PERSPECTIVE

The fostering of cross-disciplinary science as a result of the IPY: ''connectivity'' created by the Canada Three Oceans project

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Abstract

The fourth International Polar Year (IPY), which ended in March 2009, represented a ca. 50% increase in the funding of polar science, a major expansion of the observing effort across polar and subpolar seas, the deployment of a wide range of new and complex observing techniques and a gratifying new degree of international collaboration in their use. As a result, the IPY has revolutionized our polar data sets to provide our first real glimpse of the ocean–atmosphere–cryosphere operating as a complete system. Here we focus on one particular aspect of the emerging results—the "connectivities" that may develop between individual research projects over time, developing the complexity of our understanding in real if unexpected ways as new findings emerge, ramify and mesh within projects or between them. For simplicity, we illustrate this valuable but unpredictable process by using one particular Arctic–sub-Arctic project—Canada Three Oceans—as our initial reference point and attempting to trace out a small subset of its inter-connections across space, time, projects and disciplines.

The fourth International Polar Year (IPY), which ended in March 2009, represented a ca. 50% increase in the funding of polar science (about 400 million USD over the two years on top of ca. 800 million USD of existing/redirected national funding [David Carlson, IPY International Programme Office, pers. comm. 2009]), a major expansion of the observing effort across (bi)polar and subpolar seas, the deployment of a wide range of new and complex observing techniques and a gratifying new degree of international collaboration in their use (Dickson 2007, 2008). In turn, the Arctic–sub-Arctic environment under observation was in a state that seems extreme, even unprecedented, in our instrumental record. The record minimum Arctic sea-ice extent in the late-summer of 2007 is perhaps the best-known of these events, but a new record minimum ice extent for fall was later recorded in November 2009, anticipated in many climate models (Wang & Overland 2009), and the downward trend in sea-ice volume during winter continues unabated at –900 $\text{km}^3\ \text{y}^{-1}$ (Kwok et al. 2009). Though the IPY will have given us an unprecedented view of this evolving ocean–atmosphere–cryosphere system and its drivers, the fact remains that much of what we will learn from the IPY has yet to emerge.

While some of the science gains of the IPY will have been more or less expected, even as our proposals were submitted, this report intends to focus on a less predictable set of findings: the "connectivities" that may develop between individual research projects over time. This is arguably the real profit of the IPY, developing the complexity of our understanding in real if unexpected ways as new findings emerge, ramify and mesh within projects, or between them. We cannot see them all yet of course—"connectivity" may be expected to grow-in over a broad range of time-scales—but in attempting to design an effective ocean-observing system for the legacy phase of the IPY *based on what we have learned*, we are already having to seek out and build-in these unexpected results (see Dickson 2011).

The Canadian flagship project Canada Three Oceans (C3O; Eddy Carmack principal investigator) is peculiarly well-suited to illustrate this interesting process at work. Worked in conjunction with the long-established Joint Ocean Ice Study (JOIS; Fiona McLaughlin principal

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investigator), and with US and Japanese partners (principally), C3O is the IPY project that most directly addresses spatial and temporal "connectivity" by carrying out integrated and multidisciplinary observations (Fig. 1) along an annual oceanographic section some 15 000 km in length through both Arctic and sub-Arctic waters to link the eastern Pacific, Arctic and western Atlantic (Carmack et al. 2010). The latitudinal spread of C3O is as important as its longitudinal span. Since change may certainly be imposed on the Arctic from sub-Arctic seas and vice versa (Dickson et al. 2008), it is clear that we cannot understand Arctic change just by studying the Arctic. Even so, we can include only a small selection of cases from the 26 sites that form the primary foci of C3O. And most of these will still be evolving.

The lateral spread of warming through Northern seas, and the development of our thinking on its climatic impact

Very recently, the Atlantic waters flowing into the Norwegian Sea and passing north through the Barents Sea have reached a 100-year maximum in temperature (Holliday et al. 2007). The onward spread of this warmth has been documented along the Eurasian boundary of the Arctic Ocean from Fram Strait to the New Siberian Islands (Polyakov et al. 2005; Polyakov et al. 2007; Dmitrenko et al. 2008; Polyakov et al. 2010; Polyakov et al. 2011). To the collage of panels illustrating this spread (Fig. 2), we can now add the equivalent JOIS–C3O transects of the Beaufort Sea (McLaughlin et al. 2009) which confirm the arrival of an earlier warm wave along the southern margin of the Canada Basin around 2007. To do what exactly?

