Chapter 3.17

Integrated Sea Ice Observation Programs

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3.17.1 INTRODUCTION

This chapter highlights two integrated and interdisciplinary observation programs from opposite poles: first, a "permanent" coastal sea ice observatory along Alaska's arctic coast at Barrow, and second, the Ice Station Polarstern's drift in the Antarctic's Southern Ocean. Here the term *integrated* refers to efforts to bring together data from different instruments, methods, and disciplines, but importantly also efforts to interface disparate types of information and knowledge, as is especially the case in the first example where differences in epistemology are fundamentally important. In contrast to the Antarctic, research in the Arctic is increasingly acknowledging that the systems under investigation are often not remote at the edge of the earth, but rather are part of a social-ecological system which in most cases includes indigenous peoples. In both examples, however, this objective of integrated observations is to arrive at an improved understanding of the complexity of sea ice's role in supporting ecosystem services. Often, a scientific approach of addressing issues of complexity involves targeting spatial and temporal transitional boundaries. In the first example in the Arctic, the observatory targets the coastal environment, which is an area of dramatic transition as far as ice use, ecology, and sea ice dynamics are concerned. In the second example, it will be seen that placing the drifting camp at the transition between first- and second-year ice was of scientific as well as logistical importance. Periods when observations are scientifically most important and observation intensity is increased, such as during spring melt and breakup, present challenges in terms of resources and logistics, safety, and sampling strategies, as will be seen in this chapter.

The efforts presented here are the result of many people representing a diverse assortment of skills, experience, and knowledge. There are those who brainstormed the initial ideas, planned the programs, provided expert consultation, orchestrated logistics, labored in the field, interpreted results, and, perhaps most importantly, mentored the programs along the way. While it is impossible to give credit to each and every person involved in these programs, this chapter presents lists of contributors and primary funding sources at the end of each section, as well as a short compilation of relevant publications to serve as a resource for more information. Also, this chapter will refer to the techniques and methods discussed in the preceding chapters of this text, but will not go into much detail. In most cases, a cross-chapter reference is provided for accessing further information.

Other examples of integrated observation programs include the Surface Heat Budget of the Arctic Ocean (SHEBA) Project in 1997–1998 and the Ice Station Weddell (ISW) in the Weddell Sea off Antarctica in 1992. Both were interdisciplinary and international efforts to better understand the complex role that sea ice plays in the climate system.

3.17.2 COASTAL SEA ICE OBSERVATORY AT BARROW, ALASKA

In spring, the village of Barrow, Alaska, demonstrates the most significant use of sea ice by a local community as perhaps anywhere in the world. As bowhead whales migrate up through the Bering Strait to their summer feeding waters in the eastern Beaufort Sea, dozens of Iñupiat whaling crews stage a hunt from the shorefast ice of the Chukchi Sea. The development of a predictable flaw lead (see Figure 3.17.1) through which the whales migrate allows Barrow and a handful of other coastal Alaskan communities to partake in this traditional activity that utilizes the communities' rich body of local sea ice knowledge. Given that Barrow also has a long history of working with scientists to understand and monitor the arctic environment (Brewster 1997), it represents a microcosm for understanding how science and local knowledge in the Arctic can collectively examine questions related to environmental change and the associated impacts to ecosystem services or, in this case, sea ice system services.

Since the late 1990s, a sea ice observing effort has been maintained in Barrow, such that certain components of the observatory are now providing long-term data sets revealing trends in the timing of key events in the annual evolution of the seasonal coastal ice zone. The observatory location (see Figure 3.17.2) is ideal for a number of reasons. First, the local sea ice cover undergoes the full spectrum of sea ice's transitional processes to include most major ice types at different times of the year. Shorefast ice, which is typically present from November through July, is predominantly composed of first-year ice. Traces of multiyear ice are often found incorporated into the shorefast ice; however, this occurrence has become less frequent in recent years (Huntington et al. 2001; Drobot and Maslanik 2003)—a point of concern for local ice users who typically associate the multiyear ice with a stably grounded shorefast ice cover (George et al. 2004). While the coastline is exposed to open water from July to September, it is common to encounter drifting ice during

