quality of satellite observations of Polar regions (Jezek and Drinkwater, 2010). These and many other broad-ranging and easily accessible reference data on the status of the Polar regions that IPY provides will be crucial for comparisons with the future and the past (Allison et al., 2009). In fact, the STG participants have succeeded in meeting this challenge beyond initial expectations, as evidenced by the range of data types presented and illustrated here. Consequently in February 2009, the STG chose to take a step beyond data acquisition and to investigate coordinated product development (IPY-STG, 2010). These efforts, which will likely continue beyond the final year of GIIPSY and the IPY STG, are devoted to producing SAR polarization image mosaics of Antarctica, SAR image mosaics of Greenland, X-, C- and L-band interferometrically derived velocity fields for Greenland and Antarctica, and the distribution of high resolutions SPOT DEMs. The approach will be similar to the acquisition phase wherein geophysical product development loads will be distributed amongst the partners. CSA and NASA have already made progress in identifying resources to repatriate interferometric Radarsat-1 data that are needed to complete the most recent measurement of Greenland Ice Sheet surface velocity. ASI, CSA, DLR, ESA and JAXA have also begun the process of generating ice sheet wide SAR image mosaics and measurements of surface velocity (IPY-STG, 2010). In the atmospheric domain, polar science benefits from the progress in expanding our capabilities in retrieving atmospheric parameters from spaceborne data. This is a common effort of ESA, EUMETSAT, NOAA, NASA, DLR and various scientific institutes. To date, significant progress has been made during the IPY in acquiring new scientifically valuable datasets as well as ensuring access to the more routine datasets required for routine operational meteorological applications and numerical weather prediction.

IPY has provided a unique opportunity to demonstrate the value of inter-satellite operations between SAR satellites in a polar constellation as well as opportunity to illustrate the benefits of coordinated observations by a range of polar observing systems ranging from *in situ*, to airborne and to satellite-borne measurement capabilities. The STG and GIIPSY project are actively harnessing the technical capabilities of the world's space agencies and the specialized knowledge of their science communities to obtain a suite of 'polar snapshot' data, which comprise a unique IPY legacy. Through these efforts, the space

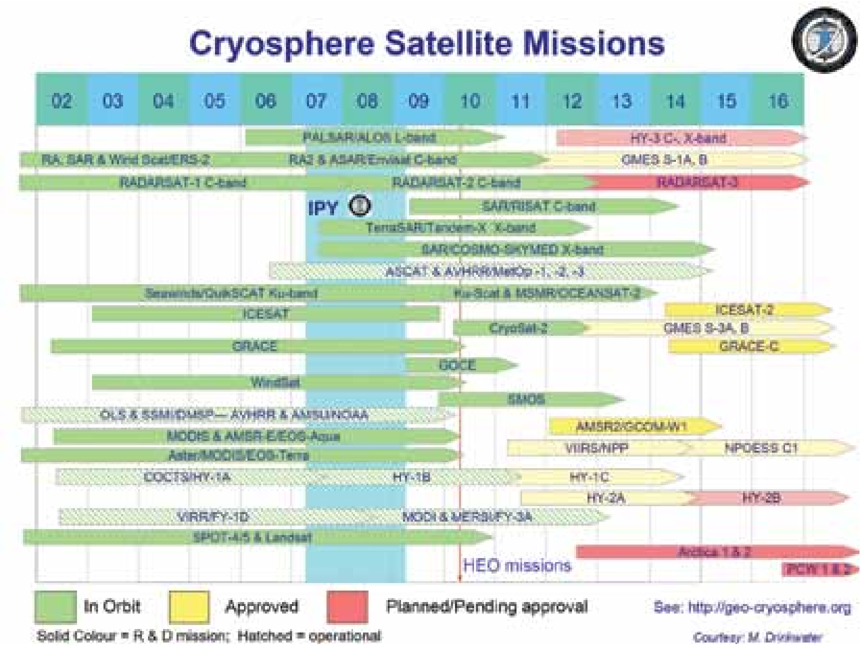


Fig. 3.1-9. Timelines of cryosphere satellite missions
(Image: M. Drinkwater, 2009)

and scientific communities involved will leave a legacy dataset compiled from multiple space agency satellite data portfolios comprising a broad range of snapshot products (Jezek and Drinkwater, 2010).

Looking toward the proposed International Polar Decade (*Chapter 5.6*), there are a number of issues that could be addressed by a follow-up to the IPY-era STG by expanding the acquisition and product suite beyond the polar regions to cover all sectors of the cryosphere (Fig. 3.1-9). More specifically and along the lines of the SAR-WG, there is consensus that an optical/IR working group could profitably address an updated list of measurements and derived products. There should be further integration of the atmospheric chemistry and polar meteorological science communities into the STG activity suite, as well as potential incorporation of gravity and magnetic geopotential missions into the STG discussion. It is also possible to envision discussion and collaboration on emerging technologies and capabilities, such as the Russian "Arktika" Project and Canadian Polar Communications and Weather (PCW) Project (Asmus et al., 2007; Garand and Kroupnik, 2009) and advanced subsurface imaging radars.

The STG has been a unique mechanism for informing the space agencies about GIIPSY science requirements. In turn the STG has been an important venue for coordinating acquisition and processing of important amounts of satellite data while distributing the data acquisition load amongst the participating agencies. Continuing a GIIPSY/STG IPY legacy activity, perhaps reconstituted with a new mission statement that addresses some of the additional points mentioned above, can be of future service by providing a direct link between both the recently formed WMO Panel of Experts on Polar Observations, Research and Services (see www.wmo.ch/pages/governance/ec/tor_en.html#antarctic), the IASC/SCAR Bipolar Action Group and the broader cryospheric science community to those offices of the space agencies responsible for mission planning, data acquisition and product development. A natural vehicle for adopting lessons learned from GIIPSY/STG into a more encompassing international effort could be the Global Cryosphere Watch (Goodison et al., 2007), recently proposed by WMO to be in support of the of the cryospheric science goals specified for the Integrated Global Observing Strategy Cryosphere Theme (IGOS, 2007). The main goal of a future effort would be continued STG coordination of international efforts in securing collections of space-borne "snapshots" of the Polar regions through the further development of a virtual Polar Satellite Constellation (Drinkwater et al., 2008) as part of the IPY legacy.

This section has been prepared on behalf of the IPY Space Task Group. Without the contributions of the participating space agencies and other supporting organizations, this effort would not have been possible.

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3.2 Towards an Integrated Arctic Ocean Observing System (iAOOS)

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The following chapter presents selected examples of new ideas that have emerged from the enhanced ocean-observing effort of IPY 2007–2008 on the role of the Northern Seas in climate. This is an incomplete sampling of the questions that must be asked to determine a sustainable observing system in the legacy phase following the completion of IPY.

Inputs to the Arctic Ocean: what questions should we be testing?

Q: *What is the relative importance of the two main Atlantic inflow branches in carrying ocean climate 'signals' from the Nordic Seas into, around and through the Arctic deep basins?*

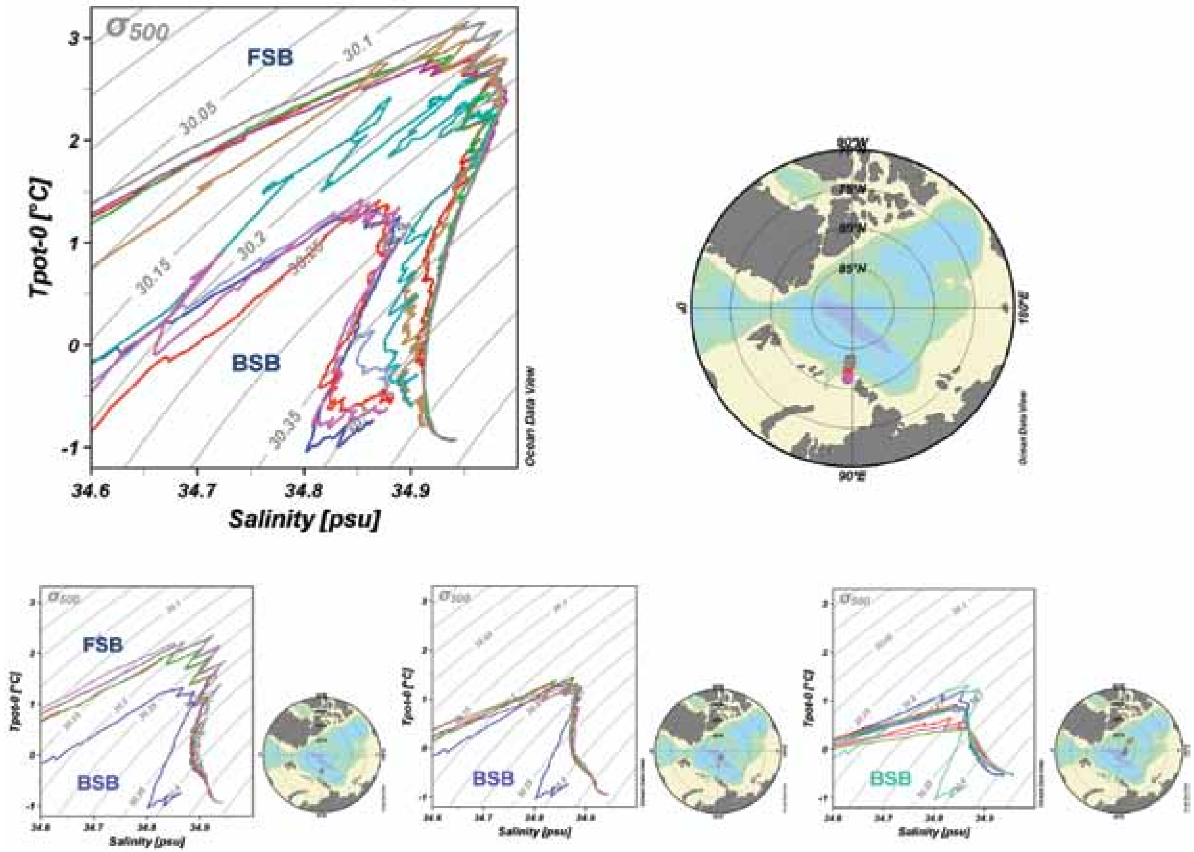
A: The basis for this as a focus question is the suggestion put forward by Bert Rudels (Univ. Helsinki) at the Arctic Science Summit Week, Bergen 2009, that the colder fresher Barents Sea inflow branch may dominate the Arctic Ocean beyond the Nansen Basin, with the Fram Strait branch seldom penetrating beyond the Lomonosov Ridge. Dmitrenko et al., (in press) would seem to agree. If so, the source of the recent warming — so graphically described along the boundary of the Laptev Sea and Canada basin by Polyakov et al., (2005; 2007), Dmitrenko et al., (2008a,b), Carmack (pers. comm.) and others — will effectively have been reassigned. As illustrated in the various panels of Fig. 3.2-1, the essence of Rudels' argument is that beyond the Gakkel Ridge the Θ-S characteristics of the Atlantic-derived sublayer are closer to those of the Barents Sea Branch (BSB in Fig. 3.2-1) than the Fram Strait Branch (FSB). Testing Rudels' idea will be an important task for the legacy phase to resolve, but the tools to do so are well proven: detailed ship-borne hydrography, sustained flux measurements through the northeast Barents Sea, and continued or intensified coverage of the boundary currents along the Eurasian margin of the Nansen basin from the point where both branches first flow together to their supposed points of separation at the Lomonosov ridge. This lends further support to the continuation of a modified NABOS (Nansen and Amundsen Basins Observational System) array across this boundary. The research team is likely to include Bert Rudels (Univ. Helsinki), Ursula Schauer (AWI), Øystein Skagseth (IMR Bergen), and Igor Polyakov (IARC).

Q: *Where can we expect the recent extreme warmth of the Atlantic–derived sublayer of the Arctic Ocean to have its main climatic impact?*

A: Very recently, the temperature and salinity of the waters flowing into the Norwegian Sea along the Scottish shelf and Slope have been at their highest values for >100 years. At the 'other end' of the inflow path, the ICES Report on Ocean Climate for 2006 showed that temperatures along the Russian Kola Section of the Barents Sea (33°30'E) had equally never been greater in >100 years (Holliday et al., 2007). As already noted, Polyakov et al., (2005; 2007), Dmitrenko et al., (2008a, b) and others have documented the onward spread of the most recent pulses of warmth along the Eurasian boundary of the Arctic Ocean.

When the IPY began in March 2007, the consensus view would likely have been that a 100-year maximum in the warmth of the inflow to the Arctic must in some way be bound up with an increased melting of Arctic sea ice. Since then our ideas have altered in response to new simulations by a group from the Alfred Wegener Institute (M. Karcher, pers. comm., also Karcher et al., 2007; 2008), which suggest that, as the warm Atlantic-

Fig. 3.2-1. Potential temperature/ salinity relations at the depth of the Atlantic-derived sublayer between the continental slope of the Kara Sea and the Alpha Ridge.
(Image: Bert Rudels U Helsinki pers comm. 2009)



derived layer spread at subsurface depths through the Arctic deep basins (see Fig. 3.2-2), it did so at a significantly greater depth and with a significantly lower density than normal. Though the increased warmth may thus be too deep to have much effect on the sea ice, the intriguing suggestion is made that, as this layer circuits the Arctic and drains south again into the Nordic seas, its changed depth and density now seem capable of altering the two factors, the density contrast across the sill and the interface height above the sill, that together determine the strength of the Denmark Strait Overflow (Whitehead, 1998), hitherto regarded as largely unchanging (Dickson et al., 2008). When Karcher re-ran his simulations by applying two periods of past NCEP forcing after 2008, both runs appeared to confirm that the anomalies will progress from the Chukchi to the Denmark Strait as hypothesised, will slow the overflow as expected from hydraulic theory, but will do so a few years earlier (in 2016-18) than had been suggested by his initial prediction, which had been based on simple statistics relating interface height anomalies north of Denmark Strait to interface heights passing through the Arctic.

Thus in the Atlantic sector, the climatic impact of the recent inflow of warmth to the Arctic may have less to do with local effects on sea ice than on the Atlantic's thermohaline 'conveyor', years later and far to the south. As a candidate for the IPY legacy phase, the importance of this result seems clear: Maintaining surveillance on these changes taking place throughout the length and breadth of our Arctic and subarctic seas over decades is likely to prove highly instructive to our understanding of the role of our northern seas in climate. However, detecting and following such decadal transient signals is likely to impose a need for new tools in observational network design. Michael Karcher (AWI) will lead the testing of this focus question by both observation and simulation.

Q: *What is the ecosystem response to sea ice retreat and what observational system do we put in place to observe it?*
A: Although recent major changes in the physical

domain of the Arctic are well documented, such as extreme retreats of summer sea ice since 2007, large uncertainties remain regarding potential responses in the biological domain. In the Pacific Arctic north of Bering Strait, reduction in sea ice extent has been seasonally asymmetric, with minimal changes until the end of June, rapid summer retreat, and then delayed sea ice formation in late autumn. The effect of this seasonal asymmetry in sea ice loss on ocean primary production is still in question. Satellite images show variable chlorophyll concentrations with sea ice retreat in recent years, although model predictions indicate the potential for enhanced productivity with increased summer/fall sea ice retreat (Arrigo et al., 2008). However, clear changes have occurred at higher trophic levels, including shifts in species ranges for zooplankton, benthos and fish, as well as loss of sea ice as habitat and platform for marine mammal species. For example, Pacific zooplankton intrusions have been documented northward into the Beaufort Sea (Nelson et al., 2009) that are coincident with observations of Pacific clam subarctic species north of the Bering Strait into the Chukchi Sea (Sirenko and Gagaev, 2007). In the Bering Sea, fish and invertebrates showed a community wide northward distribution shift (Mueter and Litzow, 2008). Commercially fished species including walleye pollock, Pacific cod and Bering flounder now occur in the Beaufort Sea together with commercial-sized snow crab. For seabirds, declines in dominant clam populations critical as prey in the northern Bering Sea are concomitant with dramatic declines in numbers of spectacled eiders (Lovvorn et al., 2009). In the western Beaufort Sea, black guillemots have lost access to ice-associated arctic cod due to the extreme ice retreats and more frequently suffer predation by land-based polar bears. Polar bears have switched denning habitat from sea ice to land (Fischbach et al., 2007), have drowned at sea, and have been seen more regularly on beaches. There was a 17-fold drop in gray whale relative abundance in the northern

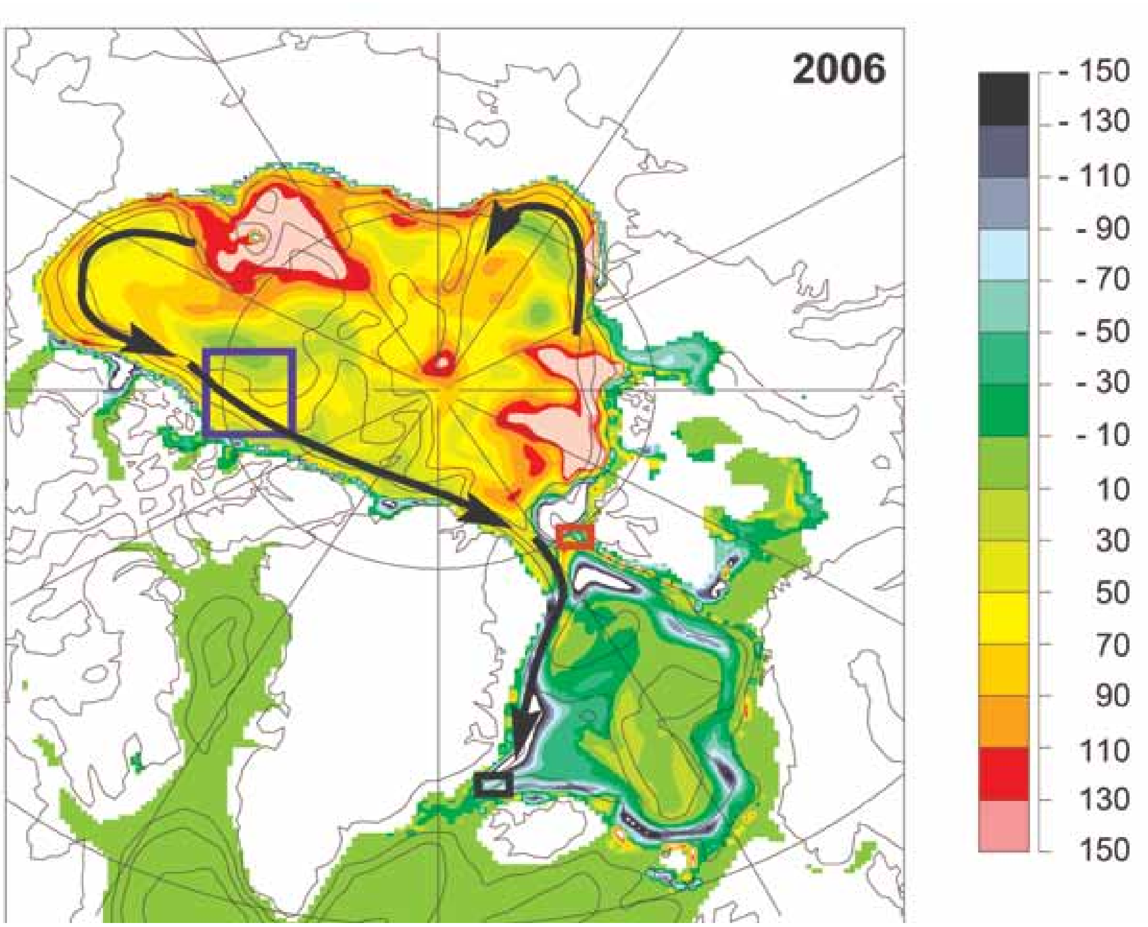


Fig. 3.2-2. Modelled location of the two deepening / low-density centres in the AW sublayer of the Arctic Ocean in 2006. The depth anomaly of the Atlantic-derived sublayer location is given in meters.

(Image: Unpublished, Karcher pers. comm.)

Bering Sea coincident with the decline in amphipod prey biomass and the nearly coincident extension of their feeding range to include over-wintering in the western Beaufort Sea (Moore, 2008). This combination of range expansions and/or changes to community composition and the timing of life history events are all clear indicators of an ecosystem in transition.

In order to evaluate ecosystem shifts, members of the scientific community are developing the concept of a 'Distributed Biological Observatory (DBO)' in the Pacific Arctic around known regional "hotspot" locations along a latitudinal gradient from the northern Bering to the western Beaufort Seas (Grebmeier et al., in press; Fig. 3.2-3). The DBO is envisioned as a change detection

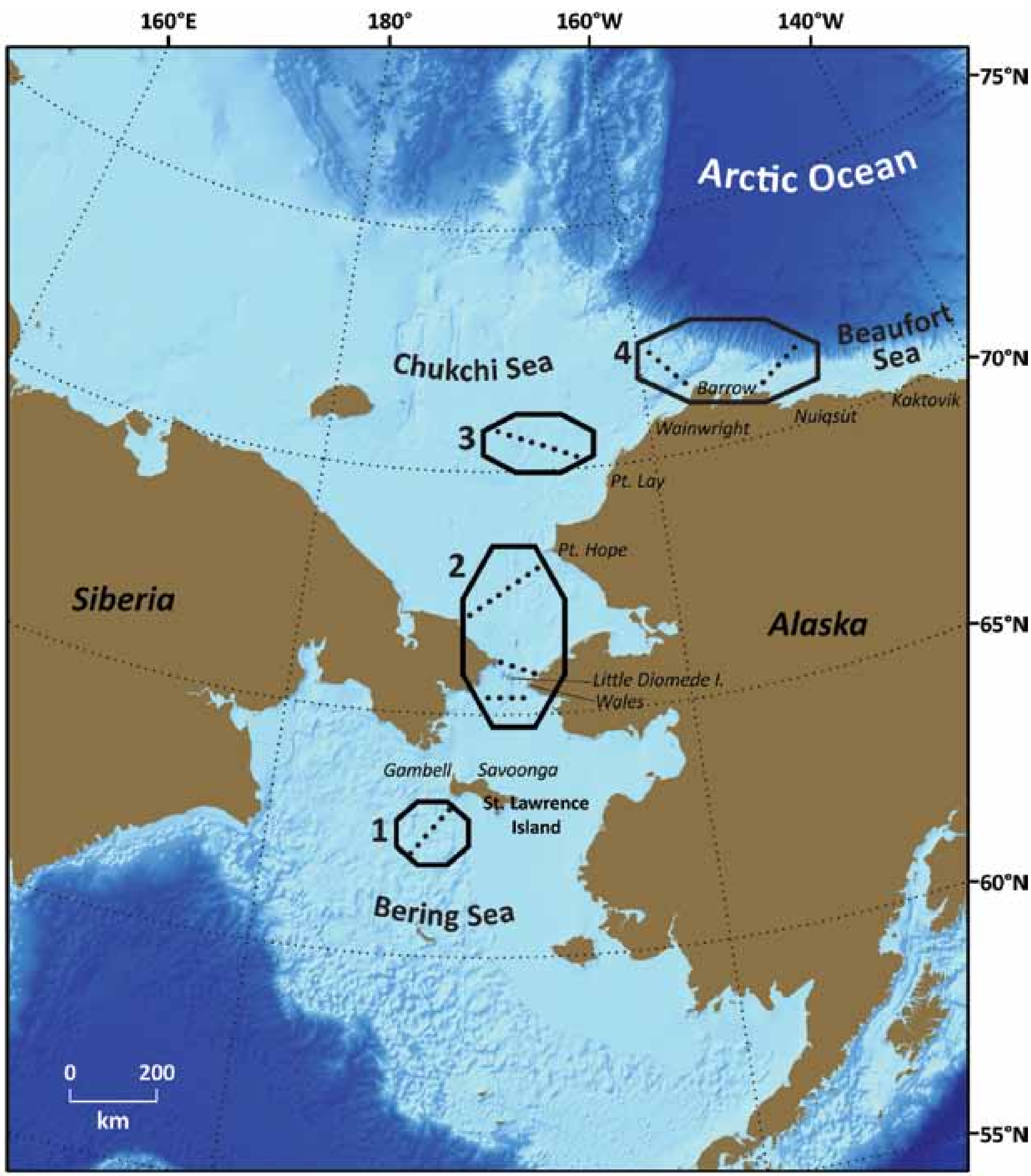


Fig. 3.2-3. A Distributed Biological Observatory concept for the Pacific sector of the Arctic as a "change detection array" to track biological response to ecosystem change in the region.
(Image: Grebmeier et al., 2010)

array for the identification and consistent monitoring of biophysical responses in pivotal geographic areas that exhibit high productivity, biodiversity and rates of change. The proposed regions are the: 1) northern Bering Sea, 2) Bering Strait/SE Chukchi Sea, 3) Central Chukchi Sea and 4) Barrow Arc. Stations in these regions can be visited through an international network of ship operations, both ongoing and planned. These include Canadian, Chinese, Japanese, Korean, Russian and U.S.A. research vessels coordinated through the international Pacific Arctic Group (PAG), and land based research from coastal communities using helicopter and small ships. A suite of primary standard station measurements are proposed for each of the DBO stations to be occupied by multiple international ships and dedicated national programs. Core hydrographic (T, S, chlorophyll, nutrients) and biological measurements (faunal diversity, abundance and biomass) of lower trophic level prey (zooplankton and benthic fauna) coincident with high trophic predators (seabirds, fish and marine mammals) would be the foci measurements. A second tier of sampling would include fishery acoustics and bottom trawling surveys on a more limited basis. Multidisciplinary moorings and satellite observations at focused regional locations would also be encouraged. The DBO would leverage ongoing and planned programs, both domestic and international. Incorporation of the DBO concept within the development of the international Sustaining Arctic Observing Networks (SAON) process (*Chapter 3.8*) will provide a foundation for investing system-level biological response to Arctic climate change and for improving the linkage between community-based monitoring and science-based measurement. An international community-developed plan of time series transects and stations for biodiversity studies of lower to higher trophic levels is being proposed in a pan-Arctic mode as part of the Arctic Council's Circumpolar Biodiversity Monitoring Program (CBMP; http://cbmp.arcticportal.org/).

The Arctic Deep Basins: what questions should we be testing?

Until relatively recently, the Arctic Deep Basins were among the least-measured places in the World Ocean. All that has now changed. The WHOI Beaufort Gyre Exploration Project [later Beaufort Gyre Observing System (BGOS)], led by Andrey Proshutinsky and employing a suite of new observing techniques has, since 2003, gradually transformed the data desert of the Beaufort Gyre into what is now one of the best-covered regions of our northern seas. The elaboration of that effort into a BGOS/C3O/JOIS collaboration and the intensive survey of its borderlands by other collaborative ventures such as JWACS (Joint Western Arctic Climate Studies between JAMSTEC and Canada DFO/IOS since 2002) and CHINARE (the Chinese National Arctic Research Expedition with EC-DAMOCLES aboard icebreaker "Xue Long" in 2008) have continued to intensify the scientific focus on the Beaufort Gyre, Canada Basin and Chukchi Sea so that our ideas of what drives change throughout this region and the significance of these changes for climate have developed rapidly. As a result, we now regard the Beaufort Gyre-Canada Basin as 'The Flywheel of the Arctic Climate' (the subtitle of the WHOI BGOS project) and as one of the key sites in the World Ocean from the viewpoint of the Ocean's role in climate.

Q: *What is the role of the Beaufort Gyre as a variable freshwater source/ reservoir?*

A: As the world warms, the expectation is that the freshwater outflows from the Arctic Ocean to the North Atlantic will strengthen and may suppress the rate of the climatically important Atlantic meridional overturning circulation. For some time, we have been aware in general terms of the link between retention/ release of freshwater from the Gyre and the state of the Arctic Oscillation. But it was relatively recently that the Beaufort Gyre has been identified as the largest marine reservoir of freshwater on Earth (Carmack et al., 2008) and the WHOI BGOS data have elaborated the details of the state, variability and controls on its freshwater content (FWC). The major cause of the large FWC in the Canada Basin is now recognised to be the process of Ekman pumping generated by the climatological anticyclonic atmospheric circulation centered on the Beaufort Gyre (Proshutinsky et al., 2008), confirming the hypothesis of Proshutinsky et al., (2002). Mechanically, the seasonal variability of FWC follows wind curl changes with a maximum in November-January and a minimum in June-August depending on changes in atmospheric circulation. The atmospheric and oceanic thermal regimes regulate seasonal transformations of liquid FWC due to the seasonal cycle of sea ice melt and growth. A first peak (June-July) is observed when the sea ice thickness reaches its minimum (maximum fresh water release from sea ice to the ocean) when Ekman pumping is very close to its minimum (maximum wind curl). The second maximum is observed in November-January when wind curl reaches its minimum (maximum Ekman pumping) and the salt flux from the growing sea ice has not reached its maximum.

The most important BGOS finding however, is the fact that the Beaufort Gyre freshwater content is a field in rapid transition with strongly increasing trends in FWC between 2003-2008 at mooring locations (Fig. 3.2-4) along Ice-Tethered Profiler trajectories and at the standard BGOS summer CTD sites. According to Proshutinsky et al., (2009), the spatially integrated FWC of the gyre increased by >1000 km^3 post-1990 relative to climatology.

Q: *What is the effect on climate of the recent transition from stable multi-year land-fast ice to free ice along the Canadian Arctic Margin?*

A: Warm Pacific Summer Water (PSW) inflow through the Bering Strait plus the creation of a Near Surface Temperature Maximum (NSTM) in the Canada Basin through the albedo feedback mechanism (Jackson et al., 2009) thins the ice against the Canadian Arctic coast. Once the multi-year ice breaks free of the coast, intensive Japanese investigations by Koji Shimada (Univ. Tokyo) suggest that the clockwise gyre circulation is able to rotate the ice out over what might now be termed the 'hotplate' of the Chukchi Borderland. The melting ice joins the transpolar drift and exits through Fram Strait. The now ice-free ocean stimulates the development of anomalously low pressure and the resulting formation of an atmospheric dipole further speeds the clockwise circulation of the Beaufort Gyre. Satellite remote sensing of sea-surface height appears to support a recent rapid intensification of the Gyre

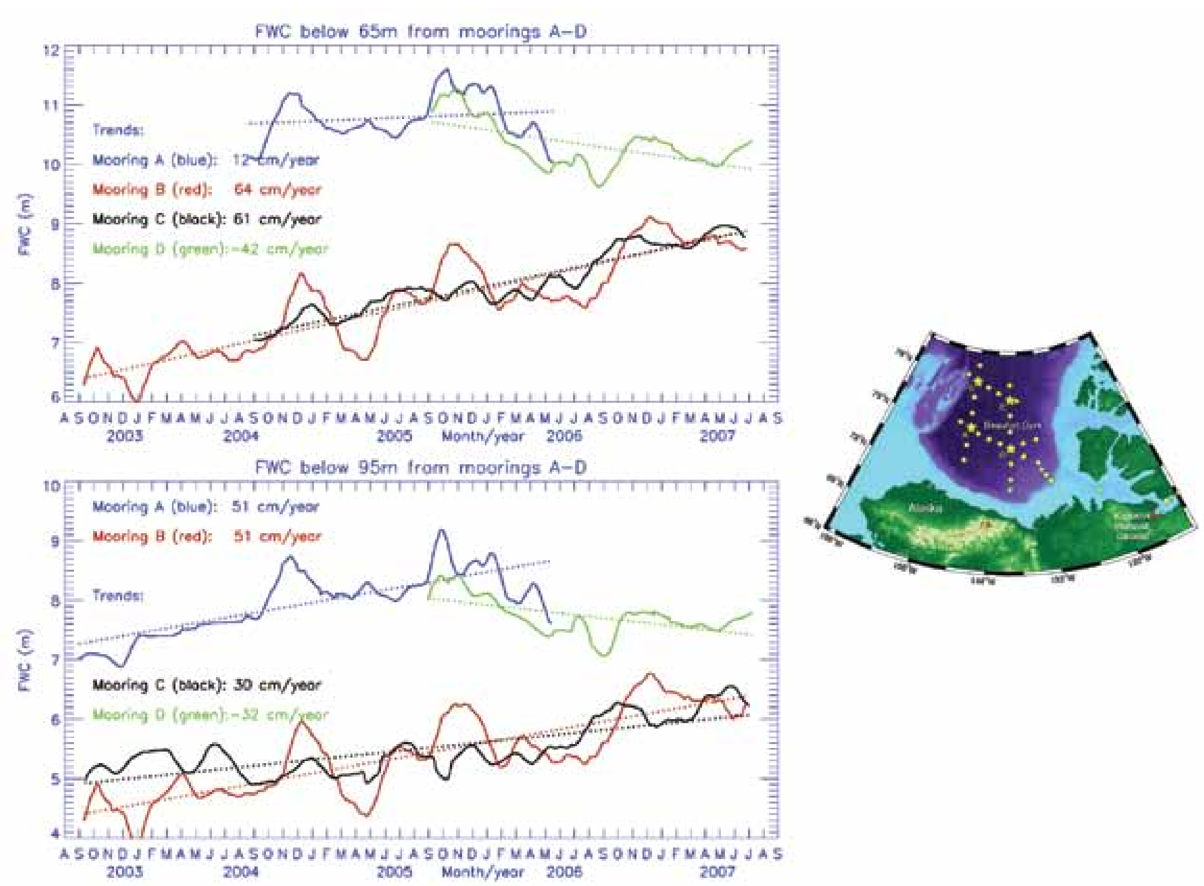


Fig. 3.2-4. Fresh water content (FWC, meters) variability and trends for moorings A-D (locations in inset map). FWC is calculated relative to 34.8 salinity at depths below 65m and 95m down to depth where salinity is less or equal to 34.8.

(Image: Andrey Proshutinsky, WHOI pers. comm.)

(Katharine Giles UCLCPOM pers. comm. and in prep) and Shimada's novel idea also gains weight from the analysis of change in the freshwater content of the Arctic Ocean by Rabe et al., (in press). As these authors point out, although there has been a fairly general increase in freshwater content of the Arctic Deep Basins between 1992-99 and 2006-08, amounting to > 3000 km3 between the surface and the 34 isohaline, the largest increase in FWC was observed in the western Canada Basin-Chukchi Cap, the area of increased ice-melt anticipated in Shimada's theory. Building on the intensive survey work during IPY by R/V Mirai (MR08-04) in summer 2008, the Japanese team intends to develop an understanding of the actual exchange of momentum, heat and salt at the interfaces between ice, ocean and atmosphere. A primary focus will be on studying the effects of sea-ice motion at a range of scales, from developing an understanding of the links between large scale sea ice motion and ocean circulation (including effects of large scale transitory events such as ENSO) to investigating the oceanic fluxes into surface mixed layer that arise through small scale sea ice motion/ocean turbulence. The Japanese team will be led by Koji Shimada (Tokyo University of Marine Science and Technology) and Kazutaka Tateyama (Kitami Institute of Technology).

Q: *What is the potential climatic impact of accessing the warm Pacific Summer Water (PSW) sublayer in the Canada Basin through an increased depth and intensity of turbulent mixing as the sea-ice retracts?*

A: The component parts of this problem are set out by Toole et al., (in press). The analysis of 5800 ITP profiles of temperature and salinity from the central Canada basin in 2004–2009 reveals a very strong and intensifying stratification that greatly impedes surface layer deepening by vertical convection and shear mixing, and limits the flux of deep ocean heat from the PSW sublayer to the surface that could influence sea ice growth/decay. At present, the intense pycnocline sets an upper bound on mixed layer depth of 30-40 m in winter and 10 m or less in summer, consistent with the analyses of Maykut and McPhee (1995) and Shaw et al., (2009). Toole et al., find these stratification barriers effectively isolate the surface waters and sea ice in the central Canada Basin from the influences of deeper waters. Although PSW heat appears not to be currently influencing the central Canada Basin mixed layer and sea ice on seasonal timescales, it is conceivable that over longer periods that heat-source could become significant. After all, as Toole et al., point out, the PSW heat now entering the central Canada Basin can't simply disappear; it is presently being stored in the ocean as intrusions in the 40-100 m depth range of sufficient magnitude to melt about 1 m of ice if its heat were somehow to be introduced into the mixed layer (Fig. 3.2-5). It is not yet obvious what physical mechanisms might allow the mixed layer to rapidly tap that heat. Winter 1-D model runs initialized with profiles in which the low-salinity cap in the upper 50 m was artificially removed failed to entrain significant PSW heat, even when more than

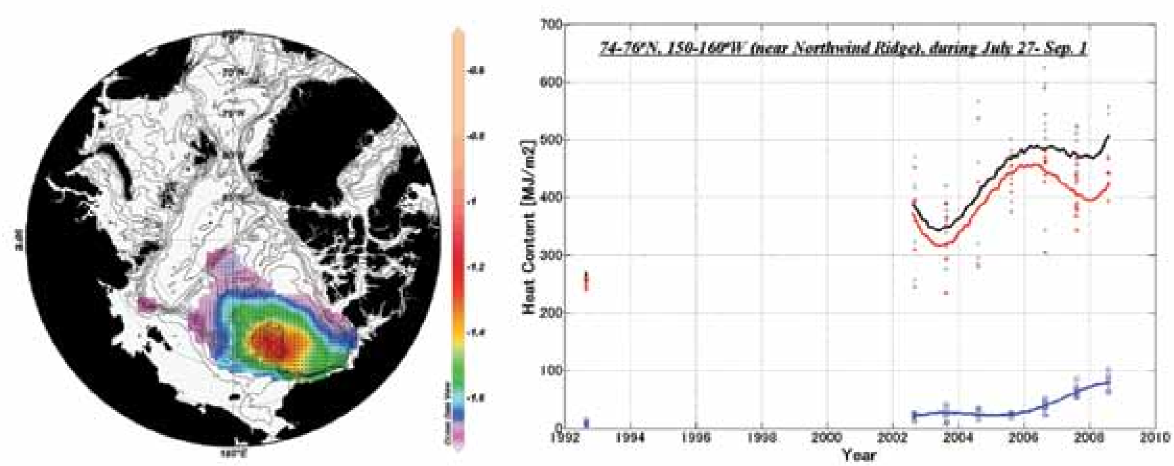


Fig. 3.2-5. (left) The extent of the warm Pacific Summer Water (PSW) sublayer in the western Arctic as shown by the subsurface ocean temperature distribution on the S=31.5 salinity surface, and (right) the temporal change in oceanic heat (MJm2) in selected upper layers of the western Canada Basin (74-76N, 150-160W), where blue: 0-20m, red: 20-150m, black: 5-150m.

(Images: unpublished by Koji Shimada, U. Tokyo)

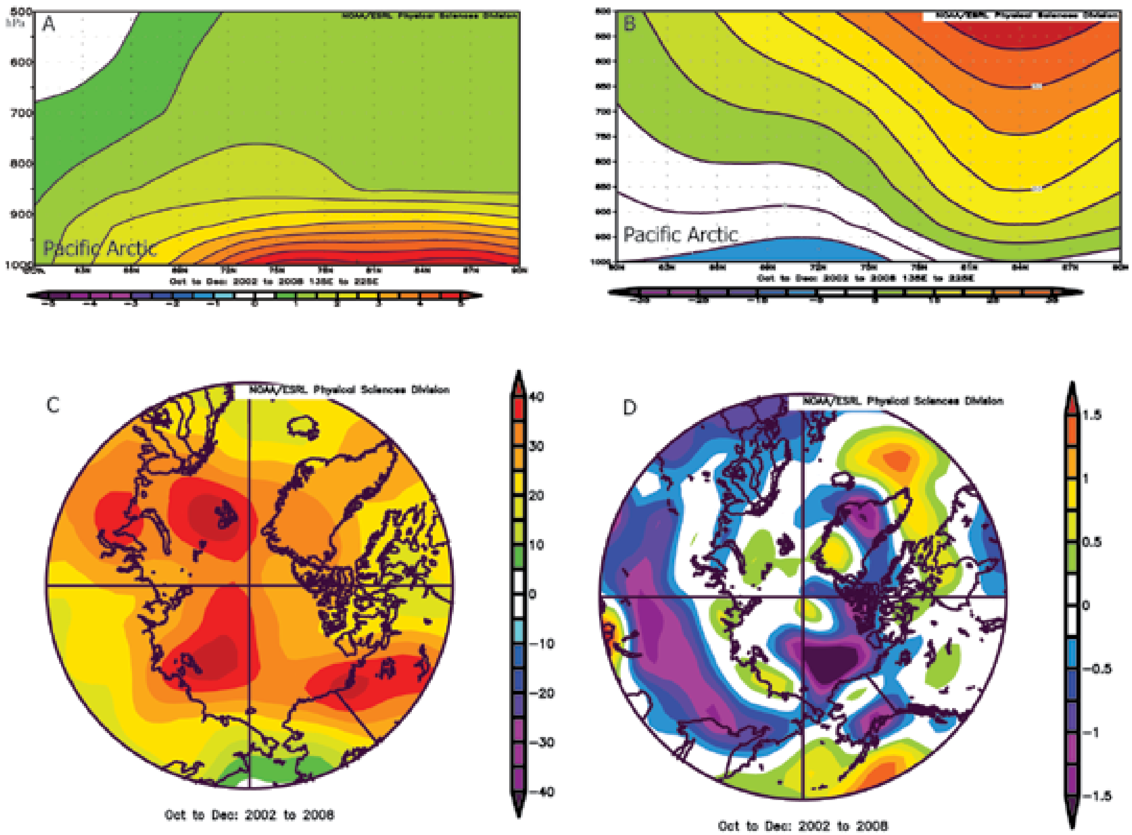


Fig. 3.2-6. Composite changes in the polar troposphere in October-December 2002-8 as the ice retracted from the western Arctic. Top left: vertical section of air temperature anomalies (ºC) from the Bering Strait to the Pole. Top right: corresponding plot of geopotential height anomalies (dynamic metres). Lower left: the 500-1000 hPa thickness field anomaly showing, in particular, the band of greater thickness from the E. Siberian Sea to N Alaska, the main region of diminished sea-ice cover. Gradients in this field are the baroclinic contribution to the flow field. Lower right: the zonal wind anomaly field (ms-1) at 700 hPa showing the reduction in zonal wind component north of Alaska and western Canada.