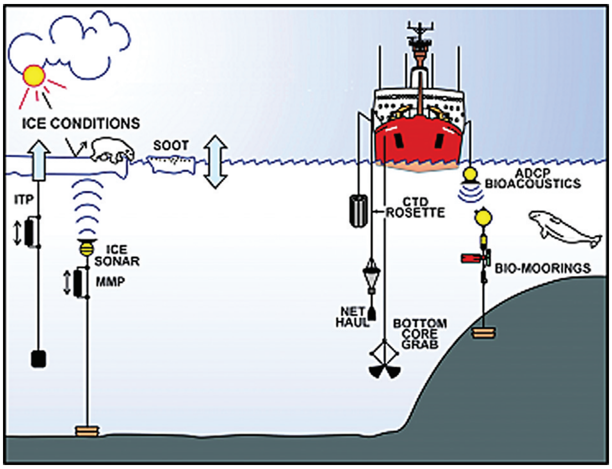

Fig. 1 Schematic illustrating the range of ocean observing techniques deployed annually by the two icebreakers of the Canada Three Oceans project (C3O) along a 15 000 km track through Canada's Pacific, Arctic and Atlantic waters. (Figure used with permission of E. Carmack.) Abbreviated terms: conductivity–temperature–depth recorders (CTD); ice-tethered profiler (ITP); McLane moored profiler (MMP); and acoustic Doppler current profiler (ADCP). See Carmack et al. (2010) for a detailed description of the observing scheme.

The answer is unclear. When the IPY began in March 2007, it would probably have been the consensus view that a 100-year maximum in the warmth of Atlantic inflow to the Arctic must in some way be bound up with an increased melting of sea ice, and such claims are still advanced (see Polyakov et al. 2010; also commentary by Carmack & Melling 2011). Or (not quite the same thing), future accessions of warmth to the western Arctic might simply be removed by increased turbulence associated with the removal of ice cover. McLaughlin et al. (2009), however, suggest that the heat input to the Canada Basin, amounting to ca. 30% of the Eurasian Basin input, will ultimately exit to modify the East Greenland Current, and this third possibility now seems the more likely as a result of new simulations by a group from the Alfred Wegener Institute (Karcher et al. 2007; Karcher et al. 2008; Karcher et al. 2011). These suggest that as the warm Atlantic-derived layer spread at subsurface depths through the Arctic deep basins, it did so at a significantly greater depth and with a significantly lower density than normal. Though the increased warmth may therefore be too deep to have much effect on sea ice, the intriguing suggestion is made that, as and when 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). By this reasoning 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", far to the south and many years later (in 2016–18 by present estimates [Michael Karcher, Alfred Wegener Institute, pers. comm. 2009]). In this example, the JOIS–C3O data set forms just one connecting link in a chain of events that extends for >12 000 km around the boundary of Arctic and sub-Arctic seas. But even so, it sits at a point in this circuit that will be crucial to determining which of three competing ideas is valid, and its study (McLaughlin et al. 2009) has already generated new ideas (e.g., the distinct mechanism of spreading by thermohaline intrusions) about how warmth passes around the Arctic boundary.