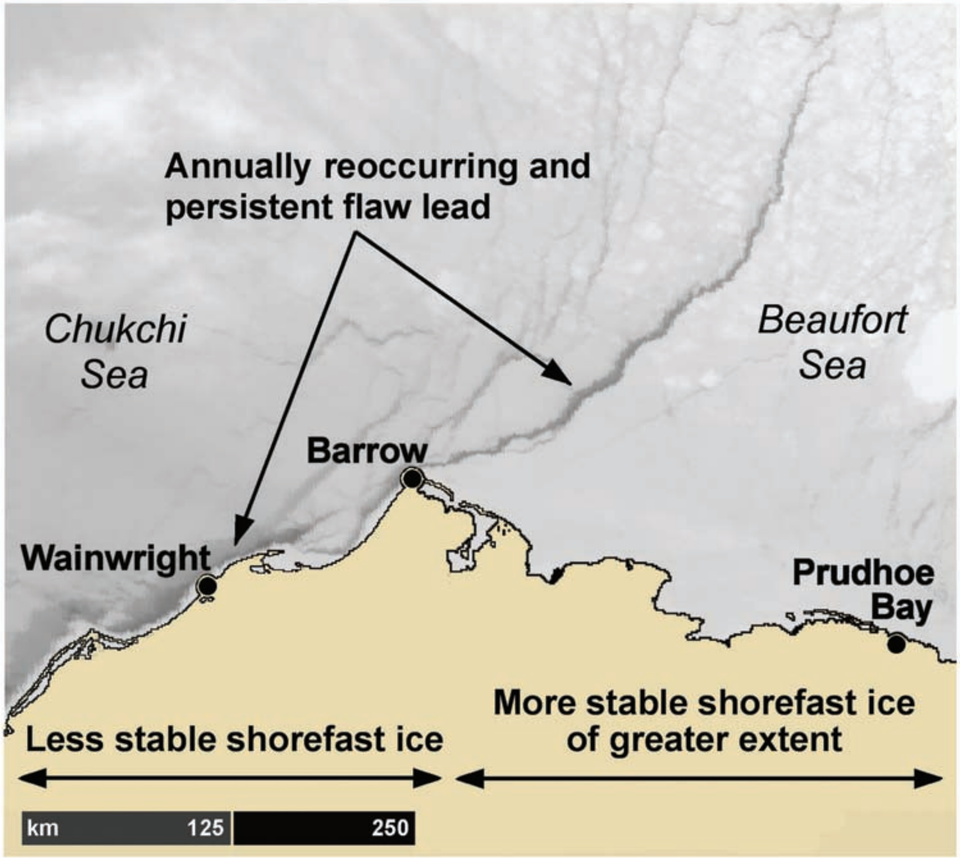

Figure 3.17.1. Alaska's northernmost Arctic coastline overlaid on an AVHRR satellite scene from 19 February 2004. An annually recurring and seasonally persistent flaw lead exists along Alaska's northwestern coast with the Chukchi Sea and extends into the Beaufort Sea. This lead provides local hunters consistent access to bowhead whales, which make use of this open water during their eastward springtime migration. Sea-ice dynamics in this region lead to relatively less stable and narrow shorefast ice along the Chukchi, while more stable shorefast ice of greater extent persists along the Beaufort coast (Eicken et al. 2006; Mahoney et al. 2007b). Barrow and Wainwright (populations of approx. 4500 and 500 respectively) are Iñupiat communities that practice spring whaling in the flaw lead. Prudhoe Bay is the origin of the Trans-Alaska Pipeline and a regional hub for near-shore and onshore oil and gas development, which typically conducts associated industrial activities from shorefast ice.

this time depending on proximity to pack ice and to areas of relatively late summer breakup (e.g., due to large grounded ridge remnants from the previous ice year). Second, the extensive list of both past and present studies in the area, ranging from coastal erosion to sea ice microorganisms to marine mammal habitat, provides broad opportunities to address questions related to the role of sea ice in supporting the current state of the ecosystem.

Following the 2000 Barrow Symposium on Sea Ice, which included bringing together a diverse assortment of sea ice experts from within and beyond the

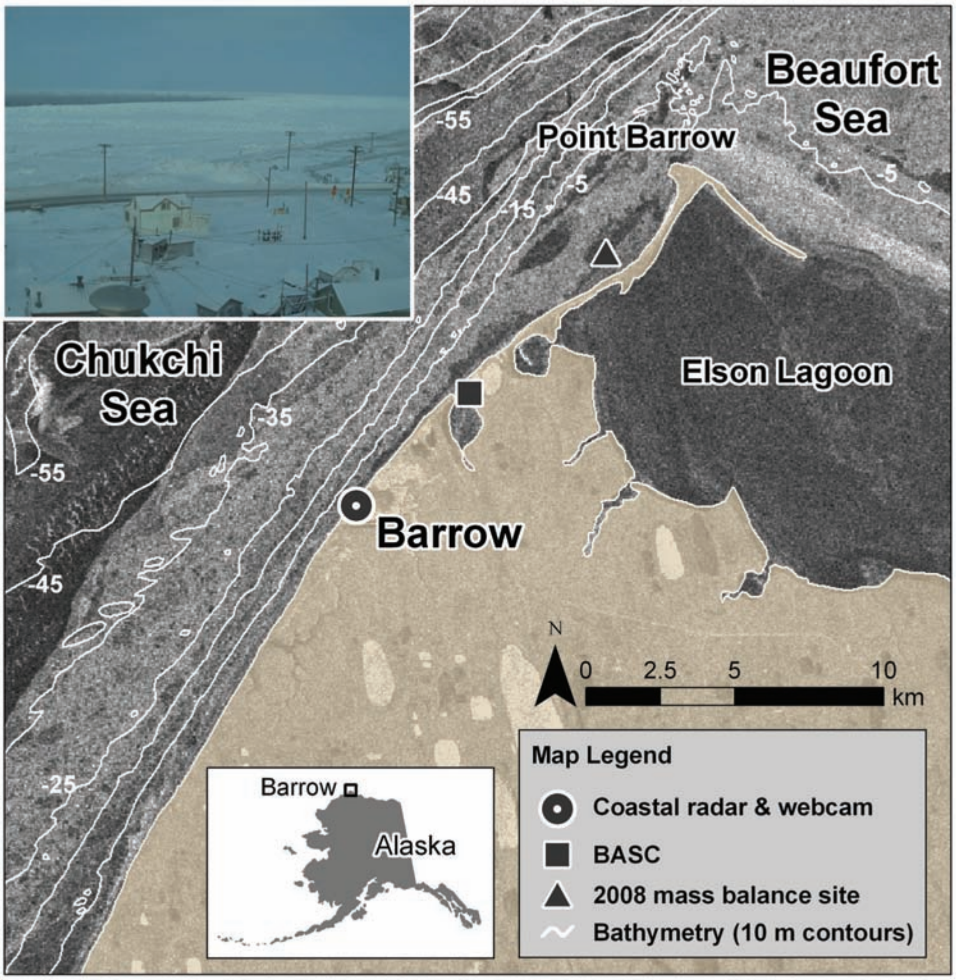

Figure 3.17.2. Map of the Barrow coastal sea-ice observatory overlaid on an ERS-2 SAR satellite scene from 22 March 2008. A winter image from the coastal webcam, which is mounted atop a four story building in downtown Barrow, is shown in the upper right corner. Field campaigns are staged from the Barrow Arctic Science Consortium (BASC), a few miles north of the village. This image shows the site of the mass balance site and sea-level gauge in 2008 located in level first year ice within the shorefast ice zone. The slight curvature of the Chukchi coastline immediately south of Point Barrow provides a semi-protected embayment of water less than 5 m in depth.

community (Huntington et al. 2001), formal collaborations with the North Slope Borough's Department of Wildlife Management and the Alaska Ocean Observing System (AOOS) and targeted exchanges with the scientific community (Hutchings and Bitz 2005; SEARCH 2005), the main focus areas for the observatory emerged:

1. Examine key events in the annual evolution of the ice cover, including such observations as the onset of freezeup, formation of stable ice, significant snowfalls, onset of bottom-ice melt, formation of melt ponds, and breakup.

