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Scientific note

The International North Water Polynya Study (NOW): A progress report

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Abstract: After three highly successful, multidisciplinary expeditions totaling 180 days at sea, what have we learned about the functioning, ecological importance, and future of the North Water ecosystem? The scientific program of NOW comprises 13 projects tightly integrated around a central hypothesis that links spatial and temporal gradients in biological productivity and carbon export to the hydrographic/meteorological forcing of the North Water.

Preliminary interpretations from observations and modeling efforts are summarized concerning (among several other topics), the relative importance of sensible and latent heat processes in maintaining the polynya; the duration, intensity and nature of biological production in the North Water; and the export of carbon to the pelagic food web and at depth.

1. Introduction

Arctic polynyas are large areas of open water or thin ice in the midst of the thick ice pack that covers the Arctic Ocean and adjacent seas (Stirling and Cleator, 1981). Because they remain free of ice in winter, some polynyas serve as feeding, mating, spawning and over-wintering grounds for key species of birds and mammals in the Arctic marine ecosystem (Stirling, 1980; Stirling and Cleator, 1981). Accordingly, polynyas have been compared to oases in terrestrial deserts. Perhaps more importantly, they are suspected to be focal points for the intense production of the plankton herbivores that ensure the transfer of the solar energy fixed by plankton microalgae to Arctic cod, seals, polar bear and native man. A significant fraction of the biogenic carbon produced in polynyas could be sequestered at depth. Polynyas are predicted to increase in area and frequency in response to global climate warming (Gradinger, 1996) and, to some extent, could be models of the response of the Arctic ocean to global warming.

The North Water in northern Baffin Bay is perhaps the most productive ecosystem north of the Arctic circle. It is located at latitudes that will be impacted early and most strongly by the present trend in climate warming. In January, the North Water area is

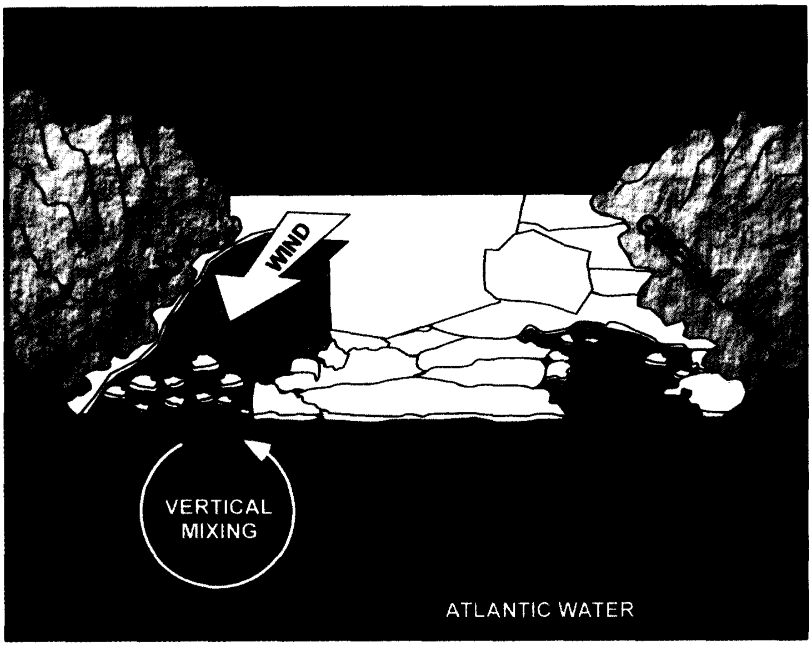

Fig. 1. Schematic representation of opening mechanisms of the North Water.

almost completely covered with thin drifting ice < 30 cm thick (Steffen, 1986; Steffen and Lewis, 1988). In late March or early April, the polynya starts to expand along the Greenland coast and begins to spread South and West between the islands of Ellesmere, Devon and Baffin to the West and Greenland to the East. The North Water reaches its maximum extent in July (*ca.* 90000 km^2) before merging with the open waters of Baffin Bay in August (Dunbar, 1969; Dunbar *et al.*, 1967). The mechanical removal of ice by currents and strong winds (latent heat) coming from Smith Sound in winter has long been considered the most important factor keeping the polynya open (Dunbar *et al.*, 1967). The recent discovery of warm water cells along the Greenland coast (Steffen and Ohmura, 1985) suggest that upwelling of warmer water (sensible heat) could also favour the opening of the polynya in spring (Fig. 1).

The functioning of the North Water ecosystem, its role in the overall Arctic biota and its potential response to global warming are the subjects of the *International North Water Polynya Study (NOW)* conducted within the International Arctic Polynya Programme (IAPP) of the Arctic Ocean Science Board (AOSB). In March 1997, the NOW Research Network was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) with the objective of assembling the international expertise necessary to conduct NOW. Thirty scientists from 7 Canadian universities, the Department of Fisheries and Oceans, the Canadian Wildlife Service, the Atmospheric Environment Service and the Department of National Defense form the Canadian component of the Research Network. Thirty additional investigators from Japan (12), the United States of America (9), Denmark (5), Poland (2), the United Kingdom (1) and Belgium (1) complete the Network.