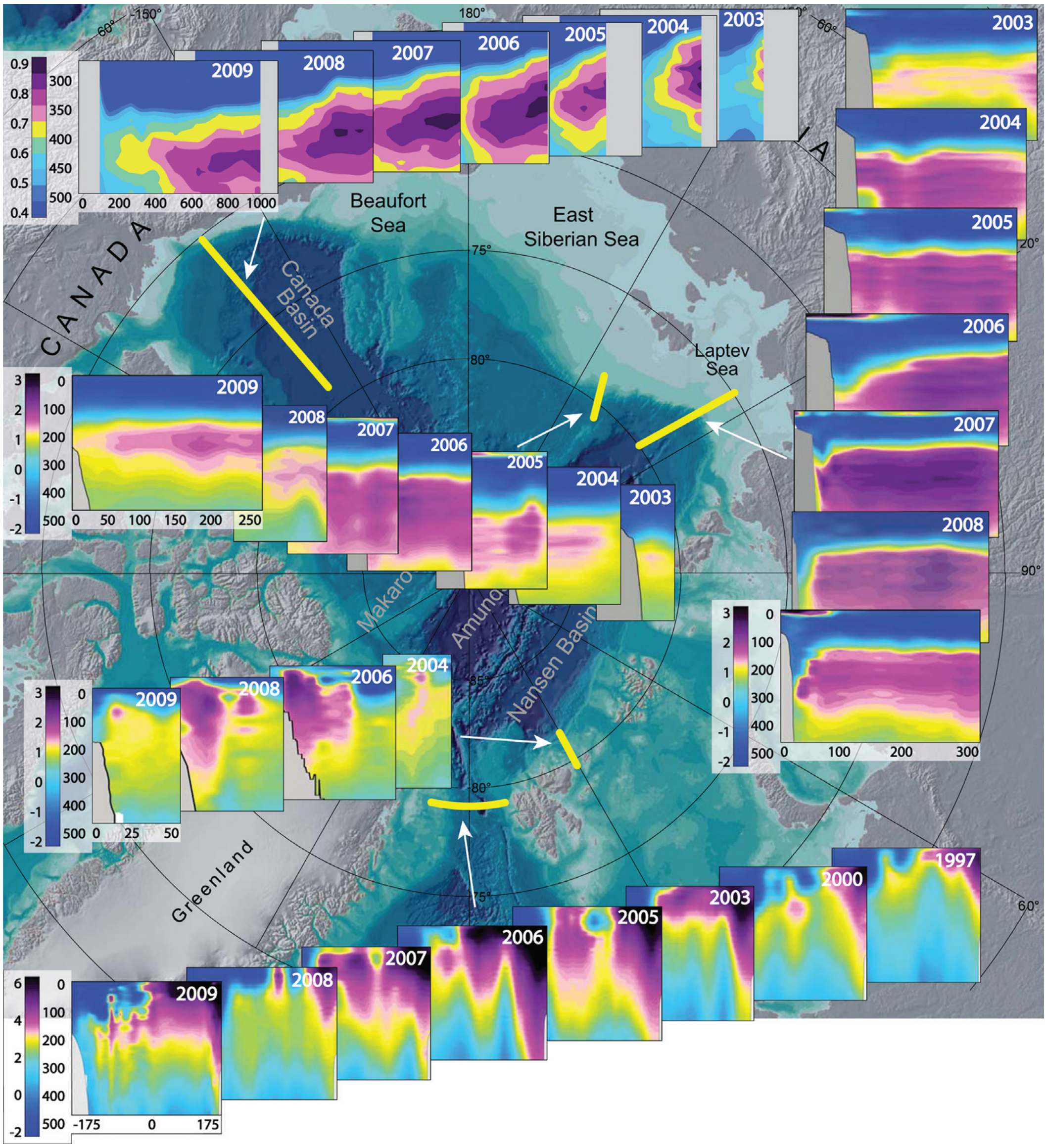

Fig. 2 Upper-ocean temperature transects across the Arctic Boundary Current from Fram Strait to the New Siberian Islands between 2003 and 2009, supplemented with Canada Three Oceans and Joint Ocean Ice Study transects across the continental margin of the Canada Basin in 2003–09. (This figure was originally printed by Polyakov et al. (2011). © American Meteorological Society. Reprinted with permission.) Note that this figure captures the passage of two separate pulses of warmth around the Arctic margin. The wave of warmth that is currently passing around the Canada Basin reflects the relative warmth of Atlantic inflow to the Arctic in the early to mid-1990s, while that shown off the Laptev Sea around 2007–08 reflects the extreme warmth of inflow in the early to mid–2000s.