2. Examine dynamic events within the shorefast ice zone, including ice shoves, shorefast ice breakout (or calving) events, and the building of ridges through interaction with adjacent pack ice.
3. Relate the above key and dynamic events to sea ice system services, with a focus on ice travel and subsistence activities.
4. Provide near-real-time data and information to the community both as a service and as a means to communicate observations in a collaborative manner such that related local observations and knowledge can be shared.
5. Collect a broad range of temporally and spatially resolved local-scale data sets to investigate cross-scale correlations with similar data sets at regional and pan-arctic scales.

In 1998 an ice core-sampling program began on the shorefast ice off Barrow to investigate ice growth history (Eicken et al. 2004) and was followed one year later by an annually deployed mass balance site to monitor in situ ice growth in level first-year shorefast ice (Grenfell et al. 2007). Shortly thereafter, a full-time coastal radar (see Figure 3.17.3) and webcam site (see Figure 3.17.2) was established to build upon earlier radar work by Shapiro (1976) to observe near-shore ice movement, deformation, and ridging. Throughout the years, ice thickness-profiling campaigns using electromagnetic induction sounding from the ice surface were performed to investigate shorefast ice morphology, including the anchoring strength of grounded ridges (Mahoney et al. 2007a; Druckenmiller et al. in press). The analysis of satellite imagery, such as thermal-IR and visible-range MODIS and AVHRR, synthetic aperture radar (SAR), QuikSCAT scatterometer, and passive microwave, has provided aerial perspective for ground-based measurements and a greater understanding for how these observations fit within the regional setting in terms of shorefast ice dynamics and morphology, pack ice interaction, and timing of key events in the annual ice cycle. Lastly, a local observer program was initiated in 2006 to provide near-daily sea ice observations from the perspective of the Iñupiat hunters and to assist in relating instrument measurements to sea ice use by the local community.

The different components of the observatory are summarized in Table 3.17.1, which lists the observed parameters, spatial and temporal coverage, as well as where further information may be found in this text on the various techniques. Much of the observatory's instrument data (radar, webcam, mass balance, and sea level) are transferred to the University of Alaska Fairbanks in near real time and made available on the Internet as the primary means of data dissemination to the public. Reviewing near-real-time data also allows for other components of the observatory to be responsive to seasonally evolving ice conditions. For example, ice coring and thickness measurements are scheduled to coincide with the onset of stable shorefast ice in winter, maximum ice thickness in midspring, and the onset of melt in

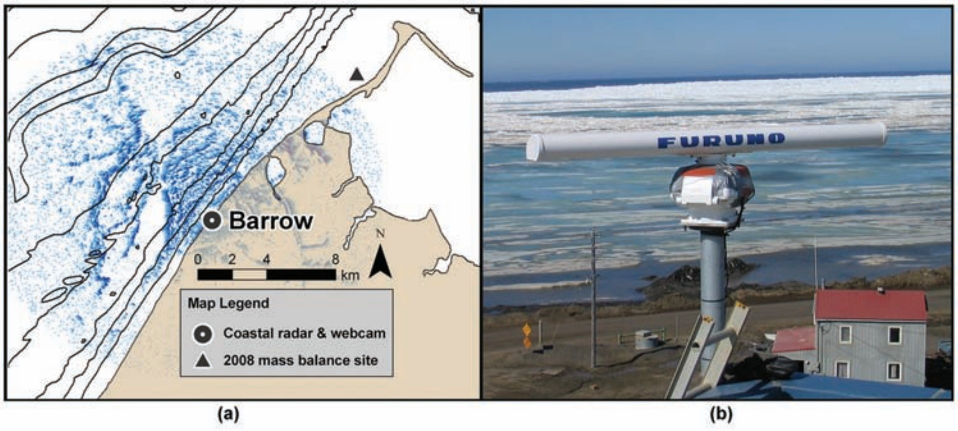

Figure 3.17.3. (a) Coastal radar image generated from backscatter from ridges, floe edges and other rough features in the near-shore during spring 2007. Areas of flat sea ice or calm open water do not generate sufficient backscatter to appear in these images. Radar images are archived every 3 minutes to be used in daily animations of ice movement to improve upon temporal and spatial resolution relative to satellite imagery. *View the multi-media CD for animations of spring time shorefast detachments.* **(b)** The Furuno FR-7112 10 kW, X-band (3 cm, 10 GHz) marine radar with a 1.65m open array positioned 22.5 m above sea level on a building in downtown Barrow (71°17'33"N, 156°47'17"W).

late spring. Depending on ongoing projects associated with the observatory, other measurements are typically performed (e.g., snow thickness, albedo, melt pond characterization, etc.). These efforts are further supported by satellite remote-sensing products made available online within hours of acquisition through various geographic information services.