(Images: Overland and Wang (2010)

three times the ocean cooling rate and 10 times the mechanical work of the standard winter model runs were applied to the mixed layer. It thus seems most likely to Toole et al., that if PSW heat is vented upwards in the central Canada Basin in the near future, that flux will be accomplished by a relatively weak, small-scale turbulent diffusive process. John Toole (WHOI) will lead on the two main questions that underlie this issue: What are the intensities and the physical mechanisms supporting turbulent diapycnal heat and fresh water fluxes between the Arctic surface mixed layer and the waters immediately underlying, and how might those fluxes change in future if we transition to a seasonal ice pack?

Q: *How might the ice-free polar ocean alter the regional atmospheric circulation?*

A: As the ice in the Pacific sector of the Arctic melted back to its record minimum in summer 2007 and the heat storage of the underlying ocean increased, the release of this heat in autumn eroded the stratification of the atmosphere to progressively higher levels leading to a clear change in the regional atmospheric circulation.

As Fig. 3.2-6 reveals, the retraction of sea-ice cover from the western Arctic in summer 2002-08 was accompanied by a warming throughout the Arctic troposphere and an increase in geopotential height anomaly in fall leading to a weakening of the poleward geopotential gradient. It is this weakening of the thermal wind that reduces the jet stream winds, according to Overland and Wang (2010). ["The consequences of increased September open water in the western Arctic and increased 1000–500 hPa thickness is an anomalous late autumn easterly zonal wind component, especially north of Alaska and Canada on the order of 40%". (op cit, P8)]. If so, this will be a highly significant result for the IPY. It therefore makes sense to inquire, in planning an observational legacy phase for the IPY, what continued coverage of the upper watercolumn would be needed to keep track of ocean-atmosphere heat exchange as the sea-ice dwindles away. It precisely this is the question that will be addressed by Jim Overland and Muyin Wang (NOAA-PMEL).

Q: *What ocean observing effort is needed to optimize the use of satellite altimetry and time-variable gravity in understanding change in Arctic Ocean hydrography and circulation?*

A: New developments in our observational capabilities present an unprecedented opportunity to make significant progress towards an integrated ability to address scientific issues of both the ocean and ice components of the Arctic Ocean system. In the coming decade, data from gravity satellites (GRACE and GOCE) and polar-orbiting altimeters (e.g., Envisat, ICESat, CryoSat-2, and upcoming ICESat-2 and SWOT) will provide basin-scale fields of gravity and surface elevation. Together with an optimally designed *in-situ* hydrographic observation network, these data sets will have the potential to significantly advance our understanding of the ice-ocean interactions, circulation and mass variations of the Arctic Ocean. Observations of Arctic Ocean hydrography have historically been sparse, consequently the circulation of the Arctic Ocean is poorly understood relative to that of lower latitude oceans. However, integrated analyses of new data from in-situ hydrographic observations, gravity satellites (GRACE and the upcoming GOCE) and polar-orbiting altimeters (e.g., Envisat, ICESat, CryoSat-2 and upcoming ICESat-2) show promise of redressing our poor understanding of the Arctic Ocean circulation and mass variations. Satellite altimeters observe the total sea level variation, including the signal caused by temperature and salinity fluctuations (the steric effect) and non-steric barotropic and mass variations. Separately, gravity satellites, like GRACE, measure temporal changes in the Earth's gravity field caused by the movement of water masses. A well-designed in-situ hydrographic sampling network – with judiciously deployed ocean instrument technologies – would ensure the most accurate quantification of the sea level, circulation and mass changes of the Arctic Ocean. Together with an optimally designed bottom pressure array for resolving shorter time scale processes, the steric (halosteric and thermosteric) and non-steric effects can be separated for quantifying changes in circulation and variability in Arctic sea level (Fig. 3.2-7). Furthermore, sea surface heights from altimetry when differenced with the mean Arctic satellite geopotential constrain the geostrophic circulation. As a first element under test, we recommend an investigation, assisted by detailed instrumented arrays, of the basis for the correlations that have been achieved to date between GRACE bottom pressure series (or ENVISAT SSH series) and time-series from Arctic bottom pressure recorders (ABPR). Second, Observing System Simulation Experiments (OSSE) will be necessary to optimize the cost and benefit of an expanded and sustained in-situ bottom pressure array, providing guidance on mooring locations and defining the measurement accuracy and frequency needed to provide acceptable levels of uncertainty. The research team will include Ron Kwok (JPL), Katharine Giles and Seymour Laxon (CPOM), Jamie Morison and Mike Steele (APL), Andrey Proshutinsky (WHOI).

Outputs from the Arctic Ocean: what questions should we be testing?

The focus of this 'outputs' subhead has largely to do with one topic – our projections of change in the efflux of ice and freshwater from the Arctic. As already mentioned, the expectation is that the freshwater outflows from the Arctic Ocean to the North Atlantic will strengthen and may suppress the rate of the climatically-important Atlantic Meridional Overturning Circulation (MOC).

Q: *Will any future increase in freshwater efflux from the Arctic pass west or east of Greenland?*

A: The climatic point of this question stems from the analysis of 200 decades of HadCM3 runs by Michael Vellinga (U.K. Met Office) who found that if the same freshwater anomaly (0.1 Sv*yr or 3000 km^3) is spread to depth, it has much less effect on any consequent weakening of the Atlantic MOC (Vellinga et al., 2008). If so, it matters whether any future increase in the freshwater outflow from the Arctic is likely to be incorporated into the dense water overflow system or is likely to pass to the west or east of Greenland. Two model studies currently make that prediction. In one, the results of coupled climate model experiments by Königk et al., (2007) using ECHAM 5 and the MPI-OM suggest that although the freshwater flux is expected to increase both east and west of Greenland, the loss of the dominant sea-ice component through Fram Strait suggests we should expect a much greater total increase in the efflux through the CAA (+48%)

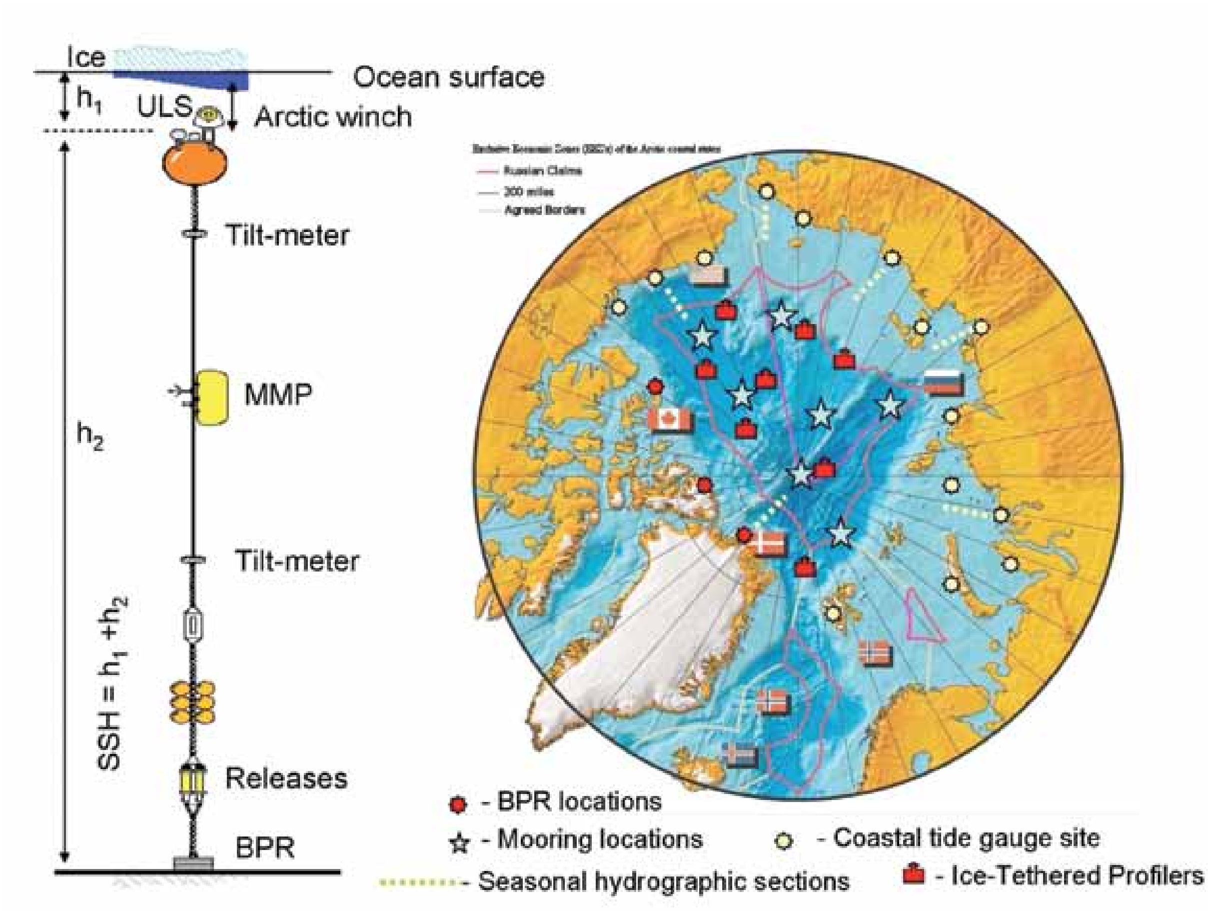


Fig. 3.2-7. Mooring components (left) and mooring, tide gauge and bottom pressure recorder (BPR) approximate locations to provide in-situ sustained observations in the Arctic Ocean to complement and validate space-borne measurements of ice thickness and sea surface heights in the Arctic.
(Image: Kwok et al., (2009)

by 2070-99 than through Fram Strait (+3% only). These results were based on IPCC AR4 experiments carried out in 2003/2004. Although the models have improved greatly in resolution and physics since these experiments were made in support of IPCC AR 4, these authors do not expect a fundamentally different result in AR5. The NCAR CCSM, which also has sufficient spatial resolution around Greenland to make the prediction, comes to the opposite conclusion, showing a much enhanced exchange between the Nordic Seas and the Arctic Ocean over the 21st Century. Rüdiger Gerdes (AWI) with Alexandra Jahn (McGill) and Laura de Steur (NPI) plan to address this important question with much higher resolved ocean-sea ice models and focusing on the ocean-observing aspects of that study.

Q: *What present and likely future factors control the freshwater outflow west of Greenland?*

A: The establishment of a simple statistical model (Ingrid Peterson, BIO) in which the surface wind anomaly outside the CAA is used to link the sea level set-up in the Beaufort Sea Shelf with the sea-level gradient along the NW Passage provides a basis for maintaining Prinsenberg's (BIO) transport series through Lancaster Sound at modest cost using a reduced moored array with modelling in support (for explanation see Dickson (2009), section 8.1.2). Humfrey Melling (DFO) has achieved, during 2009, the recovery of a full moored transport array from Nares Strait after two years. Further south, the monitoring of ocean fluxes through Davis Strait using SeaGliders to collect and return ocean profiles autonomously even in the presence of ice has become a proven technique (Craig Lee, UW pers. comm.). Thus the means of measuring the important oceanic freshwater fluxes west of Greenland in the longer term have become a reality. Our attention has now started to shift towards the actual and theoretical constraints on these transports and, most recently, towards the role of Greenland as a potential driver of change in this freshwater delivery

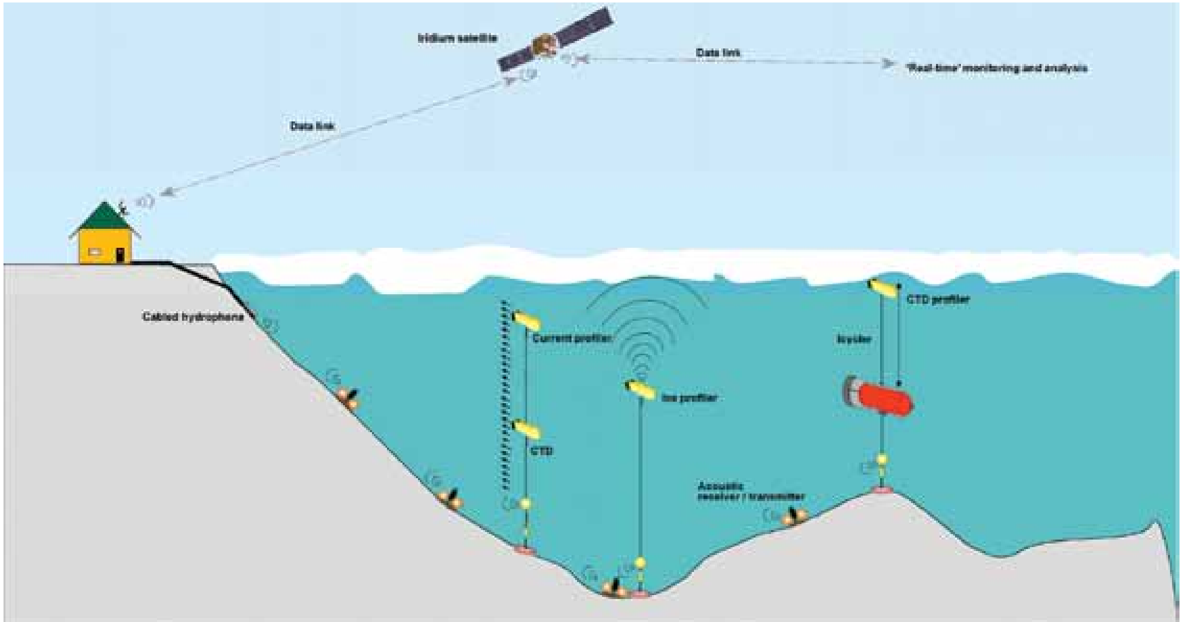


Fig. 3.2-8. A potential means of achieving a difficult but climatically-important measurement at modest cost. Through cooperation with the Canadian Defense Research Development Corporation (DRDC), it is planned to use an acoustic/cable/satellite link to provide oceanographic data from Barrow Strait in real time.
(Image: Simon Princenberg BIO)

system. Some of these constraints are reasonably well-known. In general terms, we know that when the Arctic Oscillation is in its negative phase, the atmospheric circulation tends to accumulate freshwater in the Amerasian Basin and decrease it in the Eurasian Basin (vice versa during the positive phase). This tends to increase the freshwater export by creating larger upper-layer thicknesses in the passages of the CAA compared with Fram Strait. Although the freshwater outflow leaving the CAA is normally sufficiently distinct in density to pass south along the west side of Baffin Bay or over-ride the fresh tongue passing north in the opposite sense along the W Greenland Margin, this is not necessarily an unvarying situation.

As Rudels (2009) has recently proposed on the basis of the present Θ-S structure to the west of Greenland, the freshwater transport in the W Greenland Current may well modulate or control that outflow. By this novel theoretical idea, an increased melting of the Greenland ice-cap may, in the outlook period, lower the density at large in E Baffin Bay sufficiently to alter the path or slow the southward flow of the CAA freshwater outflow. An increased freshwater production from Greenland also does not appear unlikely. On the contrary, it now appears demonstrable that warming of the seas around Greenland has been a cause of a recent acceleration in the four main outlet glaciers that drain the interior. Thus in addition to the main task of establishing an optimal observing system capable of capturing the changing character of the freshwater outflow through the CAA and Baffin Bay/Davis Strait at modest cost over years to decades (Fig. 3.2-8), a second task of establishing a sound theoretical footing for the disruptive effects of an increasing ice-melt from Greenland has arisen. Craig Lee (UW), Simon Prinsenberg and Humfrey Melling (DFO) and Bert Rudels (Univ. Helsinki) will investigate. Fiamma Straneo (WHOI) and Kelly Faulkner (OSU) will continue their fjord-scale assessment of the role of the warming ocean in accelerating the ice-flux from Greenland.

Designing an optimal ocean observing system for the IPY legacy phase

If we are to achieve more for (presumably) less funding in the post-IPY phase, it will be by close coordination and focus. This is not a new realization. The thrust of this Report is no different to the primary conclusion of the AON Design and Implementation (ADI) Project Plan following its task force meeting in November 2009, that '…there is now an urgent need for coordination, consolidation and optimization of the existing observing system elements as well as for development of a broader strategy that includes more detailed design studies to enhance and sustain the observing system'.

As Carl Wunsch made clear in his talk to the OceanObs09 meeting in Venice in September 2009, achieving a focused, coordinated and scientifically appropriate observing system will, initially at any rate, have less to do with Observing System Simulation Experiments (OSSE) than with asking and re-asking ourselves 'what is the question?'. Other studies agree. The ICSU 'Visioning' exercise in summer 2009 was one such attempt to define the observing task in hand by consulting widely on the subject of 'What is the most important research question in Earth system research that needs answering in the next decade; and why?' (See also Commentary by Reid et al., 2009). The ADI Task Force also named its first design consideration for an Arctic Observing System to be 'Guidance by science questions'. The testing of what we now believe to be the driving questions on the role of our northern seas in climate is the method we use here to bring the available effort to maximum focus. Naturally, the several lists of questions emerging from these approaches have varied. In the ICSU exercise, the questions were comprehensive, but rather broad-brush (e.g. 'How will polar climate respond to continued global warming? How and why is the cryosphere changing?'). The questions driving the science of the U.S. Study of Environmental Arctic Change (SEARCH) and of the present Arctic Observing Network are also of a rather 'large scale' nature (e.g. 'What is happening with Arctic sea-ice? Are carbon pathways in the Arctic marine system undergoing changes that are consequential, locally and globally' etc.).

The AOSB approach (this Report) is intentionally the most specific as regards the questions under test, but is different in that it covers both the pan-Arctic and the subarctic seas. This reflects the primary conclusion of the 2008 iAOOS Report for AOSB (Dickson, 2009) that we cannot understand Arctic change just by studying the Arctic; that change may certainly be imposed on the Arctic Ocean from subarctic seas, including a changing poleward ocean heat flux that would appear influential in determining the present state and future fate of the perennial sea-ice. The signal of Arctic change is expected to have its major climatic impact by reaching south through subarctic seas, either side of Greenland, to modulate the Atlantic thermohaline 'conveyor'. The changes and exchanges of both Arctic and subarctic seas thus seem necessary to understanding the full subtlety of the role of our Northern Seas in climate.

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3.3 Southern Ocean Observing System

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Historically, the Southern Ocean has been one of the least well-observed parts of the ocean. The Southern Ocean is remote from population centers and shipping lanes. Strong winds, large waves and sea ice provide additional reasons for vessels to avoid the region. Oceanography is also a young field. At the time of IGY, studies of the open ocean were rare, particularly in the Southern Ocean. Systematic circumpolar exploration of the region was conducted by George Deacon on the Discovery II in the 1930s, by Arnold Gordon and colleagues on the Eltanin in the late 1960s and early 1970s, within the framework of the International Southern Ocean Studies (ISOS) and Polar Experiment-South (POLEX-South) programs in 1970s-1980s, and during the World Ocean Circulation Experiment (WOCE) and Joint Global Ocean Flux Study (JGOFS) programs in the 1990s. Each of these expeditions was a major step forward in the exploration and understanding of the Southern Ocean. However, each survey suffered from similar weaknesses: each circumpolar survey took on the order of a decade to complete, was based on ship transects widely separated in space and time, and was heavily biased towards the summer months. A number of important Southern Ocean biological studies were conducted, including Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) in the 1980s and Global Ecosystem Dynamics (GLOBEC) in recent years, but these efforts tended to focus on particular regions since a comprehensive circumpolar survey of the shallow and deep waters around Antarctica was not technically feasible. Many valuable studies were conducted as stand-alone investigations, but from these alone it was difficult to synthesise a circumpolar view of the status of the Southern Ocean. Satellite data were however proving increasingly useful for synoptic studies, and the advent of the Argo profiling float programme around 2003 began to provide useful data from just below the surface down to 2000m, though not from areas extensively covered by winter sea ice.

Against this background, IPY was a major leap forward. The unprecedented level of cooperation and coordination during IPY – between nations, disciplines, scientists, logistic providers and communicators – allowed a synoptic "snapshot" of the state of the Southern Ocean to be obtained for the first time. Advances in technology played a huge role as well, and IPY was well-timed to take advantage of revolutions in ocean observations and genetic techniques. New tools like autonomous profiling floats and miniaturised oceanographic sensors suitable for deployment on marine mammals have allowed year-round, broad-scale sampling of the Southern Ocean for the first time, including the ocean beneath the sea ice. DNA barcoding and environmental genomics are providing completely new ways to investigate evolution and biodiversity, ecosystem function and biological processes. New cryospheric satellites provided encouragement that variables of essential relevance to climate, such as sea ice volume and other characteristics relevant to air-sea-ice interaction, might be derived from space-based observations. New trace-metal clean techniques were developed, allowing many elements and isotopes to be measured for the first time throughout the full ocean depth.

IPY was also well-timed because at least some regions of the Southern Ocean have experienced rapid change in recent decades. The western Antarctic Peninsula has warmed dramatically; the duration of the sea ice cover has decreased near the peninsula at rates comparable to those observed in the Arctic, and increased in the Ross Sea; the collapse of ice shelves has opened up new areas of ocean where the process of seabed colonisation can be observed; and large but regionally-varying changes in temperature and ocean circulation have taken place in the Antarctic Circumpolar Current. The IPY therefore provided both a unique near-synoptic assessment of the physical, biogeochemical and biological state of the Southern Ocean and insight into the extent, drivers and impacts of Southern Ocean change.

Many aspects of the Southern Ocean were measured for the first time during IPY. Examples include measurements of trace metals like iron and mercury; patterns of pelagic and benthic biodiversity from near-shore Antarctic waters to the deep sea; and the circulation and water mass properties beneath the winter sea ice. A summary of the observations completed in the Southern Ocean during IPY and research highlights from this work are presented in *Chapter 2.3*.

The IPY Science Plan called for development of ocean observing systems in both the Arctic and the Southern Ocean. In 2006, at a meeting in the margins of the SCAR Open Science Conference in Hobart, an international consortium of scientists spanning all disciplines of Southern Ocean research started to develop a strategy for sustained observations of the Southern Ocean. One of the greatest achievements of Southern Ocean science during IPY was the demonstration that sustained observations of the Southern Ocean were feasible, cost-effective and urgently needed. IPY in this sense served as a demonstration or pilot project for the Southern Ocean Observing System (SOOS). Commitment to resource and implement the SOOS will leave a significant and long-lasting legacy of Southern Ocean IPY.

The scientific rationale and implementation strategy for the SOOS is summarised in Rintoul et al., (2010) and described in detail in Rintoul et al., (2010). As discussed there, sustained observations of the region are needed to address key research questions of direct relevance to climate and society, including the global heat and freshwater balance, the stability of the overturning circulation, the future of the Antarctic ice sheet and its contribution to sea-level rise, the ocean uptake of carbon dioxide, the future of Antarctic sea ice, and the impacts of global change on Southern Ocean ecosystems.

The limited available observations suggest the Southern Ocean is changing: the region is warming more rapidly, and to greater depth, than the global ocean average; salinity changes driven by changes in precipitation and ice melt have been observed in both the upper and abyssal ocean; the uptake of carbon by the Southern Ocean has slowed the rate of climate change but increased the acidity of the Southern

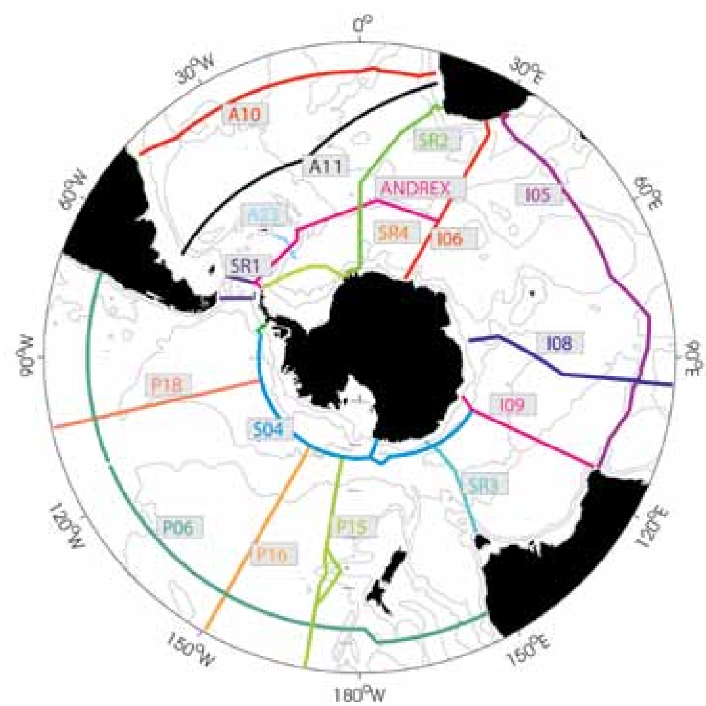

Fig. 3.3-1. Repeat hydrographic sections proposed for SOOS. Each of these lines has been occupied previously during the World Ocean Circulation Experiment and the Climate Variability and Predictability Program.

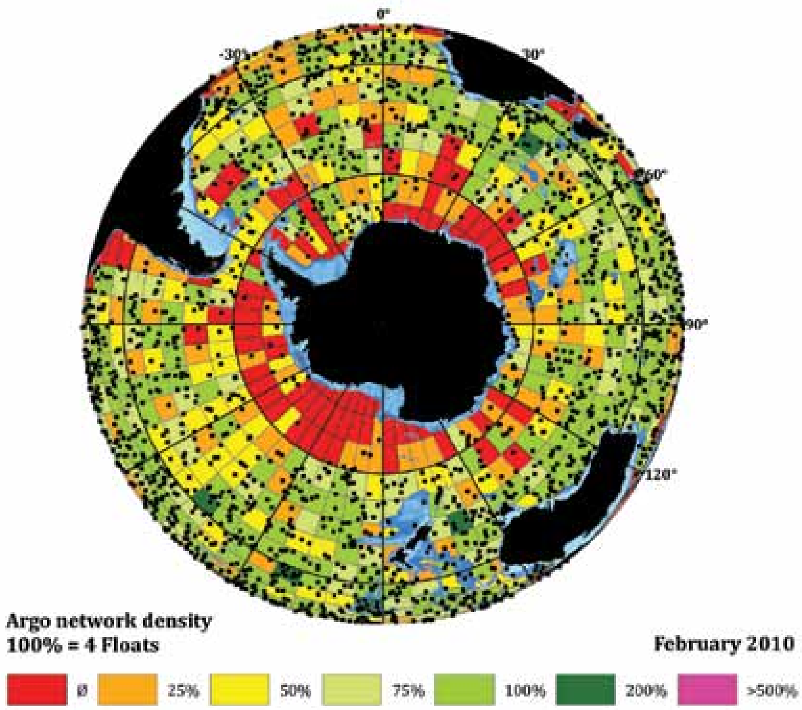

Fig. 3.3-2. Present status of Argo float array in the Southern Ocean. Note that coverage decreases with increasing latitude, with few observations in the sea ice zone.

Provided by Mathieu Belbeoch of JCOMMOPS

Ocean; and there are indications of ecosystem changes. However, the short and incomplete nature of existing time series means that the causes and consequences of observed changes are difficult to assess. Sustained, multi-disciplinary observations are required to detect, interpret and respond to change. The SOOS will provide the long-term measurements required to improve understanding of climate change and variability, biogeochemical cycles and the coupling between climate and marine ecosystems.

The SOOS includes the following elements:

- **Repeat hydrography:** Hydrographic sections from research vessels are the only means of sampling the full ocean depth. Repeat hydrography provides water samples for analysis of those properties for which in situ sensors do not exist, the highest precision measurements for analysis of change and for calibration of other sensors, accurate transport estimates and a platform for a wide range of ancillary measurements. The location of the recommended repeat sections is shown in Fig. 3.3-1. On each transect, measurements will be made of temperature, salinity, velocity, oxygen and oxygen-18, nutrients, components of the carbon system, tracers and a wide range of biological measurements (eg bio-optics, primary production, phytoplankton pigments, net tows and acoustics). Trace elements and isotopes will be measured on some sections.
- **Underway sampling from ships:** The full hydrographic sections need to be complemented by more frequent underway sampling transects, to reduce aliasing of signals with time-scales shorter than the 5-7 year repeat cycle of the repeat hydrography. Measurements will be made of temperature and salinity (both at the surface and below the surface using expendable profilers), nutrients, carbon, phytoplankton and, on some vessels, velocity.
- **Enhanced Southern Ocean Argo:** Year-round, broad-scale measurements of the ocean are needed to address many of the key science challenges in the Southern Ocean. These measurements can only be obtained using autonomous platforms like profiling floats. A sustained commitment to maintain and enhance a profiling float array in the Southern Ocean is critical. Argo has made a particularly significant contribution in remote areas like the Southern Ocean, where few ship observations exist (Fig. 3.3-2). Modified Argo floats are needed to obtain data from beneath the winter sea ice.
- **Time-series stations and monitoring of key passages:** Several key passages and boundary currents in the Southern Ocean are high priorities

for sustained observations because of their role in the global-scale ocean circulation and because they offer the best opportunities to measure water mass transport. High priority sites include Drake Passage and other chokepoint sections across the Antarctic Circumpolar Current and the dense water overflows and boundary currents carrying Antarctic Bottom Water to lower latitudes as part of the deep branch of the global overturning circulation (Fig. 3.3-4).

- **Phytoplankton and primary production:** Sustained observations of phytoplankton biomass, species distributions and primary production are needed to relate biological variability to environmental change. Ocean colour satellites are critical as they provide the only circumpolar view of biological activity in the Southern Ocean. In situ measurements are needed to refine algorithms used to interpret the satellite data, to relate surface chlorophyll to column-integrated production, for analysis of additional pigments and phytoplankton community composition, and to relate biological variables to simultaneous measurements of the physical and chemical environment. The repeat hydrographic sections (Fig. 3.3-1) provide the primary means of sampling the subsurface ocean for biological parameters; underway observations from ships of opportunity (Fig. 3.3-3) provide more frequent sampling of the surface ocean. Measurements needed include fluorometry and fast repetition rate fluorometry, phytoplankton pigments and size distribution, transmissometry and microscopy.
- **Zooplankton and micro-nekton:** Antarctic plankton may be particularly sensitive and vulnerable to climate change. Global warming will affect sea ice patterns and plankton distributions (e.g. a decrease in the geographical extent of sea ice has been linked to a decline in krill numbers). Increased UV levels, ocean acidification, invasive plankton species, pollution and harvesting impacts are also potential threats. Underway sampling by continuous plankton recorders provides the backbone of the zooplankton observing system, but needs to be supplemented by targeted net tows and acoustic sampling.
- **Ecological monitoring:** Observations of the distribution and abundance of top predators (fish, penguins, sea birds, seals and whales) can provide indications of changes in the ecosystem as a whole. Long-term monitoring programs have been established at a few sites around Antarctica and must be continued. The comprehensive sampling of physical

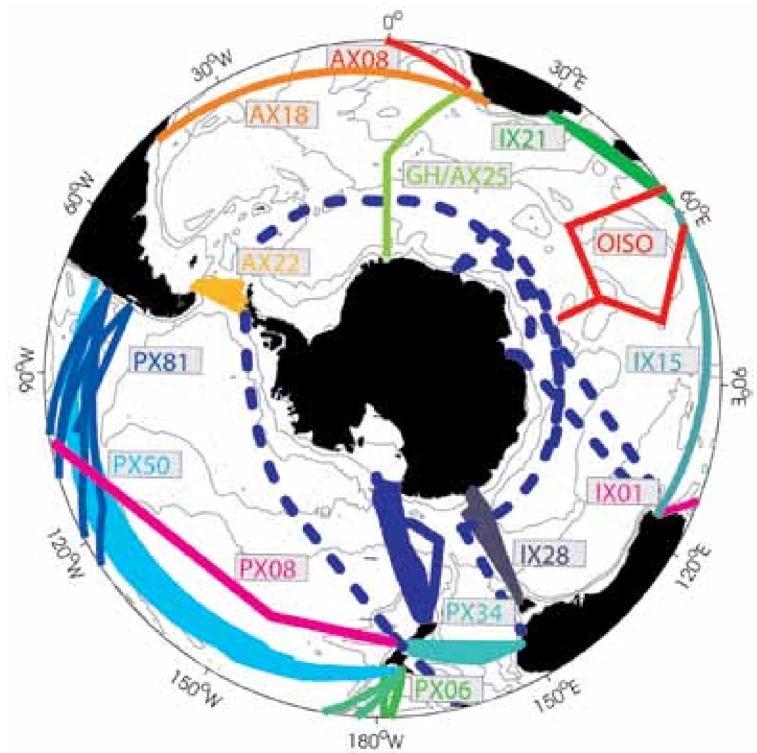

Fig. 3.3-3. Routes of ships-of-opportunity conducting underway observations in the Southern Ocean.

biogeochemical and biological variables carried out in the Palmer Long Term Ecosystem Research program, for example, has provided important insights into the dynamics of the ecosystem of the western Antarctic Peninsula and its sensitivity to change. Monitoring of predators has been carried out at a number of locations as part of the Ecosystem Monitoring Program of the Commission for the Conservation of Antarctic Marine Living Resources. However, in many cases there is a lack of simultaneous physical and biogeochemical data, and information on lower trophic levels, to allow the causes of changes observed in higher trophic levels to be determined. The SOOS aims to provide the integrated multi-disciplinary observations needed to understand the interactions between physics, chemistry and biology in the Southern Ocean. Continued long-term and large-scale observations of functional and structural changes in ecosystems are essential to assess the sensitivity of ecological key species and to ground-truth predictive models. The establishment of a series of core long-term biological monitoring sites would be extremely beneficial both in documenting biological responses and trends, and allowing explicit tests of predictive hypotheses. In addition there is a need to develop new sensors to rapidly measure biological and chemical variables.

- **Animal-borne sensors:** Oceanographic sensors deployed on birds and mammals can make a significant contribution to SOOS in two ways: by relating predator movements, behavior and body condition to fine-scale ocean structure, and by providing profiles of temperature and salinity from regions of the Southern Ocean that are difficult to sample by other means (e.g. beneath the winter sea ice). SOOS should maintain and enhance the program of seal tag deployments established during IPY (Fig. 3.3-5) and develop a multi-species tagging approach along the lines of the Tagging of Pacific Pelagics (TOPP) program.
- **Sea ice observations:** Measurements of both the extent and thickness of sea ice are needed to monitor changes in sea ice production and any related impacts on the climate system and/or Southern Ocean ecosystem processes. A variety of satellite instruments provide continuous, circumpolar observations of sea ice extent, with varying spatial resolution. Measuring sea ice volume, however, remains a significant challenge and requires in situ sampling to provide ground-truth data for the satellite sensors. These measurements need to include a combination of

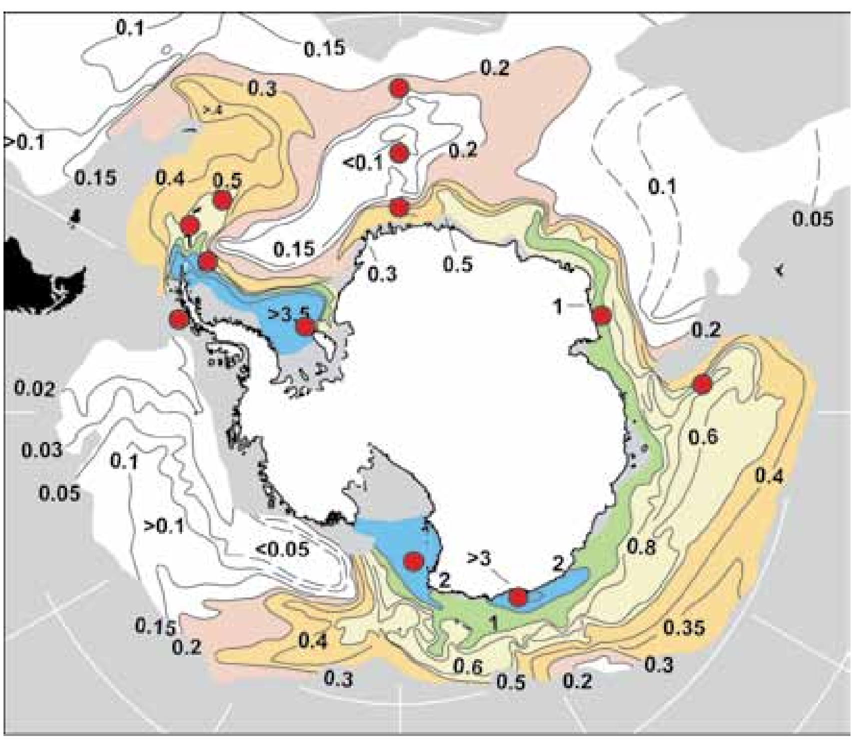

Fig. 3.3-4. Map of proposed moored arrays to sample the primary Antarctic Bottom Water (AABW) formation and export sites, as part of a coordinated global array to measure the deep limb of the global overturning circulation. The map shows the inventory of chlorofluorocarbon 11 (CFC-11) in the density layer corresponding to AABW, and thus the pathway of AABW from its source regions (blue) down the concentration gradient through green to orange.

Source: Orsi et al., 1999

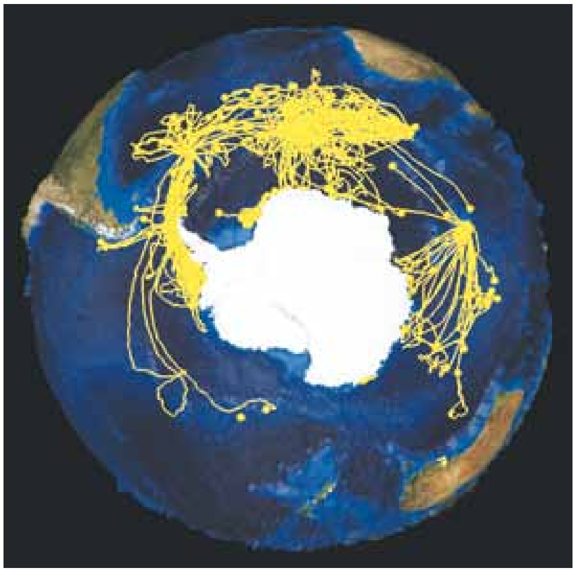

Fig. 3.3-5. Map showing the location of temperature and salinity profiles collected by seals instrumented with oceanographic sensors as part of the MEOP program of the IPY. More oceanographic profiles have been collected in the sea ice zone using seals than using traditional oceanographic tools like ships and floats.

sampling from ice stations, helicopters, autonomous vehicles, moorings and underway observations.

- **Enhanced meteorological observations:** An enhanced atmospheric observing system is needed to improve Antarctic and southern hemisphere weather forecasts. Climate research benefits from improved weather forecasts in the increased accuracy of the flux products derived from Numerical Weather Prediction (NWP) model reanalyses. The air-sea fluxes of heat and moisture are poorly known at high southern latitudes, making it difficult to diagnose the interactions between atmosphere, ocean and sea ice that lay at the heart of climate variability and change.
- **Remote sensing:** Access to high quality remote sensing data is particularly critical in the Southern Ocean, where *in situ* data is difficult to obtain. High priority satellite systems include radar and laser satellite altimetry, ocean colour, scatterometer, infrared and microwave sea surface temperature, passive microwave and synthetic aperture radar. Continuity of space-based measurements is absolutely essential, since these are the sole major source of data for the whole of the continent and its surrounding ocean, where measurements on the ground or on the sea are difficult, dangerous and not normally made year-round. Recommendations for satellite observations of the cryosphere, including sea ice, are given in the Cryosphere Theme document produced for the Integrated Global Observing Strategy (IGOS) Partnership (www.eohandbook.com/igosp/cryosphere.htm).