Our growing awareness of the Canada Basin–Beaufort Gyre as a centre of global climatic importance

The presence of a salinity minimum at the centre of the Beaufort Gyre has been known about since the 1950s (Proshutinsky, Krishfield et al. 2009), but was not convincingly explained until 2003 when the Woods Hole Oceanographic Institute (WHOI) Beaufort Gyre Observing System, led by Andrey Proshutinsky and with JOIS and C3O as partners, began applying a suite of new observing techniques to the task, gradually transforming the data desert of the Beaufort Gyre into one of the best-covered regions of our northern seas. We now know that the Beaufort Gyre is the largest marine reservoir of freshwater on Earth (Carmack et al. 2008), and that the major cause of its large freshwater content is the process of Ekman pumping, generated by the climatologically anticyclonic atmospheric circulation centred there (Proshutinsky et al. 2002; Proshutinsky, Krishfield, Timmermans et al. 2009); we know in some detail how the thermal regimes of atmosphere and ocean modulate the liquid freshwater content according to the seasonal cycle of sea ice-melt and growth; and through the Beaufort Gyre Observing System, we have become aware that the Beaufort Gyre freshwater content is a field in rapid transition, with strongly increasing trends in freshwater content between 2003 and 2008 (Proshutinsky, Krishfield, Timmermans et al. 2009). By this account, the spatially-integrated freshwater content of the gyre increased by >1000 km^3 post-1990s relative to climatology.

The IPY has now revealed far more. As the collaborating projects have recovered their separate strands of evidence to connect the Canada Basin with climate, some sort of "structure" for these ideas has begun to develop, though our knowledge of it may still be far from complete. Figure 3 is our startpoint in describing it. Figure 3a shows the presence in summer of three distinct subsurface temperature maxima in the Canada Basin: deepest, at a depth of ca. 400 m, sits the warm Atlantic-derived sublayer whose remote origins and likely remote/delayed impact on climate have just been described. Above it, at ca. 60 m and 25 m, respectively, lie a layer of warm Pacific Summer Water deriving from inflow through Bering Strait and a near-surface temperature maximum (NSTM) arising locally (or at least regionally) as the end-point of the ice-albedo feedback mechanism (Jackson et al. 2010).

Though we have known for more than a decade of the existence of a narrow temperature maximum just below the surface (ca. 25 m) of the Canada Basin in summer (Maykut & McPhee 1995), Jackson et al. (2010) have pieced together a modern conductivity–temperature–depth (CTD) record from ice-tethered and ship-borne profilers (WHOI, JOIS–C3O and JWACS mainly) to reveal much of what is important about this seemingly-delicate but in fact extensive and rather robust layer. The NSTM that they describe is first formed in June–July