Partnerships with local ice experts and the Barrow Whaling Captains Association (BWCA) have led to unique opportunities to understand how geophysically derived data sets compare with local observations and may be of value to community activities. Combining geophysical-based interpretations with the perspective of local ice users reveals the complexity of the coastal sea ice environment and the associated epistemological difficulties that a single observer may face. The knowledge of indigenous arctic residents is often described as originating from a close connection with the natural environment (Krupnik and Jolly 2002), and therefore acknowledges a greater level of interconnectedness within natural systems than does the reductionist approach of traditional scientific research. In the case of Barrow on the coast of the Chukchi Sea, local ice experts are keenly aware of the intricate coupling of the atmosphere, ocean, and ice, and how these three components annually interact to provide access to the marine life on which they subsist. Local observers in Barrow, such as Arnold Brower Sr. (2006–2007) and Joe Leavitt (2006–2009), report on near-shore ice conditions along the Barrow coastline and the associated impacts to travel, hunting, and marine mammal behavior, as well implications for the state of the ice later in the year. Their observations also help

Table 3.17.1 Components of the Barrow coastal sea ice observatory

Component	Observed parameters and processes*	Spatial coverage	Temporal coverage	Chapter reference
Satellite imagery	LF ice stabilization & extent, lead occurrence, ridging, MY ice concentration	Regional scale; dependent on sensor (resolutions typically >10 m)	Dependent on sensor (data acquired daily to monthly)	3.1
Coastal radar	Ice drift, LF ice stabilization, & breakout events, ridging	Within 6 km of coast	Updated online every 5 minutes	3.17, Figure 3.17.2
Coastal webcam	Presence of first ice, melt pond formation, snow cover, breakout events, open water	Within 2 km of coast, depending on visibility	Updated online every 5 minutes	3.17, Figure 3.17.3
Mass balance site	Ice thickness, snow thickness, water-ice-snow-air temperature profile, ice salinity	Point-based measurements at site on level first-year shorefast ice (see Figures 3.17.2 and 3.17.3)	Data updated online every 5 minutes	3.6 and 3.16
Sea level measurements	Tidal, storm surges, & wind-driven sea level fluctuations			N/A
Ice thickness & topography surveys	Ice thickness & surface elevation	Entire extent of LF ice off Barrow along approx. 20 km of coastline	2–4 campaigns throughout spring	3.6
Ice core sampling	Salinity and temperature profiles, sediment entrainment, stable isotope analysis, permeability, etc.	Point-based measurements, typically coincident with mass balance site	3–4 campaigns throughout spring	3.8
Local observations (journal entries & interviews)	Key events in the annual evolution of the ice cover, dynamic events, etc.	Typically within 20 km of Barrow, dependent on time of year & travel conditions	Near-daily journal entries; periodic interviews	3.3

** LF = landfast (or shorefast), MY = multiyear* to interpret how instrument-derived data sets of ice thickness relate to community assessments of ice stability. These perspectives often shed light on aspects of the observatory's strategy that either need strengthening or are missing. For example, discussions throughout past years have identified an existing data gap for local currents, which are routinely credited for destabilizing shorefast ice through thermal ablation of grounded ridge keels in late spring.

Most of the accumulated local sea ice knowledge that resides with the Iñupiat people of Barrow has some origin or relevance to the springtime hunt of the bowhead whale—a labor-intensive activity that successfully culminates in the catching of whales in open leads using traditional skin boats and hauling the catches onto the ice edge for butchering (see Figure 3.17.4). The cultural importance of accessing this subsistence resource from the ice edge in a safe and responsible manner requires constant evaluation of ice conditions. The proximity and drift direction of the pack ice and the strength and direction of winds and currents are critical. It is the responsibility of a whaling captain to ensure that all people involved in the hunt make it home safely from activities on the ice, which often extend as far as 10 km offshore. During this time of year, local observations made alongside the observatory's coincident measurements, especially those of the shorefast ice thickness distribution and sea level fluctuations, provide unique opportunities for understanding perspectives on shorefast ice stability as well as for cross-cultural data and knowledge exchange. In this context, these coordinated observations may be considered a strategic means for observing the unexpected. In his book *Hunters of the*

Figure 3.17.4. Iñupiat whalers from Barrow, Alaska butchering a bowhead whale on the shorefast ice following a successful spring hunt. (Photo by C. George)

Northern Ice, an account of two years living with the Iñupiat hunters of Wainwright, Alaska, Richard Nelson (1969) expressed his opinion on the breadth of their sea ice knowledge when he stated that "even those statements which seem utterly incredible at first almost always turn out to be correct." Partnering with qualified local observers enhances the observatory's ability to capture the increased uncertainty and variability often associated with environmental change in the Arctic. Arctic residents not only observe variability but maintain resilient lifestyles that continually cope with change (Krupnik and Jolly 2002; Duerden 2004).

It is not well understood how the satellite-observed retreat of pan-arctic ice extent since the late 1970s (Stroeve et al. 2008) correlates with observations of the seasonal ice zone at the local scale. For example, how reductions in multiyear ice near Point Barrow in the fall impact freezeup along the coast is an important question for local residents. In a study by Mahoney et al. (2007b) of shorefast ice along Alaska's northern coastline, it was discovered that climatologically the onset of thawing is occurring earlier in spring and freeze-up is taking place later in fall. However, in this study, the increasingly late fall formation of shorefast ice was shown to best correlate with the incursion of pack ice in near-shore waters. Fitting extensive local observations in context with broader regional and pan-arctic change, while considering potential future outlooks for local-scale sea ice system services, is one of the greatest contributions that may arise from continued measurements by the Barrow sea ice observatory.

For more information related to the type of measurements and observations performed at this sea ice observatory, explore the accompanying DVD, since much of its content has been produced near Barrow, Alaska.

Contributors: Arnold Brower Sr., Lewis Brower, Patrick Cotter, Matthew Druckenmiller, Hyunjin Druckenmiller, Guy Dubois, Hajo Eicken (Observatory Principal Investigator), Karoline Frey, Allison Gaylord, Craig George, Richard Glenn, Tom Grenfell, Jeremy Harbeck, Mark Johnson, Jonas Karlsson, Mette Kaufman, Joe Leavitt, Andy Mahoney, Don Perovich, Chris Petrich, Daniel Pringle, Lew Shapiro, Glenn Sheehan, Matthew Sturm, Christina Williams, Barrow Arctic Science Consortium, Barrow Whaling Captains Association, North Slope Borough Department of Wildlife Management, and many others

Primary sources of financial and logistical support: National Science Foundation, University of Alaska, Barrow Arctic Science Consortium, and the Alaska Ocean Observing System

Relevant publications:

"Ice motion and driving forces during a spring ice shove on the Alaskan Chukchi coast" (Mahoney et al. 2004)

"Hydraulic controls of summer Arctic pack ice albedo" (Eicken et al. 2004)

"Observations on shorefast ice dynamics in Arctic Alaska and the responses of the Iñupiat hunting community" (George et al. 2004)

“Sediment transport by sea ice in the Chukchi and Beaufort Seas: Increasing importance due to changing ice conditions?” (Eicken et al. 2005)
“How fast is landfast ice? A study of the attachment and detachment of nearshore ice at Barrow, Alaska” (Mahoney et al. 2007a)
“Thermal conductivity of landfast Antarctic and Arctic sea ice” (Pringle et al. 2007)
“Towards an integrated coastal sea-ice observatory: System components and a case study at Barrow, Alaska” (Druckenmiller et al. 2009)

3.17.3 ICE STATION POLARSTERN (ISPOL): STUDY OF PHYSICAL AND BIOLOGICAL SEA ICE PROCESSES AND INTERACTIONS IN THE WEDDELL SEA, ANTARCTICA

Although only a few humans live in Antarctica, services provided by sea ice (Chapter 2) are just as important as in the Arctic. Many arctic sea ice service aspects apply as well in the Antarctic, and some could be even more important due to the close interrelation of sea ice and ice shelves, and due to the persistence of at least landfast ice throughout the summer along the coasts of the continent proper. Sea ice is used as a loading platform for resupply of research stations and a landing platform for airplanes, for example, at the U.S. station McMurdo. However, it is also an impediment for resupply ships and for the increasing number of cruise ships visiting the continent every summer.

The climate-related regulating services of antarctic sea ice might even be larger than in the Arctic, as the seasonal variability of ice extent is much larger, with most ice disappearing during the summer. The Southern Ocean and particularly the coastal polynyas and ice shelf regions are some of the most important sources of cold, deep ocean waters worldwide and drivers of the global thermohaline circulation. However, climate models fail to realistically simulate summer ice extent in particular. This may be related to insufficient representation of some of the most striking differences between arctic and antarctic sea ice, which are the occurrence of widespread flooding due to large snow/ice thickness ratios, the absence of melt ponds, contrasting seasonal cycles of microwave properties seen by satellites, and the slow increase of antarctic sea ice extent over the past three decades. These differences are the result of a relatively thick snow cover compared to the Arctic, and of generally different climatic conditions dominated by the proximity of the cold and dry antarctic ice sheet and the remoteness from other continents.

In addition to these regulating services, antarctic sea ice is an important habitat and supports high standing stocks of bacteria, algae, and zooplankton, as well as large abundances of krill, birds and penguins, seals, and whales. One of the most striking habitat-related features is the development of porous gap layers close to the ice surface during summer (Figure 3.17.5) (Haas et al. 2001; Ackley et al. 2008), which are well supplied by nutrients and light and where record concentrations

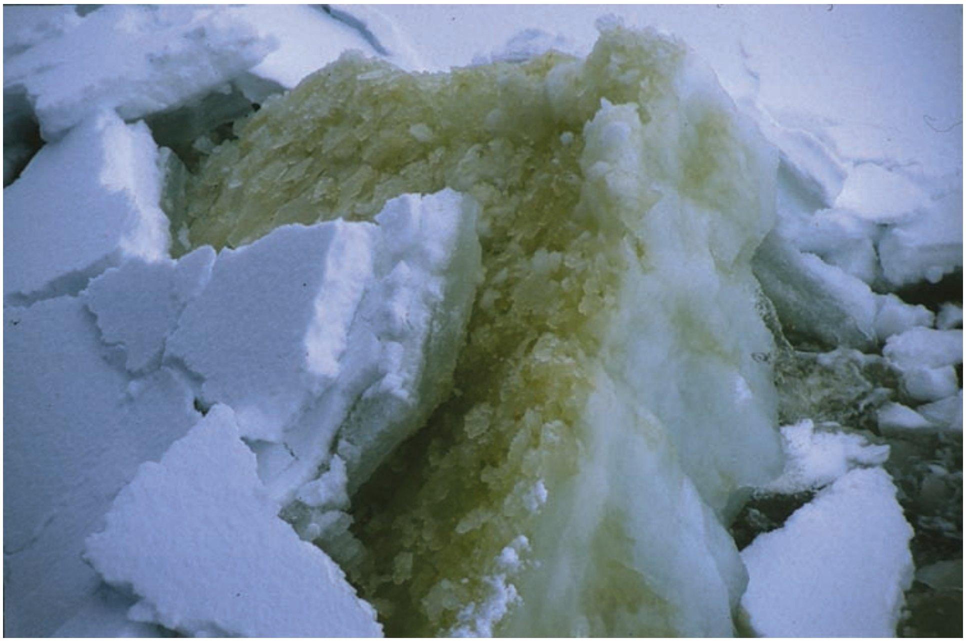

Figure 3.17.5. Photograph of a broken ice floe tilted by an icebreaker, showing the layered and porous structure of Antarctic sea ice in summer. Green and brownish discolorations are the result of high standing stocks of algae and other organisms.

of chlorophyll and particulate and dissolved organic matter have been measured (Thomas et al. 1998).

In order to improve the understanding of those physical and biological properties and processes at the beginning of summer and their relation to meteorological and oceanographic boundary conditions (see Figure 3.17.6), an international, interdisciplinary team of scientists conducted the Ice Station Polarstern (ISPOL) drift station project in the western Weddell Sea (Figure 3.17.7) (Hellmer et al. 2006).

Figure 3.17.6. Logo of the Ice Station Polarstern (ISPOL) drift station project, which studied physical and biological properties and processes on one ice floe at the beginning of summer in dependence of meteorological and oceanic boundary conditions (red and blue arrows).