The scientific achievements of IPY, summarised in *Chapter 2.3*, demonstrate the power and value of integrated, multi-disciplinary observations in the Southern Ocean. Sustained measurements of the Southern Ocean are needed to address some of the most urgent issues facing society, including climate change and its impacts and the effective management of marine resources. IPY demonstrated the feasibility and relevance of a sustained Southern Ocean observing system. The SOOS plan presents a community view of what needs to be measured as part of a Southern Ocean observing system. The challenge in the years ahead is to build on these IPY achievements to ensure a sustained commitment is made to observing the Southern Ocean. These observations will be key contributions to the Global Ocean Observing System (GOOS), which itself is the ocean component of the Global Climate Observing System (GCOS). The GCOS advises the Parties to the UN Framework Convention on Climate Change what observations to make, where to make them and to what standards. In turn, both GOOS and GCOS are elements of the Global Earth Observing System of Systems (GEOSS) developed by the Group on Earth Observations, a partnership between governments and international organisations (http://earthobservations.org/).

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3.4 International Arctic Systems for Observing the Atmosphere (IASOA)

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Introduction

International Arctic Systems for Observing the Atmosphere (IASOA) is a program developed to enhance Arctic atmospheric research by fostering collaborations among researchers during International Polar Year (IPY) 2007–2008 and beyond. The member observatories are Abisko, Sweden; Alert and Eureka, Canada; Barrow, U.S.A.; Cherskii and Tiksi, Russian Federation; Ny-Ålesund, Norway; Pallas and Sodankylä, Finland; and Summit, Greenland (Fig. 3.4-1). All of these observatories operate year-round, with at least minimal staffing in the winter months and are intensive and permanent. IASOA is one of the few IPY projects focusing on atmospheric research in the Arctic, as shown in the IPY "honeycomb" plot of projects (Fig. 3.4-2).

In this chapter we present information about the IASOA project's goals and accomplishments during IPY, including our participation in high-profile meetings and conferences, our commitment to supporting long-term atmospheric measurements in the Arctic, the development of a comprehensive web site (www.iasoa.org) and observatory upgrades.

IASOA Outreach and Legacy Activities

International Polar Year Media Day

During the last few weeks of IPY, the outreach and education staff at the IPY International Program Office organized a "media blitz" to showcase IPY projects. As a part of this, IASOA was featured on 10 February 2009 on www.ipy.org. For this media day, researchers at each IASOA observatory were asked to provide up-to-date information on IPY research at their observatories and to be available for journalists to interview by phone. On www.iasoa.org a media day page was created (Fig. 3.4-3), which highlighted recent activities at six of the observatories (http://iasoa.org/iasoa/index.php?option=com_content&task=blogcategory&id=40&Itemid=147).

American Geophysical Union (AGU) Sessions

In an effort to encourage and support pan-Arctic research, IASOA proposed a session to the 2008 Fall American Geophysical Union (AGU) conference. The response to our session was very good, with enough abstracts to have both oral and poster sessions. Authors were encouraged to submit papers on studies using data from two or more IASOA observatories. Twenty-seven papers covering a broad range of topics were presented. All abstracts submitted to our AGU session can be found on the IASOA web site science page: http://iasoa.org/iasoa/index.php?option=com_content&task=blogcategory&id=41&Itemid=149.

Cooperative Arctic Data and Information Service (CADIS)

The Cooperative Arctic Data and Information Service (CADIS) is an IPY data management and archival project, primarily for Arctic Observing Network (AON) and Study of Environmental Arctic Change (SEARCH) principal investigators (http://aoncadis.ucar.edu/home.htm, Fig. 3.4-4). The National Science Foundation (NSF) supports CADIS, which is a joint project of the University Corporation for Atmospheric Research (UCAR), the National Center for Atmospheric Research (NCAR) and the National Snow and Ice Data Center (NSIDC). IASOA is currently in the exploration phase of supplying metadata and data links to CADIS.

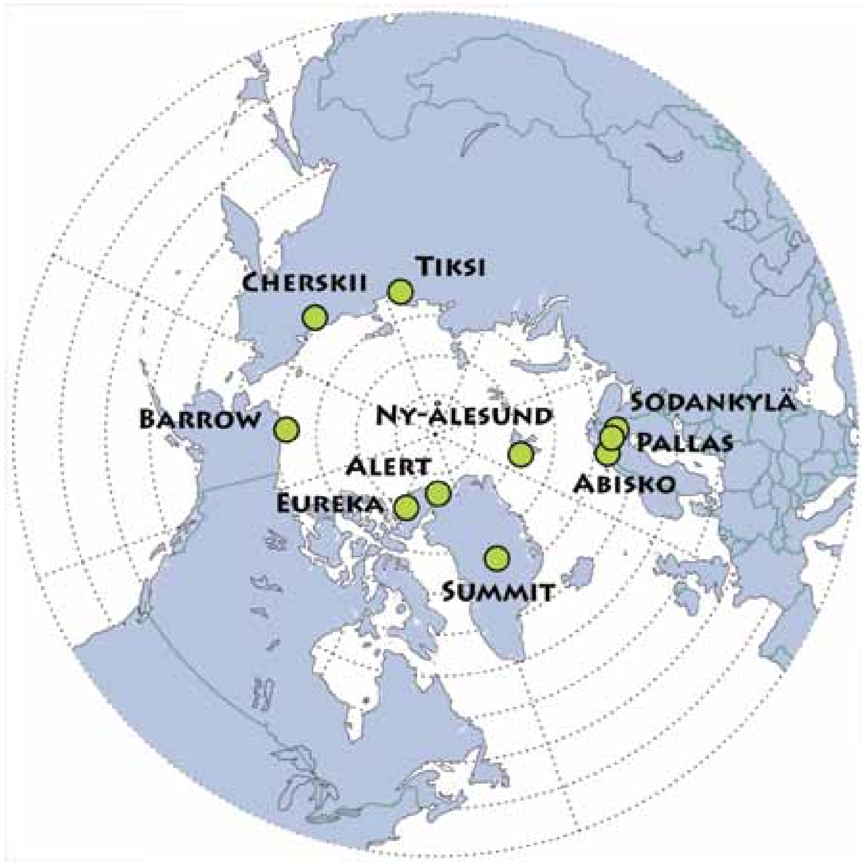

Fig. 3.4-1. Map of IASOA stations.
(Illustration: Lisa Darby)

IASOA post-IPY Legacy Plans

Now that IPY is over, we are planning for IASOA's future. As part of the process of establishing a legacy of operations for IASOA after IPY, IASOA has requested that the International Arctic Science Committee (IASC) consider endorsing IASOA.

We anticipate that IASOA will function as one of the building blocks for the atmospheric component of Sustaining Arctic Observing Networks (SAON).

We are also currently in the planning stages for establishing a scientific steering committee that will oversee the continuation of the promotion of pan-Arctic research utilizing measurements obtained at the IASOA observatories. Ideally we would like to have two representatives from each observatory participate. Additionally, we will organize science meetings focusing on atmospheric measurements from IASOA observatories.

IASOA Web Site

The IASOA website (www.iasoa.org, Fig. 3.4-5) is a continually evolving resource for Arctic researchers. There is a page for each IASOA observatory, which includes a general overview of the observatory, a listing of available measurements and principle investigators, links to data bases, news stories and observatory contacts (Fig. 3.4-6). In recent months we have posted more information about available data sets. The easiest way to look for information about Arctic atmospheric data is through the "Observatories-at-a-Glance" page (Fig. 3.4-7). We provide links directly to the data when possible, otherwise we post contact information for requesting the data. Also in recent months we have added a "Weather-at-a-Glance" page that shows web cams and current weather data for each observatory. We have also added a travel blog page so visitors to our web site can see pictures from various observatories. We welcome contributions from researchers to post on the web site, particularly links to data bases, news stories and meeting announcements.

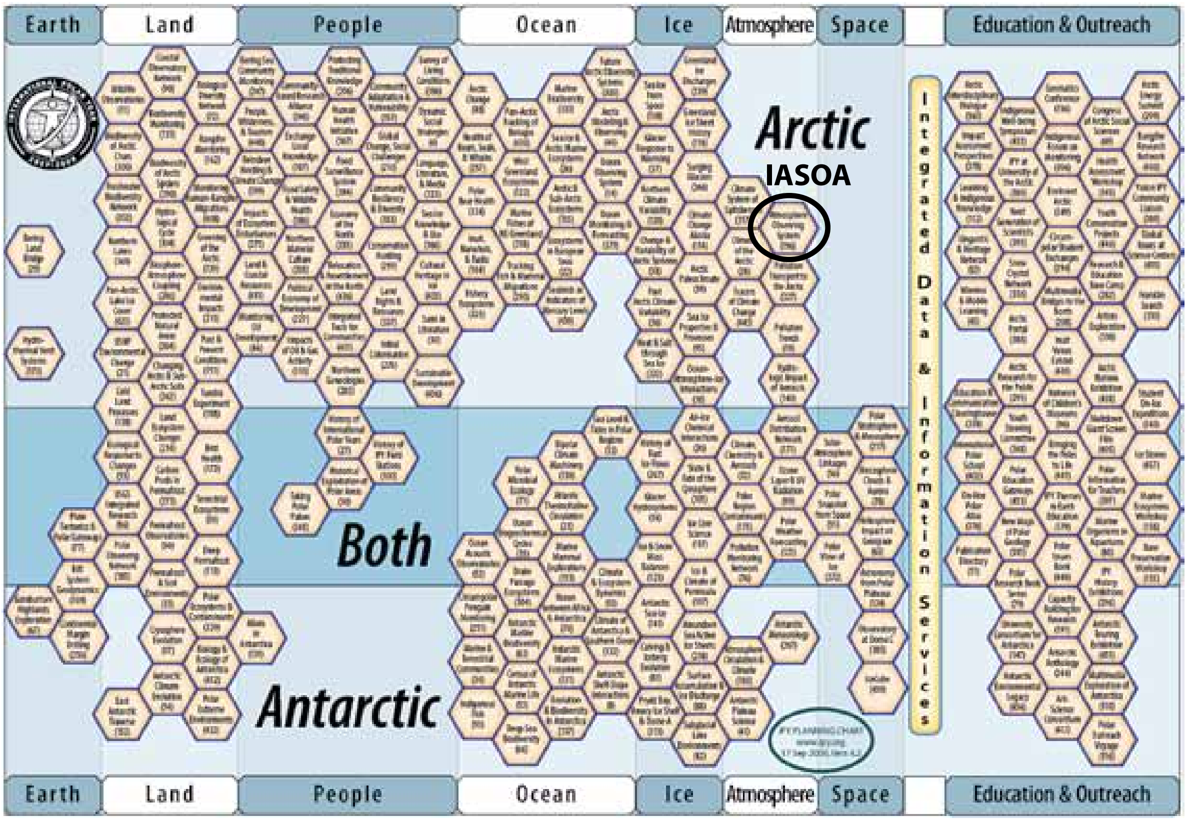

Fig. 3.4-2. IPY project chart showing the position of the IASOA project (no. 196).

Observatory Upgrades

Numerous instrument upgrades, new instrument installations and new programs occurred over the course of IPY at several of the IASOA observatories. A few examples follow.

Eureka, Nunavut, Canada *(80.050 N, 86.417 W, 10 m ASL (32.8 ft ASL))*

- A new flux tower (Fig. 3.4-8)
- Several CIMEL sunphotometers for the Aeronet Network
- A Baseline Surface Radiation Network (BSRN) station
- Starphotometer
- Precipitation sensor suite
- VHF wind tracking radar
- All sky imager
- Spectral airglow temperature imager
- The Canadian Network for the Detection of Atmospheric Change (CANDAC) Millimeter Cloud Radar (MMCR) replaced the National Oceanic and Atmospheric Administration (NOAA)/ Study of Environmental Arctic Change (SEARCH) MMCR.
- Rayleigh-Mie-Raman lidar and a tropospheric ozone lidar
- With IPY funding, the level of technical support at the site was increased to provide more reliable data collection and transmission
- In addition to equipment upgrades, Eureka scientists hosted visiting diplomats as part of the "Northern Diplomatic Tour," as well as Grade 11-12 students and teachers as part of the Northern Experience Program.

Summit, Greenland *(72.580 N, 38.48 W, 3238 m ASL (10623.4 ft ASL))*

- Summit observatory released a strategic plan highlighting climate sensitive year-round observations, innovative research platforms and operational plans to increase renewable energy to maintain the pristine platform. Summit also has a new multi-channel gas chromatograph for

Top left -
Fig. 3.4-3: Screen shot of media day page.

Top right -
Fig. 3.4-4: Screen shot of CADIS web site main page.

Bottom left -
Fig. 3.4-5: IASOA home page.

Bottom right -
Fig. 3.4-6: Summit, Greenland site page.

Fig. 3.4-7: Screen shot of Observatories-at-a-Glance page.

continuous measurement of trace halocarbon and chlorofluorocarbons gas concentrations.

- A CO_2 and NOx flux facility went online in summer 2008. The flux facility was built underground and covered with snow, with only the flux tower exposed.
- The new Temporary Atmospheric Watch Observatory was constructed.

Cherskii, Russian Federation *(69° N, 161° E)*

- A collaboration between the University of Alaska Fairbanks (UAF) and NOAA has resulted in tower measurements of CO_2 and CH_4. The CH_4 measurements will be combined with new modeling methods developed at NOAA to infer regional-scale CH_4 fluxes. These estimates will complement CH_4 fluxes determined by UAF using a flux gradient method. This work is timely and important due to the large carbon stores, mostly CH_4, that could be released from permafrost regions

in response to Arctic warming.
- The researchers at Cherskii also partnered with The Polaris Project (www.thepolarisproject.org/), providing undergraduate students with the chance to do field work in the Siberian Arctic.
- Scientists at Cherskii are comparing disturbed and undisturbed areas of permafrost to determine the effects of thawing permafrost.

Barrow, United States *(71.323 N, 156.609 W, 11 m ASL (36 ft ASL))*
- Barrow observatory has two new systems for aerosol size and chemistry composition, as well as new persistent organic pollutant (POPs) measurements. The meteorology measurement and data system has been completely upgraded.
- Barrow provided ground services and lodging for the Polarcat campaign.

Tiksi, Russian Federation *(71.580 N, 128.92 E)*

Tiksi is located in a boundary region at the confluence of Atlantic and Pacific influences, resulting in exposure to a wide variety of air mass types. Atmospheric conditions range from pristine to polluted, providing a natural laboratory to assess the radiative effects of aerosols and resulting cloud properties and also the influences various pollution source regions of Russia, Northern America, Europe and Central Asia have on regional air quality.

Tiksi is located in the Lena River basin. The Lena River is the only major Russian River for which most of the drainage basin is underlain by permafrost, making it hydrologically complex and particularly vulnerable to climatic warming. Tremendous stores of carbon are presently locked in the permafrost of this river basin, and the regimes of precipitation and evaporation are very important for regional changes in the surface fluxes of CO_2 (increases to atmosphere with surface drying) and CH_4 (increases to atmosphere with surface wetness).

The Laptev Sea is an area of such large ice production that it has been termed "the ice factory of the Arctic Ocean." As such, this region is the source of much of the sea ice that transits the Arctic Ocean and exits through the Fram Strait.

Given all of these critical features of the Tiksi region that are relevant to understanding climate change, the need to modernize and upgrade the facilities at Tiski has been recognized by several Russian, U.S. and European agencies. Collaborations have been established among the following agencies to implement the modernization of the Tiksi Hydrometeorological Observatory: Roshydromet Arctic and Antarctic Research Institute (AARI), NOAA, the Russian Academy of Sciences (RAS), the U.S. National Science Foundation (NSF) and the Finnish Meteorological Institute (FMI, Makshtas, 2007). During and after IPY, numerous planning meetings among these agencies have taken place, as well as agency visits to Tiksi. Some of these meetings included:
- The Logistics Team Meeting held in St. Petersburg in March 2009, resulting in a construction plan for finishing the site and Clean Air Facility improvements in August 2009).
- A Science Team Meeting held in Boulder in May 2009, resulting in the finalization of a science plan with 14 identified joint science projects.
- The Operations Team met in September 2009 to work out the details of continuing operations,

Fig. 3.4-8. New flux tower at Eureka.
(Photo courtesy of Rob Albee)

including how to incorporate new projects from the NSF, the Russian Academy of science, other agencies (e.g. the National Aeronautics and Space Administration) and other countries. Details about the September 2009 trip to Tiksi, including a list of recently completed and planned installations can be found on the IASOA web site: http://iasoa.org/iasoa/index.php?option=com_content&task=view&id=282&Itemid=175 (English) and http://iasoa.org/iasoa/index.php?option=com_content&task=view&id=281&Itemid=174 (Russian)

As a result of these intensive collaborations, in spring 2010 the following installations will be completed at the Tiksi Hydrometeorological Observatory:

Spring 2010 Installations	Measured Parameters
Automated meteorological station (AMS)	Air temperature, humidity, ground temperature, wind speed and direction, atmospheric pressure
Climate Reference Network (CRN) station	Temperature, precipitation solar radiation, surface skin temperature, surface winds, soil moisture and soil temperature at 5 depths
Vector-M Upper Air Measurements	Air temperature, relative humidity, instantaneous and average wind speed and direction, atmospheric pressure
Baseline Surface Radiation Network (BSRN) station	Direct, downward and upward solar radiation at various spectral intervals
Global Atmosphere Watch (GAW) station	Primary greenhouse gases (CO_2, CH_4, CO, H_2); N_2O, SF_6; water vapor concentrations

These installations mark the beginning of continued observatory upgrades and international collaborations.

Summary

The International Polar Year 2007–2008 was a fantastic opportunity to harness the immense interest in Arctic meteorology during this time of rapid change. The concepts behind IASOA were articulated in IPY Proposal (http://classic.ipy.org/development/eoi/proposal-details.php?id=196). The goals of the program, as outlined in the proposal, have been addressed during and after IPY with very limited funding. So far, the significant outcomes of the IASOA program are (Darby et al., 2009):

- The IASOA web site (www.iasoa.org)
- Strong collaborations among SEARCH scientists and engineers at several of the IASOA observatories
- Instrument loans to observatories (e.g., NOAA/ESRL loaned a cloud radar to FMI)
- The science sessions at AGU where scientists became more acutely aware of scientific investigations and data sets at many of the observatories
- The new instrumentation and infrastructure at the Tiksi Hydrometeorological Observatory.

There is still much work to do for IASOA to reach its full potential and we look forward to serving the Arctic atmospheric community.

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3.5 Meteorological Observing in the Antarctic

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Reviewers:
Colin Summerhayes and Eduard Sarukhanian

The International Geophysical Year of 1957–58 (IGY) provided a big impetus towards setting up continuously operated stations in the Antarctic. Over forty were constructed during and following the IGY years, of which over a dozen are still operating today. This was the peak of manned observation in Antarctica and since then the number of staffed stations has declined (Fig. 3.5-1), though this is offset by an increasing number of automatic stations (Fig. 3.5-2). Some improvement to the observing network took place during International Polar Year of 2007–2008 (IPY), however, the main thrust of IPY initiative was a boost to polar research.

Most manned stations are at coastal sites, primarily so that stores can easily be transported ashore. This means that in some ways their weather is not a true representation of the continent as a whole, as they are much milder due to the influence of the sea. Automatic stations are much more widely spread across the continent and give a broader picture of the meteorology.

At most manned stations meteorological observations are made regularly throughout the "day" according to WMO standards, however, there is increasing reliance on automatic systems during the "night". Surface temperature, humidity, sunshine, pressure, wind speed and direction are largely measured by automated instruments, but an observer is needed to estimate the visibility and the amount, type and height of clouds, although automatic instruments are being introduced. An observer also needs to keep note of the weather: rain, snow, fog, gale etc., as well as more unusual phenomena, such as diamond dust, halos, mirages and the aurora australis. Traditional weather observing on the polar plateau brings additional problems, with the combination of very low temperature and high altitude. At the Russian Vostok station special suits are worn for outdoor work under these conditions.

The observations are expressed in a numeric code and transmitted to meteorological centres, largely in the northern hemisphere, using the Global Telecommunication System (GTS), the meteorological equivalent of the Internet, where they join thousands of other observations from all over the world. The observations are processed by super-computers, used to forecast the weather and archived for climate studies. The transmission technique has steadily improved since IGY when HF radio was the only medium available to send data from Antarctica in real-time. Satellite relay became widely used in the 1980s, either using Data Collection Platforms (DCPs) transmitting to geostationary satellites at fixed times or random transmissions making use of the ARGOS service on polar orbiting satellites. During IPY, email transmission over permanent Internet links became more common along with short data burst (SDB) transmissions on the Iridium mobile phone system.

Automatic stations (Fig. 3.5-3) generally measure a reduced range of parameters, usually pressure, temperature and wind, although some may measure humidity and have housekeeping data such as snow depth. Where there is significant snow accumulation, stations require annual maintenance visits while others may not be revisited after deployment. Most provide real-time access to their data, but others store the data locally for recovery during maintenance visits. Several new stations were set up during IPY. In particular, Russia installed automatic weather stations (AWS) at their formerly manned stations at Leningradskaya, Molodezhnaya and Russkaya, resuming a data series that was interrupted due to closure of these stations in the 1990s. In addition the private operator Adventure Network International, installed an AWS at their Thiel Mountains site and, in a co-operative arrangement with the British Antarctic Survey and U.K. Meteorological

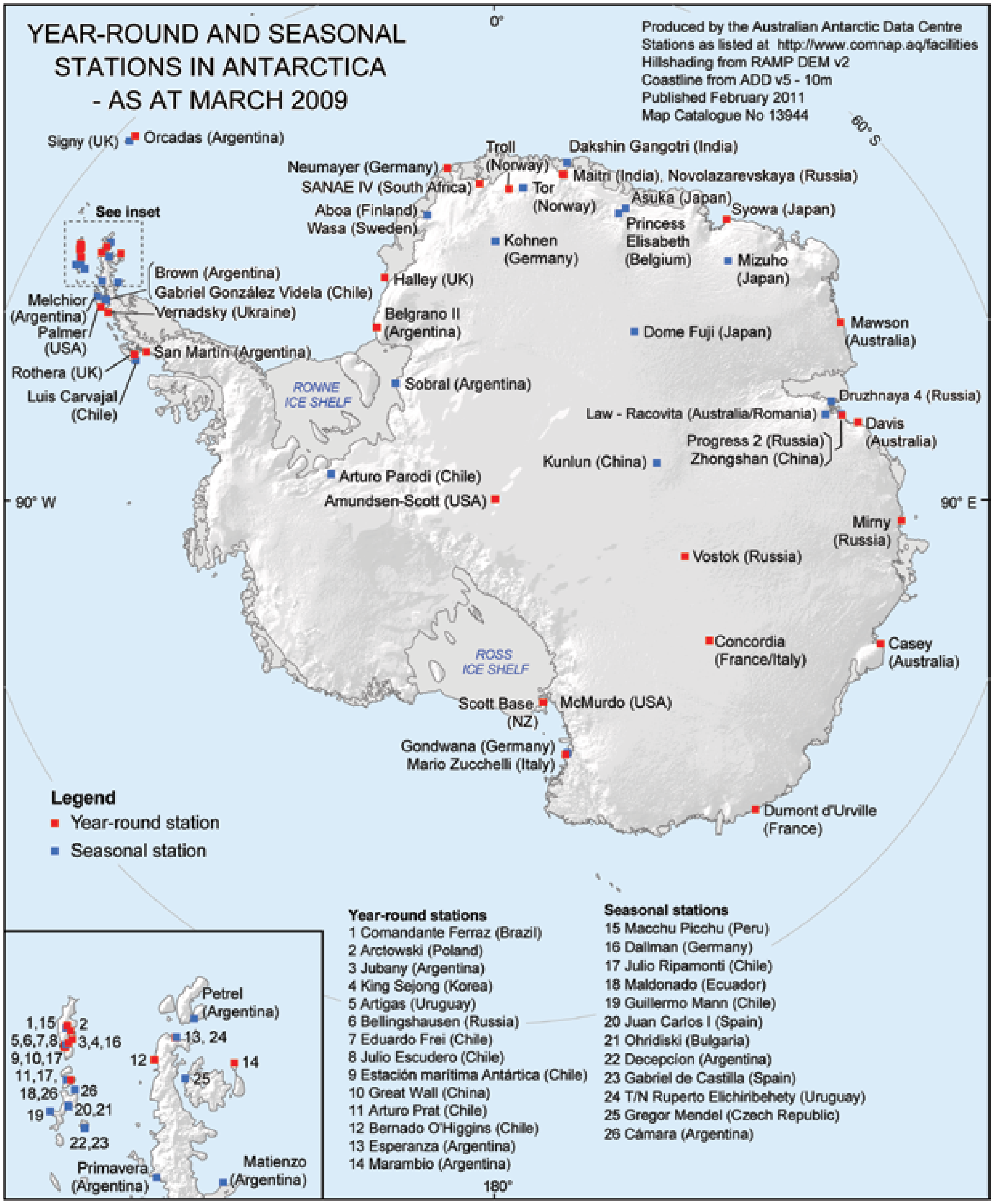


Fig. 3.5-1. Antarctic stations at the end of IPY, March 2009.
(Courtesy: Australian Antarctic Data Centre)

Office, made the data available on the GTS. Altogether there are now 35 manned stations, complemented by about 65 AWS with data available in real-time, and over a dozen more whose data is available after some delay. Major AWS networks are run by Australia (Bureau of Meteorology), Italy (PNRA), the Netherlands (Utrecht University), U.K. (British Antarctic Survey) and U.S.A. (University of Wisconsin).

In general, it should be stressed that despite the renovation of several manned stations, such as Neumayer (Germany), and the establishment of new station Princess Elisabeth (Belgium) during IPY period, the availability of operational synoptic data could still be improved. No new funding was available for this particular purpose, so some already planned projects were re-badged as IPY projects. For example, IPY COMPASS project was essentially a continuation and expansion of the SCAR READER project. Although READER data is still being collected, by 2010 only about half of SCAR Member countries had contributed their full synoptic data sets for the IPY years. The global financial situation is likely to impact on funding and in future real-time data is likely to become restricted to those sites where it is necessary to meet operational and forecasting needs.

Weather

Stations near the Antarctic coast are on average quite cloudy because of the frequent passage of depressions and the influence of the sea. The further a station is inland, the less cloudy it becomes. Signy (60°S) has an average cloud cover of 86%, Halley (76°S) 66% and the South Pole an average of 41%. Visual observation of cloud height is difficult at stations on ice shelves or the polar plateau, where the high albedo reduces contrast and there are no references to estimate height. Cloud lidars give a big improvement in

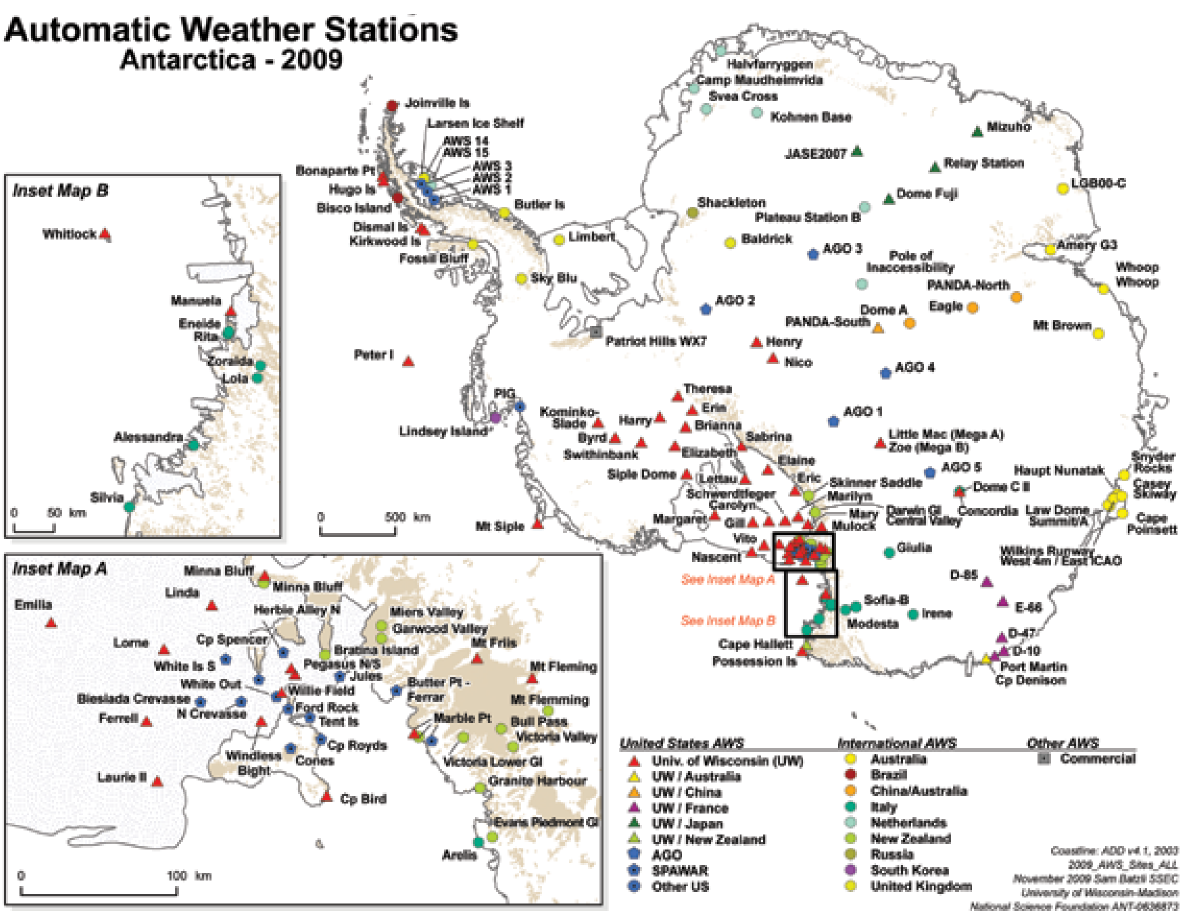


Fig. 3.5-2. Location of AWS sites.

(Image: University of Wisconsin–Madison)

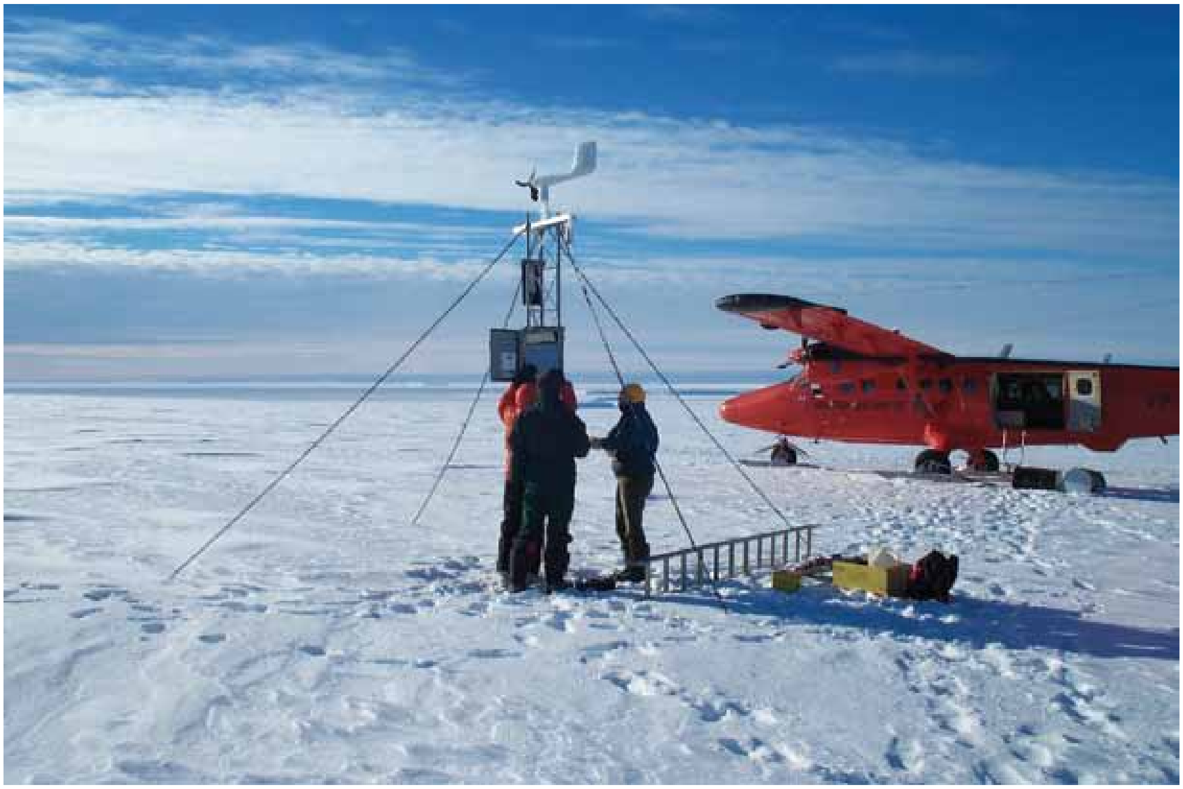


Fig. 3.5-3. Servicing the AWS at Butler Island (U.K./U.S.A.). (Photo: Jon Shanklin)

the measurements and can also monitor precipitation falling from clouds (Fig. 3.5-4).

Measuring the amount of precipitation is difficult. The snow is generally dry and what falls into a standard rain gauge just as easily blows out again. Equally, precipitation that has fallen elsewhere or at a previous time can be blown around by the wind and into the gauge. A simple technique is to measure the depth of freshly fallen snow and assume that in the long term there is a balance between transported and falling snow. Specially designed snow gauges may provide a solution, but gauges that work well in temperate regions where snow falls do not cope well with Antarctic precipitation and further design studies are needed (Fig. 3.5-5). Electronic precipitation detectors using scintillation in an infrared beam are now being deployed in Antarctica and combination of the outputs of two detectors at different heights may provide the necessary discrimination between precipitation and transport.

Upper atmosphere

The Antarctic atmosphere is very clear as there are few sources of pollution. On a fine day it is possible to see mountains well over 100 km away. In these conditions, estimating distances can be very deceptive. Objects may appear to be close by, when in fact it would take many hours of travel to reach them. Automatic instruments, which use infra-red scintillation and scattering to measure near-surface visibility, are becoming more common, however, some have difficulty in discriminating variation in visibility above 20km. Higher in the atmosphere, the stratospheric aerosol load, largely originating from volcanoes, is measured using sun tracking pyrheliometers or photometers. In IGY, the primary instrument was the Angstrom pyrheliometer, a manual device, which even in skilled hands, took ten to fifteen minutes to complete an observation. By IPY a number of stations had installed automatic sun-photometers, either as part of an international network or stand-alone. These use measurements through a series of filters to calculate the amount of obscuring material in the solar beam (Fig. 3.5-6).

Fig. 3.5-4. Vaisala CT25K cloudbase recorder at Rothera (U.K.).
(Photo: Jon Shanklin)

Fig. 3.5-5. A modern aerodynamic automatic tipping bucket gauge at Rothera (U.K.). It doesn't work well in Antarctica, particularly in light snow or strong wind, and needs a shield.
(Photo: Jon Shanklin)

At approximately a dozen stations, balloons are launched once or twice a day each carrying a package of meteorological instruments known as a radiosonde (Fig. 3.5-7). The instrument package signals back the temperature, humidity and pressure to an altitude of over 20 km, with wind speed and direction found by tracking the package with global positioning system sensors. One particular problem affected latex balloons during winter: the combination of low ambient temperature and darkness made the balloon fabric brittle and they burst early, often before reaching 100 hPa. The traditional remedy was to briefly dip the balloon in a mixture of oil and avtur immediately prior to launch and to allow excess fluid to drain off. This plasticized the fabric and gave much improved performance, however, it did have significant health and safety implications. Modern balloons such as the Totex TX series, which use a synthetic rubber, perform much better, with even 350 gram balloons regularly reaching above 20 hPa in the summer and still managing 50 hPa during the winter.

Special ascents are sometimes made to help study the lower part of the atmosphere called the troposphere, where weather systems are active. These include flights to investigate very stable conditions in the lowest layer, which mainly occur during the winter and other flights to study, for example, depressions forming offshore. Such studies are augmented by atmospheric profiles measured using captive packages carried aloft by kites or blimps, or by sodars (sonic radars). Further studies are made using instrumented aircraft to study the composition of clouds *in situ*.

Ozone

The *ozone* hole was discovered in ground-based observations from Antarctica and most manned stations continued with long term measurements of the ozone column during IPY. Ground-based sensors include the traditional Dobson ozone spectrophotometer, the Brewer spectrometer and the SAOZ spectrometer, or variants of these. (Fig. 3.5-8) All use the sun as a source and measure the differential absorption of light as it passes through the ozone

Fig. 3.5-6. Sonde launch at Halley (U.K.). (Photo: BAS)

layer. At a few stations, ozone sondes are flown that give precise profiles of ozone in the atmosphere. These bubble air through a cell generating a current that is proportional to the amount of ozone present. Satellites give a global view of the ozone layer, but need the ground-based data both for scale verification of their sensors and to determine aging trends in the harsh environment of space.

The ozone holes during IPY years were broadly typical of those seen during the period of maximum ozone depletion between 1990 and 2010. The 2007 polar vortex was large and at times quite elliptical, hence significant ozone depletion was already present in early August. By contrast the 2008 vortex was more stable, giving a late start to the ozone hole and producing a long lasting hole (Fig. 3.5-9).

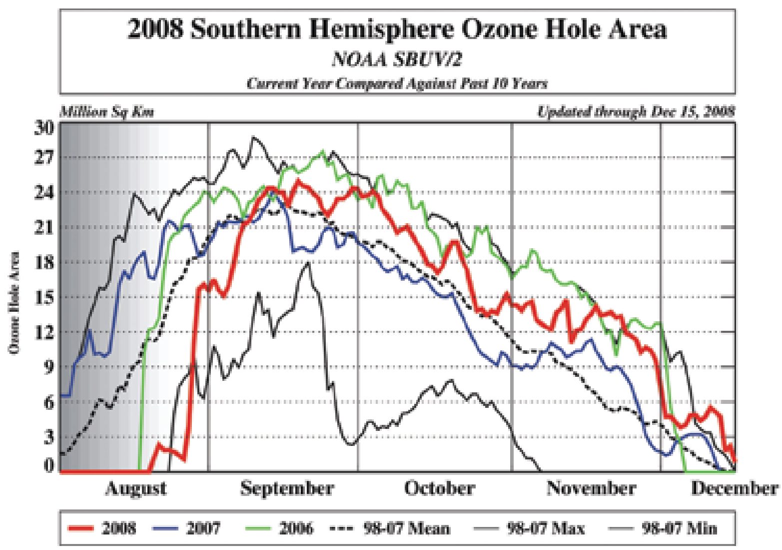
The creation of the Antarctic ozone hole is dependent on the stable south polar vortex giving very cold temperatures in the ozone layer, allowing polar stratospheric clouds to form throughout its centre during the winter. By contrast, the Arctic polar vortex is less stable and the temperature within it is generally warmer so that the clouds are much less frequent. Chlorine and bromine from CFCs, and halons and other ozone-depleting substances undergo complex reactions on the cloud surfaces. The reactions create halogen oxides, which can then photo-catalytically destroy ozone in the presence of sunlight. Levels of these ozone-depleting substances in the atmosphere were declining during IPY and just after its close, all of the world's governments had finally signed the basic Montreal Protocol.

Recent research shows that the ozone hole has played a significant role in determining the recent climate of Antarctica. Its presence has stabilized the temperature of the bulk of the continent and contributed to the continued warming of the Antarctic Peninsula. Global warming of the near surface of the planet feeds back into the ozone hole process by creating a colder stratosphere. This will delay the recovery of the ozone hole, which is likely to continue forming each year, until the last decades of this century.