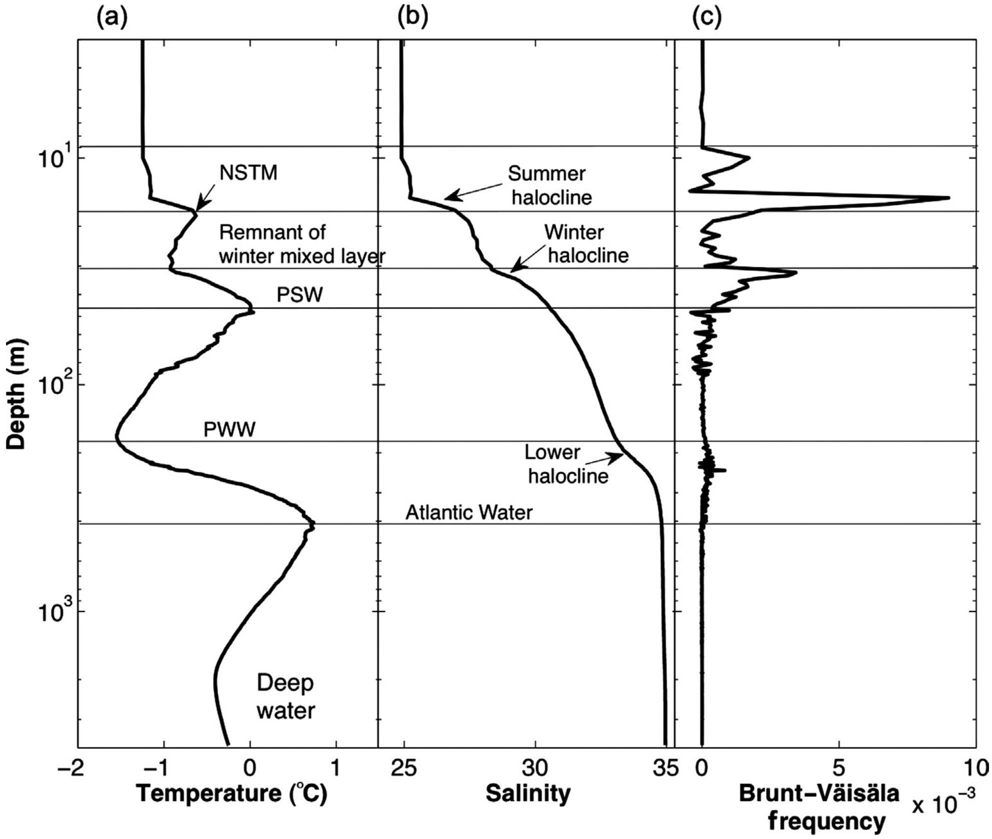

Fig. 3 Water mass structure of the Canada Basin as characterized by (a) temperature, (b) salinity and (c) Brunt-Väisälä frequency profiles. (This figure was originally printed in Jackson et al. [2010] and is reproduced here with permission of J. Jackson.) Note the depth axis is log scale. In summer, there are up to three temperature maxima (the near-surface temperature maximum [NSTM], Pacific Summer Water [PSW] and Atlantic Water), two temperature minima (the remnant of the previous winter's surface mixed layer and Pacific Winter Water [PWW]), and three haloclines (the summer halocline, the winter halocline and the lower halocline).

when sufficient solar radiation enters the upper ocean through narrow leads and melt ponds to warm the near-surface waters. Ice melt from these warmed surface waters then accumulates to form a strengthening near-surface halocline (see Fig. 3b, c), effectively capping-off the NSTM and trapping solar radiation in the ocean until late September when sea ice begins to form once again, allowing penetrative convection (from brine rejection) and ice–ocean or air–ocean stresses (Jackson et al, unpubl. ms.) to deepen the surface mixed layer. This is not an unvarying process. During the so-called "Arctic Warm Period" (Overland et al. 2008), the temperature of the NSTM in the Canada Basin has increased north of 75°N at a rate of 0.13°C per year since 2004. Some of the inter-connections between this result and others *within* the C3O project are already evident (Yamamoto-Kawai et al. 2009), but the *external* implications of these results have perhaps the greater potential significance.

As we understand it, the next few connected steps are these. As the warm (and warming) layer just below the surface thinned the ice against the Canadian Arctic coast, what was once land-fast multi-year ice was able to break free. Intensive Japanese investigations (Shimada et al. 2006) suggest that the clockwise gyre circulation was then able to rotate the thinner, now more mobile ice (Spreen et al. 2011) out over what might now be termed the "hotplate" of the Chukchi Borderland north of Bering Strait; the melting ice joins the transpolar drift and exits through Fram Strait; the now ice-free ocean in the western Arctic stimulates the development of anomalously low pressure; and the resulting formation of an atmospheric dipole further speeds up the clockwise circulation of the Beaufort Gyre.

There is already a developing web of connecting evidence for these ideas. Ice mass balance buoys (Perovich et al. 2008) directly confirm the extraordinary amount of basal ice-melt in the Beaufort Sea in the summer of 2007, amounting to 2 m of bottom melt in August 2007 (11 cm per day in the last week of that month!). Satellite remote sensing appears to support a recent rapid intensification of the Gyre (Morison et al. 2010). Release 4 data from the Gravity Recovery and Climate Experiment satellite describe a declining trend in bottom pressure throughout the Beaufort Sea and eastern Canada Basin in 2005–08 due to the persistent freshening trend there (Morison et al. 2007; Kwok, Farrell et al. 2009). C3O results (Yamamoto-Kawai et al. 2009) partition that freshening trend into its separate sources to reveal the importance of the sea-ice contribution (summer ice-melt and reduced winter formation rate) compared with runoff. And the most comprehensive recent analysis of change in the freshwater content of the Arctic Ocean (Rabe et al. 2011) shows that as part of a fairly general increase in freshwater content across the Arctic deep basins between 1992–99 and 2006–08, amounting to $> +3000$ km^3, the largest increase in freshwater content was observed in the western Canada Basin–Chukchi Cap, the area of increased ice-melt anticipated in Shimada's theory (Shimada et al. 2006).