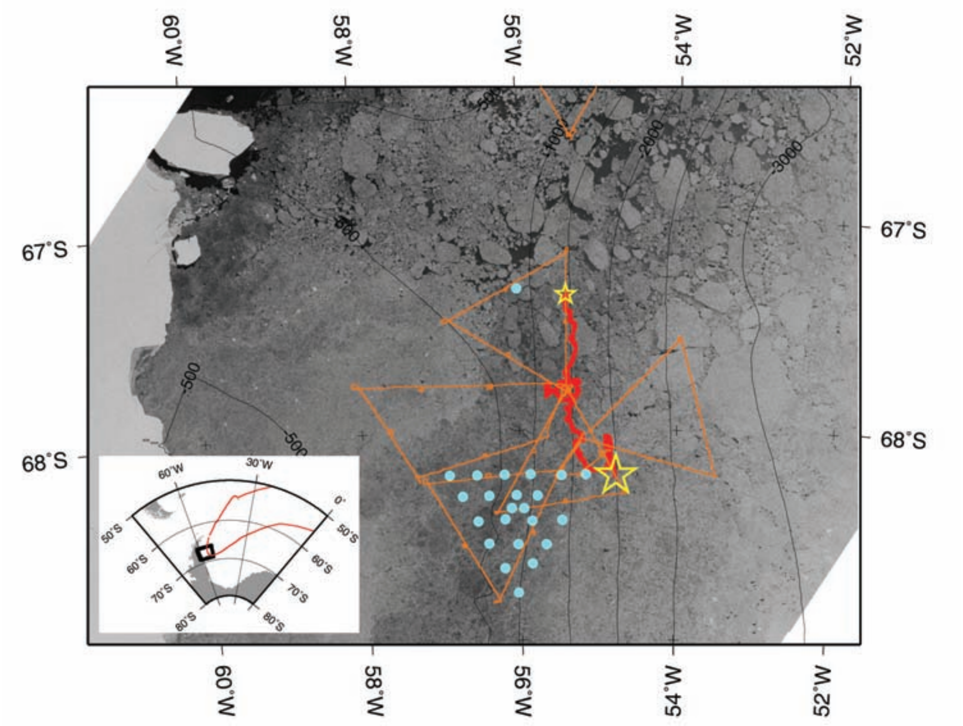

Figure 3.17.7. Envisat synthetic aperture radar (SAR) image acquired on 30 November 2005, showing the Ice Station Polarstern (ISPOL) study area in the western Weddell Sea (inset, plus cruise track) and the start (27 November 2004, large yellow star) and end points (2 January 2005, small yellow star) of the drift (Hellmer et al. 2006). The western border of the image shows the Larsen-C ice front; the northern boundary is close to the sea ice edge. Black contours show water depth in meters. Blue symbols indicate locations of buoy deployments, and orange lines show the tracks of HEM thickness surveys. Note the north-south extending, dark appearing band of first-year sea ice at about 56ºW.

Most methods described in this handbook were applied to obtain a most complete data set of all ocean-ice-atmosphere processes and their interactions. Numerous results were published in the scientific literature, and in particular in a special ISPOL issue of *Deep Sea Research*, Part II, *Vol. 55*, No. 8–9 (Hellmer et al. 2008).

During December 2004, the German research icebreaker *Polarstern* was anchored to an ice floe and served as accommodation, laboratory, and platform for field and water column studies. The satellite radar image in Figure 3.17.7 shows the location of the station and its 98 km long (net distance) south-north drift track. Compressed files of satellite radar imagery, particularly from the QuikSCAT scatterometer and Envisat SAR (Chapter 3.1), were transmitted to the ship in near real time and played a critical role in supporting ice navigation, site selection, and interpretation of observed ice properties and seasonal changes. Based on these, the ISPOL floe location was chosen to be at the transition between two prominent bands of second- and first-year ice, allowing sampling of more varied ice types. It was also chosen to be far enough south to have not yet been affected by any melting before the onset of observations, and to prevent too early disintegration of the floe while drifting north towards the ice edge.

Long-range helicopter flights were performed to survey numbers and types of seals (Chapter 3.14), as well as the ice thickness and floe size distributions of the various ice regimes by means of EM sounding (Figure 3.17.7; Chapter 3.6) and aerial photography (Chapter 3.15). The satellite images also served the design of a triangular array of ice-deployed GPS buoys (Chapter 3.16), which were operated to study the motion and deformation of the ice and to improve the representation of these processes in sea ice models (Chapter 3.2).

Figure 3.17.8 shows a map of measurement stations on the ISPOL floe. These were selected to cover the main ice types, and to perform joint, interdisciplinary investigations of the same ice. The main activities of ice coring (for both physical