Fig. 3.5-7. Tracking skyradiometer at Rothera (U.K.).
(Photo: Jon Shanklin)

Fig. 3.5-8. Brewer at Marambio (Argentina).
(Image: Servicio Meteorologico Nacional)

Fig. 3.5-9. The development of the ozone hole from 2006 to 2008.
(Image: NOAACPC courtesy Craig Long)



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3.6 The Sea Ice Outlook

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Introduction

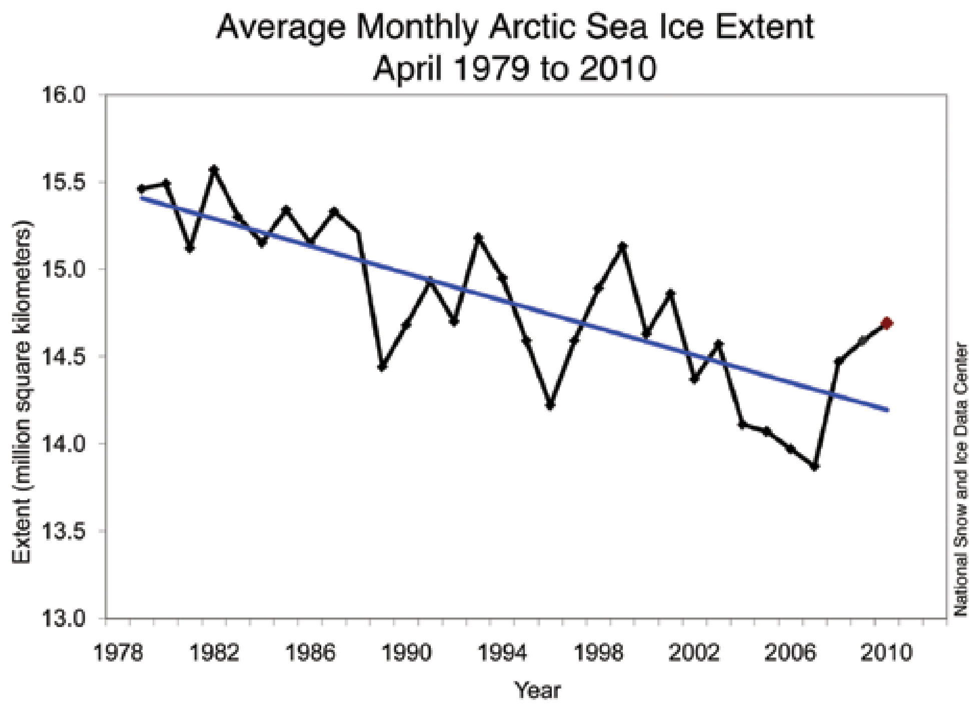
IPY catalyzed significant additional funding and redirection of some existing support that was used to investigate a number of critical scientific issues in the Arctic. Enhanced study of Arctic sea ice was a focus for a number of research groups. In the U.S., the pre-existing Study of Environmental Arctic Change (SEARCH) program supported a number of activities related to Arctic sea ice. In Europe, IPY project Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) was supported as an integrated ice-atmosphere-ocean monitoring and forecasting system. The SEARCH and DAMOCLES activities were linked through a special coordinating activity called "SEARCH for DAMOCLES (S4D)". One of the coordinating activities was a joint workshop held in March 2008 at Palisades, NY (SEARCH, 2008; see www.arcus.org/search/meetings/2008/aow/index.php for more information). One outcome of the workshop was recognition by the participants of the need for better understanding of the Arctic sea ice system, given the drastic and unexpected sea ice decline observed by satellites in summer 2007 (Fig. 3.6-1). The sea ice cover retreated to well below its previous record minimum extent, with potentially substantial physical, biological and socio-economic impacts on the Arctic. This fact underscores the immediate need for increased integration and coordination of sea ice observations and modeling. As a result, several participants agreed to pool their insights and work collaboratively to prepare an "outlook" on how Arctic sea ice extent might evolve over summer 2008. It was also agreed that other interested experts should be invited to participate in this activity and thus the SEARCH-DAMOCLES Sea Ice Outlook (SIO) effort was initiated.

Preparations for undertaking the SIO involved formation of a "core integration group", led by James Overland, and an "advisory group". Broad international participation was sought; North America and Europe were well represented in these two groups from the outset. A Japanese group joined the effort later in 2008 and 2009.

The SIO groups developed an open and inclusive process for conducting the work to ensure that any scientist could participate. The objective of the SIO is to produce monthly reports during the arctic summer sea ice season that synthesizes input received from participating scientists representing a broad range of scientific perspectives:

1. Each month during the summer sea ice melt season, a request to the international arctic science community (http://siempre.arcus.org/4DACTION/wi_ai_getArcticInfo/3606) solicits information on the expected state of the September arctic sea ice.
2. The community submissions are synthesized and reviewed by the Sea Ice Outlook Core Integration Group and Advisory Group (www.arcus.org/search/seaiceoutlook/organizers.php).
3. An integrated monthly report is produced that summarizes the evolution and expected state of Arctic sea ice for the September mean Arctic sea ice extent, based on the observations and analyses submitted by the science community. These reports are posted in the "monthly reports" section of the SIO website (www.arcus.org/search/seaiceoutlook) and widely distributed (see Fig. 3.6-2, June 2009 Report).
4. The process for producing the monthly Sea Ice Outlook reports is repeated through September of each sea ice season.

Fig. 3.6-1. Average monthly sea ice extent from 1979 to 2010 shows a continued decline. The rate of sea ice decline since 1979 has increased to 11.2 percent per decade. (NSIDC - http://nsidc.org/images/arcticseaicenews/20100504_Figure3.png)



5. Retrospective analyses after the season examines the success of the Sea Ice Outlook in advancing scientific understanding of the arctic sea ice system, and provide guidance to future research efforts.

The results from the Outlook activities as of late spring 2009 are summarized in a paper by Overland et al., (2009).

Summary of 2008 and 2009 efforts

The projections of the Sea Ice Outlook groups for the September 2008 minimum ice extent, based on May data, had a median value of 4.2 million square kilometers (msk) and a range of 3.1 to 5.5 msk (see Fig. 3.6-1). The median value is roughly the same as the minimum observed in September 2007 (4.3 msk). With observations from early summer, the projected median sea ice extent value increased to 4.9 msk for the July Outlook with a range of 3.2 to 5.6 msk. Both of these Outlook projections are substantially lower and nearer to the observed September 2008 minimum value (4.5 msk) than to the 1979–2000 mean value (7.1 msk) or to the linear trend line of previous September minima (5.6 msk). Both sea ice models and seasonal melting projections provided the main semi-quantitative information for the 2008 SIO.

In a retrospective analysis, the SIO team determined that the agreement between projections and observations is consistent with the conclusion that initial conditions of spring sea ice are often an important factor in determining ice development over the course of the summer. They also noted that the role of summer atmospheric forcing is important, but was less important in 2008 compared to 2007, which had very unusual atmospheric circulation patterns. The SIO team felt that this result bodes well for future seasonal Sea Ice Outlooks. They concluded that during the next few summers it will be important to track potential recovery or further decline of the summer ice pack with late spring/early summer satellite and *in situ* sea ice observations providing important information.

Following the SIO effort for summer 2008, the participants agreed to continue and prepare similar reports during summer 2009 and again in 2010. The same process used in 2008 was repeated for 2009. The initial Outlook released in June and based on May data showed a mean projected value for September sea ice extent minimum of 4.7 msk and a range of 3.2 to 5.0 msk (see Fig. 3.6-1). For the August report, based in July data, the mean projected value for September sea ice extent minimum was 4.6 msk, with a range of 4.2 to 5.0 msk, with more than half of the 14 estimates in a narrow range of 4.4 to 4.6 million square kilometers, representing a near-record minimum. All estimates were well below the 1979–2007 September climatological mean value of 6.7 million square kilometers. The uncertainty/error values, from those groups that provided them, were about 0.4 million square kilometers, thus most of the estimates overlapped.

In actuality, the 2009 Arctic sea ice minimum extent was reached on 12 September 2009, according to the National Snow and Ice Data Center (NSIDC; http://nsidc.org/arcticseaicenews/2009/091709.html), with a value of 5.1 msk (Fig. 3.6-3). In a retrospective analysis, the SIO team concluded that September 2009 sea ice extent was driven by preexisting sea ice conditions at the end of spring, as well as variable wind patterns and cloudiness over the course of the summer. They stated that 2007 remains as an anomalous year, dominated by steady meteorological conditions during the entire summer that were favourable for sea ice loss, while in 2009, August and September wind patterns and increased cloudiness were not conducive to major sea ice loss.

The SIO team stated concern over the fact that all 2009 Outlook projections were below the observed September 2009 value. Yet they noted that, when projection uncertainty is taken into account, as well as it can be, the observed value is within an expected range of values. This was explored further by two groups from Germany and the U.S.A. that provided ensemble simulations with coupled ice-ocean models allowing for probabilistic assessments of expected minimum ice extent (Zhang et al., 2008; Kauker et al., 2009). The Outlook participants remained concerned over the convergence of the Outlook projections into a narrow range. They agreed that the last point emphasizes that further development and analysis of probabilistic

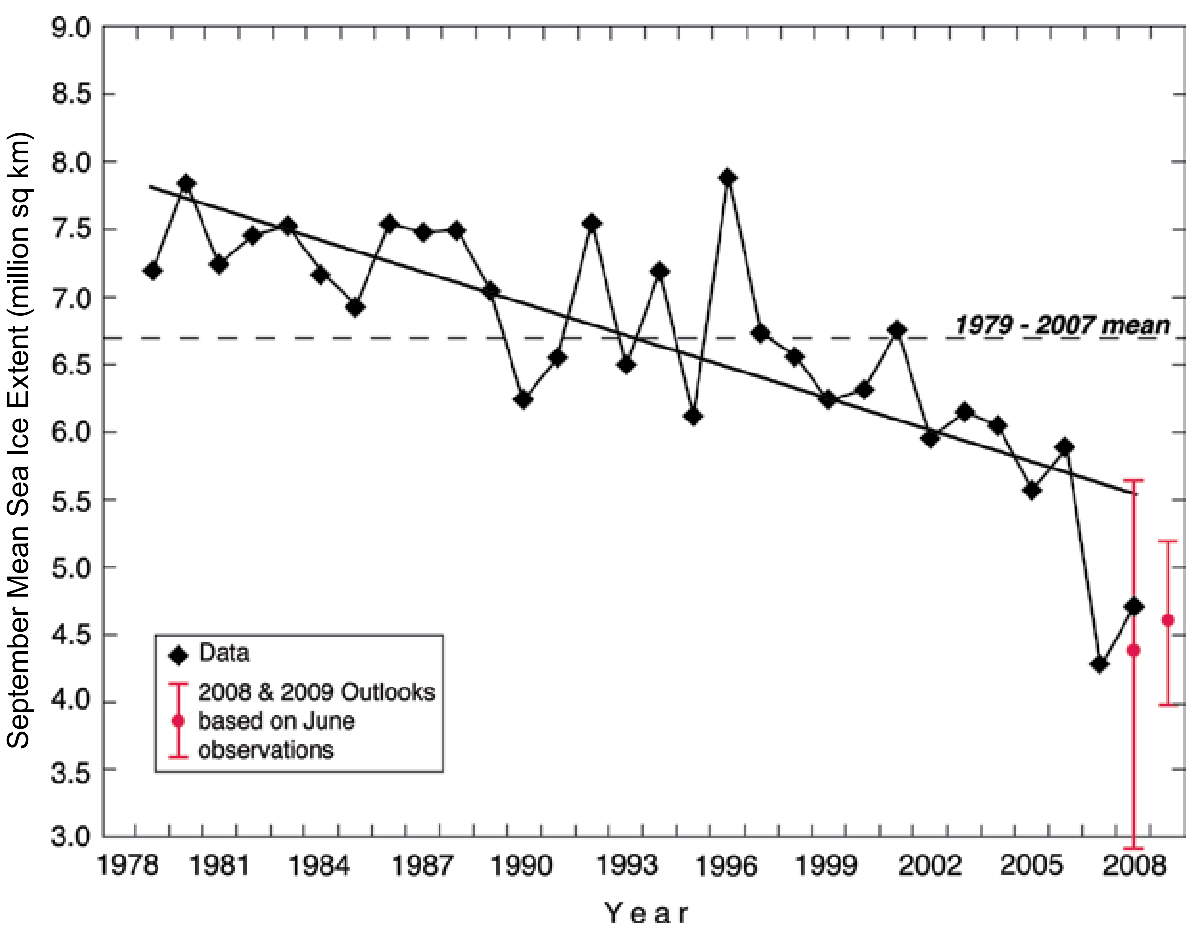


Fig.3.6-2. Observed monthly mean Arctic sea ice extent in September (million sq km), 1979–2008. The vertical red lines shows the median value and range of estimates for the June 2008 and 2009 outlook forecasts for the following September sea ice extent.

forecast ranges and measures of uncertainty will be critical to improvement in future efforts.

The SIO team stated that the sea ice evolution in 2009 signals that it could be several more years, in a probabilistic sense, before conditions favour another major sea ice loss event. Nevertheless, they noted that the increase in sea ice extent for 2009 relative to 2008 does not exceed past interannual variability in a near-continuous, 30-year downward trend in summer sea ice extent (Fig. 3.6-4).

They also noted that melt-out of sea ice near the North Pole continues to be less than in the Beaufort and Siberian sectors because of the decreasing importance of solar forcing. They concluded that this may be a limiting factor in the rate of future sea ice loss.

In 2009, the outlook also included a regional outlook examining ice evolution in several regional sectors of the Arctic by nine contributing research groups (Fig.3.6-5). Combining statistical models, ensemble simulations and heuristic approaches, seven of the nine categorical forecasts were accurate. These results indicate that a thorough understanding of local ice conditions and long-term records of ice variability can go a long way towards enhancing the reliability of such regional projections on seasonal time scales. Forecasts of seasonal break-up of coastal ice, of relevance for a number of different stakeholder groups, also demonstrated that cloudiness and down-welling shortwave radiation plays a key role in driving summer ice retreat, both at the hemispheric and local level (Petrich et al., in prep.).

In thinking about how to improve the ability to forecast sea ice conditions in future summers, the SIO team stated:

- Consideration of multiple sources of data, including visual observations, is important for reducing

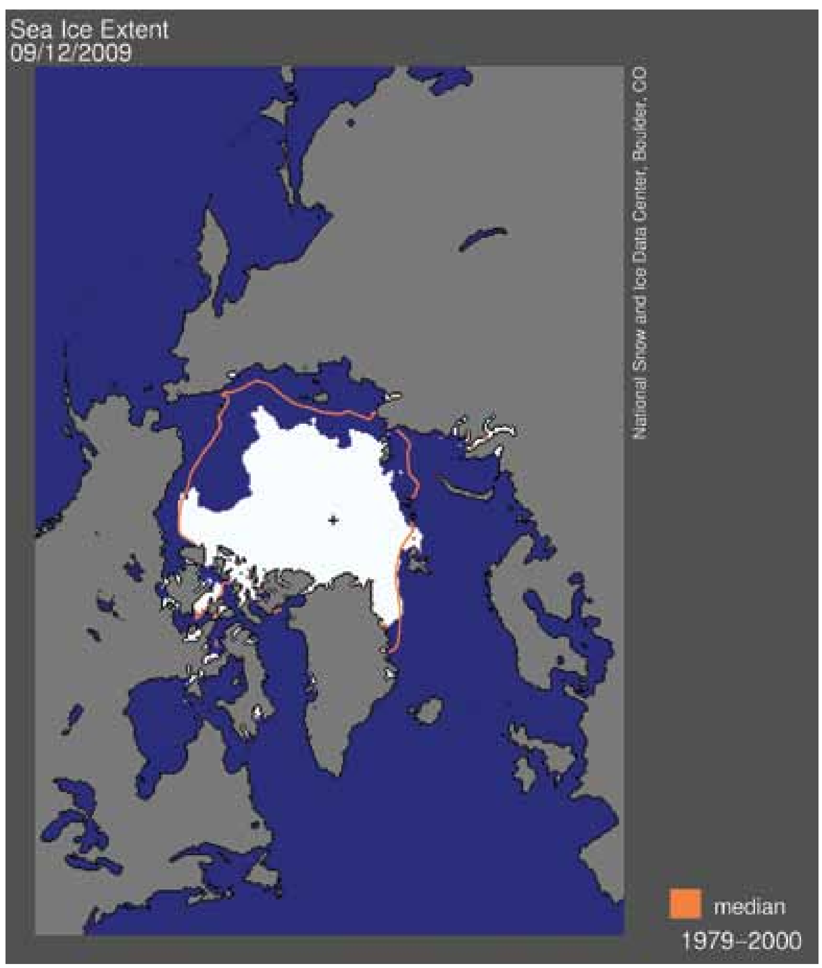


Fig.3.6-3. Minimal sea ice extent for summer 2009 reported on 12 September 2009.
(Photo: NSIDC)

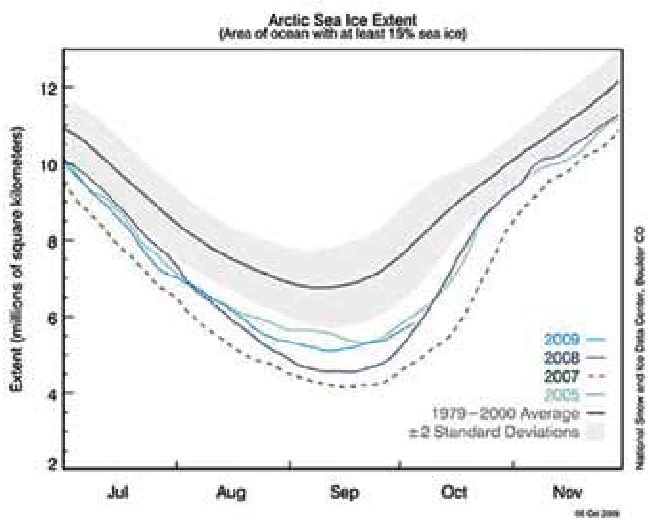


Fig.3.6-4. Daily arctic sea ice extent from passive microwave satellite data (SSM/I). The solid light blue line indicates 2009 relative to 2005, 2007 and 2008. The solid gray line indicates average extent from 1979 to 2000.
(National Snow and Ice Data Center)

uncertainty in the Outlooks. Buoys provide key observations for mapping and attributing summer ice loss: drift, bottom vs. top melt, amount of snow accumulation, nature of ponds (even if anecdotal from webcams) and thickness of level ice. Considerable effort should be made to estimate thickness distributions of ice and snow cover needed to initialize simulations. Aircraft and other reconnaissance are also helpful.

- Because of the importance of initial conditions for the sea ice state, more work is needed on remote sensing retrieval and interpretation of spring and summer ice concentrations and ice conditions, even if the present operational algorithms are not changed.
- Both full sea ice models and seasonal melt projections applied to detailed sea ice distributions and trajectories provided the main semi-quantitative information for the Outlook.

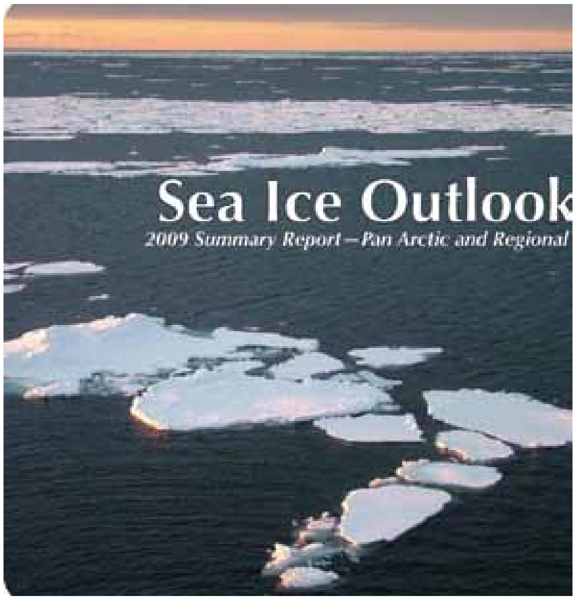
The SIO for 2009 went further than in 2008 by looking not only at the progression of ice melt, but also evaluating the rate of regrowth of ice in the fall. There was evidence that growth of ice in October and November was retarded and in fact the sea ice extent in portions of fall 2009 was less than in the corresponding period of the record minimum year of 2007.

The SIO team is continuing the Outlook process again in 2010. While it is too early to state with confidence, there is a possibility that the SIO process might continue and evolve into one of the valuable "legacy" activities of the IPY.

The specific outcomes of the Outlook activities include the following:

- Synthesis of remote-sensing or ground-based observations and modeling efforts to further understanding of variability and seasonal-scale predictability of the Arctic atmosphere-ice-ocean system.
- Creation of a forum that allows both the scientific community and educated laypeople to obtain better insight into cutting-edge Arctic system research.
- Enhanced scientific communication between field researchers, remote-sensing experts and modelers at time scales commensurate with the rapid change observed in the Arctic (i.e. faster than typical scientific publication cycles).
- Improved information exchange between researchers in academia and government agencies tasked with operational support in Arctic areas, in particular by providing a testbed for different forecasting approaches and creating a forum that allows agency personnel to draw on the broad expertise of the international research community.

Fig.3.6-5. Sea Ice Outlook: 2009 Summary Report www.arcus.org/search/seaiceoutlook/2009_outlook/2009_pan-arctic_summary.php



How the IPY changed the science

One of the major goals of the IPY was to encourage greater international collaboration. The SIO is an excellent example of the added value that can be obtained by bringing together scientists from diverse institutions. Would there have been a SIO effort at all if the joint SEARCH-DAMOCLES workshop hadn't been held? Or would the effort have been a U.S.-only effort rather than an international one? We can't answer these questions, but we do know that as a result of an international workshop, there were 18 groups participating in the 2009 Outlook process from seven different countries. They employed different approaches to the problem, including sophisticated numerical models, statistical evaluations and pattern matches with prior years. Each group was willing to state openly their projection for the sea ice minimum extent and their method for arriving at the value. In addition to the value of collaboration and information sharing, the rapid communication required to complete the monthly reports meant that the groups were quickly reanalyzing based on rapidly changing environmental conditions and learning from each other as the reports were released. The pace of advancement of scientific understanding most certainly exceeded that which would have resulted from traditional single group publications that were months to years in arrears of actual events.

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3.7 Global Cryosphere Watch and the Cryosphere Observing System

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The cryosphere collectively describes elements of the Earth system containing water in its frozen state and includes sea-, lake- and river-ice, snow cover, solid precipitation, glaciers, ice caps, ice sheets, permafrost and seasonally frozen ground (Fig. 3.7-1). The cryosphere is global, existing in various forms at all latitudes and in approximately 100 countries. "The State and Fate of the Cryosphere" (IPY project no. 105) provided a framework for gaining a better understanding of the state of the cryosphere, as well as its past, present and future variability in time and space. The project aimed to:

- **assess the current state** of cryospheric parameters in the high latitude regions, providing a **snapshot** of the cryosphere and an evaluation of its current (IPY) state in the context of past states and projections of the future;
- **formulate the observational requirements** of cryospheric variables for weather, climate and hydrological monitoring and prediction and for other environmental assessments (IGOS-P Cryosphere Theme);
- **strengthen international cooperation** in the development of cryospheric observing systems.

In order to gain a more complete understanding of the role of the cryosphere in the global climate system, it was recognized that the cryosphere is arguably the most under-sampled domain in the climate system and that a more comprehensive, coordinated cryospheric observation system is needed. Some international programmes such as the Global Climate Observing System (GCOS) address the cryosphere in part, but none cover it in total. A programme dedicated to observing the cryosphere was deemed necessary to create a framework for improved coordination of cryospheric observations and to generate the data and information needed for both operational services and research. IPY 2007–2008 provided a unique opportunity to develop polar observing systems and, by doing so, began to close one of the most significant gaps in global observations. The Integrated Global Observing Strategy (IGOS) Cryosphere Theme and the Global Cryosphere Watch (GCW) were major outcomes.

The Cryosphere Observing System: Legacy of IPY 2007–2008

During the early phase of IPY, it was recognized that there was a strong need for close coordination of cryospheric observations serving the various user communities and nations, a need to strengthen national and international institutional structures responsible for cryospheric observations, and a need for increased resources to ensure the transition of research-based cryosphere observing projects into sustained observations. The likelihood of achieving these goals would be significantly enhanced through the development of a comprehensive, coordinated, integrated and coherent approach of the kind represented by an Integrated Global Observing Strategy (IGOS) theme. An IGOS theme for the entire cryosphere would provide economies of scale and ensure that the cryosphere is adequately addressed by the observing systems that support climate, weather and environmental research and operations. Led by the Climate and Cryosphere (CliC) project of the World Climate Research Programme (WCRP) in collaboration with the Scientific Committee on Antarctic Research (SCAR) and in consultation with several IGOS partners, the IGOS Cryosphere Theme proposal was implemented as a major contribution

Fig. 3.7-1. Examples of the cryosphere.

to IPY and to improving our ability to describe the state and fate of the cryosphere. We refer to the IGOS Cryosphere Theme's goal of a coordinated, robust network of snow and ice measurements as CryOS, the Cryosphere Observing System.

Three major workshops were held in Canada, sponsored by the Canadian Space Agency (CSA), Japan co-sponsored by the Japan Aerospace Exploration Agency (JAXA), in cooperation with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and the Netherlands sponsored primarily by the European Space Agency (ESA) to engage the scientific and user communities. Input from approximately 100 scientists in 17 countries provided the basis for the IGOS Cryosphere Theme Report. The report is a robust compilation of observing system capabilities, needs and shortcomings, with separate chapters covering the elements of the cryosphere. Specific recommendations for each cryospheric element (e.g., terrestrial snow, ice sheets, permafrost) are listed in the individual chapters of the report. An example for snow is shown in Table 3.7-1. General recommendations are given for the near-, mid- and long-term, with near-term recommendations focussing on the IPY period. The report was accepted by the IGOS Partners in May 2007, subsequently published with the support of the WMO and first "released" at the Group on Earth Observations (GEO) Plenary Meeting in Capetown, South Africa, November 2007. It has since been widely distributed and has provided the guidance for many IPY initiatives. More information is available at http://igos-cryosphere.org.

The initial phase of CryOS development coincided with IPY. The approach was to engage relevant IPY projects and increase coordination between them with the objective of producing legacy datasets and the capability to extend them continuously after the end of IPY. In this regard, the IGOS Cryosphere Theme team and the collective cryosphere community have been very successful. Accomplishments during IPY include:

- an evaluation of current measurement capabilities, observing system requirements and gaps;
- a comprehensive set of recommendations in three time frames;
- improved coverage of cryospheric elements in the GCOS Implementation Plan and contributions to the GCOS-CEOS (Committee on Earth Observation Satellites) plan for satellite-based products;
- efforts to ensure an IPY legacy through the Group on Earth Observations (GEO) Work Plan;
- involvement in the satellite mission planning process resulting in the approval of three orbital cycles of coordinated, experimental inter-satellite SAR interferometry, the Global Monitoring for Environment and Security (GMES) Sentinel-1A C-band SAR mission, the GMES Sentinel-3A SAR altimeter mission that will provide sea-ice thickness measurements, RADARSAT Modified Antarctic Mapping Mission (MiniMAMM) SAR mapping of Antarctica and CryoSat-2;
- new satellite products for real-time applications, e.g. sea ice concentration, thickness and motion from optical imagers, and a variety of other new satellite products and acquisitions coordinated through Global Interagency IPY Polar Snapshot Year (GIIPSY) project and the IPY Space Task Group (*Chapter 3.1*);
- contributions to the planning of ongoing SCAR scientific research projects including ISMASS (Ice Sheet MASS balance and sea-level), ASPeCT (Antarctic Sea Ice Processes and Climate), PPE (Permafrost and Periglacial Environments) and AGCS (Antarctica in the Global Climate System).

The community involvement in CryOS gave it the credibility needed for these accomplishments, the

Parameter	C T O	Measurement Range			Measurement Accuracy		Resolution				Comment or Principal Driver
							Spatial		Temporal		
		L	H	U	V	U	V	U	V	U	
Snow Cover	C	20	100	%	15-20	%	1	km		day	e.g. MODIS
	T	0	100	%	10	%	0.5	km	1	day	Hydromet
	O	0	100	%	5	%	0.1	km	12	hr	
Snow Water Equivalent, satellite (Shallow)	C	0	0.2	m	2-10	cm	25	km	1	day	e.g. AMSR-E
	T	0	0.3	m	3	cm	0.5	km	6	day	Hydromet
	O	0	0.3	m	2	cm	0.1	km	12	hr	
Snow Water Equivalent, satellite (Deep)	C	none	–	–	–	–	–	–	–	–	Need HF SAR
	T	0.3	3	m	10	%	0.5	km	6	day	Hydromet
	O	0.3	3	m	7	%	0.1	km	12	hr	
Snow Water Equivalent, in situ (Shallow)	C	0	3	m	1	cm	1	m	30	day	Hydromet
	T	0	3	m	1	cm	1	m	7	day	Hydromet
	O	0	3	m	1	cm	1	m	1	day	
Snow Depth, satellite (Shallow)	C	0	-0.7	m	5-35	cm	25	km	1	day	e.g. AMSR-E
	T	0	1	m	10	cm	0.5	km	6	day	Hydromet
	O	0	1	m	6	cm	0.1	km	1	hr	Transportation

Table 3.7-1. A portion of the observational requirements and gaps table for snow, from the IGOS Cryosphere Theme report.

first time this has been done internationally for the cryosphere. The community that started with CliC and SCAR expanded through CryOS. The Cryosphere Theme team has been, and continues to be, an active participant in several related IPY initiatives in which the Theme Report has proved its usefulness as an authoritative source of requirements in cryospheric observations and recommendations on the means to establish them. The Space Task Group for IPY has been an important implementation mechanism for some of the space-based recommendations of the Theme. In particular, the GIIPSY project has worked with space agencies to develop new satellite products and special acquisitions (examples of new satellite products developed for IPY are given on Figs. 3.1-2 and 3.1-6 in *Chapter 3.1*).

The Theme activities and recommendations played an important role in the three IPY Workshops on Sustaining Arctic Observing Networks (SAON) in 2007 and 2008 (Stockholm, Edmonton and Helsinki), as well as in the 2008 U.S.-Canada GEO Workshop on Water and Ice (Washington, D.C.). The Committee on Earth Observation Satellite (CEOS), which was an IGOS Partner and is a GEO Participating Organization, has evaluated a number of potential gap analysis "threads", where gaps in the observing system were identified by following a thread from a high level question, through products and service, to models and satellite measurements. One of the threads addresses the question "How do changes in the cryosphere impact sea level?" Currently, the Theme is contributing to the Arctic Council's Snow, Water, Ice and Permafrost in the Arctic (SWIPA) project (www.amap.no), which will produce a report in 2011 on the state of cryosphere in the Arctic.

Thus, there is no question that the development of the IGOS Cryosphere Theme has been a worthwhile effort, resulting in a comprehensive assessment of the cryosphere observing system and a significant contributor to other observing system efforts. The development and acceptance of the IGOS-P Cryosphere Theme Report, which provided the conceptual framework for a Cryosphere Observing System (CryOS), may now provide the basis for a more comprehensive, coordinated and integrated cryospheric observing system (Figs. 3.7-2 and 3.7-3) and be a central part of WMO's new initiative, Global Cryosphere Watch (GCW).

Global Cryosphere Watch – an IPY Legacy

The Global Cryosphere Watch (GCW) was stimulated by several initiatives, in addition to the IGOS Cryosphere Theme, all of which identified the urgent need for a sustained, robust end-to-end cryosphere observing and monitoring system, not only for polar regions, but also globally, These included the "Scope of Science for the IPY 2007–2008" produced by IPY Joint Committee, IPCC WG1 and WG2 reports, the Arctic Climate Impact Assessment (ACIA) and the 2nd Conference on Arctic Research Planning (ICARPII), Sustaining Arctic Observing Networks (SAON) and WMO's desire for integrated observations of the polar environment as part of its establishment of integrated observing systems over the globe. The Fifteenth World Meteorological Congress (Cg-XV, May 2007) supported the concept of establishing a Global Cryosphere Watch as a WMO legacy of IPY 2007–2008.

A WMO ad-hoc expert team on GCW (Geneva, December, 2008) explored the feasibility of such a global system and prepared recommendations for its development. The GCW, in its full/comprehensive concept, would include observation, monitoring, assessment, product development, prediction and related research. It should build on and integrate what is being done already. It should provide authoritative, clear, understandable and useable information on the past, current and future state of the cryosphere for use by the science community, decision and policy makers, media, and the public. Response from widespread consultation within WMO, with the National Meteorological and Hydrological Services and other potential partners, organizations, agencies and the scientific community was very positive.

To develop an effective GCW, the expert team agreed on some basic principles and characteristics for the initiative. GCW:

- would be a mechanism for implementing IGOS Cryosphere Theme (CryOS);
- should ensure a comprehensive, coordinated and sustainable system of cryospheric observations and information, and access to related information to allow full understanding of the cryosphere and its changes;
- should initiate a comprehensive cryosphere observing network "CryoNet", a network of reference sites in cold climate regions operating a sustained, standard program for observation and monitoring changes in components of the cryosphere for developing and validating models and remote sensing products, and producing valuable long-term records, while covering key areas of the globe with cryospheric observations;
- will be based on the premise that agreed-upon standards, recommended practices and procedures will apply to the cryospheric observing systems. Where these do not currently exist, GCW would work with WMO and partners to develop appropriate best practices, guidelines and standards. This

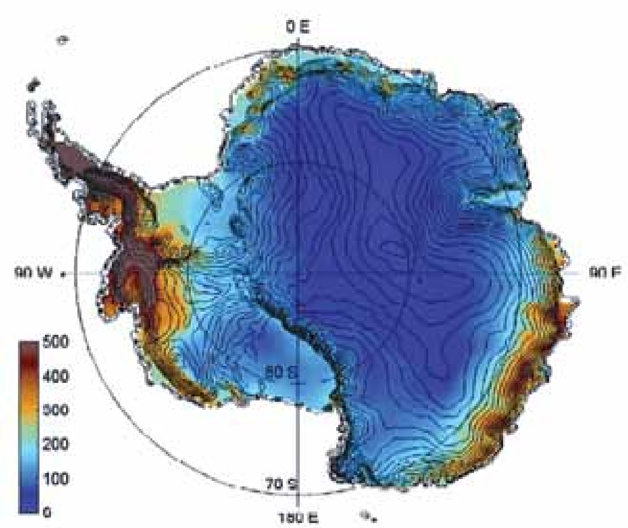

Fig. 3.7-2. Antarctic snow accumulation over Antarctica from merged satellite-in situ observations.
(IGOS Report 2007, 49, courtesy of British Antarctic Survey)

should include homogeneity, interoperability and compatibility of observations from all GCW constituent observing and monitoring systems and derived cryospheric products;

- will include all elements of the cryosphere at national, regional and global scales, and appropriate temporal and spatial requirements. It should provide access to data and information on past, present and future cryospheric conditions, drawing on operational and research-based observation and monitoring (*in situ* and space-based monitoring) and modeling.
- would improve monitoring of the cryosphere through the integration of surface- and space-based observations, which is essential to understand global climate change, optimizing knowledge of current environmental conditions and exploiting this information for predictive weather, climate and hydrological products and services;
- should provide a mechanism to ensure availability of real, near-real time and non-real time access to cryospheric data and products, ultimately through the WMO Information System (WIS). GCW will respect partnership, ownership and data-sharing policies of all observing components and partner organizations;
- should have an organizational, programmatic, procedural and governance structure that will significantly improve the availability of, and access to, authoritative cryospheric information;
- would logically encompass: standardization of instruments and methods of observation, WIS information infrastructure and end product quality assurance;
- should organize assessments of the cryosphere and its components on regional to global scale to support climate change science, decision-making and formulation of environmental policy;
- is the response to meet the need for integration of cryospheric data and information, work with

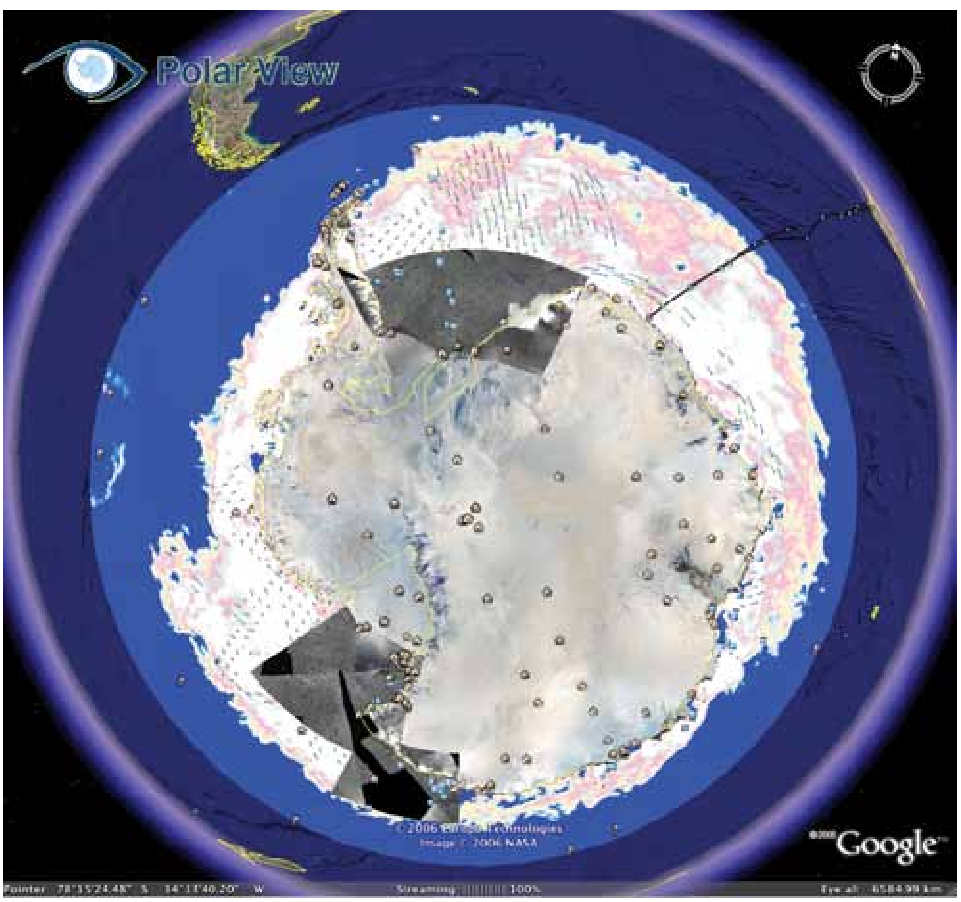

Fig. 3.7-3. Google Earth visualization of Polar View data over Antarctica, including AMSR-E ice cover, ice drift from ENVISAT ASAR, drift buoys, ASAR 3-day mosaic, and meteorological stations.

(IGOS Report 2007, 65; courtesy of British Antarctic Survey) and build on existing programs such as GCOS, and work with external partners such as space agencies, World Data Centres and external cryospheric observing programs.

Pilot projects to demonstrate operation of GCW were strongly endorsed by the community during consultations. They will focus on the elements of the cryosphere and identify how the projects would: contribute to implementing CryOS, meet the GCW principles and characteristics, contribute to demonstrating integration of cryospheric data and information from research to prediction, and provide authoritative cryospheric information. Pilot projects would develop and strengthen partnerships with operational and research organizations and international programs, such as NSIDC, BAS, GCOS, GTOS, WCRP, GPCC and the many space agencies, in addition to NMHSs.

A key to the ultimate success of GCW is to have a GCW portal that will serve as the "single-point entry" to access GCW data, information and products. There are several portals now being implemented for other related studies. The concept of the portal and demonstration of its attributes and characteristics need to be defined. The portal must be WIS compliant. A pilot project to demonstrate the operational capabilities of a GCW portal and prepare a design document for the portal, without an agency having to commit to long-term operation of the portal, is one approach.

The community also stated the need for a limited number of demonstration projects that would focus on regional or national contributions as well as focus on specific tasks to demonstrate standardization, integration and interoperability. There was a very strong desire to implement a standardized network of cryospheric observatories (reference sites/supersites) in cold climate regions for long-term monitoring. Initially, this is to involve a few stations, which would build on existing cryosphere observing programs or add standardized cryosphere observing programs to existing observing facilities to minimize operating costs (e.g. CryoNET) and would be suitable for validation of satellite and model outputs of cryospheric elements.

Successful implementation of GCW will require the engagement of WMO Members and other research and operational agencies engaged in cryospheric observation, monitoring, assessment, product development and research. The WMO Panel of Experts on Polar Observation, Research and Services (EC-PORS) provides the guidance and momentum for implementing GCW in co-operation with the Observing and Information Systems Department and the World Climate Research Program. The latter has provided the stimulus for both CryOS and GCW and close liaison with WCRP and GCOS is envisaged.

3.8 Sustaining Arctic Observing Networks (SAON)

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In advance of International Polar Year 2007–2008, a "framework report" was released in 2004 (Rapley et al., 2004) to lay out the concept, vision, rationale and objectives for the planned IPY. According to this report, "the fundamental concept of the IPY 2007–2008 is of an intensive burst of internationally coordinated, interdisciplinary, scientific research and observations focused on the Earth's polar regions", with a corollary aim of "leaving a legacy of new or enhanced observational systems, facilities and infrastructure". The Arctic Council (AC) is the only intergovernmental body that focuses on the Earth's northern polar region, the Arctic and, in its Salekhard Declaration (2006), responded positively to the plan for IPY and especially to the desire for a legacy of observational capability.

The Arctic Council Ministers stated that they "welcome the International Polar Year (IPY) 2007–2008, as a unique opportunity to stimulate cooperation and coordination of Arctic research", "urge Member States and other entities to strengthen monitoring and research efforts need to comprehensively address Arctic change and to promote the establishment of a circumpolar Arctic observing network", and "request the SAOs to direct the Arctic Monitoring and Assessment Program (AMAP) to cooperate with other AC working groups and relevant scientific bodies in continuously reviewing needs and gaps in climate monitoring in the Arctic so that coordinated action might be taken to ensure the full realization of a comprehensive Arctic observing network". Taken together, these Ministerial statements stimulated the creation of a coalition of Arctic organizations that became known as the Sustaining Arctic Observing Networks Initiating Group (SAON-IG).