Though calculations (Perovich et al. 2008) appear to suggest that solar heating of the upper ocean was the primary cause of the extreme basal ice-melt in 2007, it is unclear whether or to what extent the deeper Pacific Summer Water sublayer participated in this process. The analysis of 5800 ice-tethered profiler records of temperature and salinity from the central Canada Basin in 2004–09 (Toole et al. 2010) reveals that intense stratification sets an upper bound on mixed layer depth of 30–40 m in winter and 10 m or less in summer, greatly limiting the flux of deep ocean heat from the Pacific Summer Water sublayer to the surface. However, as that report points out, it is conceivable that over longer periods this heat source could become accessible. And if it could and does, the Pacific Summer Water heat presently stored as intrusions in the 40–100 m depth range is of sufficient magnitude to melt about 1 m of ice. The question at issue then is: what are the intensities and the physical mechanisms supporting 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 seasonally ice-free Arctic?

Many of these findings, and the "connectivities" between them are very recent—less than a year in print. For the present, as the data set and theory come together, it seems adequate to discuss the roles of the Canada Basin–Beaufort Gyre in climate as half-a-dozen separate issues: heat stored in the ice-free summer ocean being released in fall to alter the regional atmospheric circulation (Overland & Wang 2010; Overland et al. 2011); the Beaufort Gyre as the largest marine reservoir of freshwater on Earth (Carmack et al. 2008; Proshutinsky, Krishfield, Timmermans et al. 2009); the increase in the freshwater loading of the Arctic watercolumn (Rabe et al. 2011); and the ideas (just described) that the three warm sublayers of the Canada Basin may have distinct local (Shimada et al. 2006), potential (Toole et al. 2010) and remote (Karcher et al. 2011) influences on climate. They are not separate issues of course, and as the meshing of project results continues to develop, the hope is that we will one day be able to model change in the ocean–atmosphere–cryosphere system of Arctic and sub-Arctic seas as the workings of one inter-connected system.

The connectivities of inflow and throughflow, and the sparking of new ideas in ecology and biogeochemistry

From an increasingly diverse body of evidence, we choose four illustrative topics.

Arctic throughflow mediates between regions of denitrification and of nitrogen fixation

In a study made just prior to the IPY but continuing through C3O, we now have startling new evidence (Yamamoto-Kawai et al. 2006) that unique biogeochemical processes in one region can be advected downstream by through-flowing water masses to affect nutrient budgets, microbial/molecular processes and diversity in another. In brief, the Atlantic contains organisms that fix nitrogen, using up phosphate in the process, and causing Atlantic waters to be enriched in nitrate relative to phosphate. Upstream, the highly productive waters of the Chukchi Shelf are relatively rich in phosphorus. The imbalance is redressed by connecting flows from the Arctic to the Atlantic through Fram Strait and the Canadian Archipelago, and the phosphate supplied by these throughflows is shown to account for 16% or more of the nitrogen fixation in the North Atlantic. As these authors conclude, "the role of the Arctic throughflow as a mediator between regions of denitrification and of nitrogen fixation has until now not been specifically acknowledged" (Yamamoto-Kawai et al. 2006: 43). And as a new related facet of this work, it was later shown (Galand et al. 2009) that *Archaea* in the Arctic outflow (Nares Strait) have a gene specifically for the oxidation of ammonia, thus taking advantage of the residual phosphorus in Pacific-origin waters. This too has challenged the accepted view in suggesting that shifting currents and watermass boundaries resulting from climate change "may well impact patterns of microbial diversity by displacing whole biomes from their historic distributions" (Galand et al. 2009: 971).