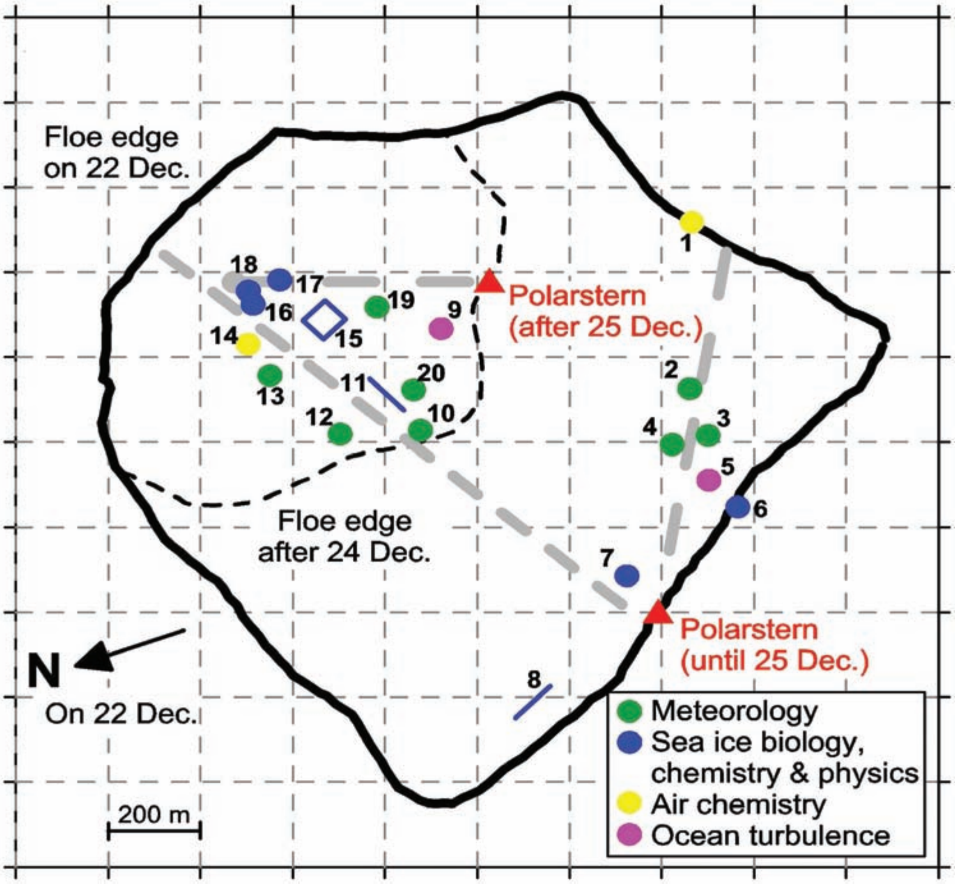

Figure 3.17.8. Sketch of the ISPOL floe with locations of long-term sampling sites on different ice types (thick and thin first-year ice, and second-year ice) for studies of physical and biological ocean-ice-atmosphere interactions (Hellmer et al. 2008). An aerial photograph of part of the floe detailing regions of different ice types, ice thickness, and sampling sites is shown in Figure 3.6.40).

and biological/biogeochemical parameters; Chapters 3.9, 3.12, and 3.13) and measurements of snow properties (Chapter 3.5) and ice thickness (Chapter 3.6; Figure 3.6.40) were repeated throughout the study period. Seven dedicated coring days were chosen every five days to allow for the best possible cross-comparison between sites. In addition, Conductivity-Temperature-Depth (CTD) and ocean turbulence measurements (Chapter 3.15) were performed throughout the study period to quantify ocean heat flux and to relate it to observations of ice warming and thinning. Similarly, atmospheric heat flux was measured at various locations, as well as the exchange of gases like CO_2 and DMS. Nets and water samplers were operated from the ship to study biology and biogeochemistry in the water column and their exchanges with the ice (Chapter 3.13). This work was partially supported by divers sampling more dedicated regions of the ice underside. Sediment traps were suspended under the ice to collect biological matter released from the ice—a potential food source for higher trophic levels.

All results obtained during ISPOL contributed unique information about ocean-ice-atmosphere properties and processes in this rarely studied sea ice region of the Southern Ocean. Although it was indeed expected that no melt ponds would form and that the snow would remain intact, arguably the most surprising result was the slowness of changes throughout the early summer observational period, in contrast to extreme conditions in the Arctic, where strong melting typically commences in early June (comparable to early December in the Southern Hemisphere) and at much higher latitudes. However, ocean and atmospheric heat fluxes averaged only a few watts per square meter, merely leading to snow and ice thinning of more than one or two decimeters. Changes in the snow cover were too small to trigger an albedo feedback that would enhance melt (Chapter 3.10). Similarly, despite significant drift and deformation of the ice field, ice concentration remained high throughout and prevented the absorption of heat in the surface water and the initiation of lateral and bottom melt.

However, the available heat led to warming of the ice and snow by up to 2 K to temperatures close to melting, which has fundamental consequences for important ice and brine properties like porosity, salinity, and stratification (Figure 3.17.9). These strongly impacted the biological productivity and chemistry within the ice, and their role in seeding growth under the ice and modifying ocean-atmosphere gas fluxes. Figure 3.17.10 shows how other parameters varied as a consequence of these changes. The higher porosity also allowed larger organisms like various zooplankton species to enter the ice proper and even the surface.

The results shown in Figure 3.17.10 also point to methodological problems of repeated, destructive ice core and snow sampling to measure small changes (Chapters 3.5, 3.8, 3.9, 3.12, and 3.13). Due to the general small-scale variability and patchiness, temporal changes were not easily separated from lateral changes, despite a sophisticated sampling strategy developed to include the sampling of several cores within a very small region and the prevention of disturbances to the

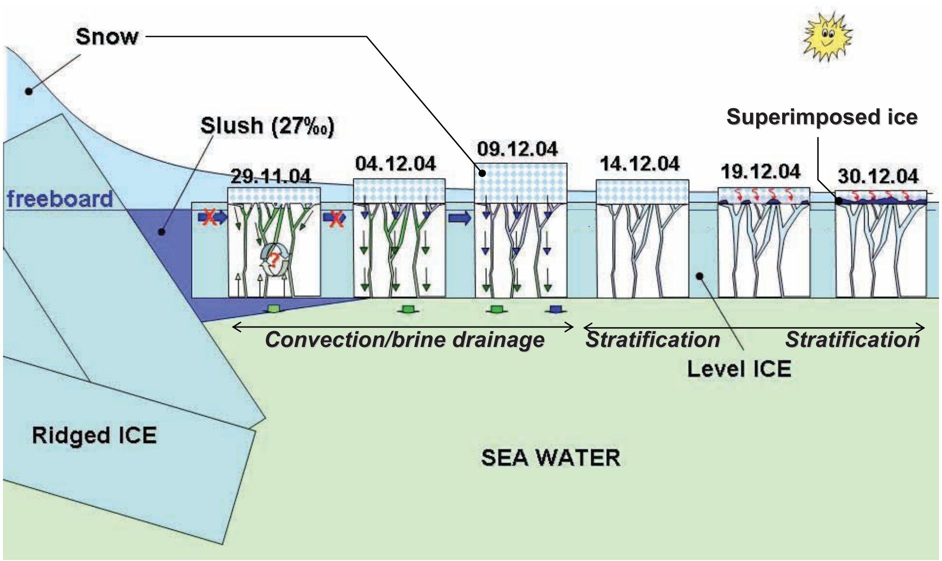

Figure 9: A simple model for the degradation of the first year level sea ice cover at the ISPOL clean site.