The SAON-IG began its work in early 2007 and adopted the goal of developing a set of recommendations on how to achieve long-term Arctic-wide observing activities that provide free, open and timely access to high-quality data that will realize pan-Arctic and global value-added services and provide societal benefits. It decided to pursue this goal by holding a series of workshops to gather information from a broad spectrum of scientists, government agencies, indigenous organizations and non-governmental organizations, and distilling this information into actionable recommendations. To cement the relationship between the SAON-IG and IPY, the Swedish and Canadian IPY Committees agreed to take the lead in the launch of the SAON initiative by running a succession of workshops together with the SAON-IG. Sweden also agreed to create the SAON website – www.arcticobserving.org (see Fig. 3.8-1) and operate it for an initial period. In late 2009, Sweden and Iceland facilitated transfer of the SAON website to the Arctic Portal complex that also houses the international IPY website. All materials related to the workshops described below are available from this website.

The first SAON workshop took place in Stockholm, Sweden on 12-14 November 2007; it was hosted by the Swedish IPY Secretariat and addressed the question: Are current Arctic observing and data and information management activities sufficient to meet users' needs? The second SAON workshop took place in Edmonton, Canada, 9-11 April 2008 and was hosted by the Canadian IPY Secretariat. This workshop addressed the question: How will Arctic observing and data and information management activities be coordinated and sustained over the long-term? The third SAON workshop was held in Helsinki, Finland 15-17 October 2008, hosted by the Finnish Meteorological Institute. The scope of the workshop included recommending a successor to the SAON-IG that would continue the development of a program of internationally coordinated, sustained observations in the Arctic. An important element was to synthesize the advice and information gathered at previous workshops into the final set of recommendations.

From the very first workshop, there was a sentiment that international top-down coordination at the level of operational and funding agencies was needed. Also expressed was the need for an international body to facilitate coordination and work toward intercomparability and easier sharing of data. At the second workshop, during a breakout session composed mostly of government agency officials, the desire to have a coordinated and sustained set of observing networks and a coordination mechanism was not disputed. This group also expressed the feeling that all interested countries and agencies should be welcomed in this effort and that there must be a linkage between the research community and the operational and services community. During the third workshop, another breakout session of mostly government officials made a number of points: integration and coordination of observing activities are ways to provide value; data sharing is important; an intergovernmental statement of intent and cooperation agreements among agencies would be useful; and opportunities for early success should be identified. There was a sentiment that a sharp focus on defined projects would be of greater value in achieving international agreement than more sweeping statements of open ended nature. It must be stressed that no attempt was made to arrive at consensus views during these workshops. Nevertheless, there was no disagreement with the general view that improved coordination among national Arctic observing activities was essential and that some type of formal structure would be needed to make this happen (see: Fig. 3.8-2).

One smaller additional SAON-workshop was held in St Petersburg, Russia prior to the SCAR-IASC IPY Science Conference in July 2008 (*Chapter 5.5*). A number of Russian scientists and government officials provided their insight on current and future observing activities in the Russian sector of the Arctic.

In September 2008, the SAON process was introduced to the Asian Forum on Polar Science in Seoul, Korea (*Chapter 5.3*). There is a strong and growing interest in the Arctic by Asian countries and their participation in long-term observations in the

Fig. 3.8-1. SAON website - www.arcticobserving.org/.

Fig. 3.8-2. Cover page of the SAON brochure (2009) www.arcticobserving.org/.

Arctic area is greatly welcomed by the SAON process.

The final action of the SAON-IG was to produce a report, released in December 2008, based on the collective effort of the 350 people who participated in the various SAON-IG activities (see Fig. 3.8-3). These participants identified many opportunities to enhance the value of observations through better coordination within and among existing networks. These existing networks provide significant amounts of high quality data and are the foundations, or building blocks, on which the future of SAON will be built. Yet the SAON process confirmed that existing observing activities do not adequately cover the Arctic region, data are fragmentary and not always easily available, and only a part of existing Arctic observing is funded on a long-term basis.

The SAON-IG made four recommendations that can be summarized as follows:

1. The Arctic Council should lead the facilitation of international collaboration among government agencies, researchers and northern residents, especially indigenous people at the community level, to promote a sustainable pan-Arctic observing system.
2. The governments of the Arctic Council member states should commit to
   a. Sustaining their current level of observing activities and data and information services;
   b. Creating a means to make data and information freely, openly and easily accessible in a timely fashion.
3. The Arctic states are urged to increase intergovernmental cooperation in coordinating and integrating Arctic observing activities.
4. Arctic Council member states are urged to welcome non-Arctic states and international organizations as partners to the international cooperation that will

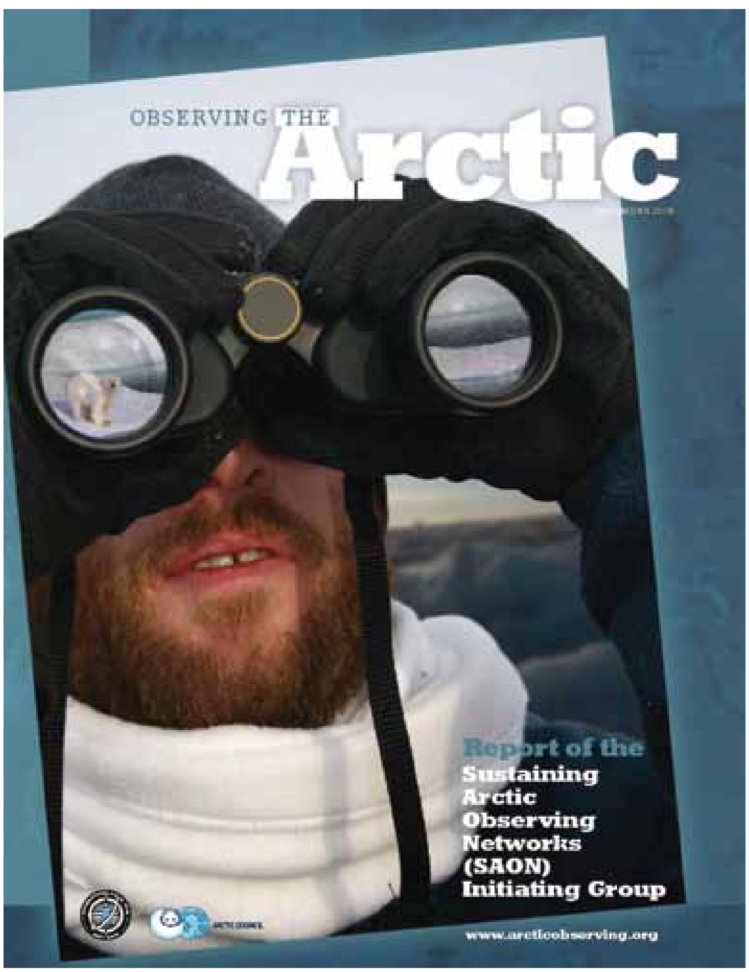

Fig. 3.8-3. Cover page of SAON Report, "Observing the Arctic" (2008) distributed at the Senior Arctic Officials (SAO) meeting in Tromsø in April 2009 www.arcticobserving.org/.

be necessary to sustain and improve Arctic observing capacity, and data and information services.

The SAON-IG agreed to present its report to the Arctic Council in April 2009 in Tromsø and at that point to disband, leaving the Arctic Council with the opportunity to consider its role in future development of sustained Arctic observing (see Fig. 3.8-4). After deliberation, the Arctic Council accepted the main points of the SAON-IG recommendations and provided its decisions in the Tromsø Declaration. This declaration stated that the Arctic Council will:

a. Support continued international coordination to maximize the legacy of IPY within the following areas: observations, data access and management, access to study areas and infrastructure, education, recruitment and funding, outreach, communication and assessment for societal benefits, and benefits to local and indigenous people.
b. Recognize the valuable contribution of the Sustaining Arctic Observing Networks (SAON) process as an IPY legacy to enhance coordination of multidisciplinary Arctic data acquisition, management, access and dissemination, encourage the continuation of this work with emphasis on improving sustained long-term observation, and welcome the participation of indigenous organizations in future work.
c. Decide to take the lead in cooperation with IASC and other relevant partners in the continuation of the SAON process, including to consider ways to develop an institutional framework to support circum-Arctic observing, and the preparation and implementation of a workplan for the next two years to initiate work on priority issues including sustained funding and data management.
d. Call for consultations involving national funding and operational agencies to create a basis for

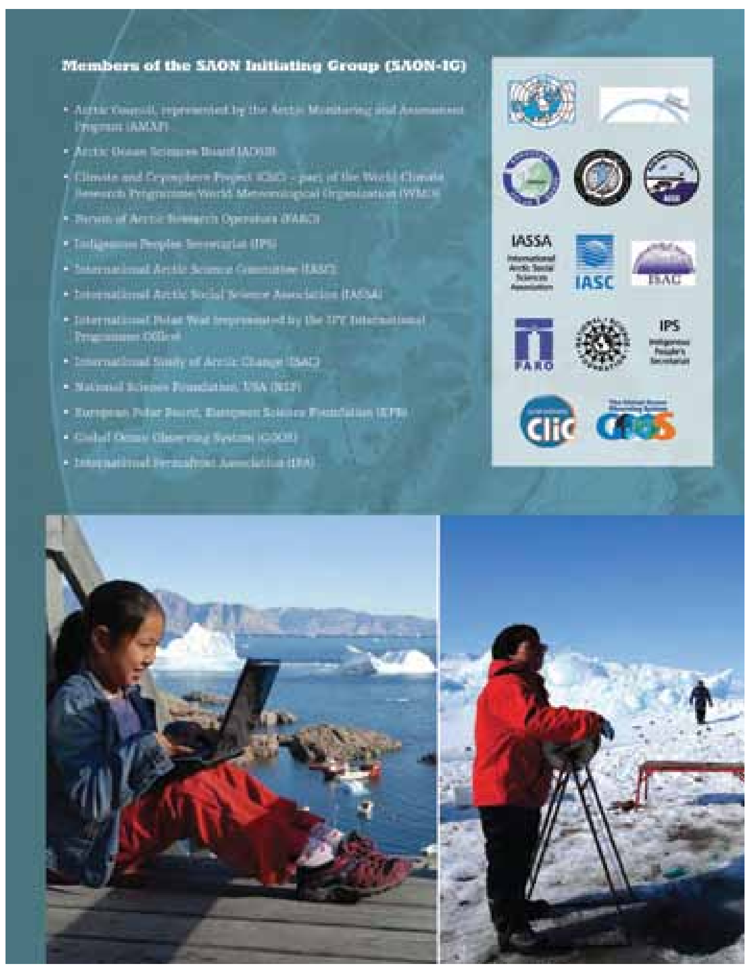

Fig. 3.8-4. Members of the SAON Initiating Group (IG) with their logos.
(From the SAON IG Report, 2008)

internationally coordinated funding and shared infrastructure and enhance the recruitment of young scientists into polar science.

e. Encourage the exploration of ways to continue the innovative forms for IPY outreach and the presentation of outcomes of the IPY, including the use of scientific data and traditional knowledge in future assessments.

As a direct result of these statements, the Arctic Council, International Arctic Science Committee and World Meteorological Organization formed the SAON Steering Group (SG) to continue to develop the SAON process. Co-chaired by John Calder (AMAP) and David Hik (IASC), the Arctic Council was represented by one representative formally appointed by each of the eight Arctic Countries and representatives of relevant AC Working Groups and Permanent Participants. The SAON SG reaffirmed the SAON-IG's vision of "free, open, and timely access to high-quality data that will realize pan-Arctic and global value-added services and provide societal benefits" and determined that its three top priority tasks were to engage government agency officials to seek a path toward sustained Arctic observing, to work more closely with local Arctic communities to better integrate community-based observations with scientific observations and to improve data management and data access practices.

Members of the SAON SG attended an IPY Data Management workshop in Ottawa, Ontario in September 2009. They were informed of the plans for creating an international comprehensive data base of all IPY projects over the next year or so. It was acknowledged that the SAON networks should be incorporated in this data base, even though many pre-dated the IPY. To ensure that this happens, the SAON SG and the IPY Data Management Subcommittee (DMS) held a joint workshop during the IPY conference in Oslo in June 2010 (*Chapter 5.6*) to share information on current data management practices of the networks and expose the networks to the desired data management practices developed by the IPY DMS (*Chapter 3.11*).

Members of the SAON SG engaged with community-based monitoring groups to explore integration of their results with those obtained by the scientific community. A very useful collaboration was developed with the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) project created under IPY funding from the U.S. National Science Foundation (*Chapter 5.2*). The goal of ELOKA is to facilitate the collection, preservation, exchange and use of local observations and knowledge of the Arctic by providing data management and user support services. A key challenge of community-based research and monitoring is to have an effective and appropriate means of recording, storing, and managing data and information. Another challenge is to find an effective means of making such data available to Arctic residents and researchers, as well as other interested groups such as teachers, students, scientists and decision makers. Without a network and data management services to support these efforts, a number of problems have arisen such as, misplacement or loss of extremely precious data from Elders who have passed away, lack of awareness of previous studies causing repetition of research, research fatigue in communities and wasted resources, as well as a reluctance or inability to initiate or maintain community-based science activities without an available data management system. Thus there is an urgent need for effective and appropriate means of recording, preserving and sharing the information collected in Arctic communities. Geographic Information Systems and web-based mapping are important for displaying and communicating community-based science. Rather than duplicating work, the SAON SG looks to ELOKA as one of the key building blocks for the future sustained Arctic observing network and will seek ways to enhance its capabilities.

A workshop for government agency officials was held in March 2010 in association with the "State of the Arctic" Conference in Miami, Florida. Approximately 60 participants discussed the merits of the SAON process and provided recommendations for the actions needed to transform SAON from the planning stage to the implementation stage. The main recommendation was to define specific tasks with their resource requirements that should form the initial phase of implementation. Explicit was the recognition that financial commitments would be needed from the interested governments and that the central component of SAON would almost certainly have to be funded as a project activity. Additional tasks would also need support, but could be conducted either as in-kind contributions or funded activities. Examples of specific tasks were suggested with most focused on data sharing and access, improving coordination among sites and networks, defining standards and best practices, improving geospatial displays of data, linking observations to models and forecasts, and exploring solutions to wide-spread issues and problems.

The SAON SG agreed to develop specific project descriptions for the implementation of SAON and to discuss the concept of an "institutional framework" for continuation of the SAON process. These objectives were described to the Arctic Council at its meeting in April 2010. The Senior Arctic Officials expressed wide-spread support for SAON and options for implementation were presented at the Deputy Ministers meeting in late May 2010.

The SAON SG met in Reykjavik in August 2010 to discuss the scope of SAON and the roles and responsibilities of SAON and existing monitoring networks and government agencies. The SAON SG agreed that SAON itself will not undertake observations, conduct research, perform scientific analysis or assessment, nor be a source of funding for these activities. SAON will identify issues, gaps and opportunities related to Arctic observing and data sharing and take a multi-national approach to demonstrate improvements to the current situation, and consequently, SAON will work with a broadly defined Arctic observing community and with national and multi-national organizations and non-governmental partners. The Arctic Council Senior Arctic Officials and IASC Executive Committee endorsed these views and called for the preparation of an implementation plan for SAON and an initial list of SAON activities or tasks.

The SAON SG recommended that the implementation phase should adopt a task-based approach, with voluntary participation by any country or organization that could make a contribution to the goals of SAON. These tasks could include support for data management and data sharing, development and enhancement of observing activities, and synthesis of existing observation information. Members of each Task Team and their partners would be responsible for providing the resources needed for each task. To provide an initial focus, the SAON SG asked its members and some of the existing observing networks to propose tasks that could be undertaken during the next few years.

The report of the SAON SG to the Arctic Council and IASC (SAON SG, 2011) recommended that the Arctic Council (AC) and the IASC jointly establish a SAON Council, with each organization providing a permanent Co-Chair. The Council would report to both the AC and the IASC. The Council would be composed of representatives of participating countries, along with representatives of Arctic Council Working Groups and Permanent Participant organizations, and IASC. The WMO would be a member of Council, with other international organizations invited at a later stage. The Council would be supported by a Secretariat drawn from the existing Secretariats of the Arctic Council Arctic Monitoring and Assessment Program and the IASC. A key feature of the SAON Council is that it would establish its own rules of operation and not be bound by either the AC or IASC rules. In this way, both Arctic and non-Arctic countries may participate on an equal basis. If the Arctic Council and IASC support these recommendations the SAON Council will convene in 2011. SAON will represent a major advance in securing the legacy of IPY 2007-2008.

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3.9 The Circumpolar Biodiversity Monitoring Program (CBMP)

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Overview

The Circumpolar Biodiversity Monitoring Program (CBMP), an IPY "cluster program" (no.133) was initiated in 2003–2004 as an international network of scientists and local resource-users working together to enhance Arctic biodiversity monitoring to improve detection, understanding and reporting of significant trends in biodiversity and to inform management decisions (Strategy, 2004; Zöckler and Harrison, 2004). The CBMP was established as the cornerstone program of the Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council. Launched in 2005 and currently led by Canada, the CBMP has over 60 global partners, 33 of which are Arctic biodiversity monitoring networks connected to the CBMP. Many of these networks received substantial support from IPY and became integrated parts of its activities (CAFF 2006a,b; Fleener et al., 2004; Russel and Kofinas, 2004; Petersen et al., 2004). Arctic Nations currently spend over $500M monitoring biodiversity, yet there is an urgent need to improve coordination, data management and sharing.

The CBMP takes an ecosystem-based management approach and operates as a network of networks by coordinating existing species, habitat and site-based networks (Fig. 3.9-1). The CBMP has started the establishment of four Expert Monitoring Groups—Freshwater (1), Marine (2), Coastal (3) and Terrestrial (4)[1]—that were tasked with developing long-term integrated monitoring plans for the major Arctic systems: marine, freshwater, coastal and terrestrial, respectively. Furthermore, a special focus group is currently developing a protected-areas monitoring framework and another community-monitoring guidance group was called for in 2009. Also, the CBMP has begun the development of coordinated reporting and outreach tools, including a suite of Arctic biodiversity indicators, as well as a web-based data management and depiction tool (data portal) for biodiversity data.

The CBMP was strategically linked to a number of other Arctic biodiversity conservation-related efforts. It is a part of the Global Earth Observations-Biodiversity Observation Network (the Arctic-BON) and a member of the 2010 Biodiversity Indicators Partnership (2010 BIP), a global network aimed to improve the tracking and reporting of Convention on Biological Diversity indicators. The CBMP has been identified as the biodiversity component of the Sustaining Arctic Observing Networks (*Chapter 3.8*) initiative and was also closely linked with other Arctic Council initiatives in protecting arctic biodiversity. The CAFF Working Group supported the Convention on Biological Diversity of 1993 (CBD) and its so-called '2010 Biodiversity Target' (www.cbd.int/2010-target/),[2] and charged CBMP to monitor the Arctic region's progress towards this global initiative to arrest the biodiversity loss.

Across the Arctic biodiversity conservation community there is a wide range of data sources, formats and subjects. As a network of networks, the CBMP seeks to provide universal access to these resources through its publications (the *Arctic Species Trend Index*) and on-line data portal (the *Arctic Data Portal*). The CBMP has asked partner programs within the Arctic Council as well as other organizations to contribute to its data collection efforts.

During IPY years, the CBMP was and continues to

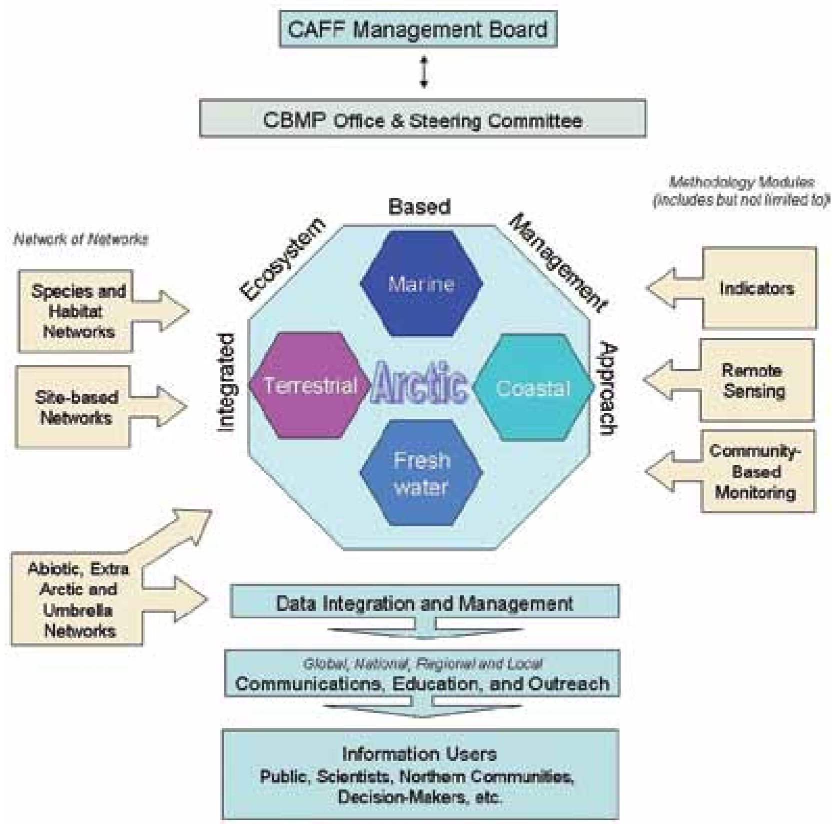


Fig. 3.9-1. CBMP organizational structure linking species networks, indicators and integrated ecosystem-management planning to information and decision-makers. (Courtesy: CBMP)

be focused on the following nine key initiatives: 1) CBMP Data Portal, 2) the Arctic Species Trend Index (the Headline Indicator for CBMP), 3) Integrated Arctic Marine Biodiversity Monitoring Plan (developed by the CBMP's Marine Expert Monitoring Group), 4) Integrated Arctic Freshwater Biodiversity Monitoring Plan (developed by the CBMP's Freshwater Expert Monitoring Group), 5) Community-Based Monitoring Handbook, 6) Pan-Arctic Protected Areas Monitoring Plan, 7) Circumpolar Polar Bear Research and Monitoring Plan, 8) Circumarctic Rangifer Monitoring and Assessment Network (CARMA, IPY no. 162), and 9) Circumpolar Monitoring Strategies for Ringed Seals and Beluga Whales. These key CBMP initiatives are described below.

CBMP Data Portal

Circum-arctic biodiversity research and monitoring currently comprise a multitude of networks that produce information in diverse formats with little integration. Much of this information remains inaccessible, unreported, or in non-user-friendly formats. Two of the CBMP's key objectives are to create an accessible, efficient and transparent platform to house and display information on the status and trends in Arctic biodiversity, and to integrate biodiversity information with relevant abiotic information (Fig. 3.9-2). By facilitating this, CBMP aims to improve the accessibility of biodiversity trend data, as well as the capability to correlate such trends with possible drivers. The ultimate goal is to accelerate data sharing and analysis.

The CBMP has initiated the development of a biodiversity data portal in the form of a user-friendly web-based information network that accesses and displays information on a common platform, so that users can share data over the Internet (http://cbmp.arcticportal.org). When fully operational, the portal would access to immediate and remotely distributed information about the location of Arctic biological resources, population sizes, trends and other parameters, including relevant abiotic information. The pilot version of the data portal was launched

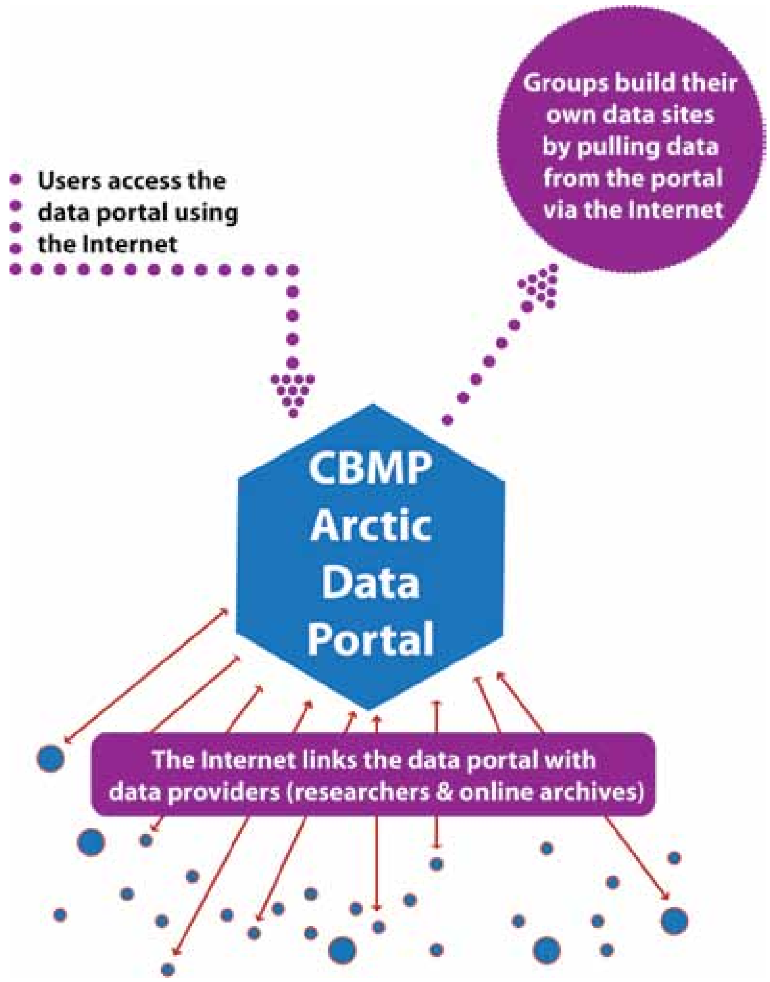


Fig. 3.9-2. Simplified data portal schematic linking data sources and providers to various user groups via the CBMP data portal.
(Courtesy: CBMP)

in November 2009 and displays the information on the distribution and abundance of almost 60 Arctic seabird species (Fig. 3.9-3). The development of this interoperable and distributed web-based system was initiated by the CAFF Circumpolar Seabird Group (CHASM, 2004; Hagemejer et al., 2004, see below) that focuses on accessing information on seabird colonies in the Arctic, including location, colony size by species, productivity and other parameters.

In addition to providing a focal point for Arctic biodiversity information, the data portal provided an effective conduit for experts to share information via the Internet. The most recent data source linked to the data portal is the Arctic Breeding Bird Condition Survey (ABBCS). The data portal project is a joint effort by the Circumpolar Seabird Group, the Circumpolar Biodiversity Monitoring Program, U.S. Fish and Wildlife Service and United Nations Environmental Program (UNEP) World Conservation Monitoring Centre with the participation of all the Arctic countries and Arctic Council observer organizations.

The Arctic Species Trend Index (Headline Indicator for the CBMP)

The Arctic Species Trend Index (ASTI – McRae et al., 2010) is an effort commissioned and coordinated by CBMP; it uses population-monitoring data to track trends in marine, terrestrial and freshwater Arctic vertebrate species. The index allows for a composite measure of the overall population trends of Arctic vertebrate populations between 1970 and 2004.

Fig. 3.9-3. Screenshots of the CBMP data portal. On the left are population data locations and summary information being provided from a distributed data node. On the right is an example of an analysis tool that indicates where a seabird colony is located as it relates to various land-use designations. (Courtesy: CBMP)

The index can also be organized to display trends based on taxonomy, biome, or region (Fig. 3.9-4). The index currently tracks almost 1000 Arctic vertebrate population datasets of 365 species by biome, taxa, migratory status, etc.

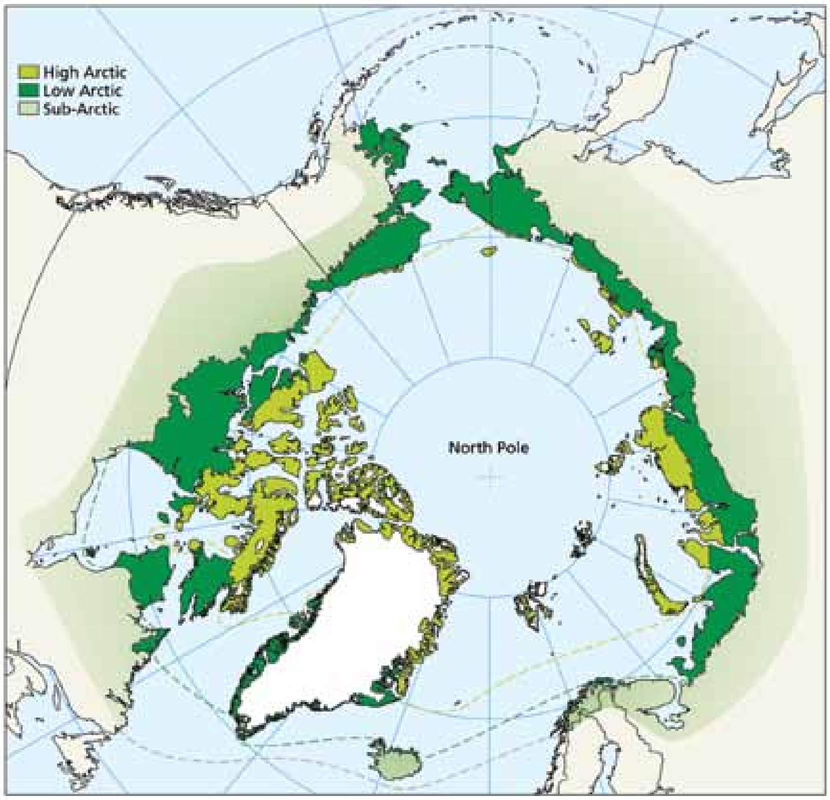
To facilitate the examination of regional trends, the Arctic was divided into three sub-regions: Sub-Arctic, Low Arctic and High Arctic. Species population data were classified by the broad habitats they inhabit (land, lakes and rivers, or oceans). Ocean habitats were further delineated by ocean basin: Arctic, Atlantic, or Pacific. The individual populations in the ASTI were further classified based on migratory status, trophic level and other relevant categories. The ASTI allows for tracking broad trends in the Arctic's living resources and identifying potential causes of those trends, whether they are responses to natural phenomena or human-induced stressors (Figs. 3.9-5 and 3.9-6).

The development of the index was a collaborative effort between the CBMP, the Zoological Society of London, UNEP World Conservation Monitoring Centre and the World Wildlife Fund (Gill and Zöckler, 2008). Funding for the project was provided by the Government of Canada. The first assessment indicates that the abundance of tracked High Arctic Species declined 26% between 1070 and 2004, whereas Low Arctic species have increased in abundance and the Subarctic species, though in decline since the mid-1980s, show no overall change over the 34-year period (McRae et al., 2010). Although the ASTI currently represents population data for 35% of all Arctic vertebrate species (a very high proportion for such an index), more information is needed to understand how Arctic vertebrate populations are faring.

Marine Expert Monitoring Group—Integrated Arctic Marine Biodiversity Monitoring Plan

The goal of the Marine Expert Monitoring Group (MEMG) of CBMP is to promote and coordinate marine biodiversity-monitoring activities among circumpolar countries, and to improve the ongoing communication among scientists, community experts, managers and disciplines both inside and outside the Arctic. Specifically, the MEMG is charged with developing a multi-disciplinary, integrated, pan-Arctic long-term marine biodiversity monitoring plan, and facilitating its implementation (Vongraven et al., 2009).

Co-led by Reidar Hindrum (Norway) and Kathleen Crane (U.S.A.), and with 15 members from Russia, Denmark/Greenland, Canada, Iceland, Aleut International Association and the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) Protection of the Arctic Marine Environment (PAME), the MEMG has been working to develop the marine biodiversity monitoring plan since 2008 (Table 3.9-1). Norway convened the first MEMG planning workshop in January 2009 in Tromsø, Norway. It brought together scientists and community-based experts from across the Arctic and launched the process of identifying the key elements (drivers, focal ecosystem components, indicators and existing monitoring programs) that should be incorporated into a pan-Arctic monitoring plan.



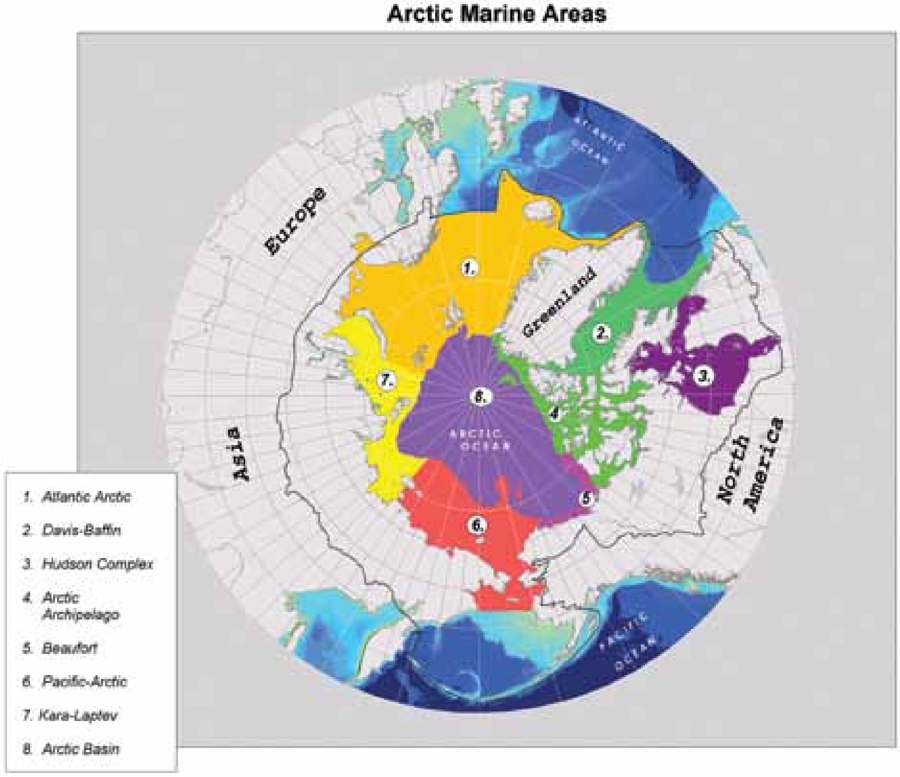


Fig. 3.9-4. (a) Arctic terrestrial ecosystems as defined by floristic boundaries (credit: AMAP Assessment Report, 1998); and (b) Regional divisions of the marine Arctic, as determined by the CBMP Marine Expert Monitoring Group. Note that this map is preliminary and boundaries will be modified to align with the Arctic Large Marine Ecosystem delineations once finalized.
(Courtesy: CBMP)

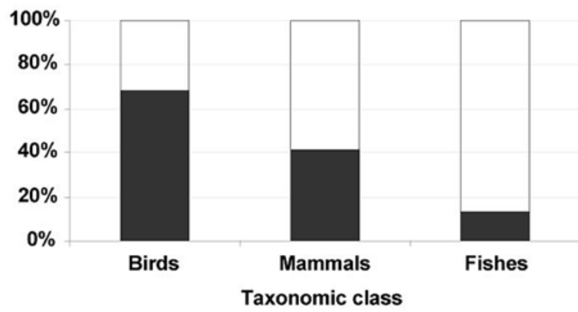


Fig. 3.9-5. (left) Data Coverage by Taxonomic Class that were represented in the ASTI analysis. Black bars represent proportion of Arctic species in each class for which there are population data available. White bars are the proportion of Arctic species with no available population-trend data.
(McRae et al., 2010)

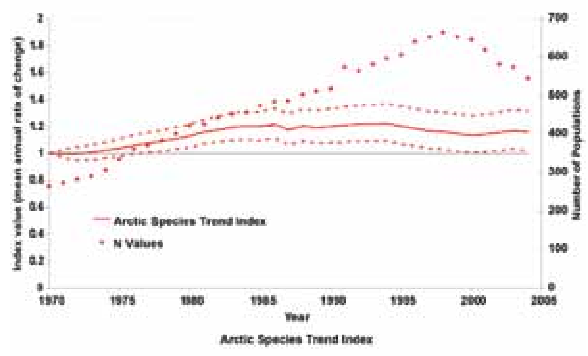


Fig. 3.9-6. (right) ASTI (with 95% confidence intervals) for all species within the Arctic boundaries and total population (N) values for that year, for the period 1970–2004. (ASTI, n=306 species, 965 populations).
(McRae et al., 2010)

Table 3.9-1. General timeline of the Marine Expert Monitoring Group

August 2008	MEMG established
December 2008	MEMG Background Paper edited
January 2009	1st MEMG Workshop
April 2009	First Workshop Report completed
November 2009	2nd MEMG Workshop
June 2010	Integrated Monitoring Plan completed and submitted for CAFF review

This first workshop drew heavily on the background paper (Volgrled, by the Norwegian Polar Institute). This workshop report detailed the existing monitoring programs and the focal ecosystem components, drivers and indicators to be considered as part of a monitoring plan for each focal marine area. Upon completion of the draft plan, a second workshop was held in Washington, D.C. (Fall 2009) to identify key partners and a process for implementing the monitoring plan.

The MEMG identified eight focal areas for the initial monitoring program development: 1) Atlantic Arctic Gateway, 2) Pacific Arctic Gateway, 3) Arctic Basin, 4) Hudson Complex, 5) Baffin Bay – Davis Strait – Lancaster Sound, 6) Beaufort Sea – Amundsen Gulf – Viscount Melville – Queen Maud, 7) Kara – Laptev Seas and 8) the Arctic Archipelago. The six countries participating in the MEMG—Canada, Greenland/Denmark, Iceland, Norway, Russia and the U.S.—have chosen or are in the process of choosing sentinel stations in each marine area that have long monitoring histories and are likely to be monitored in the future. Stations are chosen based on discipline e.g. benthos, plankton, ice species, fish, seabirds, marine mammals and polar bears. Sentinel station maps are being produced for each of the disciplines and are supported by the participating countries (Fig. 3.9-7).

Freshwater Expert Monitoring Group—Integrated Arctic Freshwater Biodiversity Monitoring Plan

The establishment of a Freshwater Expert Monitoring Group (FEMG), suggested in 2008 (CBMP, 2008) and co-led by Canada and Sweden, is aimed at facilitating an integrated, ecosystem-based approach to the monitoring of Arctic freshwater biodiversity. The group was created to support the development of an integrated, pan-Arctic monitoring plan to include optimal sampling schemes, common parameters and standardized monitoring protocols, and to identify critical monitoring gaps and develop strategies to fill gaps in data. The group also serves as a forum for providing on-going scientific and traditional knowledge to enhance current monitoring. The FEMG is expected to make full use of existing monitoring and data drawn on the expertise from both inside and outside the Arctic and from other relevant disciplines (e.g. climate science), incorporate both community-based knowledge and science-based approaches, and use new technologies, such as remote sensing and genetic bar-coding, where appropriate.

The group was initiated in May 2010. It includes community, scientific and indigenous experts. The group will not only work with existing research stations and monitoring networks to develop integrated, forward-looking monitoring programs,

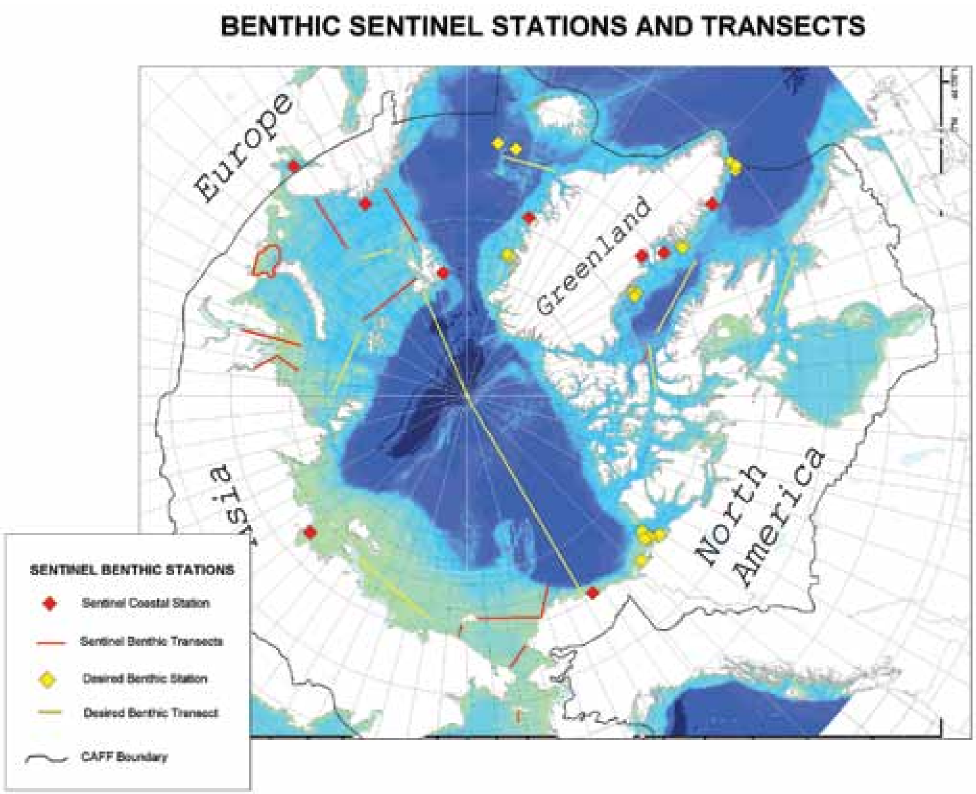


Fig. 3.9-7. Arctic Marine Biodiversity Benthic Sentinel Stations Marine Expert Monitoring Group, CBMP 2010.

but will also focus efforts on the retrieval and use of historical information, be it traditional knowledge or archived scientific data.