Aragonite undersaturation increases as the sea ice retracts

The increase in anthropogenic carbon dioxide emissions and the attendant increase in global temperature and ocean acidification act together to decrease the saturation state of calcium carbonate in the Arctic Ocean. It has now been demonstrated (Yamamoto-Kawai, McLaughlin, Carmack, Nishino & Shimada 2009) that in 2008, as a direct consequence of the recent extensive melting of sea ice, the surface waters of the Canada Basin were undersaturated with respect to aragonite (a relatively soluble form of calcium carbonate found in plankton and invertebrates) much earlier than predicted and before other high-latitude oceans. A further link with present climate trends should develop as the ice edge retracts beyond the shelf break, allowing enhanced upwelling (Carmack & Chapman 2003) to bring aragonite-undersaturated water onto the circum-Arctic shelf.

Smaller organisms thrive as the Arctic Ocean freshens

The recent decrease in upper ocean salinity observed in the Canada Basin carries biological implications. Ice retraction and the attendant increase in stratification will both stimulate and lengthen the growing season and decrease nutrient loading to the surface layer. Competitive advantage will accrue to small cells because they are more effective in acquiring nutrients and less susceptible to gravitational settling than large cells. Since 2004, across the 23 stations of the JOIS grid in the Beaufort Sea, there has been an increase in the smallest algae and bacteria along with a concomitant decrease in somewhat larger algae (Li et al. 2009). This has major implications for the efficiency of energy transfer through the food web.

Southern species become established in the Arctic Ocean through climate warming

Not all changes in Arctic Ocean food web structure come from bottom–up mechanisms; advection of zooplankton and invasion by southern species also play a major role in determining the future state of Arctic ecosystems through top–down cascades. Connectivity examples here include: (1) advection of Bering Sea *Calanus glacialis*, with a specific genotype, through Bering Strait and into the Canada Basin where they survive, graze and follow the pathway of Pacific-origin waters, but fail to reproduce (Nelson et al. 2009); (2) the continued range expansion of orca (*Orcinus orca*) into the Canadian Arctic Archipelago from the east (Ferguson et al. 2010); and (3) the possible migration of Pacific salmon in the Beaufort Sea from the west (Irvine et al. 2009).

Linking the patterns of human settlement to ocean physics

In the late 1970s and early 1980s, Peter Schledermann of the University of Calgary, working in the Bache Peninsula of north-east Ellesmere Island, proposed that Arctic settlement distribution over the past 4500 years was conditioned by the location of polynyas (Schledermann

1980). Polynyas are widely distributed across the Canadian Arctic Archipelago, representing areas of enhanced air–sea fluxes in winter relative to the neighbouring ice-covered regions and so acting as sites of particular ecological significance, especially for marine mammals and seabirds. Within C3O, a tidal model of the Canadian Arctic Archipelago has been used (Hannah et al. 2009) to explore the idea that tidal currents make an important contribution to the formation and maintenance of these recurring polynyas. By mapping three parameters—the strength of tidal currents, tidal mixing (h/U^3), and the vertical excursion associated with the tidal currents driving water up and down slope—this study was able to show that the "hot spots" in these quantities do indeed correspond to the location of many of the small polynyas in the archipelago. Significantly, a known polynya was identified with every region that had $\lambda < 3$ and vertical excursion > 10 m ($\lambda = \log10\ h/U^3$). Though the link between h/U^3 and summer plankton productivity has not yet been demonstrated in the archipelago it is likely that the hot spots of h/U^3 that correspond to polynyas have the potential to be biologically important year round. Very recently, the comparison of recurrent polynyas with the location of local archaeological sites across the Canadian Arctic Archipelago indicates an association, with settlements in many locations recurring over a period of 3–4000 years adjacent to both large and small polynyas (Murray & Hannah 2010).