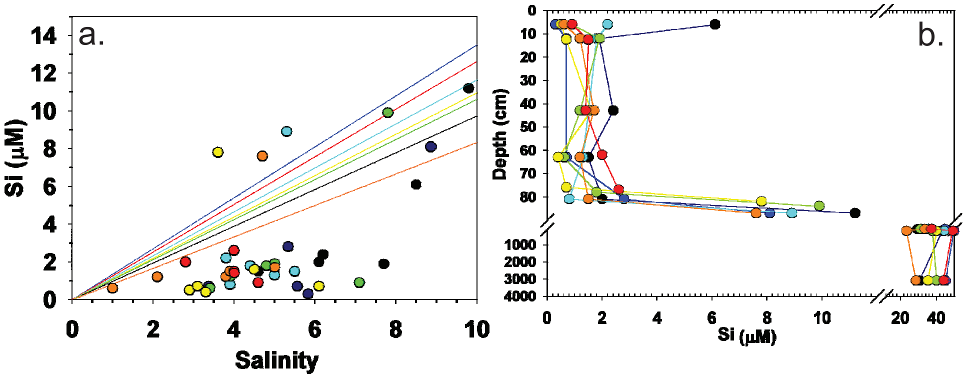

Figure 3.17.9. Illustration of property changes of thin first-year ice during early summer, as concluded from extensive ice coring on six sampling days throughout the ISPOL study period (Tison et al. 2008). Main changes occurred with respect to temperature-dependent ice porosity and consequent horizontal and vertical brine motion and gas exchange.

original snow and ice surface. In addition, the thick second-year ice presented challenges for the processing of large numbers of samples within the short time available between sampling days, and led to a focus on thinner first-year ice for most biological and biogeochemical studies. The small changes occurring over the study period also affected most other applied methods, as their accuracies were hardly good enough to detect these changes. In addition, close-to-melting conditions and

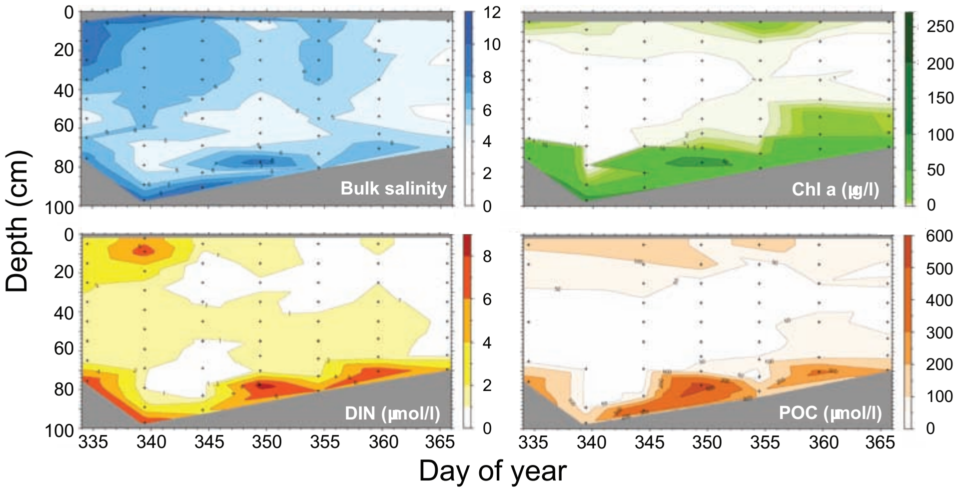

Figure 3.17.10. Temporal evolution of ice thickness, salinity, Chlorophyll a, dissolved inorganic nutrients (DIN) and particulate organic carbon (POC) in thin first-year ice of the ISPOL floe (Courtesy of Matthias Steffens and Gerhard Dieckmann).

high irradiance affected many instruments installed on the ice for more continuous, automatic measurements.

Long-term observations were hampered by two breakup events, which made revisiting of sites difficult and partially required the relocation of some instruments. Here, the unavailability of more automatic systems for the measurement of biological and biogeochemical ice properties was a clear disadvantage. This general problem of long-term sea ice studies was, however, overcome by the use of helicopters and inflatable boats allowing continued revisiting of more remote sites and crossing of leads after the breakups. ISPOL's observations had to be concluded before any really strong melting occurred, leading to further disintegration of the ice. However, an extension of the study period was impossible because of higher-level logistical and organizational requirements, as the ship could only operate for a certain period without resupplies and also had to serve other antarctic and arctic research programs during the short summer seasons. More dedicated and extensive ship time will be required for future studies of summer melt processes in the Southern Ocean, as was available for the Ice Station Weddell (ISW) and Surface Heat Budget of the Arctic (SHEBA) drift stations.

Contributors: ISPOL was proposed, planned, and coordinated by Gerhard Dieckmann, Christian Haas, Hartmut Hellmer, and Michael Schroeder. The cruise was led by Michael Spindler. However, ISPOL's program and success was only possible through the engagement and participation of 57 scientists from 11 countries, and the support of a ship's crew of 43. In addition, numerous people worked on land to prepare and assist the ship before and during the cruise.

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Relevant publications:

There are too many publications to be listed here. However, two key publications are:

"Ice Station POLarstern (ISPOL): Results of interdisciplinary studies on a drifting ice floe in the western Weddell Sea," a special ISPOL issue of *Deep Sea Research*, Part II, *Volume 55*, No. 8–9 (Hellmer et al. 2008)

"The Expeditions ANTARKTIS-XXII/1 and XXII/2 of the research Vessel 'Polarstern' in 2004/2005" (El Naggar et al. 2007)

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