Community-Based Monitoring Handbook

Community-based monitoring (CBM) is a complex research field that is becoming an essential and often required component in academic research and natural resource management (Fleener et al., 2004; Huntington, 2008). It is often used as a validation of results produced by conventional research methods. CBM enabled researchers to reach beyond traditional data collection strategies by using the best available knowledge, be it academic, indigenous or local. CBMP commissioned the development of a *Community-Based Monitoring Handbook* (Gofman and Grant Friedman, 2010). The handbook aims to enhance the role of community-based observations in the current and emerging Arctic research projects. Handbook recommendations could easily be applied to broader monitoring efforts and in non-Arctic regions.

The *Handbook* reviews several ongoing community monitoring programs, such as the Arctic Borderlands Ecological Knowledge Co-op (http://taiga.net/coop/), Bering Sea Sub Network: International Community-Based Environmental Observation Alliance for Arctic Observing Network (IPY no.247 – *Chapter 3.10*), Community Moose Monitoring Project and Community Ecological Monitoring Project, ECORA (Integrated Ecosystem Approach to Conserve Biodiversity and Minimize Habitat Fragmentation in the Russian Arctic, www.grida.no/ecora/), Fávllis (Sámi Fisheries Research Network www.sami.uit.no/favllis/indexen.html), Marine Rangers Project in Australia (www.atns.net.au/agreement.asp?EntityID=4923), Siku-Inuit-Hila Project (*Chapter 3.10*) and Snowchange Network in Finland (www.snowchange.org/web/index.php). The handbook is written for a diverse audience that includes scientists, students, Arctic community residents and government officials.

Pan-Arctic Protected Areas Monitoring Plan

In addition to the ecosystem-based Expert Monitoring Groups, the CBMP aims to establish a Pan-Arctic Protected-Areas Monitoring Group, recognizing that protected areas represent important existing platforms for the implementation of pan-Arctic, coordinated biodiversity monitoring. The CBMP is working collaboratively with the various national and regional Arctic protected-areas agencies to identify current biodiversity-monitoring efforts and opportunities for establishing a standardized suite of parameters that can be monitored within protected areas (Gill et al., 2008). The main objective is to identify a small suite of biodiversity measures that would be common across the Arctic and implemented in the same way by the agency responsible for its respective protected area. This pan-Arctic set of measures will allow coordinated reporting of biodiversity in Arctic protected areas and provide a broader context to regional changes, thereby assisting managers in monitoring changes within their own protected areas.

During 2010, the Pan-Arctic Protected Areas Monitoring Group held workshops focused on reviewing current monitoring programs and selecting a suite of standardized parameters to monitor and indicators to report. The goal is to track and promote implementation of the monitoring plans.

Circumpolar Polar Bear Research and Monitoring Plan

Despite the sustained attention given to polar bears *(Ursus maritimus)*, we have only limited baseline information on most polar bear regional populations and a poor understanding of how polar bears will respond to a rapidly changing Arctic climate (Table 3.9-2). Meeting this challenge requires an efficient coordinated effort spanning all Arctic regions. An integrated pan-Arctic research and monitoring plan is needed to improve our ability to detect trends in polar bear populations, understand the mechanisms

Table 3.9-2. Current status, trends, harvest and risk of decline for polar bear populations.
(Unpublished data, courtesy of Dag Vongraven, Norwegian Polar Institute)

Population	Abundance Estimate	Year of Estimate	Annual Kill (5-year mean)	Trend	Status	Estimated Risk of Future Decline (10 years)
East Greenland	unknown	–	58	Data deficient	Data deficient	Data deficient
Barents Sea	2650	2004	no catch	Data deficient	Data deficient	Data deficient
Kara Sea	unknown	–	n/a	Data deficient	Data deficient	Data deficient
Laptev Sea	800-1200	1993	n/a	Data deficient	Data deficient	Data deficient
Chukchi Sea	unknown	–	n/a	Decline	Reduced	Data deficient
Southern Beaufort Sea	1526	2006	44	Decline	Reduced	Moderate
Northern Beaufort Sea	1202	2006	29	Stable	Not reduced	Data deficient
Viscount Melville Sound	161	1992	5	Data deficient	Data deficient	Data deficient
Norwegian Bay	190	1998	4	Decline	Data deficient	Very high
Lancaster Sound	2541	1998	83	Decline	Data deficient	High
M'Clintock Channel	284	2000	2	Increase	Reduced	Very low
Gulf of Boothia	1592	2000	60	Stable	Not reduced	Very low
Foxe Basin	2300	2004	101	Data deficient	Data deficient	Data deficient
Western Hudson Bay	935	2004	44	Decline	Reduced	Very high
Southern Hudson Bay	900-1000	2005	35	Stable	Not reduced	Very high
Kane Basin	164	1998	11	Decline	Data deficient	Very high
Baffin Bay	1546	2004	212	Decline	Data deficient	Very high
Davis Strait	2142	2002	60	Decline	Not reduced	Very high
Arctic Basin	unknown	–		Data deficient	Data deficient	Data deficient

driving those trends and facilitate more effective and timely conservation responses. Such a plan was called for in the March 2009 Meeting of the Parties to the 1973 Agreement on Polar Bears. CAFF/CBMP and the IUCN/SSC Polar Bear Specialist Group (funded by the U.S. Marine Mammal Commission) have agreed to initiate the development of this plan.

This project has established a Pan-Arctic Polar Bear Research and Monitoring Plan to be adopted across the Arctic. The plan will identify standardized parameters for 'reference populations,' extensive measures[3] for 'secondary populations,' optimal sampling schemes, population models and new methods for research and monitoring.

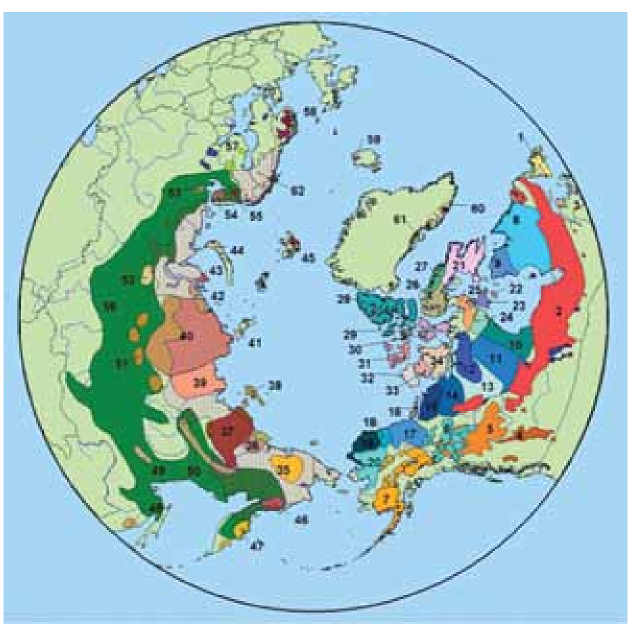
Circum-Arctic Rangifer Monitoring and Assessment Network (CARMA)

CARMA (IPY no.162, since 2005) is a consortium of scientists, managers and community experts who have a common interest in the future survival of the northern *Rangifer* (caribou and wild reindeer) herds (www.carmanetwork.com). CARMA is primarily focused on the status of most of the large migratory *Rangifer* herds in Eurasia and North America (Russel and Kofinas, 2004) and, as yet, does not deal with the woodland caribou and Peary caribou populations in North America or forest and marine reindeer in Fennoscandia and Russia (Fig. 3.9-8). It also does not focus on the domestic reindeer herds and the herding economy, which are the domains of the EALÁT project (IPY no. 399 *Chapter 3.10*).

Presently, CARMA is funded primarily under the Canadian IPY program; this funding supports more than 30 regional projects in caribou/reindeer physiology, body composition, pathogens, regional herd assessment and modeling, habitat assessment and community training (www.carmanetwork.com/display/public/Projects).

Observations from community members, particularly caribou and reindeer hunters, collected in the field or via various co-management groups are an important component of CARMA (*Chapter 3.10*). CARMA's overall objective is to produce a pan-Arctic assessment of the vulnerability of *Rangifer* herds to global changes. This will be accomplished by conducting cross-herd comparisons among a number of regional herds that have active CARMA partners and a substantial retrospective database. To accomplish that objective, CARMA has developed six "synthesis questions" (www.carmanetwork.com/display/public/Research+Tools) related to the role of seasonal habitat changes, individual

Rangifier Herds of the Circumpolar North



1 Newfoundland
2 Boreal
3 Atlantic
4 Southern Mountain
5 Northern Mountain
6 Yukon
7 Alaska
8 George River
9 Leaf River
10 Qamanirjuaq
11 Beverly
12 Ahiak
13 Bathurst
14 Bluenose East
15 Bluenose West
16 Cape Bathurst
17 Porcupine
18 Central Arctic
19 Teshekpuk
20 Western Arctic
21 South Baffin Island
22 Coats Island
23 Southampton Island
24 Lorillard
25 Wager Bay
26 North Baffin Island
27 Northeast Baffin Island
28 Eastern Queen Elizabeth Islands
29 Bathurst Island
30 Prince of Wales-Somerset-Boothia
31 Western Queen Elizabeth Islands
32 Banks Island
33 Northwest Victoria Island
34 Dolphin-Union
35 Chukotka
36 Sudrunskaya
37 Yana-Indigirka
38 Novosibiriski Ostrova
39 Lena-Olenek
40 Taimyr
41 Severnaya Zemlia
42 Gydan
43 Belyi
44 Novaya Zemlia
45 Svalbard
46 Parapolskii
47 Kamchatka
48 Amur
49 Okhotsk
50 Yakutsk
51 Evenkiya
52 Nadym-Pur (Yamal Okrug)
53 Arkhangelsk Oblast
54 Terskii Bereg (Kola)
55 Laplandskii Zapovednik (Kola)
56 Range of Forest Reindeer
57 Finland
58 Norway
59 Iceland
60 Greenland
61 Greenland Feral Reindeer
62 Range of Domestic Reindeer

Fig. 3.9-8. Rangifer herds of the Circumpolar North. (CARMA and Environment Canada 2007, www.carmanetwork.com) herd dynamics, pathogens and predators and human pressure on caribou/reindeer herds to be integrated in the "cumulative assessment model."

Circumpolar Monitoring Strategies for Ringed Seals and Beluga Whales

The U.S. Marine Mammal Commission and U.S. Fish and Wildlife Service convened an international workshop in Valencia, Spain 4–6 March, 2007 to develop monitoring strategies for Arctic marine mammals (Simpkins et al., 2007). Outcomes of the meeting included linking population responses to key factors and recommendations for a monitoring framework for arctic marine mammals, including the key factors that drive their population dynamics, such as health status, trophic dynamics, habitat quality and availability, and the effects of human activities (Fig. 3.9-9). Some of these factors are likely to respond quickly to climate change and new human activities in the Arctic; those changes, in turn, might trigger rapid changes in the status of marine mammal species. Two marine mammal species, ringed seals and belugas, have been selected as case studies under the CBMP-led monitoring framework for Arctic marine mammals (Simpkins et al., 2007).

Circumpolar Seabird Expert Group (CBird)

The concept of a Circumpolar Seabird Group (CBird) was approved by CAFF in 1993 in recognition that Arctic countries often share the same seabird species' populations and, therefore, share joint responsibility for their conservation. CBird has been instrumental in addressing the priority of circumpolar Arctic seabird conservation. Over the years, it has published two conservation action plans (for Murres and Eiders), six CAFF technical reports, two editions of the *Circumpolar Seabird Bulletin,* three posters, 13 progress reports and participated in numerous meetings and workshops.

CBird is one of the groups of under the CBMP program. It meets once a year to evaluate the status of its many projects, such as the Circumpolar Seabird Colony Database, Circumpolar Seabird Monitoring Plan, Birds of Arctic Conservation Concern, International Ivory Gull Conservation Strategy, Seabird Information Network, Harvest of Seabirds in the Arctic and others (Petersen et al., 2008). Funding for the Seabird Information Network and Circumpolar Seabird Colony Database was recently obtained and promises to accelerate the completion of these projects.

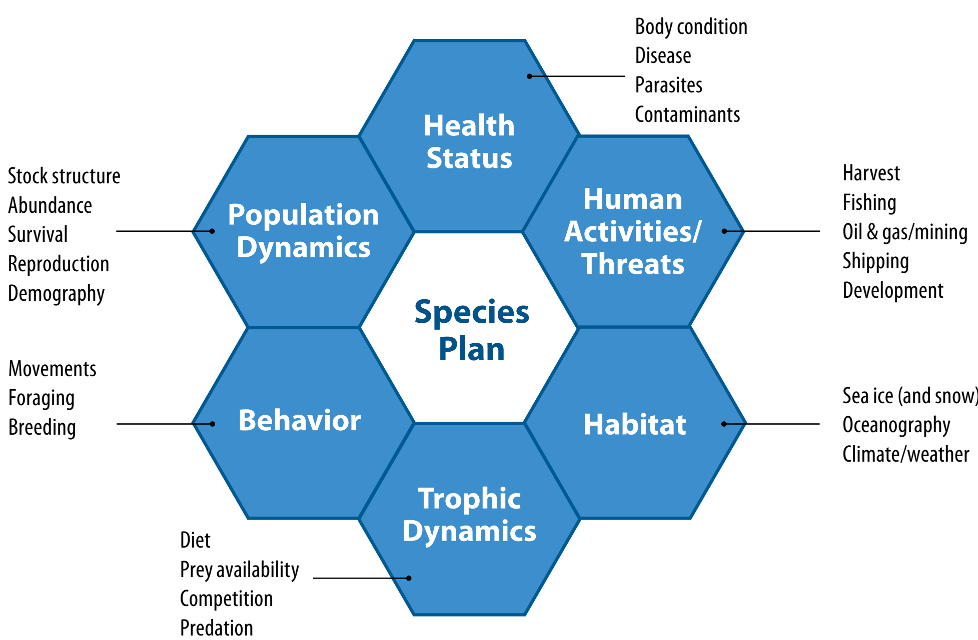


Fig. 3.9-9. The components of a comprehensive plan for monitoring the status of a marine mammal species or stock, including population dynamics, the factors that influence those dynamics, and examples of parameters that might be monitored for each factor. (Simpkins et al., 2007)

Summary: The Circumpolar Biodiversity Monitoring Program as an IPY Legacy

IPY 2007–2008 was instrumental in both marketing and implementing the concept of international coordination of polar research and monitoring. It, therefore, became an important catalyst for Arctic biodiversity monitoring, which was an important factor in the successful implementation of CAFF's Circumpolar Biodiversity Monitoring Program. With the CBMP successfully implemented during IPY to coordinate and integrate many Arctic expert biodiversity-monitoring networks in place, we can build on this progress to ensure continued long-term, coordinated monitoring of the Arctic living resources.

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Notes

1 Four CBMP Expert Monitoring Groups (EMG) are the (1) Freshwater, (2) Marines, (3) Coastal and (4) Terrestrial EMGs. The Coastal and Terrestrial EMGs have yet to be initiated.

2 In April 2002, the Parties to the Convention on Biological Diversity committed themselves to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth (www.cbd.int/2010-target/). That pledge is known as '2010 Biodiversity Target.'

3 Extensive measures are parameters measured less intensively in areas with limited monitoring resources as part of a larger, scaled research and monitoring approach involving reference populations (monitored intensively) and secondary populations (monitored less intensively).

3.10 Human-Based Observing Systems

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Introduction

The *Arctic Climate Impact Assessment* report (ACIA) was the first seminal scientific overview of the Arctic environment to include indigenous knowledge and a discussion of its relationship to environmental research and management (ACIA, 2005). The report identified five key areas in which indigenous knowledge and observations have proven particularly illuminating about climate change research. These are: (1) changes in weather, seasons, wind, etc.; (2) sea ice; (3) permafrost and coastal erosion; (4) marine life; and (5) land-based animals, birds, insects and vegetation (Huntington and Fox, 2005). At the same time, the ACIA report noted the lack of integration or linking of indigenous and scientific observations of climate change and the interpretation of these observations. It cited a lack of trust between the indigenous and scientific communities, which ultimately determines how indigenous data and observations can best be incorporated into scientific systems of knowledge acquisition and interpretation (Huntington and Fox, 2005). Nonetheless, the ACIA team viewed further extensions of collaborative research as the most promising model and recommended involving indigenous communities in research design and setting the research agenda, to ensure that the polar science is relevant locally.

That recommendation was also reflected in the *Framework* document produced by the IPY Planning Group roughly at the same time (Rapley et al., 2004). The 'framework' science plan for IPY 2007–2008 advanced "six interdisciplinary observational strategies" for IPY, including one focused on observations in human- and community-based developments, in order to "investigate crucial facets of the human dimension of the polar regions, which will lead to the creation of datasets on the changing conditions of circumpolar human societies" (Rapley et al., 2004: 7). This emerging focus on human- and community-based observations was further strengthened in later IPY documents and science projects (Allison et al., 2007; Hovelsrud and Krupnik, 2006; Krupnik and Hovelsrud, 2009). Two scientists working with indigenous communities on environmental monitoring (Lene Kielsen Holm from Nuuk, Greenland and Tatyana Vlassova from Moscow, Russia) served on the IPY Subcommittee on Observations.[1]

IPY 2007–2008 has engaged an unprecedented number of Arctic residents in its many projects through "research planning, observation, processing and interpretation of the various data sets created" (Allison et al., 2007). In the special section of the final IPY Science Outline titled "Integration of the Knowledge and Observations of Polar Residents," local communities were recognized to be "integral" and "vital" to the IPY data collection, monitoring, data analyses and data management processes, particularly in the social, physical and biological disciplines. Such engagement of polar residents was anticipated to play a dual role in the IPY efforts. First, it was viewed as an integral part of many science-driven observational projects that involved local communities and their knowledge; that is, observations and interpretations of the changing polar environment. This referred primarily to social and human-oriented studies but also, increasingly, to projects undertaken by scientists in physical and biological disciplines, like the research in sea ice dynamics, climate variability, marine and terrestrial ecosystem health, and environmental change. Second, and at least as important to the IPY 2007–2008 agenda, were the projects initiated by polar communities and indigenous organizations, involving their own knowledge and observations of local processes and phenomena (see more in *Chapter 5.4*). The scope of such efforts increased dramatically, in large part thanks to IPY 2007–2008. It now includes the sustainable use of local resources, primarily in fisheries, exploitation of reindeer/caribou populations and environmental-friendly tourism; indigenous culture and language sustainability; increased resilience of local economies and social systems through co-management, self-governance and information exchange among local stakeholders; and interactions with the industrial development in the polar regions, including monitoring of environmental and social impacts, primarily in oil and gas, and other mineral exploitation (Allison et al., 2007).

The extent to which this has been attempted and success attained is provided in the following sections of this chapter. It overviews a fraction of IPY 2007–2008 projects—eight in total—out of a much larger group of international and national initiatives during IPY years that included, what is increasingly referred to as, Community-Based Monitoring or CBM (see Gill and Barry (2008); *Chapter 5.4*) where researchers work with individual local experts or via community-run observational networks. The overall number of known IPY projects that employed community-based monitoring is probably close to 20-25 (Hovelsrud and Krupnik, 2006). Though not every proposed initiative in that group eventually received funding and was implemented, many other local ventures during IPY years engaged indigenous observers and local communities in environmental, health and social monitoring efforts.[2] The impact of these activities will be fully understood as more project reports and publications become available.

Project Overviews

The eight international IPY projects reviewed in this chapter (no. 46, 157, 162, 166, 187, 247, 399, and 408) submitted the most detailed accounts of their respective community-based monitoring efforts. The projects differed substantially in their geographic scope as well as in the number of communities and local experts involved, from truly circumpolar studies covering the entire Arctic region (no. 157, 162) or its major sections (no.166, 399) to regional (no. 46, 247) and even community- or area-specific ventures (no. 187, 408). Four of the reviewed projects are focused on the land-based resources and processes: Traditional Indigenous Land Use Areas in the Nenets Autonomous Okrug (MODIL-NAO, no. 46), Circum-Arctic Rangifer Monitoring and Assessment Network (CARMA, no. 162), Reindeer Herders Vulnerability Network Study (EALÁT, no. 399), and Monitoring the

Fig. 3.10-1. Vehicle tracks across summer tundra near the oil terminal Varandey; driving on unfrozen ground leads to a rapid destruction of the tundra cover and is considered an unlawful activity in Russia, though rarely prosecuted.
(Photo: Association of Nenets People Yasavey, September 2002)

Human-Rangifer link (NOMAD, no. 408). Three others are oriented toward the sea, ice, marine and coastal resources: Sea Ice Knowledge and Use (SIKU, no. 166), Exchange for Local Observations and Knowledge of the Arctic (ELOKA, no. 187), and the Bering Sea Sub-Network (BSSN, no. 247). The largest project, both in its geographic scope and the number of communities involved, Community Adaptation and Vulnerability in Arctic Regions (CAVIAR, no. 157) has a number of land-focused case studies in reindeer herding and terrestrial resource use, but also incorporates coastal fisheries and other marine resources and concerns.

Besides an unprecedented diversity in geographic setting and local conditions, the eight reviewed projects cover major fields identified by IPY planners as "integral" or "vital" to the IPY program. These include climate change; analysis of major forces, both environmental and social, that forge the development of the polar regions; and the polar-global linkages, in terms of the impacts of global processes upon polar environments and societies, and vice versa. They also illuminate the main areas that are instrumental to the successful integration of indigenous and scientific knowledge, such as the monitoring of climate and polar ice change, the impact of industrial development upon polar land and waters, and co-management of the vital polar biological resources, both on land and at sea.

The contribution of the eight IPY 'case' projects in community-based monitoring is reviewed here along three main factors: (1) innovative local observation and monitoring strategies implemented in each project; (2) new and improved knowledge acquired through respective research; and (3) what scientists from other IPY disciplines may learn from observational records produced by each project. Four land-focused projects are presented first (no. 46, 162, 399, and 408) followed by three projects in marine environment monitoring (no. 166, 247, and 187). The most diverse project (no. 157), which also has the most complex approach and methodology, offers a natural transition to the concluding summary section.

MODIL-NAO

The project, "Monitoring of the Development of Traditional Indigenous Land Use Areas in the Nenets Autonomous Okrug, NW Russia" (MODIL-NAO no. 46) was initiated by the representatives of the local organization of indigenous people (Association of the Nenets People, Yasavey) in collaboration with the Norwegian Polar Institute (http://npolar.no/ipy-nenets/). It was implemented by a joint Norwegian-Russian team of 20+ participants, including scientists, key partners in local communities, local experts and technical personnel.

Observation and monitoring strategies. The MODIL

Fig. 3.10-2. Drilling sites often completely destroy large patches of the former tundra pastures; but little effort is made to keep the affected areas as small as possible.

(Photo: Association of Nenets People Yasavey, September 2002)

Fig. 3.10-3. Modern-day Nenets herding camp in the Varandey Tundra.
(Photo: Association of Nenets People Yasavey, September 2002)

NAO Project was initiated by the Association of the Nenets People-Yasavey in response to the growing concerns by indigenous stakeholders over the deterioration of environment, new health risks and alienation of their pasture lands by oil and gas industry across their traditional area in Northwestern Arctic Russia (Figs. 3.10-1, 3.10-2). Collaboration between scientists and representatives of local indigenous communities (Fig. 3.10-3) ensured the exchange of data collected and the verification of the interpretation of the project results. In seeking to document changes in land use across the Nenets Autonomous Okrug (NAO) due to oil- and gas-related activities, the project employed a number of complementary techniques. First and foremost were extensive on-site interviews with local reindeer herders (103 total, most with maps and audio recordings) regarding their observations of change in pastures, landscape, vegetation, level of pollution, etc. The change in socio-economic conditions and influence of oil development on traditional livelihoods was assessed based on the questionnaire survey (Fig. 3.10-4).

Another important research technique was the mapping of the impacts of oil development in the study area from the interpretation of satellite images. The project developed the first GIS database with public Internet access (through GoogleEarth) combining indigenous people's traditional and industrial modern land use data. The traditional land use data held in the GIS database has been collected from the same six study areas across the Nenets Autonomous Okrug, while oil-related data attempt to cover the entire area of activities. The project database also includes a collection of federal (Russian) and regional (Nenets AO) legislations as well as outlines of judicial issues relevant for indigenous people and modern industrial land use.

New and improved knowledge. Local observations collected during the MODIL-NAO project drew attention to the increasing pressure affecting Nenets reindeer-herding communities in this area of the Russian Arctic. New stress factors ranged from socio-cultural, such as the loss of traditional knowledge, decreasing prestige of reindeer herding and growing unemployment, to concerns regarding the deterioration and reduction of the pasture areas and the responsibility of oil companies for pollution, poaching, reindeer harassment, and other destructive impacts upon traditional land use. The project noted the lack of influence exerted by the Nenets herders in oil and gas installation planning, and the paucity of effective environmental regulation and enforcement in the region. While documenting many negative impacts of oil and gas development in their region, local residents acknowledged certain improvements in the economic situation due to investments by oil

Fig. 3.10-4. MODIL-NAO workshop at which local representatives from villages were trained as interviewers for the questionnaire survey. (Photo: Winfried K. Dallmann, September 2007)

companies in the social security system. A further vulnerability was noted regarding the decreased availability of traditional food and potentially negative health effects should traditional foods be substituted with store-bought foods.

Value for other IPY science fields. MODIL-NAO has created a comprehensive project report (Dallmann et al., 2010) and a GoogleEarth-based GIS database (Fig. 3.10-5) accessible through the Internet (http://npolar.no/ipy-nenets), which is intended to serve indigenous stakeholders, local and international specialists in environmental protection, community leaders, and policy-makers. The database is an open product that will be maintained and expanded via future monitoring and research. This GoogleEarth-based atlas and database were conceived to support the Nenets people and their organizations in planning and discussing the land use issues and to combat the degradation of their traditional pasture areas through oil development. The project produced an 'IPY 2007–2008 snapshot' of the environmental and socio-economic conditions in one of the Arctic regions most heavily affected by oil and gas development and of its indigenous people struggling to maintain their life ways and economic practices under the growing industrial pressure on their land and resources.

CARMA

The CircumArctic Rangifer Monitoring and Assessment Network (CARMA no. 162 www.carmanetwork.com/display/public/home) involved an extensive network of more than 60 participants from the U.S.A., Canada, Norway, Greenland, Russia, Iceland and Finland. Representatives were drawn from agencies, indigenous organisations, co-management boards and universities, which enabled the creation of a network for sharing information and mutual learning. The project sought to assess the vulnerabilities and resilience of wild, barren ground caribou herds *(Rangifer tarandus)* to global change and further to document people's relationship with this important resource.

Observation and monitoring strategies. The project established a standard protocol for collecting data for monitoring caribou herd conditions, health, range, population levels, and remotely sensed data (*Chapter 2.9*) (www.carmanetwork.com/pages/viewpage.action?pageId=1114257). Local hunters from several participating communities in Alaska, Nunavut, Nunavik, Canadian Northwest Territories, Labrador, Greenland, Arctic Norway, and the Taymyr and Chukotka areas in Russia have been involved in these activities; they have been trained to report the information based upon systematic monitoring of individual local caribou herds. To ensure consistency of data collection across many Arctic regions, special videos on how to collect body condition data on reindeer have been developed. Indigenous user communities were also engaged in the development of the Caribou Atlas project, which sought to document scientific and indigenous names and uses for parts of the caribou. Local perspectives of change have been documented through videography. A documentary "Voices of Caribou People," involving six caribou user communities in North America, has been produced recording indigenous perspectives of change. All relevant information on the project can be accessed on its website (www.carmanetwork.com/display/public/home).

New and improved knowledge. The CARMA project is based on both western science and community experience, and the synthesis of the knowledge gained will be compiled in a project volume (to be published in 2011) describing the current understanding on how large migratory herds of *Rangifer* function across the circum-Arctic zone in various habitats. This will include an emphasis upon: 1) the characteristics of the herds; 2) the current state of knowledge on herd regulation; 3) how we can monitor and link changes to habitat to individual condition and health to responses at the population level; 4) how managers can assess the vulnerabilities of the herds; and 5) what will be the likely impacts of global change on the future of the herds.

Value for other IPY science fields. The CARMA team gained extensive experience, particularly in standardizing monitoring and reporting practices used by local stakeholders, in the videography research methods, as well as in the analysis of data and records collected on 20-some individual herds across the Arctic region. It will be useful to all similar projects focused on monitoring of other Arctic species with geographically wide, often trans-national distribution that cannot be successfully assessed and monitored by the respective national wildlife agencies. The contribution of indigenous stakeholders is being viewed as absolutely essential to the success of any such efforts. The project has developed several simulation models in caribou herd population dynamics and distribution change under numerous environmental, socio-economic and cultural variables. These will serve in the scientific analysis and function as decision-support tools for caribou management groups, scientists and policy makers. The project has also built a database and meta-database as a legacy for further efforts in monitoring Arctic caribou herds.

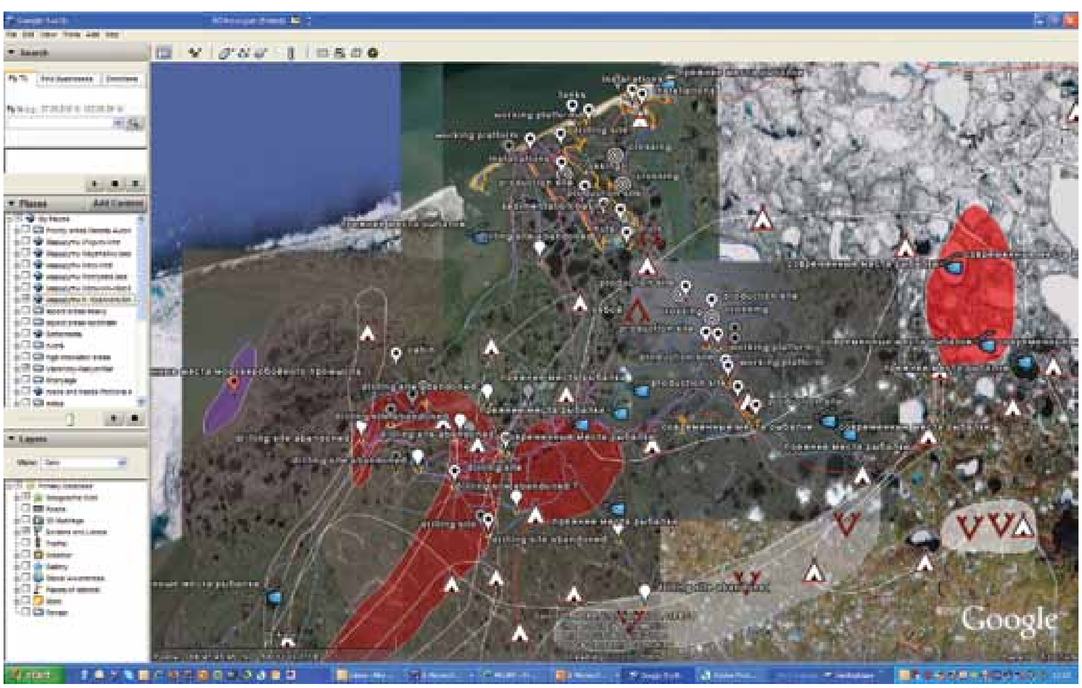

Fig. 3.10-5. Combining data on traditional reindeer herders' land use and satellite image interpretation of oil activities on combined. GoogleEarth maps (Photo: Winfried Dallmann)

EALÁT

The EALÁT project (IPY no. 399), "Reindeer Herders Vulnerability Network Study: Reindeer Pastoralism in a Changing Climate," was initiated by the Association of World Reindeer Herders (WRH) and coordinated by the Sámi University College (SUC) and the International Centre for Reindeer Husbandry (ICR) in Kautokeino, Norway. The project was provided institutional and personnel support from six other nations: Russia, Finland, Sweden, the U.K., Iceland and the U.S.A. With the aim of reducing the vulnerability of reindeer herders, their communities and management authorities through increasing preparedness for effects of climatic change and variability, the IPY EALÁT project developed research, information, teaching and outreach activities across the circumpolar north. The main focus of the project has been the Sámi (Norway, Sweden, Finland and Russia), particularly in the Norwegian county of Finnmark and also the Nenets people, involving detailed case studies in Sapmi, Yamalo-Nenets Autonomous Okrug (region), Sakha-Yakutia and Chukotka Okrug in Arctic Russia - (http://icr.arcticportal. org/index.php?option=com_content&view=frontpage&Itemid=78&lang=en).

The IPY EALÁT project voiced concern that societal transformations associated with globalization are leading to the loss of understanding of Nomadic reindeer herding practices. These practices represent models in the sustainable exploitation and management of northern terrestrial ecosystems through the incorporation of generations of adaptive experience. Key aims of the project are thus to ensure that traditional knowledge is made available, communicated and is used alongside scientific knowledge in governance, public plans and development projects.

Observation and monitoring strategies. EALÁT project acts as a venue through which Arctic reindeer-herding communities and groups can cooperate with each other and can communicate with international research and educational institutions in bringing and sharing new knowledge. Community-based workshops (such as those held in Kautokeino, Norway, Salekhard, Russia, Kanchalan in Chukotka, Topolinye in Sakha-Yakutia and Inari, Finland) have been used as prime venues for knowledge generation and exchange. They brought together reindeer herders, scientists and local and regional authorities to address the challenges of climate and land-use change through a focus on adaptation, traditional knowledge and the provision of best technology and scientific knowledge to local herders. The new partnerships included cooperation with the Norwegian Meteorological Institute and the Arctic and Antarctic Research Institute in St. Petersburg (AARI) that led to statistical downscaling of place-based climate scenarios. Workshop outcomes were reported to the Arctic Council and published on the multi-lingual project website that presents information in Sámi, English and Russian (http://icr. arcticportal.org/index.php?option=com_content&view=frontpage&Itemid=78&lang=en).

The main aim of the project was to empower reindeer herders and the communities in which they live with the best technologies available combined with traditional skills and knowledge, including systematic monitoring of reindeer health, behaviour, pasture conditions, etc., to further enhance the development of sustainable reindeer husbandry and improve the efficiency of local adaptation strategies

New and improved knowledge. The EALÁT project demonstrated that the human-ecological systems in the North, in this case, based upon reindeer pastoralism, are sensitive to climate change due to the high variability of Arctic climate and the characteristic ways of life of indigenous peoples. It is important to support capacity building for indigenous societies facing climate change and the loss of grazing land through enhanced recruitment of young scientists from local communities and by supporting institution building for indigenous organizations.

The project also revealed that the restructuring and flexible adjustment of reindeer herds may decrease the vulnerability to climate change. It indicated the need to modify government incentives and to improve understanding of bio-diversity and traditional knowledge. The EALÁT project is concerned with the major increase in human activities linked to climate change and with the resulting loss of grazing land for reindeer and caribou. Grazing land has to be protected as an adaptive measure to cope with climate change and to support sustainable Arctic societies.

Value for other IPY science fields. One the project's main contributions is making traditional herders' knowledge available to many more people via community workshops, scholarly and public presentations, and dissemination to the Arctic Council. Another major contribution is to pave the way for wider application of traditional knowledge, alongside scientific data, in governance, public plans and industrial development projects.

IPY EALÁT has produced a series of scientific and popular articles, book chapters and lectures. A major project volume comparing the vulnerability of reindeer herding in Finnmark, Norway and Yamal AO, Russia, is scheduled for publication in 2011. A website, www.reindeerportal.org, has been launched as a major platform for outreach information concerning reindeer herding in the circumpolar north. A forty-minute film will be released in mid 2010.

The IPY EALÁT consortium has established a unique institutional data- and knowledge-sharing network in the circumpolar North. It should be maintained for the future cooperation between peoples and states beyond the IPY era. In implementing these efforts, the Association of World Reindeer Herders, the International Centre for Reindeer Husbandry and the Sami University College have taken the initiative to establish a *University of the Arctic Institute for Circumpolar Reindeer Husbandry* (UArctic EALÁT Institute) as a legacy of International Polar Year 2007–2008. It has already developed courses in reindeer herding and human-coupled ecosystems (more than 30 students at the bachelor's level). Both master's and PhD students (seven) work within the EALÁT project and a special online course for reindeer herders (with 40 students) has been developed by EALÁT at the Sami University College. It is envisaged that the institute will expand the network thereby further advancing the goals of IPY and IPY EALÁT.

NOMAD

The 'Social-science migrating field station: Monitoring the Human-Rangifer link by following herd migration' Project (NOMAD, no. 408) ran from early 2006 until September 2009. The project was focused upon the Kola Peninsula in Northwestern Russia. It involved a multi-national team from Bulgaria, Russia, Denmark, Norway, Sweden and Finland

Fig. 3.10-6. NOMAD Expedition camp at Ketkozero Lake, Kola Peninsula, 21 April 2007. Twenty years ago, calving used to take place approximately in this area; but these days the female herd passes by already in April, before the lake ice melts, eager to get away from human presence and to give birth closer to the Barents Sea coast. (Photo: Vladislava Vladimirova)

Fig. 3.10-7. Spotting the fall reindeer migration, near Lake Porosozero, Kola Peninsula 15 September 2007. Local herders: Kamrat (to the left) and Grigorii Khatanzei (in the middle); Yulian Konstantinov, project PI is to the right. (Photo: Vladislava Vladimirova)

(Vladimirova and Konstantinov 2008; www.polarjahr.de/NOMAD.201.0.html) plus substantial input from the local Sámi, Nenets and Komi reindeer-herders.

Observation and monitoring strategies. In contrast to fixed-site monitoring, a mobile research facility permitted the team of researchers to follow the herd in the same manner as the herders practice throughout the year (Fig. 3.10-6) and thus closely observe human-reindeer *(Rangifer)* interactions. By placing the team in close contact with the migrating reindeer herds, NOMAD applied an innovative field method of data gathering and evaluation. NOMAD engaged several reindeer herders in its data collection and interpretation (Fig. 3.10-7) thereby ensuring the continual functioning of the research camp as well as communication and coordination with the host community. The field station may be used for future research.

New and improved knowledge. NOMAD observations show that over the last 20 years reindeer husbandry practices in this part of Arctic Russia have changed from highly intensive to highly extensive, with an increasing reliance on fence-building, snow-scooters and heavy tracked vehicles. The associated institutional change, however, has had several "unintended" consequences. All parties involved in the herding business make efforts to retain a state-supported and controlled "private-in-the-collective" form, rather than shift to independent private herding. Climate change discourse that is eagerly invoked by all parties in this rapidly changing environment (see Huntington and Fox, 2005) is often used as a political instrument to sustain the current herding cooperatives as meta-state farms.

Results of this research were shared with the local community via several presentations and through publications in the local newspapers, and involvement at the Village Professional School in the area hub Lovozero that teaches reindeer herding as a subject. A wider community was addressed by a conference organized by the Murmansk State Pedagogical University and by a seminar on the International Sámi Day (6 February 2008). The expedition diaries were posted as a blog at www.polarjahr.de/NOMAD-Blog-und-Forum.196.0.html.

Value for other IPY science fields. The NOMAD project produced mainly qualitative data (in textual and visual format), including extensive diaries, interview transcripts (Fig. 3.10-8) and video footage. Certain quantitative data can be useful to other IPY projects (e.g. for components of the Circumpolar Biodiversity Monitoring Program, CBMP – *Chapter 3.9*). The most important outcome of the project is the concept of synergetic development, that is, of rapid cascading changes triggered by both natural and social transitions. To local users, such a *synergetic* development often appears as a catastrophe to which they cannot adapt. The main reason is that under a *synergetic* transition certain components, like economic and property change, may be obscured or ignored, whereas the impact of others, like climate change or decline in reindeer population, is exaggerated in local discourse. NOMAD teaches that *all* factors are to be properly addressed to develop reasonable explanation and mitigation strategy.

SIKU: Documenting Indigenous Knowledge of Sea Ice

The "Sea Ice Knowledge and Use (SIKU): Assessing Arctic Environmental and Social Change" project (IPY no. 166 http://gcrc.carleton.ca/siku) produced the first detailed insight and comparative documentation of the patterns of indigenous knowledge and use of sea ice across the core section of the Arctic region, from the Bering Strait to Greenland. The continuous active use of and transmission of sophisticated local knowledge related to sea ice is currently threatened by socio-economic changes, weakening of indigenous languages and the ongoing transformation of the polar ice through rapid climate change (Fig. 3.10-9).