Where next? Shifting down-scale in our science and our services

Little more than a decade ago, the complete hydrographic record for the Arctic, pieced together by the US–Russia International Working Group, still described one of the greatest data deserts on Earth (Arctic Climatology Project 1997, 1998). Though the exercise was successful in revealing change *per se*, most notably a large-scale shift in the mutual boundary between Atlantic-derived and Pacific-derived water masses across the Arctic deep basins (Morison et al. 2000), it provided little more than tantalizing hints as to what might be driving these changes or what might be their significance to climate. Since then the elaboration of observing techniques and the expansion of effort and funding culminating in the IPY has revolutionized our Arctic data set to provide our first real glimpse of the ocean–atmosphere–cryosphere of the pan-Arctic operating as a complete system. As just one example of the explosive growth in our capability, the WHOI ice-tethered profiler system has alone contributed more than 28 000 CTD profiles to the Arctic hydrographic record since 2004, the majority since the start of the IPY (see http://www.whoi.edu/page.do?pid=20781). Using the full range of new ocean-observing systems from satellites to seabed has provided a sufficient depth and complexity of observation to identify (we think) the sort of question that we should be testing over the "legacy phase" of the IPY, if we are to develop our understanding of the processes of Arctic change, their feedbacks and their likely climatic impacts to the point where they can be of use to climate models. An observing plan, based on what we have learned, has now been designed by the Marine Working Group of the International Arctic Science Committee (Dickson 2011) and a new Arctic Climate Systems Network has been established to coordinate these tests.

However, as we press on with that task, we encounter a dilemma: that although we cannot understand global change in the ocean–atmosphere–cryosphere system except at the largest space and time scales accessible to us (pan-Arctic; years to decades) we cannot do much that is useful with that understanding unless and until we find some way of downscaling the science to the local and regional scales that make sense to people. So "downscaling" has become our next and most difficult challenge, ideally one that would allow the Intergovernmental Panel on Climate Change (IPCC) to get on with its main task of assessing *climate* change while other organizations—perhaps at national level—reorganize to provide a range of climate services in the gap between local weather and global climate (Visbeck 2008). There is no doubting the importance of this shift in thinking. The First World Climate Conference, in 1979, established the World Climate Programme and launched the World Climate Research Programme, as well as the IPCC. The Second World Climate Conference, in 1990, initiated negotiations that resulted in the adoption of the United Nations Framework Convention on Climate Change in 1992 and the establishment of the internationally co-sponsored Global Climate Observing System; an outcome of the third, in 2009, is the establishment of the Global Framework for Climate Services ("climate prediction for decision-making" [see Visbeck 2008; World Meteorological Organization 2009]), which is what we are talking about here. Neither is there much doubt that the task of downscaling is achievable. To quote a recent title by Shukla et al. (2009), "Revolution in climate prediction is both necessary and possible." And since we now know that internal variability contributes increasingly to uncertainty as the space-scales of prediction decrease (Hawkins & Sutton 2009), the potential to narrow uncertainty in regional climate predictions will depend critically on observing the system and assimilating its changes at finer scale.

So this too has become the latest thrust of C3O. On a sunlit cruise through the Northwest Passage aboard the CCGS *Louis S St Laurent* in the summer of 2009, while the ship got on with the established "global" tasks of C3O, a group representing a broad range of science disciplines and those concerned with Canada's "Northern Strategy" explored ways and means of downscaling science to inform policy at the local level. The upshot is that in fall/winter 2010, the Canadian Rangers Patrol Group, operating out of villages across the Canadian Arctic, initiated a first trial of the resulting plan, compiling a simple yet climatically valuable set of measurements throughout the North-West Passage—ocean temperature, salinity, dissolved oxygen, chlorophyll-a, nutrients, snow and ice thickness, snow–ice interface temperature at a much finer scale in space and time than the *Louis* might ever achieve, and leaving behind transmitting buoys frozen in the ice to record ice temperature profiles. The real issue under test of course is whether the science of change in the Canadian North can, in any practical sense, be downscaled to the point where it begins to make real and practical connections with a whole web of local needs. If it can and if it does, the connectivity of C3O will have reached a most practical end-point. As Carmack & Holling put it, "We now have the planet's oceans being monitored; add to this the seas immediately off shore of the indigenous communities and the scales are bridged and the people engaged" (2009: 1).

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