Observation and monitoring strategies. Indigenous partners from more than 30 communities in Canada, U.S.A. (Alaska), Greenland and Russia (Chukotka) have been involved in the SIKU project. Their contribution was provided through a variety of techniques, including individual, group and community meetings and testimonies; local ice and weather monitoring; and historical and GPS-based mapping. Altogether, indigenous monitors from ten communities in Alaska, Canada and Russian Chukotka – Barrow, Clyde River, Gambell, Novo-Chaplino, Provideniya, Shaktoolik, Sireniki, Uelen, Wales and Yanrakinnot – were engaged in daily ice and weather observations between 2006 and 2009 (Krupnik, 2009; 2010; Krupnik and Bogoslovskaya, 2008). In addition, six Nunavik communities in Eastern Canada (Akulivik, Ivujivik, Kangiqsujuaq, Kangiqsualujjuaq, Umiujaq and Kawawachikamach) developed their own system of sea ice monitoring based upon weekly ice measurements, site visits and interviews (http://climatechange.krg.ca/index.html). In three Alaskan communities (Barrow, Gambell and Wales) the observations were extended for a fourth winter thus providing an unbroken indigenous record of four consecutive ice seasons:

Fig. 3.10-8. Vladislava Vladimirova interviews two retired herders, Nikolai Galkin (to the left) and Ivan Chuprov, on 9 December 2007 in Lovozero, Kola Peninsula.
(Photo: Tatyana Sherstiuk)

Fig. 3.10-9. Two hunters watch for seals from the top of ice pressure ridge. Gambell, St. Lawrence Island, Alaska, February 2008.
(Photo: Igor Krupnik)

2006/2007, 2007/2008, 2008/2009 and 2009/2010.

When setting local ice and weather observations, village monitors were asked, at a minimum, to report daily temperature, wind direction, wind speed and the ice condition at each location. They were also encouraged to add local details they believed were important, such as data on subsistence activities; marine mammals, birds and terrestrial species; community events; and personal travel across the observation area (Fig. 3.10-10). All village monitors were also asked to include local terms, place names and key descriptions in their respective native languages whenever possible. This resulted in a more nuanced, contextualized and community-vetted documentation of indigenous knowledge and the use of ice. The age of monitors varied from 33 to 84, with the main group in the 50s and 60s age-group. Altogether, local SIKU observations in 2006–2009 produced a dataset of more than 150 monthly logs from nine communities totalling several hundred pages. It constitutes a unique database of its kind on local ice and weather conditions on the ground, but also on subsistence activities, communal life, personal travelling and the status of environmental knowledge in several communities during the IPY era.

New and improved knowledge. The project offered a unique window to learn how indigenous ice and weather monitoring is organized and to identify the key parameters of sea ice dynamics as directed by indigenous hunters. For example, local monitors identify the ice not only by its age, thickness, type, etc. (as ice scientists also do), but also by its history during a particular ice season; how many times it was broken and refrozen and even by its geographic origin. In the Bering Strait region, hunters can detect where the incoming ice has originated, whether it carries game (or not) and whether it is safe and stable to travel. On St. Lawrence Island, hunters distinguish four to five different 'waves' of the passing spring ice, according to their origin, whereas on the scientists' scale it is just one single 'spring break-up' period.

Hunters also use several 'proxy' indicators to judge

Fig. 3.10-10. Group of hunters camping on ice near a calved iceberg frozen into the first-years ice, Nunanvut, Canada.
(Photo: Gita J. Laidler 2007)

Fig. 3.10-11. Igah Sanguya (foreground) of Clyde River, Nunavut, and Toku Oshima of Qaanaaq, Greenland, watch for bowhead whales during the spring hunt at the floe edge off Barrow, Alaska in 2007. The two along with other Inuit from Clyde River and Qaanaaq were in Barrow as part of the Siku-Inuit-Hila Project, a sea ice knowledge exchange project between scientists and Inuit from Greenland, Nunavut, and Alaska, and a parter project of the SIKU initiative (IPY no. 166).
(Photo: Shari Gearheard, 2007)

the safety of ice or ice dynamics through the season, including tides and currents, persistent winds of certain direction, local current gyres unknown to the oceanographers, recurrent weather cycles, animal and bird behaviour and many other indicators. Altogether, experienced hunters may use up to 30 various indicators throughout the winter to monitor and assess ice safety and availability of game animals.

Value for other IPY science fields. Most of the information on which hunters based their assessment of sea ice and of individual ice season is not available in standard instrumental records. But thanks to the observational records accumulated during the SIKU project, we may eventually learn how to 'read' some of the past and current ice data by applying indigenous indicators. For example, satellite imagery, the main source of modern scientific analysis of sea ice conditions, cannot detect early forms of ice that look like 'open water' on the images, but these early forms of ice formations are carefully detected by local monitors. The beginning of the ice season may be thus established with much higher precision. This same 're-calibration' applies to the spring break-up time, with local observers documenting ice deterioration and disintegration much more intimately than satellite imagery can ever afford. Local monitors can, similarly, identify many local forms of ice, including the presence of thick and/or multi-year ice (Fig. 3.10-11) that is crucial for ice modelling and assessment, which may not be easily tracked by other sources. These and other examples illustrate why many of the sea ice scientists are now anxious to include indigenous data under their observation programs (*Chapters 3.6 and 5.2*) and why many weather and ice forecasting services in the post-IPY era are deliberately reaching out to local stakeholders and their knowledge (*Chapter 5.2*).

BSSN

The "Bering Sea Sub-Network (BSSN): International Community-Based Observation Alliance for the Arctic Observing Network" (IPY no. 247) focused its research on developing a process for gathering and managing local observations on the environment and subsistence harvest in six Bering Sea coastal communities: Gambell, Sand Point and Togiak in Alaska (Fig. 3.10-12), U.S., and Kanchalan (Chukotka), Nikolskoye and Tymlat (Kamchatka) in Russia. BSSN was implemented by the Aleut International Association (www.aleut-international.org) in collaboration with the University of Alaska, Anchorage, the Alaska Native Science Commission, and UNEP/GRID-Arendal (Norway) (www.bssn.net/). It was also a project of the Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council. There were approximately 330 participants in the pilot phase of the project, including researchers, staff, collaborators and interviewees (Fig. 3.10-13).

The six communities studied during the Pilot Phase (2007-2009) share a dependency upon the Bering Sea and its biological resources, such as fish, birds, marine mammals and other marine organisms. BSSN provided the opportunity for local communities to contribute to the overall efforts to increase our knowledge and understanding about processes affecting the Bering Sea by sharing local observations and perspectives on the environment.

Observation and monitoring strategies. In the BSSN project, for the first time, diverse indigenous communities formed an organized regional network for gathering, processing and data storage of local observations about the change in the environment and about species important for traditional fishing and hunting. Particular attention was paid to the development of standard questionnaire for data reporting and monitoring, and to the training of local monitors and research assistants. The BSSN team developed a network model consisting of the following steps: 1) a survey utilizing uniform questionnaires to be used across the area; 2) training of local research assistants to conduct interviews; and 3) a centralized database of local datasets to be used for further community and research needs. Of equal importance is improving data accuracy as questionnaire entries are collected by local project associates and entered in their original languages.

New and improved knowledge. In the BSSN project, the pilot phase findings point to several trends that will be tested in further studies, such as 1) the higher rate of diseased fish (e.g. Whitefish and salmon) on the Russian side of the Bering Sea, possibly as a result of anthropogenic factors, such as contamination; 2) increased instances of encounters with species new

Fig. 3.10-12. BSSN Research Assistants Esther Fayer (left) and Olia Sutton (center) with an Elder in Togiak, Alaska.
(Photo: Aleut International Association (AIA)

Fig. 3.10-13. Local Koryak residents participating in the BSSN monitoring interviews with Svetlana Petrosyan (second from right), Community Research Assistant. Tymlat, Kamchatka.
(Photo: Aleut International Association (AIA)

to the area (e.g. White King salmon), particularly in the Alaskan communities; and 3) an increase in abundance of certain species in the study the area (e.g. whales) that indicates shift in spatial distribution likely due to climate change.

Value for other IPY science fields. The BSSN project through its pilot phase (available at www.bssn.net) paved the way to a much larger study (Phase II), which is funded by a five-year grant from the U.S. National Science Foundation. It will continue and expand the gathering of local observations in the Bering Sea region, particularly in the field of wildlife distribution and habitat change that is useful to other science disciplines. The project metadata has been published through ELOKA, CADIS (Cooperative Arctic Data and Information Service) and IPY DIS (International Polar Year Data and Information Service). BSSN has presented project progress reports in a number of conferences and symposia, including Arctic Council meetings, IPY Open Science Conference in 2008 and the 5th Northern Research Forum, Anchorage 2008.

Preserving and Sharing Indigenous Knowledge: ELOKA

For projects and organizations that work with local and traditional knowledge and other social science information, there are few, if any, resources to help with data management and archiving (Fig. 3.10-14). ELOKA, the Exchange for Local Observations and Knowledge of the Arctic (IPY no. 187) was conceived as an IPY initiative to provide the first data management and user support network for local and traditional knowledge (LTK) and community-based research and monitoring activities in the Arctic (see http://eloka-arctic.org/, also *Chapter 5.4*).

Observation and monitoring strategies. ELOKA originally comprised two partners, the community of Sanikiluaq in Nunavut, Canada and the Narwhal Tusk Project (IPY no. 163) located in three Nunavut communities and one Greenland community (*Chapter 5.4*). ELOKA now collaborates with the SIKU project (IPY no. 166), Alaska Native Science Commission, Bering Sea Sub-Network (BSSN – IPY no. 247), Seasonal Ice Zone Observing Network (SIZONet), Muohta ja

Fig. 3.10-14. Community members in Clyde River, Nunavut, work on mapping present day and traditional travel routes for the Igliniit Project, a sub-project in the Inuit Sea Ice Use and Occupancy Project (ISIUOP-SIKU IPY no. 166). Clockwise from bottom right: Sivugat Palluq, Jacopie Panipak, Elijah Kautuq, Apiusie Apak, Laimikie Palluq, David Iqaqrialu, Peter Paneak, Jayko Enuaraq, Amosie Sivugat, Raygilee Piungituq, Aisa Piungituq, James Qillaq.
(Photo: Shari Gearheard, 2008)

Fig. 3.10-15. The Siku-Inuit-Hila Project, a sea ice knowledge exchange project between scientists and Inuit from Greenland, Nunavut and Alaska, and a parter project of the SIKU initiative (IPY no. 166), established community-based sea ice monitoring in the communities of Qaanaaq, Clyde River, and Barrow. Here David Iqaqrialu and Teema Qillaq (left) check on one of the Clyde River sea ice monitoring stations with visiting Qaanaarmiut Toku Oshima and Mamarut Kristiansen, who use the same system to observe sea ice in their home community of Qaanaaq Greenland. (Photo: Andy Mahoney, 2008)

Jiekna (Snow and Ice), SnowChange, CADIS, IPY DIS and NSIDC.

The goal of ELOKA is to develop a data management and user support service to facilitate the collection, preservation, exchange and use of local observations and knowledge of the Arctic. ELOKA team has not done community-based monitoring as a part of its IPY mission, but rather it collaborated with other projects and communities in need of storing and processing of their observational data (Fig. 3.10-15). As such, ELOKA is deeply involved in developing protocols for various data storage, online and other access engines, and in standardizing templates for records collected in IPY projects and beyond. ELOKA is also spearheading an effort to organize a network of services ('Data Centres') for local and traditional knowledge and community-based monitoring in the North. Such efforts require building new partnerships among various international organizations, universities, researchers, government agencies, science projects, and communities engaged in Local and Traditional Knowledge (LTK) and community-based monitoring (CBM) research and data management (*Chapter 5.4*).

New and improved knowledge. Once the practical templates for recording, storing and managing data and information are designed and the initial challenge of implementing an effective searchable database is achieved, ELOKA mission enters its second phase. It involves ensuring that the data stored may be exchanged between Arctic residents and researchers, as well as other interested groups such as teachers, students and decision-makers. The main challenge is that to ensure the integrity of the data, local providers retain control over certain sensitive components of the dataset, as they see it fit or in accordance to their cultural values and economic needs. None of those issues have been resolved in the previous data-management efforts involving local communities, hence ELOKA innovations in interactive web-based presentations, search tools and electronic and digital products may be indispensable.

Value for other IPY science fields. The ELOKA project is still under development and it is currently in its second post-IPY phase, 2009–2012, thanks to additional funding provided by the U.S. National Science Foundation. Its ultimate goal is to provide a searchable, web-based database for efforts in local monitoring and documentation of knowledge about the Arctic, covering all Arctic areas and primarily environmental themes. When this database is put in place, its data providers will be any project or organization that works with local and traditional knowledge (Fig. 3.10-16) and its prospective users include northern residents, educators, scientists, students, organizations, governments and the public.

CAVIAR

The "Community Adaptation and Vulnerability in Arctic Regions," CAVIAR project (IPY no. 157) initiated coordinated community vulnerability studies in 26 communities across eight Arctic countries. The main research areas were in Alaska, Arctic Canada (Nunavut, Inuvialuit, Yukon, Northwest Territories, NWT), Arctic Russia (Kola Peninsula, Yamal-Nenets AO, Nenets AO), Fennoscandia (Lapland in Finland, Finnmark and Nordland Counties in Norway, Norrbotten in Sweden) and West Greenland (Qeqertarsuaq). The CAVIAR project was designed with the intent to: document the particular environmental conditions to which local communities are sensitive; assess the strategies employed when dealing with change in the Arctic; identify the factors that facilitate or constrain adaptive capacities and resilience of local communities; and integrate information from local and indigenous knowledge with scientific knowledge (see Ford et al., 2009; Pearce et al., 2008; 2009). To achieve this, relationships were established with several organizations of polar indigenous people including the Inuit Circumpolar Conference, the Sámi Council, the World Reindeer Herders Association, Greenland Home Rule Government, Inuit Tapiriit Kanatami, the Government of Nunavut, the Inuvialuit Joint Secretariat and Nunavut Tunngavik Incorporated. More information on the specific project activities is available at http://ipy.arcticportal.org/news-a-announcements/item/2097-caviar-community-adaptation-and-vulnerability-in-arctic-regions.

Fig. 3.10-16. Lasalie Joanasie (left) and Shari Gearheard, one a hunter and one a researcher and both residents of Clyde River, Nunavut, keep an eye on a passing polar bear while travelling the sea ice off the coast of Baffin Island near Clyde. (Photo: Edward Wingate, 2009)

Fig. 3.10-17. Meeting with officers of Lebesby Municipality (Kommune), Finnmark, Northern Norway in 2008. The participants are discussing climate and adaptation of relevance to municipal planning. (Photo: Grete K. Hovelsrud, CICERO)

Observation and monitoring strategies. Through applying a common vulnerability assessment framework (Smit et al., 2008; Ford et al., 2008; 2010; Sydenysmith et al., 2010), the project has documented a range of stresses and exposures encountered by local communities across the Arctic, related to climatic, ecological, social, economical, cultural and political changes. The project developed a participatory methodology, including both local/indigenous and scientific knowledge that best explains how combinations of environmental and societal exposure sensitivities create vulnerability and necessitate community adaptation.

Data has been collected through extensive fieldwork using primary sources (interviews, focus groups, participant observation, questionnaires – Figs. 3.10-17, 3.10-18) and established protocols and procedures from secondary sources (government records on socio-economic and climate conditions, satellite imagery, reports). The development, in association with the Norwegian Meteorological Institute and the Arctic and Antarctic Research Institute in St. Petersburg (AARI), of downscaled climate change projections for the Norwegian and Russian cases study sites provided essential and innovative tools in supporting community understanding and response. The development of the climate scenarios was an iterative process among the local communities, who defined the relevant climate elements, and the scientists making and analysing the models (Hovelsrud and Smit, 2010).

New and improved knowledge. The CAVIAR project has designed and framed the research in collaboration with local communities, allowing for multiple drivers and conditions in each locale, a prerequisite for understanding adaptation and vulnerability to change. For each case, the researchers investigated the aspects of current conditions, livelihoods and institutions that increased the manner and degree of community sensitivity. Some common aspects emerge across many of the studied cases despite their cultural, geographic or economic differences. These include, in broad terms, the consequences of changes in coupled social-ecological systems with respect to resource accessibility, allocation and extraction policy; limited economic opportunity and markets access constraints for distant northern communities; demographics; attitudes and perceptions of change; local-global linkages; infrastructure; threats to cultural identity and well-being; transfer of local and traditional knowledge; economic and livelihood flexibility; and enabling institutions. These aspects

Fig. 3.10-18. Local researcher and Inuit hunter Roland Notaina records changes to hunter's travel routes in the Ulukhaktok region. Changes in sea ice have affected travel routes to polar bear hunting areas forcing hunters to travel further and over precarious ice conditions.
(Photo: Tristan Pearce)

are rarely independent of each other and frequently combine across scale and sectors, which may facilitate or limit adaptation in each particular case.

The 26 community case studies undertaken in eight Arctic countries under the same general methodology and in the course of relatively short period (2006–2009) illustrate the importance of integrating natural and social sciences. Without the input from both we would not have fully understood how the particular biophysical changes in the fisheries in northern Norway or in the river deltas in Northwest Territories in Canada have had consequences for communities.

Value for other IPY science fields. The CAVIAR project has demonstrated the complexities involved in understanding the linkages in coupled social-ecological systems. The involvement of local partners from the start and integration of their perspectives and knowledge increases the possibility of producing locally relevant results. The method of communicating the 'downscaled' climate change results will be useful for other projects, particularly to climate and sea ice scientists working on bringing their more general models and projections to down to the regional and local scale.

The CAVIAR metadata will be held under the Norwegian IPY data portal organized by the Norwegian Meteorological Institute. Besides contributing evidence to multiple media and conference events and the publication of numerous journal articles, a full project volume (Hovelsrud and Smit 2010) featuring 15 case studies was published in 2010. Numerous presentations on the CAVIAR project have been held in the case communities, for decision-makers and at international scientific meetings.

Conclusion

This overview of eight projects in local and community-based monitoring launched during IPY 2007–2008 introduces a complex and multi-layered field in its formative stage. On the one hand, several IPY-generated efforts in community-based monitoring produced impressive sets of local data related to areas critical to the IPY science themes, such as climate change, environmental preservation, status of the Arctic land and waters, documentation of indigenous knowledge, impacts of modern industrial development in the polar regions and the like. Several projects, such as CAVIAR, BSSN, EALÁT, CARMA and others, invested substantial effort in developing standard observational protocols and used the same or close methodologies across large study areas. This has allowed for new comparative analyses across a broad sample of participating communities and regions.

Nevertheless, little coordination was achieved among many IPY 2007–2008 efforts in community-based monitoring and the documentation of local knowledge. There was hardly a common vision on what particular aspects of polar environment and change are more (or less) important to the common understanding of natural, physical and social developments at the Poles. Individual project teams had several productive meetings during their planning and implementation years and they shared information broadly and freely. Nevertheless, there was no 'across-the board' exchange and comparison of the goals and needs of community-based monitoring projects in IPY 2007–2008 and no 'multi-project' meetings to develop a common agenda, in the way it has been done for oceanography, meteorology, satellite observations and other more 'matured' science disciplines.

For these and other reasons, the field of community-based monitoring and local knowledge documentation in IPY 2007–2008 was very much a 'work in progress.' One should acknowledge that the field had not even developed until the late 1990s and that it has been advanced to the polar research arena only by the time when IPY 2007–2008 was being planned—via ACIA Report (2005), the International Conference for Arctic Research Planning (2005), the development of the U.S. SEARCH (Study of Environmental Arctic Change) program, the *Inuit Qaujimajatuqangit* (Inuit traditional knowledge/values/way of thinking) movement in Nunavut and across Arctic Canada (see www.gov.nu.ca/hr/site/beliefsystem.htm) and a few summary publications available by that time (McDonald et al., 1997; Krupnik and Jolly, 2002; Helander and Mustonen, 2004; Oozeva et al., 2004; and others). Its status may be thus compared to the original science plan for the first IPY of 1882–1883 of three pillars (same time, same methodologies, many nations – *Chapter 1.1*), of which only two—same time and many nations—have been implemented.

Of course, to reach maturity the field of community-based observations and monitoring does not have to wait for its 'second' and 'third' IPY in the next 50 or 75 years. Several important publications based upon the IPY projects reviewed in this chapter are already published (Hovelsrud and Smith, 2010; Krupnik et al., 2010) or will be produced shortly and the overall impact of IPY 2007–2008 studies will increase manifold in the coming years. In addition, many projects are laying groundwork for rapid expansion of the field through new funding to expand their scope of operation in terms of time, community engagement and geographic coverage during the post-IPY era and beyond (like EALÁT, ELOKA, BSSN). Another line of action would be to argue for a radical change of approach to community-based monitoring—from short-term research and pilot projects funded via national science agencies or scientific initiatives (like IPY 2007–2008) to permanent activities, like SAON (*Chapter 3.8*), supported by regional governments and major indigenous organizations. This would naturally encourage local capacity building, self-government and developing new formats of community-based education and knowledge preservation. Certain IPY projects, particularly EALÁT and BSSN, are clearly moving in this direction (see more in *Chapter 5.4*). Yet other IPY initiatives are increasingly viewing themselves as precursors to the future 'services' for both indigenous and scientific communities to emerge as the lasting legacy of the post-IPY era. Two examples of this new strategy including ELOKA and a new project called "Sea Ice for Walrus Outlook" (SIWO) (*Chapter 5.2)*. Similarly, SAON, the Sustained Arctic Observing Networks initiative, has identified community-based monitoring as a priority for future Arctic research and monitoring activities (*Chapter 3.8*).

The field of indigenous and community-based monitoring has emerged as one of the least anticipated, yet most inspirational, outcomes of IPY 2007–2008. To achieve its full potential, it needs new successful efforts, more resources and continuation of its momentum into the post-IPY era.

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Notes

[1] Two first lead authors for this chapter are both members of the IPY Joint Committee and also PIs on their respective IPY projects with strong focus on indigenous and local monitoring of environmental and social change (CAVIAR, IPY no. 157 and SIKU, IPY no. 166).

[2] Other IPY projects with substantial component of local and indigenous monitoring include: Understanding environmental change and its biological, physical, social, subsistence and cultural effects in national parks and protected areas of Alaska, Chukotka and the Yukon through research, monitoring, education and outreach (no. 21); International Study of Arctic Change (ISAC, no. 48); Network for Arctic climate and biological diversity studies (no. 72); Circumpolar Biodiversity Monitoring Program (CBMP, no. 133); Present-day processes, past changes and spatiotemporal variability of biotic, abiotic and socio-environmental conditions and resource components along and across the Arctic delimitation zone (PPS, no. 151); Narwhal Tusk Research (NTR, no. 163); Community Resiliency and Diversity (no. 183); Engaging Northern Communities in the Monitoring of Country Food Safety and Wildlife Health (no. 186); Environmental baselines, processes, changes and impacts on people in sub-arctic Sweden and the Nordic Arctic regions (no. 213), and other.

3.11 The State of Polar Data–the IPY Experience

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Introduction

International Polar Year 2007–2008 (IPY) was the world's most diverse international science program. It greatly enhanced the exchange of ideas across nations and scientific disciplines. This sort of interdisciplinary exchange helps us understand and address grand challenges, such as rapid environmental change and its impact on society. The scientific results from IPY are only now beginning to emerge, but it is clear that deep understanding will require creative use of myriad data from many disciplines.

The ICSU IPY 2007–2008 Planning Group emphasized the need to "link researchers across different fields to address questions and issues lying beyond the scope of individual disciplines" and noted the importance of data in enabling that linkage. Furthermore, they planned to "collect a broad-ranging set of samples, data, and information regarding the state and behavior of the polar regions to provide a reference for comparison with the future and the past, and data collected under IPY 2007–2008 will be made available in an open and timely manner." In some ways, data were seen as the centerpiece of IPY: "In fifty years time the data resulting from IPY 2007–2008 may be seen as the most important single outcome of the programme." The planners, therefore, incorporated data management as a formal part of the overall IPY Framework (Rapley et al., 2004).

Now, most IPY field programs have ended. They have produced a lot of data. Are those data available? Are they well-documented for broad, interdisciplinary use and long-term preservation? Are they supported by robust and useful organizations and infrastructure? Have we enhanced interdisciplinary science and data sharing? Have we met the data goals of IPY? In short, what is the state of polar data?

This report is the result of the collective experience of the IPY data management community, especially participants at an IPY data management workshop in Ottawa, Canada hosted by the Canadian Ministry of Indian and Northern Affairs 29 September – 1 October 2009. Section 1 provides background and describes the state of data management before IPY. Section 2 describes the IPY data plans, strategy and progress toward meeting IPY plans and objectives. Section 3 assesses how well IPY performed against specific objectives and discusses lessons learned in four broad data management areas that follow the structure of the IPY Data Policy and Strategy, namely:

- data sharing and publication;
- interoperability across systems, data and standards;
- sustainable preservation and stewardship of diverse data; and
- governance and conduct of the virtual organization that coordinates data access and stewardship around the globe.

An overall summary and final recommendations for multiple IPY stakeholders is provided at the end of this Chapter.

Background

In 2004, when IPY planners were developing the Framework Document (Rapley et al., 2004), the state of polar data management was highly variable across disciplines and nations, and even between the Arctic and Antarctic. Some disciplines, such as oceanography and meteorology, had extensive experience in international collaboration and data sharing. These disciplines had also developed fairly robust data systems either for specific global experiments (e.g.

the World Ocean Circulation Experiment) or as part of ongoing global networks (e.g. the International Arctic Buoy Program). Other disciplines, notably in the life and social sciences, had little established culture of collaboration and data sharing. Many investigators in all disciplines viewed the data they collected as their hard-earned property to be guarded and only shared sparingly or with significant restriction. Regardless of discipline, when the data were managed in data centers or repositories, the data centers tended to be very focused on their specific discipline. There was very little interoperability, or even open sharing, across disciplines.

At the national level, some countries had very open data policies while others were more restrictive—curtailing commercial use, for example. Other countries had no explicit data policy or were highly restrictive. Some countries had well-established data centers, some did not. No country had data centers covering all polar disciplines. By the time of IPY, the Scientific Committee on Antarctic Research (SCAR) had made some progress on encouraging international data sharing through its Standing Committee on Antarctic Data Management (SCADM) and the associated Antarctic Master Directory, which describes many data sets from Antarctica and the Southern Ocean. Many nations involved in SCAR had nominally established National Antarctic Data Centers, but the capacity and participation of the different nations was highly variable. The existing relationship between SCADM and the Global Change Master Directory (GCMD), through the Antarctic Master Directory, was key to the establishment of the IPY Metadata Portal by the GCMD.

In the Arctic, some programs – notably those under the Arctic Council, such as the Arctic Monitoring and Assessment Programme (AMAP) – had structures for international collaboration and data sharing, but there was no overarching body to coordinate Arctic data management as a whole. In the 1990s, the Global Resource Information Database (GRID) and the United States Geological Survey (USGS) established the Arctic Environmental Data Directory. This directory eventually had members in all Arctic nations and Arctic Council working groups, but it inexplicably closed early in the 21st century.

At the global level, an International Council for Science (ICSU) Program Area Assessment questioned the viability and collaboration of World Data Centers and recommended a major overhaul of ICSU data structures (ICSU, 2004). The Global Earth Observing System of Systems (GEOSS) was just getting started and was paying little attention to the unique observational and data requirements of the polar regions.

Recognizing this chaotic state of polar data management, IPY planners included a basic data management plan in the IPY Framework Document based on guidance from the Joint Committee on Antarctic Data Management[1] and the World Climate Research Programme's Climate and Cryosphere Programme (WCRP-CliC) Data and Information Panel. The plan recommended creating an IPY Data Policy and Management Subcommittee (Data Committee) to develop the IPY data policy and strategy. The strategy was to be implemented by a "full-time, professional data unit," the IPY Data and Information Service (IPYDIS). Furthermore, the plan required each project to develop and fund specific data management plans, including dedicated data managers within projects. Throughout the document, the planners emphasized the need to start early, plan data management in advance of data collection and fully fund data management within individual projects and through the IPYDIS. They also emphasized the need to reuse or re-engage existing systems such as the World Data Centers.

ICSU and the World Meteorological Organization (WMO) established the Joint Committee (JC) for IPY in fall 2004 but were unable to provide support for the recommended Data Committee. In consultation with the polar data management community, the JC appointed an unfunded Data Subcommittee late in 2005. The Subcommittee met for the first time in March 2006, prior to an initial IPY data workshop sponsored by the U.S. National Science Foundation (NSF) and hosted in Cambridge, U.K. by the British Antarctic Survey and the International Programme Office (IPO). At this initial meeting, the Data Subcommittee worked to finalize the IPY Data Policy and was guided by the participants at the workshop on comprehensive data management planning. This was a critical workshop for IPY. The recommendations from this workshop and the IPY Data Policy provided the foundation for subsequent Data Subcommittee plans and IPYDIS activities. A workshop report is available at http://nsidc.org/pubs/gd/Glaciological_Data_33.pdf. Unfortunately, the workshop occurred after investigators had already submitted their coordination proposals to the JC. As a result, investigators were agreeing, in their proposals, to a data policy that was not complete and they were submitting generally cursory data management plans with very little guidance and no review by the Data Committee.

The IPY Data Policy was completed and endorsed by the JC in mid-2006. It builds off existing ICSU, WMO and related policies, but seeks to better encourage international and interdisciplinary collaboration as well as further the themes and objectives of the IPY. The policy has generally been praised as forward-looking in its call for open and timely release of data with limited exceptions and for formally crediting data authors. As part of their coordination proposal to the JC, all IPY projects agreed to adhere to the Data Policy, but much in the culture of science, resisted open and timely access.

The IPYDIS was initially proposed and endorsed as an IPY project (no. 49) in collaboration with the Electronic Geophysical Year (see Box1). The original proposal involved a diverse global group of several dozen data managers, scientists and specialists. Over time, the partnerships evolved to incorporate data activities within individual IPY projects and national IPY data centers and coordination services, as well as many previously existing national and international data centers, including the SCADM data network. A key challenge, however, was to fund the effort. Starting in mid-2007, NSF supported a small coordination office for the IPYDIS at the National Snow and Ice Data Center to track the data flow for IPY. This office was to help researchers and data users identify data access mechanisms, archives and services; they would also provide information and assistance to data managers on compliance with standards, development of a union catalog of IPY metadata and other data management requirements for IPY. Another coordination office, focused on near-real time and operational data streams, was established at the Norwegian Meteorological Institute. Together, these offices have provided a general communication forum for all matters related to accessing, managing and preserving IPY and related data (http://ipydis.org), but they are modest efforts, ending soon. The IPYDIS announcement of opportunity recommended in the Framework document (Rapley et al., 2004) never materialized and national funders varied in their requirements for data management within individual projects.

The JC made several written appeals to individual nations defining requirements and requesting formal support for IPY data management within projects, nations and internationally. Eventually, some support emerged at the national level, primarily through the creation of national data coordinators and national IPY data systems. Data committee members worked hard within their countries, often behind the scenes, to make this possible. Unfortunately, most of the support came well after IPY had started and there was little success in creating the core cyber infrastructure to support the full suite of IPY data, build interoperability across systems and enable international coordination.

Box 1 The Electronic Geophysical Year

In 1999, the International Union of Geodesy and Geophysics (IUGG) called on its scientific associations to propose activities to mark the 50-year anniversary of the IGY. The International Association of Geomagnetism and Aeronomy (IAGA) responded through a resolution passed at the IUGG General Assembly in Sapporo in 2003 to lead an Electronic Geophysical Year (eGY).

The eGY began on 1 July 2007 and ended on 31 December 2008, exactly 50 years after the start and end of IGY. Support for eGY came from IAGA, IUGG, NASA, the United States National Science Foundation, United States Geological Survey and the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado. In kind contributions came from the American Geophysical Union (AGU), the National Centre for Atmospheric Research in Boulder, Colorado and the volunteer labor of eGY participants.

The eGY focused the international science community to achieve a step increase in making past, present and future geoscientific data (including information and services) rapidly, conveniently and openly available. The themes of the eGY included electronic data location and access, data release and permission, data preservation and rescue, data integration and knowledge discovery, capacity building in developing countries (mainly improving Internet connectivity) and education and outreach. Promoting the development of virtual observatories and similar user-community systems for providing open access to data and services was a central feature of the eGY.

Principal legacies of the eGY are stronger awareness of the role that informatics plays in modern research, expanding adoption of virtual observatories and similar systems for accessing data, information and services, and an expanding infrastructure at the international and national levels. As with the IGY, the mission of the eGY is being carried forward through existing or newly formed national and international organizations (Peterson et al., in prep.).

In the period leading up to the start of IPY, data stewardship was undervalued despite robust data management plans within the Framework Document, strong recommendations of the ICSU Program Area Assessment and telling examples from earlier international projects.

Developments and Current Status of IPY Data

Following the March 2006 Cambridge workshop, the Data Committee began their work in earnest, despite a general lack of funding. The Committee conducted a series of outreach activities, including conference sessions and town hall meetings. The Committee also appealed to national committees and funding agencies, wrote reports to sponsors and provided general information for the public and IPY participants. Many documents are available at http://ipydis.org/documents. See alsowww.earthzine.org/2008/03/27/securing-the-legacy-of-ipy/. These activities continued through IPY and beyond.

In fall 2006, ICSU's Committee on Data for Science and Technology (CODATA) endorsed the Data Committee as a formal CODATA Task Group. The current Data Subcommittee formally ended in October 2010 when its current term as a Task Group ended. Some IPY data managers recently applied for task group renewal, under a new charter and new membership, for a third two-year term extending through October 2012.

Data Management Planning

Starting in 2006, the Data Subcommittee and IPYDIS Office made multiple attempts to contact each of the funded IPY science projects to determine their data management plans (Education and Outreach projects and unfunded projects were not considered). Based on these multiple surveys, Mark Parsons, manager of the IPYDIS, made a subjective assessment of each project's data management plan. The assessment focused on short-term distribution plans because there was insufficient information to truly consider the full data life-cycle, notably long-term preservation. The results of the assessment are shown in Fig. 3.11-1 with colour codes representing the data management plan status of each project in the IPY "honeycomb" (project) chart. The honeycomb was a popular way of displaying all of the IPY-endorsed collaborative projects and was roughly arranged by discipline and region.

A fuller assessment of the data management plans that considered the full data life cycle would probably look worse. Many projects were unaware of appropriate long-term archives and many archives do not exist. At a cursory level, it appears that only the 30 projects with good data distribution plans have adequately considered long-term preservation. This leaves 94 IPY projects collecting data without clear plans or resources for archiving their data.

It is also telling that many projects never responded. The gaps in the Land and People columns may reflect an actual lack of data management planning and structure. The gaps in the Ocean, Ice and Atmosphere columns are more likely to reflect a lack of participation in the overall IPY organization because these disciplines typically have fairly robust

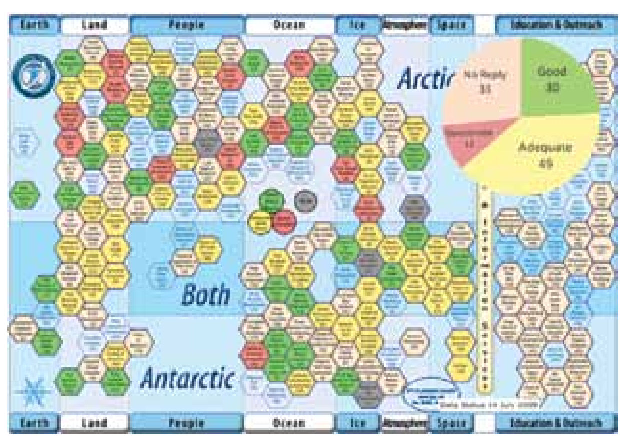

Fig. 3.11-1. Status of IPY Project Data Distribution Plans, July 2009. Good data distributionn plans are those with a clearly designated and funded repository for their data. Adequate plans are those that may not have identified permanent archives or professional data managers, and there may be some minor funding or coordination issues. Questionable plans do not have any data management plan or identified repository; data management funding may not have been identified; or they did not provide sufficient information to adequately assess their plan. Some projects did not respond to the survey, even after multiple queries. Of the funded science projects, 13 reported that they are not collecting data. So they are not included in the assessment.

data management structures. Unfortunately, many of these robust data management structures are very independent or siloed and do not necessarily collaborate with other systems.

IPY Data Strategy

As IPY began, the Data Subcommittee laid out a basic four-point data strategy briefly described in points A to D below, and summarized in Fig. 3.11-2.

A. Identify and share the data (Identification).
Goal: *all metadata by March 2009*

All projects should create brief descriptions of their IPY data in a standard metadata format in accordance with the IPY Metadata Profile. Metadata should be provided to the IPY Metadata Portal at the GCMD (http://gcmd.nasa.gov/portals/ipy/) or at an appropriate national registry. National registries should enable ready discovery of their holdings through the GCMD either through metadata sharing, such as the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) or open search (ISO23950) protocols. National data coordinators greatly facilitate this process.

B. Serve the data in interoperable frameworks (Availability).
Goal: *ongoing demos of integration, all data available March 2010*

All IPY projects should make their data fully and openly available in standard data formats through standard data access mechanisms. Data may be served by individual projects or by designated archives, but the data must be linked directly to the discovery level metadata described above. IPY projects and data centers should work to make their data as interoperable as practical and to work with other projects and data centers to develop targeted interoperability arrangements. Projects and centers should also participate in global interoperability initiatives, notably the Global Earth Observing System of Systems (GEOSS) and the WMO Information System (WIS).

C. Preserve the data (Preservation).
Goal: *all data in secure archives by March 2012*

All IPY data and associated documentation (including metadata) should be deposited in secure, accessible repositories within three years after the end of the IPY. Archives should follow the ISO-Standard Open Archival Information System Standard Reference Model. National governments and international organizations must develop means to sustain archives over the long-term.

D. Coordinate the process (Coordination).
Goal: *ensure broad international collaboration and agreement on standards*

Nations should designate national data co-ordinators and participate actively in the IPYDIS to ensure the other elements of the strategy are met. Note the original strategy envisioned the coordination role fading out as data were secured, but actually coordination still needs to continue for several years.

The JC endorsed this strategy in October 2007. Subsequently, the JC, the IPO and the Data Subcommittee actively urged participating countries to designate national data coordinators and support IPY data archives. To date, 16 countries have designated national IPY data coordinators. Some nations formally designated IPY coordinators through national IPY Committees, research councils or other agencies. Because some IPY countries are only active in the Antarctic, their SCADM representatives act as *de facto* IPY coordinators. Many of these coordinators were not designated until well after IPY began and some will not continue very long after the IPY.

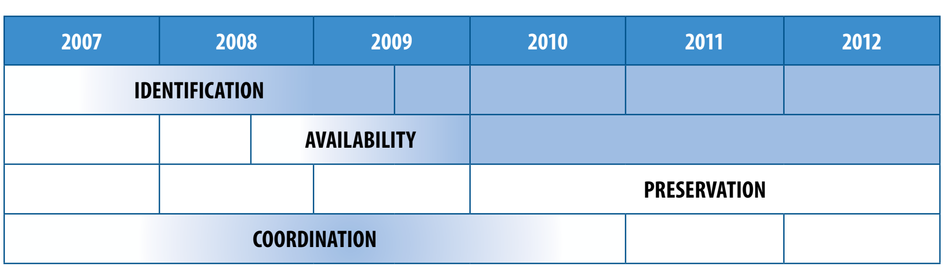

Fig. 3.11-2. Timeline for implementing the IPY Data Strategy

IPY has led to the creation of many new national, disciplinary and project-level data portals, but implementation of the IPY Data strategy is now a year or more behind schedule. We still strive to have all of the data in secure archives by 2012. At the time of writing, about 400 data sets were described in the IPY metadata portal at the GCMD. Given that there were tens of thousands of IPY investigators, this is likely to be a very small percentage of the data collected. The GCMD acts as a central portal to all IPY data, but as of yet, not all available data are advertised there. Several nations, including Canada, China, New Zealand, Norway, Sweden and Russia have developed national IPY data portals. In addition, many project data portals have been developed: the Antarctic Drilling Project, the Arctic Observing Network, the Circumpolar Biodiversity Monitoring Programme, the Polar Earth Observing Network, the SCAR-Marine Biodiversity Information Network and others. These portals are working to become increasingly interoperable and provide data through a common portal. Meanwhile, they do provide access to approximately 1000 datasets not yet available through GCMD (see below).

Assessment of Performance against Strategic Objectives

In the following subsections, we provide an assessment of how well IPY performed against specific objectives within each of the four elements of the data strategy and discuss lessons learned as well as what IPY sponsors and data centers can do to advance IPY data management. We provide a simple five-star rating system as a quick summary assessment for each objective. Key lessons and recommendations are highlighted throughout and then summarized below for aspects of data sharing and publication; interoperability; preservation; and coordination and governance.

Data sharing and publication

Objectives

1. *Data should be accessible soon after collection, online wherever possible, in a discovery portal such as the GCMD.*

Assessment: ★★★☆☆

Significant amounts of IPY data are available. In some countries, including Canada, Sweden, China,

Country	Coordinator	Affiliation
Australia	Kim Finney	Australian Antarctic Data Centre
Belgium*	Bruno Danis, Maaike Van Cauwenberghe	SCAR Marine Biology Information Network
Canada	Scott Tomlinson	Indian and Northern Affairs Canada
China	Parker Zhang, Zhu Jiangang	Polar Research Institute of China
France	Thierry Lemaire	French Polar Institute
Germany	Hannes Grobe	Alfred Wegner Institute
Japan*	Masaki Kanao	National Institute for Polar Research
Malaysia*	Talha Alhady	
Netherlands	Ira van den Broek	Royal Netherlands Institute for Sea Research
New Zealand*	Shulamit Gordon	The New Zealand Antarctic Institute
Norway	Øystein Godøy	Norwegian Meteorological Institute
Russia	Alexander Sterin	Russian Research Institute for Hydrometeorological Information
Spain*	Oscar Bermudez	
Sweden	Barry Broman	Swedish Meteorological and Hydrological Institute
United Kingdom	Julie Leclert	British Antarctic Survey
United States	Mark Parsons	National Snow and Ice Data Center

**Ad hoc or self-designated through their role in SCADM*

Table 3.11-1. National IPY Data Coordinators.

Netherlands, Norway and the United States, some data are being made available much earlier after collection than they were historically. For example, in the U.S., investigators in the IPY Arctic Observing Network Program routinely share their data in an open system within a few months after they return from the field. There is no embargo period as there has been in the past and program officers keep investigators accountable. Less progress has been made in other countries. Data availability is also highly variable across disciplines due, in large part, to existing procedures and special circumstances. For example, social science data has proven to be a particular challenge especially when data for human subjects are involved. Overall, data sharing is commonly recognized as a scientific imperative, but the technical mechanisms require further development and the cultural norms of science still resist sharing.

2. *Data users should provide fair and formal credit to data providers.*

Assessment: ★★☆☆☆

Data citation is increasingly recognized as a valid process, but implementation is sporadic at best. The issue is a growing topic of discussion in the data management and scientific publication communities and the IPY guidelines are gaining increased attention (Nelson, 2009; Parsons, Duerr and Minster, 2010).

Discussion

Data policy

The IPY Data Policy emphasizes the need to make data available on the "shortest feasible timescale." Rapid changes in the polar regions make this need to share data more acute because alone, no single investigator or nation can understand these changes. We note that underlying any discussion related to Arctic science is an awareness of rapid climate change in the Arctic and the occurrence of a unique and dynamic set of phenomena. A recurrent theme is whether the Arctic has moved to a "new state" or has passed a "tipping point." These terms are becoming more explicit in the literature and formal discussions of science (e.g. Hansen, 2007; SEARCH, 2005; Walker, 2006). Furthermore, climatic changes and other factors of modernity are driving large changes in Arctic society (ACIA, 2005). Similarly, science is confronted with rapid change. Fast growing data volumes pull us from hypothesis-driven science to science that seeks hypotheses and patterns in the data, be they climate model projections or the wisdom of an Inuit hunter. Nevertheless, the IPYDIS still struggles to identify data from IPY and make them broadly available.

The first issue is simply to identify what data were collected as part of IPY. The JC endorsed certain internationally collaborative efforts as IPY projects, but these collaborations were not always recognized or funded by individual nations and some countries paid scant attention to the international program when funding national IPY projects. This ad hoc approach, along with a lack of rigor in enforcing the data policy during project planning and implementation has made it very difficult to describe exactly what data were collected as part of IPY.

The Data Subcommittee has developed a specific definition of "IPY data". Data centers and investigators should identify and specifically flag their IPY data. To date, approximately 1400 data sets have been catalogued in the Global Change Master Directory and other portals as resulting from the IPY. This is likely to be a small fraction of the actual data collected.

More challenging and more important than simple identification is the actual unrestricted release and publication of the data. The IPY policy of general openness built from existing policies appears to be an initial success; fewer people now challenge the principle of open data access. The timely release requirement of the IPY policy is vague because no specific time limit is indicated, but it does require investigators to act quickly to meet the ideals of open data. This requirement has made some participants uncomfortable, but it keeps a certain pressure on data providers and forces the community to develop fair and equitable data sharing mechanisms.

It is significant that the community conversation about data sharing is no longer concerned with *whether* to share data, but rather with *when* and *how*. For example, the Norwegian data coordinator found investigators were more willing to share their data in common formats once they were provided basic data conversion tools. Other countries, such as Canada and Sweden, required adherence to the IPY data policy as a requirement for project funding. They then discovered that they needed to educate investigators on basic data management concepts, such as the difference between data and metadata, and that they also needed to provide data archives to which the investigators submit their data. These are promising developments and the conversation on the particulars of open access must continue. IPY sponsors need to lead this conversation, developing more consistent and rigorous data policy across organizations and nations to ensure rapid and open data sharing. Good data policy helps move open data sharing forward, but it must be enforced. IPY has had the greatest success with timely release of data in countries that explicitly require data sharing as part of funding arrangements and withhold future funding until data are made available. This was demonstrated in the Netherlands, the United States, Canada and possibly elsewhere.

Ultimately, to maximize their value and reuse, data should be made freely available in the public domain. This is a major focus of the Polar Information Commons (PIC, polarcommons.org), an ICSU project following from IPY to establish an improved framework for polar data sharing and preservation. A central tenet of the PIC is that data should be as unrestricted as possible, but scientists need to establish norms of behavior that ensure proper, informed and equitable data use. Some of the norms have been established or reinforced as part of IPY and the community should continue this discussion working to share data in the PIC framework.

The national data coordinators described above have been invaluable in identifying IPY data and helping investigators publish their data. Ideally, professional data managers should be directly included as part of data collection efforts, whether in the field or in the lab. These "data wranglers" can significantly improve the consistency and completeness of data and, therefore, the quality of the science in addition to ensuring that data policy obligations are met (Parsons, Brodzik and Rutter, 2004).

Demonstrating the value of data centres

Data centers also need to encourage data submission by clearly demonstrating value. In other words, data providers need to see a benefit in submitting their data to a professional archive. Of course, the ultimate benefit is the long-term preservation of and access to the data, but providers want to see immediate, practical benefit from the efforts they have made to archive the data. This benefit can be as simple as having submitted data immediately appear on a map in a WMS or Google Earth, but a broader benefit should also include increased provider recognition and possibilities for collaboration.

Different data management strategies for different types of data

IPY discovered that different strategies are necessary for different types of data. Because of IPY efforts, routine operational and remote sensing data are more broadly available than ever (*Chapter 3.1*), but much of the data collected by individual researchers or field projects remain largely inaccessible. The IPY Operational Data Coordinator in Norway has helped the European Center for Medium Range Weather Forecasting (ECMWF) to make their re-analyses more broadly available (http://ipycoord.met.no/). An active collaboration of national space agencies, the IPY Space Task Group, has led to greater collaboration and fewer restrictions in data access across remote sensing programs. Polar science is still very dependent on conventional, in situ research collections, however, these data tend to be less accessible. In some cases, there are legitimate restrictions to protect privacy or sensitive assets, but most restrictions are rooted in the culture and norms of science. Different disciplines have different attitudes and norms of behavior around data sharing (Key Perspectives Ltd., 2010). They also have highly variable data infrastructures. These disciplinary disparities were not well-recognized by IPY data planners. There was a tacit assumption that data management philosophies were the same in all disciplines, as it is in many geophysical disciplines.

Ultimately, we are talking about cultural differences in data sharing across disciplines; discussing a change in culture can be sensitive, especially in the context of the Arctic. Yet it is important to note the parallel rapid change in both science and the polar regions. These changes in environment and society create uncertainty and tension that foster a sense of urgency and a need for adaptation. An indigenous Arctic participant at an IPY Sustained Arctic Observing Network (SAON) workshop urged, "[w]e have no time to argue over how we feel and how we observe the changes. We need to work together." At a Canadian workshop, another northerner quoted Robert Hutchings in *Mapping the Global*

Future, "[l]inear analysis will get you a much-changed caterpillar, but it won't get you a butterfly. For that you need a leap of imagination." (National Intelligence Council, 2004). Furthermore, open data are central to the integrity of science. As the controversy around the emails stolen from the British Climate Research Unit illustrate, scientists are under greater scrutiny than ever. Data and methods need to be fully open and accessible to for science to be beyond reproach.

This new world of change, urgency and scrutiny creates a context in which a data sharing network must operate while some elements of science lag behind. The reward structures of academic research and scholarship remain largely the same as they were 50 years ago. For example, some scientists who spend a lot of time in the field monitoring various parameters often feel they get less respect in the scientific community. Collecting data takes time away from analysis and journal publication, yet the intellectual effort in collecting and compiling data is not adequately recognized. This can increase the proprietary attachment "monitoring scientists" will have for their data. They feel compelled to restrict access to their data until they get an opportunity to publish something based on the data they collect because publication is a primary measure of a scientist's merit. The data themselves should be considered a valuable and recognized publication in their own right. Indeed, data sharing itself can be a means toward greater interdisciplinary collaborations and publications.

Data citation

The IPY Data Policy encourages formal recognition of data providers: "...users of IPY data must formally acknowledge data authors (contributors) and sources. Where possible, this acknowledgment should take the form of a formal citation, such as when citing a book or journal article. Journals should require the formal citation of data used in articles they publish." Furthermore, the IPY Data Subcommittee has developed specific guidelines on how to cite data (http://ipydis.org/data/citations.html) and data citation is encouraged by many disciplines (Costello, 2009; Klump et al., 2006; Schofield et al., 2009). Nevertheless, data citation remains erratic. Few journals explicitly require data to be cited and referees rarely demand it during peer review. More importantly, data publication is rarely considered by promotion panels or tenure review boards even though the intellectual (and physical) effort behind most data collections rival that of a journal article. Overall, investigators see little incentive to publish their data, especially if it is not routinely cited.

Building from the IPY guidelines, data centers need to provide the clearest possible guidelines on how their data should be cited. They need to work with the broader community to continue to research closely related issues such as accurate citation of different versions and changing time series, the use of unique and permanent identifiers, and potential peer review processes. This is an ongoing discussion in the data management community and while there are many issues outstanding, IPY guidelines provide a firm foundation. Digital Object Identifiers (DOIs) also emerge as the *de facto* standard for identifying complete data collections, if not the specific elements of a collection. ICSU bodies, such as CODATA, could help further develop data citation standards and guidelines.

Finally, any discussion of data sharing must consider how researchers define their personal and professional identities, and how that affects their attitudes toward collaboration and data sharing. Polar research is rooted in the age of heroic exploration. There is a romance and toughness associated with historic polar exploration that attracts some people to study the poles. The difficulty of collecting data in the poles helps create a narrative that researchers use to define themselves and to create bonds with other members of their research community. The physical challenge and difficulty of collecting data in the poles not only helps define the identity of the researchers, but also can create a sense of proprietary ownership that can restrict data sharing to narrow communities of a single discipline or a few colleagues. Scientists can exhibit a sort of cliquishness restricting access of those they consider "outsiders" or of those they fear may misunderstand and therefore misuse their data.

Issues of trust are not unique to scientists. A major concern expressed by Arctic residents is that researchers come in and take information and knowledge from the North without permission or that they might reuse data in new ways without checking with the people who provided the knowledge behind the data. See *Chapters 3.10 and 5.4* for more on challenges around handling community-based monitoring and local and traditional knowledge. IPY has done much to build trust and enhance collaboration across disciplines and cultures. To sustain this collaboration, we need to encourage greater data sharing by building familiarity and relationships. Sponsors should continue to support cross-disciplinary workshops that include scientists, northern residents and other stakeholders. Data managers need to be included to help facilitate the equitable means of data sharing and mutual respect necessary for productive collaboration.

Interoperability

Objectives

1. *Metadata should be readily interchangeable between different polar data systems to enable data discovery across multiple portals.*

Assessment: ★★★☆☆

The main IPY data portal is hosted by the GCMD and builds from the success of the Antarctic Master Directory developed in partnership with SCADM. The Data Committee created a metadata profile for the GCMD's Directory Interchange Format (DIF) with crosswalks to other geospatial metadata standards. Multiple IPY data centers have adopted the profile and several have begun automatically sharing metadata through open protocols. The most challenging issue has been agreeing on and harmonizing specific controlled vocabularies, especially those describing scientific parameters. The IPY profile uses the GCMD's science keywords, which are broadly, but not universally adopted. They also grow from a geophysical perspective and are less complete in other areas, especially social sciences.

2. *Data from different projects, disciplines and data centers should be easily understood and used in conjunction with each other in standard tools and analysis frameworks.*

Assessment: ★★☆☆☆

The interdisciplinary nature of IPY inhibits interoperability of data. Different communities use different data formats, tools and exchange protocols. Some standard data formats, such as the Network Common Data Form – Climate and Format (NetCDF-CF), which includes usage metadata, are becoming more broadly adopted especially in the oceanic and atmospheric sciences, but there is still great variability. Some data are in closed proprietary formats (especially if they were generated with specialized commercial sensors) and there are thousands of variations of ASCII formats even within similar scientific disciplines. Open Geospatial Consortium data and image sharing protocols (WMS/WFS/WCS/KML) are broadly used by many disciplines and form the foundation of the emerging Arctic and Antarctic Spatial Data Infrastructures. The Open-source Project for a Network Data Access Protocol (OpeNDAP) is also used for sharing data and provides network interfaces to data within several tools (e.g. MATLAB, Ferret), but is mostly used within the oceanographic community.

3. *Data should be well-described so as to be useful for a broad audience.*

Assessment: ★☆☆☆☆

The IPY Data Policy required detailed documentation and adoption of formal metadata standards. Standards have been more broadly adopted, but detailed documentation is still lacking for most data.

Discussion

Wikipedia defines interoperability as "a property referring to the ability of diverse systems and organizations to work together (interoperate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system to system performance." In the IPY, with its interdisciplinary focus, interoperability also includes the ability of scientists to effectively access and use data from disciplines in which they are not expert. This suggests that IPY needs to consider the broader definition of both technical and social interoperability. We discuss many of the social and political issues elsewhere. Here, we focus primarily on technical and organizational issues, and use a more narrow definition from the Institute of Electrical and Electronics Engineers (IEEE)[2]: "the ability of two or more systems or components to exchange information and to use the information that has been exchanged."

From this perspective, interoperability often revolves around the organization and completeness of metadata, the structure of the data itself, and the availability and use of tools used to discover, assess, access and manipulate the metadata and data. We, therefore, consider technical interoperability at several different levels or stages of the data flow.

Data submission

Earlier, we discussed some of the social issues restricting data submission. In addition, we need to consider the difficulty and cumbersomeness of formally describing and submitting data to an archive. Investigators need practical methods to publish their data. Several nations have created specific data systems to handle IPY data and have provided tools and assistance to help investigators describe and submit their data and documentation. Some countries conducted data provider workshops to educate providers on the importance and mechanisms for data publication. Provider training has proven to be very effective at improving both the quantity and quality of data submissions, but it is vital to have clear and explicit data submission instructions and tools. IPY data centers should continue to develop and improve tools for investigators to easily describe and submit their data from the field and the lab. They should provide specific instructions or "cookbooks" to help data providers meet their policy obligations.

Where applicable, data centers should share these tools and also coordinate instructions, metadata schemas and content to make processes similar across disciplines and locations. This will aid with data discovery and assessment across centers. The Polar Information Commons is one attempt at harmonizing data submission that seeks to enable highly distributed, cloud-based data distribution and discovery through XML-based broadcasts of basic RDF-structured metadata. It builds on the principles of open, linked data to reduce dependency on centralized registries and ultimately to make barriers to sharing as low as possible. Polar data centers should use and re-purpose PIC tools to broadly expose their data.

Data discovery and assessment

Finding and making sense of diverse IPY data is a significant challenge, even with powerful search engines such as Google. Search engines and data portals rely on sufficient, consistent metadata to assess relevance, rank listings and narrow searches, especially for specialized items like scientific data. Current practice is to create portals to data set description catalogs or registries that contain consistently formatted metadata, increasingly with a direct link to the online data and an automated request scheme for off-line data.

IPY has resulted in a number of data catalogs, both at the national and international level, including the overarching IPY metadata portal at GCMD. There are multiple different metadata formats and vocabularies in use by these catalogs. This complicates both the submission as well as the use of these catalogs. The Data Committee defined an IPY metadata profile that being used at several IPY data centers and at the GCMD. The profile needs to be extended and cross-walked to the ISO19115/19139 standard, which is emerging as the most broadly mandated geospatial standard.

As a result of IPY, several data centers have established pilot projects to exchange metadata records using the IPY profile and the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH). Metadata from centers in Canada, Norway, Sweden, the U.K. and the U.S. are directly provided to the GCMD. In addition, certain projects will provide more specialized discovery services on subsets of the data. For example, there is collaboration between the European Developing Arctic Modelling and Observing Capability for Long-term Environment Studies (DAMOCLES) project and the U.S. Arctic Observing Network (AON) to share data, not just metadata, between their respective data systems. This is the beginning of the "IPY Union Catalog" outlined in the 2006 Cambridge Workshop. More data centers need to adopt the IPY profile and join the union catalog to provide both a central and specialized portals to distributed data.

The greatest challenge for data centers in adopting the profile is adhering to the required GCMD science keywords. In some cases, the keywords may not adequately describe certain data types and disciplines (e.g. indigenous knowledge) or data centers may have adopted other vocabularies more specific to their discipline (e.g. oceanography). Much more work needs to be done in this area of semantics to develop more complete vocabularies and taxonomies, crosswalks between them and potentially even structured ontologies. The interdisciplinary data and use cases produced by IPY can be the starting point for funding agencies to support more semantic research, applications and communities of practice around polar research.

Data access

Data discovery, without actual access, is not very useful so it is critical that data catalogs include direct links to the exact data described. Too often, metadata registries only provide an e-mail contact or a link to another search engine that may then permit actual access to the data. Data providers must work with data centers to make all digital data available online and data centers must provide direct links to that data in their shared metadata records.

The pre-IPY and, in many cases current, situation is that there are many data centers holding data in many different formats without much uniformity or standardization. The data may or may not be fully described; this is necessary to enable the user to judge the quality and fitness for purpose of the data. As a result, it is almost impossible to get an overview of data holdings. If the user does get access to the data, the user has to convert formats and do much data manipulation before being able to use the data. Many users may easily spend more than half of the time of a project trying to locate, obtain and convert data, instead of doing science. The situation becomes even more problematic if one tries to find and use data across disciplines in an interdisciplinary research project.

IPY has demonstrated geospatial interoperability, primarily through Open Geospatial Consortium (OGC) protocols, WMS, WCS and KML in particular. The Senior Arctic Officials of the Arctic Council recently approved the Arctic Spatial Data Infrastructure, an initiative that grew out of two IPY data conferences that invited all Arctic national mapping agencies to provide topographic data openly through OGC protocols. In the Antarctic, the Standing Committee for Antarctic Geospatial Information (SCAGI) is already serving topographic data through OGC protocols from the Antarctic Digital Database. In addition, KML was widely adopted by many IPY projects as an easy way to display diverse data in a three-dimensional context. Nevertheless, there is a great disparity of formats for IPY data.

Data centers and science communities need to work together to identify a small set of well-defined formats. These formats must be well-described, open source and function independently of platform and operating systems. Self-describing formats, which include descriptive metadata embedded in the data file, are especially useful. Some disciplines in the IPY have had some success standardizing around NetCDF, with Climate Forecast (CF) extensions, and tools are increasingly available to convert formats. No one format is going to work for all disciplines or applications so data centers need to be flexible and provide data in multiple formats, especially self-describing formats.

Much IPY data is in simple ASCII text formats. ASCII is a useful, sustainable, highly portable, human readable format, but it can be problematic. It is so flexible that data can be represented in many specific implementations. These implementations are what most generally consider the data format. They can be very general like XML or can be very well-defined, such as a precise tabular layout relating to data from a particular instrument. There are literally thousands of ASCII formats used to described polar data with great variability even within disciplines. Science communities need to recognize that interoperability begins at the time of data collection. It starts with using the same protocols and measurement techniques, which can, in turn, drive data formats. Funding agencies should support community workshops to harmonize techniques and formats within disciplinary communities. In one example that grew out of IPY, Fetterer (2009) describes a community attempt to define data management best practices for sea ice field measurements.

Data use

Perhaps the greatest value of data lies in its reuse, now and by future generations of scientists. Much of what we have already discussed in terms of metadata, semantics, and formats also improves the usability of the data. It is also important to have comprehensive documentation for each data set to enable non-expert use and to avoid misuse. Data centers and scientists need to collaborate to produce accurate documentation. It is especially important to explicitly describe data uncertainties (Parsons and Duerr, 2005). Data centers should formally engage users to advise on the presentation, documentation and appropriate application of the data while recognizing that no one group can represent all interests. Where possible, make use of the English language within data and documentation, to ensure the broadest international use.

Preservation

Objectives

1. *All raw IPY data should be preserved and well-stewarded in long-term archives following the ISO-standard Open Archives Information System Reference Model (ISO, 2003).*

Assessment: ★☆☆☆☆

Plans for the *long-term* management of IPY data are even worse than what is shown in Fig. 3.11-1. Many disciplines do not have long-term archives. Long-term, archival standards are still evolving and adherence to good practices is highly variable cross projects and disciplines. Beyond ongoing government commitment in some disciplines, no clear and sustainable business models have emerged to support long-term data stewardship.

2. *Data should be accompanied by complete documentation to enable preservation and stewardship.*

Assessment: ★☆☆☆☆

Most documentation is *ad hoc* and largely geared towards discovery. Some guidelines on documentation have been developed on a disciplinary or project basis, but some issues, such as describing detailed and ongoing provenance, have not been resolved in the general archiving community.

Discussion

"In fifty years time the data resulting from IPY2007–2008 may be seen as the most important single outcome of the programme."
(Rapley et al., 2004)

Because much IPY data collection has only recently been completed, it is hard to assess progress in data preservation at this stage. Nonetheless, the IPY data policy emphasized that data preservation should be considered during project planning. We can, therefore, look to the data management plans of each project to assess the readiness of IPY data to be preserved appropriately. As discussed already, it appears that only 30 projects have adequately considered long-term preservation. This leaves 94 IPY projects collecting data without clear plans or resources for archiving their data and it has been a challenge to simply identify all the IPY data collected, let alone ensure they find their way to secure archives. The data coordinators listed in Table 3.11-1 have been essential in this effort, but their level of ongoing support and activity is highly variable and many will not continue in their role as a national IPY data coordinator beyond 2010. All told, there is deep concern about the likelihood of being able to adequately preserve much of the IPY data legacy.

Many may have assumed that the ICSU World Data Centers (WDCs) would be the natural home for much IPY data since they were established to manage the data collected during the IPY's predecessor, the International Geophysical Year (IGY). In retrospect, that seems unrealistic and may reflect the perspectives of the IPY data planners who largely came from physical science disciplines. Certain WDCs have contributed in developing an IPY data system, but the WDCs as a whole have not been a central or leading force for IPY data management. As ICSU President, Catherine Bréchignac, noted in her remarks at the IPY 'closing celebration' in Geneva, "an unfortunate but crucial impact of IPY was to help expose weaknesses in the current collection of WDCs and it is hoped that the new World Data System (WDS) will better serve polar science in the long run by growing a true data network." Parsons (2009) provides further "Observations on World Data Center Involvement in the International Polar Year" and although critical issues need to be resolved, we still look to the emerging WDS as the long-term IPY data archive. This is in keeping with the recommendations of the ICSU ad hoc Strategic Committee on Information and Data (ICSU, 2008) and the charters of both the WDS and its sister advisory body, the ad hoc ICSU Strategic Coordinating Committee for Information and Data (SCCID). Both bodies see IPY as a critical test case.

Many of the issues already discussed above have direct impact on data preservation, but critical issues can be summarized as follows:

- Only a small proportion of projects completed data management plans to identify long-term repositories for their data.
- Identifying data sets, especially research collections, and obtaining metadata remains a large challenge and many projects have still not provided any

metadata.

- Many national and international data centers have not been engaged in IPY data preservation.
- Many investigators are unclear about their data preservation responsibilities or where they should submit their data. In many disciplines, long-term archives simply do not exist.
- There is no comprehensive data preservation strategy reaching across disciplines and nations.
- There needs to be a way to preserve the tools, systems and ancillary data that have been developed through IPY.
- Preservation description information (ISO, 2003) is generally lacking, especially detailed information about provenance and context.

Two general causes underlie these issues:

a) the ability and willingness of scientists to invest time to prepare data for preservation, and

b) sustained resources for data centers to preserve IPY data and ensure coordination across these centers.

Ability and willingness of scientists to prepare data for preservation

Scientists need incentives to share and describe their data and to adhere to relevant data strategies and policies. Incentives can include both rewards and punishment or "carrots and sticks." Incentives for investigators should include recognized data citations and increased value of data through easier data integration and analysis. Experience in IPY and SCADM has shown the most effective enforcement mechanism is through funding mechanisms that either withhold some funding or reduce the ability of scientists to obtain future funding opportunities if they do not adhere to the data policy. At the same time, data centers need to provide tools and guidance to make data submission to archives as easy as possible.

Ultimately, long-term preservation needs to be a consideration throughout the entire scientific process. This requires a major shift in some of the institutions of science. Universities need to include data management instruction as a core requirement of advanced degrees. They should consider data publication and stewardship equally with journal publication in conferring degrees, advancement and tenure. Scientific journals and reviewers must also demand clear citation and availability of any data used in a peer-reviewed publication.

Sustained resources for preservation

An obvious major issue with data preservation is having appropriate long-term repositories. Even though there are many IPY data centers, many disciplines do not have discipline-based data centers at all. Currently only 13 IPY projects are being actively supported in data preservation by World Data Centers. Clearly, as recommended elsewhere, IPY data preservation should be a major focus of the renewed World Data System that ICSU is developing.

Data preservation requires resources. There is a need for new business models that can provide sustained support for dynamic and evolving scientific data. We are encouraged by efforts around their world, such as the U.S. NSF DataNet program, the European Commission e-Infrastructure initiative and the Australian National Collaborative Research Infrastructure System that work toward these sustainable models. The experience from IPY is that data preservation is most successful when nations commit program resources to data management and coordination, and provide an explicit repository for preservation. Future polar programs should be supported by an early commitment of resources for data management and coordination. This support should include resources for repositories to cover all disciplines included in the program. Funding for national and international data centers is often uncertain; as a result, they have limited ability to support new programs.

IPY was very interdisciplinary, but science data stewardship in the past has been primarily discipline focused. To fully support programs such as IPY, it is vital to ensure that all disciplines have well-funded permanent data repositories and to encourage these repositories to collaborate and support interdisciplinary work. Nations should fund archives to fill disciplinary gaps and require archives to work together on standards and interoperability as a contingency of their funding.

Another important issue identified through IPY is the lack of an overall consistent strategy for all polar data preservation. It will take much more discussion across disciplines and data centers to develop this strategy, but as an example, IPY data and information could be divided into five broad categories:

1. Project management information, project background and administrative documents
2. Raw data, metadata and documentation (including a proper citation)
3. Processed data, revised metadata and documentation (including updated citation)
4. Data outputs, derived products and tools
5. Publications

By dividing the data and information into categories, we can begin to define consistent retention schedules across disciplines for IPY legacy. Each retention schedule will be defined by asking the question of "what would be useful in the future". This may then lead to some categories only being kept for the short-term and others, such as raw data, being kept in perpetuity. It is vital to remember here that data are only useful if fully documented and are even more valuable with contextual information, therefore, those factors will also have to be considered when deciding on the retention schedules for each of these categories of data and information. IPY sponsors need to establish a forum, probably within the International Arctic Science Committee (IASC) and SCAR, for developing a comprehensive polar data preservation strategy. This strategy must include a data acquisition component to acquire IPY data that have not been securely archived. The development of this strategy should be closely coordinated and allied with the PIC, WIS, and WDS implementation.

Coordination and Governance

Objectives

1. Identify, evolve, or develop a sustained virtual organization to enable effective international collaboration on data sharing, interoperability and preservation.

Assessment: ★★☆☆☆

Antarctic data issues are coordinated through SCADM, SCAGI and the recently endorsed *SCAR Data and Information Management Strategy* (Finney, 2009). The Arctic has no overarching data strategy or focal point. Furthermore, polar issues (unique phenomena, extended darkness, complex logistics, polar projections, etc.) need to be better considered in global data organizations such as GEOSS, WIS and the evolving WDS.

Discussion

To address all of the issues discussed so far and to maximize the legacy of IPY, it is imperative to have a governance mechanism. Good governance will help develop preservation strategy, coordinate policy, agree on common standards and develop interoperability agreements to enable broad interdisciplinary data discovery. The IPY process has provided the scientific research and data management communities many opportunities to learn lessons on scientific data management for a multidisciplinary, multijurisdiction program. In general, having a dedicated coordination body, with national representatives for data management, has proven to be a very important aspect of the success of the IPY program. As well, having dedicated data coordinators in countries involved in IPY has been critical. These coordinators also need to have sufficient authority to apply the requirements of the data policy to the research.

It is also useful for this coordination body, in this case the IPY Data Management Committee, to have resources to hold national and international meetings and workshops. These workshops are important to develop common understanding and to develop broad buy-in for the overall data strategy, specific tactics and protocols related to data management.

The governance and coordination of polar data management is an important activity that needs to be continued. At the same time, it is recognized that many existing global and national data committees and systems exist. There is little appetite to create a new international coordination body that may be redundant with existing bodies. Rather than establishing a new international organization dedicated to polar scientific data management, we seek a governance structure that integrates polar data and the unique issues around polar data into existing global data systems, virtual organizations and governing bodies. That said, IPY revealed that these bodies do not currently address the needs highlighted by IPY. These needs include broad interdisciplinary collaboration, monitoring of unique polar phenomena (e.g. sea ice) in conditions that challenge remote and in situ sensing methods, extensive use of diverse research collections even in operational context, complex logistical support, geospatial tools optimized to handle polar projections and representations, etc.

A major initial focus of this governance structure will be to formally transition the activities of the IPY Data Committee and IPYDIS into relevant international data structures and organizations.

Members of the IPY Data Committee have proposed a new CODATA Task Group to help plan this transition, but SCAR and IASC are the most logical organizations to provide leadership in this area. Antarctic data issues are coordinated through SCADM and SCAGI and are guided by the *SCAR Data and Information Management Strategy*. The Arctic has no overarching data strategy or focal point. The Arctic Council has shown leadership in certain areas, such as in the Arctic Monitoring and Assessment Programme (AMAP), and by endorsing and initiating the Arctic Spatial Data Infrastructure, but this only represents a subset of polar data. Furthermore, Arctic data are collected by many nations outside of the Arctic. IASC, which has broader international representation, still lacks any sort of data coordination body. The Sustained Arctic Oberving Network (SAON) process *(Chapter 3.8)* has provided an opportunity and has consistently considered data sharing issues, but it remains unclear how data issues would be coordinated under SAON.

Both SCAR and IASC have benefited from their increased coordination during IPY. They must continue coordination over data policy and governance issues. SCAR and IASC must also consider global connections and work to be actively engaged and directly represented in the development and implementation of the WDS, WIS and GEOSS. National data coordinators need to have sufficient authority to implement recommendations and sufficient time to dedicate to the initiative.

The following are some critical governance and coordination issues that must be addressed:

- Disciplines must achieve better integration on standards and exchange protocols. The strength of IPY was the multidisciplinary nature of the research. This also exposed many shortcomings in terms of integration of research and results, particularly between disciplines with differing approaches to data and data management. There is much to be gained by having better integration of data across all disciplines of a given project; more meaningful results, better understanding of processes and the resulting science questions, and exchange of techniques and knowledge transfer among team members.
- IASC must develop a data policy and strategy considering the existing SCAR strategy while ensuring input from social and health sciences. IASC and SCAR must ensure their data policies and strategies work in harmony. Consistent international data policies are important in ensuring that requirements of project participants are well understood and not open to interpretation based on jurisdiction. In addition, consultation among the physical, health and social sciences should occur to harmonize the unique data management requirements for each discipline. CODATA and the Polar Information Commons are important partners in this area.
- Networks established by IPY must be maintained to continue and enhance information flows among groups, nations and organizations. The formal and informal networks established during IPY are valuable resources and should be maintained if possible. The communication among groups through these networks has been beneficial in moving the agenda for data management forward. Future polar data management will involve well-connected groups that will form a web connecting communities of practice, international networks, national organizations and intergovernmental organizations.
- The IPY community must develop and sustain sufficient data infrastructure. An important lesson learned from the IPY process is that there needs to be sufficient pre-existing infrastructure to support the requirements set out in the data policy and that data strategies need to address infrastructure gaps and development plans. Many countries found that the researchers were willing to abide by the IPY data policy and submit their data to an archive only to discover that no relevant archive existed.

Summary and Conclusion

The IPY has provided an excellent case study of data management for an intensive, international and highly interdisciplinary project—the sort of project that will increasingly be needed to understand and address grand societal challenges, such as rapid climate change. IPY revealed a critical global need for better planned, funded and integrated data management, but this is not a new revelation. Important assessments, such as the ICSU Program Area Assessment (ICSU, 2004), the SCAR Data and Information Management Strategy for Antarctica (Finney, 2009) and even the IPY's own framework document made clear recommendations on how to address integrated data management. Therefore, another grand challenge is to recognize the value of data management, act on these recommendations and fund the full data life cycle, especially advance planning and long-term preservation. IPY data centers need to provide clear direction and the science community at large needs to move more rapidly toward a culture of open data to truly realize the benefit of the large and diverse IPY data collection.

This report outlined IPY overall performance against key objectives. The results are summarized in Table 3.11-2. The discussion sections also included many specific recommendations, many of which parallel those in existing reports. Rather than recount all the details here, we provide a summary of actions that different IPY stakeholders should take in the short-term to ensure the availability and preservation of IPY data and actions that, over time, work to develop a sustained polar data system. Stakeholders include IPY investigators and the general polar science community, the international sponsors of the IPY (ICSU, WMO, IASC and SCAR), the national funding agencies that made IPY a reality and the data centers working to support IPY.

IPY investigators and the scientific community

In the short term: IPY investigators must publish their data immediately in an appropriate archive. Published data should include full documentation, including detailed descriptions of data uncertainty and appropriate use. What constitutes "complete documentation" is variable across disciplines and user communities, but the U.S. Global Climate Change Research Program (1999) provides sensible guidelines. Digital data should be in an open, non-proprietary format, ideally a standard, self-describing format used broadly within their discipline. Where possible, data should be fully in the public domain and free from restriction. Data authors should also provide basic discovery-level metadata to the GCMD or appropriate national registry including a direct link to online data. If no appropriate archive is available, investigators should seek guidance from their funding agency or consider publishing the data within their own institution. Regardless of where the data are archived, investigators should still register their data in the GCMD or a national registry.

Over time: The overall scientific community needs to recognize the value of good data stewardship in order to create consistent time series and to speed and maximize data reuse. Data publication should be formally recognized and promoted. Scientific journals and reviewers must demand clear citation and availability of any data used in a peer-reviewed publication. Universities, government agencies and scientific institutions in general should consider quality data publication and stewardship as equal to journal publication when conferring degrees, advancement and tenure. To foster this culture change, universities need to include data management instruction as a core requirement of advanced degrees.

International sponsors

In the short term: ICSU, through the World Data System, must lead an aggressive initiative to ensure all IPY data are in secure archives by June 2012. The initiative must include an active data rescue program to identify and preserve unavailable IPY data with a special focus on data from the life and social sciences. The WDS must be an active partner in the Polar Information Commons to ensure that valuable data shared through PIC mechanisms end up as well-curated collections in secure archives. ICSU and WMO must be strong and determined voices on the need to fund ongoing data stewardship.

IASC must develop an effective and pragmatic data strategy to ensure active pan-Arctic data sharing and collaboration. The *SCAR Data and Information Management Strategy* (Finney, 2009) provides an initial blueprint while IASC and SCAR collaboration on data issues must continue in a real and tangible way. It is telling that there is still no focal point for coordinating Arctic data management. SAON may provide an initial focus and is a logical leader of an initial pan-Arctic data strategy, but it is important that this strategic

Table 3.11-2. Summary assessment of how well the IPY performed against specific data management objectives.

Objective	Assessment
Data Sharing and Publication	
Data should be accessible soon after collection (online wherever possible) in a discovery portal such as the GCMD.	★★★
Data users should provide fair and formal credit to data providers.	★★
Interoperability	
Metadata should be readily interchangeable between different polar data systems to enable data discovery across multiple portals.	★★★
Data from different projects, disciplines and data centers should be easily understood and used in conjunction with each other in standard tools and analysis frameworks.	★★
Data should be well-described so as to be useful for a broad audience.	★
Preservation	
All raw IPY data should be preserved and well-stewarded in long-term archives following the ISO-standard Open Archives Information System Reference Model(ISO 2003).	★
Data should be accompanied by complete documentation to enable preservation and stewardship.	★★
Coordination and Governance	
Identify, evolve or develop a sustained virtual organization to enable effective international collaboration on data sharing, interoperability and preservation.	★★

effort extend beyond the Arctic Council to include all nations collecting data in the Arctic and to address research data, not just data gathered from observing networks. The proposed CODATA Task Group will help address some of these issues, but IASC must be dedicated to making work. Finally, IASC, SCAR, ICSU and WMO must aggressively work to ensure polar issues are addressed in global data systems, notably the WIS, GEOSS and WDS.

Over time: ICSU and WMO must continue to lead the global discussion to harmonize data policies to promote openness as rapidly as possible, while recognizing legitimate, moral restrictions. These restrictions should be extremely limited and not include commercial or proprietary restrictions of publicly-funded data. Data should be shared under the least restrictive terms possible and be fully in the public domain wherever possible.

ICSU and WMO must include a detailed and funded data management plan as an integral part of any future scientific initiative they lead. The value of advance planning and support cannot be overstated.

National funding agencies

In the short term: National funding agencies must support data archiving and insist that data from projects they fund be archived. Agencies must create new archives where appropriate archives do not exist, ideally in collaboration with the WDS and other countries. Nations should also maintain (or establish) national IPY data coordinators for the next three years to help ensure all IPY data are identified and archived. These coordinators should be supported to participate in international coordination activities.

Research funding agencies should take advantage of the interdisciplinary use cases generated by IPY science questions to support activities that improve interdisciplinary data management and interoperability. This support could be for workshops around certain issues of interoperability (e.g. common metadata content and data formats), the development of communities of practice or fundamental research on semantic and data visualization approaches to aid interdisciplinary data use. IPY created unique interdisciplinary data management challenges that also present opportunities.

Over time: Funding agencies should collaborate with ICSU and WMO in the establishment of consistent open data policies. Agencies also need to develop consistent data strategies that include enforcement mechanisms to ensure data policies adherence. The IPY experience suggests that the most effective enforcement mechanism occurs when funding is linked to policy adherence.

Data Centers

In the short term: Data centers must develop partnerships with other data centers in other countries and other disciplines to enhance data accessibility and interoperability. Data should be exposed through common open protocols and web services (e.g. OGC) and be available in multiple standard formats. Data centers must adhere to the IPY metadata profile and share their metadata with GCMD and other relevant data portals and systems (e.g. WIS).

Over time: Data centers should partner with their scientific community. They should work with their community to meet user needs and demonstrate the value of submitting data by making the data more accessible, useful and integrated with other data. They should assist data providers by providing tools, documentation and assistance to help providers document and publish their data. Data centers should encourage proper credit for data providers by providing citation recommendations for all data sets.

IPY pushed polar science to new level of interdisciplinary collaboration. This collaboration was perhaps IPY's greatest success, but truly capitalizing on this success requires that the data collected during IPY be readily discoverable, useful and preserved. IPY highlighted critical data management issues, fundamental strategic differences in Arctic and Antarctic data management and how interdisciplinary science can challenge some assumptions of data management institutions. At the same time, the global scientific community increasingly recognizes the need for open data linked across borders and disciplines. This recognition is evident in everything from a special *Nature* issue on data sharing (461:7261) and the rapid growth of informatics foci in some scientific unions to major data initiatives, such as the U.S. DataNet program and the European Inspire program. The polar science community must take advantage of their renewed collaboration and the international enthusiasm to ensure the most significant IPY legacy – the data.

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Notes

1 Note JCADM was a joint committee between SCAR and the Council of Managers of National Antarctic Programs (COMNAP) but formal links with COMNAP ceased in January 2009 and JCADM became a SCAR Standing Committee and was thus renamed the Standing Comittee on Antarctic Data Management (SCADM).

2 Institute of Electrical and Electronics Engineers. IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. New York, NY: 1990.