The science program of NOW rests on the central hypothesis that both sensible and latent heat mechanisms contribute to the opening of the polynya, maintaining a west-east

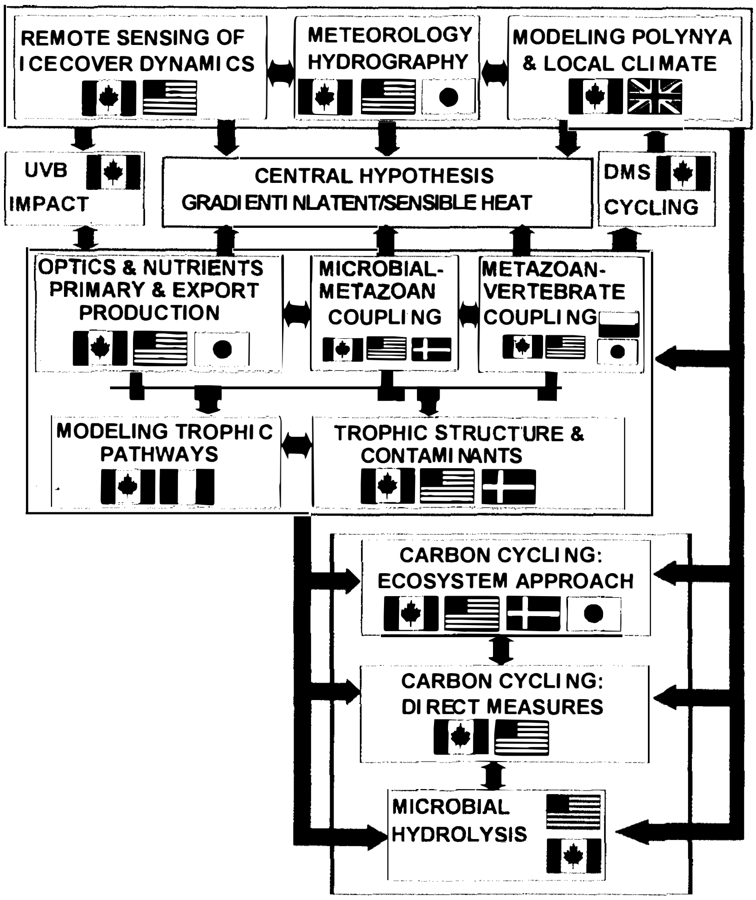

Fig. 2. NOW research net work and information flow.

gradient in biological productivity. In areas and at times when sensible heat prevails (upwelling), the stratification of the surface layer resulting from the melting of the ice cover triggers a diatom bloom immediately after the opening of the waters. When latent heat prevails (winds and currents), the algal bloom is delayed until solar heating stratifies the surface layer. Built around this central hypothesis, the science program is made of three modules that each integrate several sub-projects (Fig. 2): (1) physical generation of the North Water; (2) the North Water pelagic ecosystem; (3) biogeochemical cycling in the North Water. After three successful expeditions to the North Water in 1997 (August–September), 1998 (April–July) and 1999 (August–October), the international network is now in a position to assess inter-annual variability in the biological productivity of the ecosystem in relation to ice cover dynamics and climate.

2. Expeditions

2.1. 1997

Work at sea started in August 1997 with a 19 days expedition on board the Canadian Coast Guard icebreaker Louis S. St-Laurent. The successful deployment of 9 instrument lines supporting 14 current meters, 6 ADCPs, 3 CTDs, one tide gauge and 10 sediment traps allowed scientists to record the winter conditions that led to the opening of the polynya in the spring of 1998, as well as the annual cycle of exportation of organic matter to depth. Hydrographic and biological measurements were taken at 19 stations covering the region of the North Water. Measurements on station included profiles of temperature, salinity, light transmittance, fluorescence and chlorophyll *a* concentration. Helium and tritium, microbial densities and processes as well as picoplankton densities were sampled/measured at selected depths. Plankton nets were hauled for the determination of zooplankton and juvenile fish areal densities. In between stations, salinity, temperature and chlorophyll *a* were continuously monitored. XBT profiles were obtained along some of the sampling transects. Mammal and bird abundance was monitored during the displacements of the ship in the North Water and in Lancaster Sound during the return trip to Resolute. In addition to ship-based operations, two teams studied bird ecology on the Canadian (Coburg Island) and Greenlandic (Hakluyt Island) coasts of the North Water.

2.2. 1998

The 1998 expedition to the North Water was an historical success. From 26 March to 29 July, over 100 experts took rotations on board the icebreaker CCGS Pierre Radisson to study the oceanography, ecology and biogeochemistry of the North Water. From the multitude of measurements taken, we can stress the continuous logging of satellite images, of meteorological and hydrographical conditions, measurements of light, CO_2, contaminants, DMS, thorium, fluorescence and chloropigments, sampling of microbes, of picoplankton, of zooplankton and fish larvae, and the surveying of marine birds and mammals. Apart form ship-based operations, the helicopter and zodiacs were used to describe the structure of the forming ice, the development of ice algae, to install weather stations, sediment traps and gill nets, and to record marine mammals vocalizations. Canadian and Danish teams studied bird ecology on both shores of the polynya and a joint Canada-Poland team based at Cape Hershel monitored ice formation and the influx of salt, heat and plankton from the Arctic into the North Water. In total, over 12000 researcher-days of intense work at sea and on land enabled the scientists to describe, dissect and quantify the functioning of the ecosystem, from its forcing by winds and currents to the fate of the carbon assimilated in its waters, including the entire food web from viruses to whales.

2.3. 1999

This third and last expedition of the NOW was jointly funded by Canada, Japan and the USA. The main scientific objectives of the expedition were (1) to recover the instruments moored in July 1998, which recorded circulation and the deep flux of particles in the polynya from August 1998 to August 1999, (2) to quantify pre-winter primary and secondary productions in the area, and (3) to identify the biological sources of the significant deep particle flux measured in the fall of 1997 by the moored instruments. All three objectives were fulfilled and the overall operation was a great success. 34 of the 43 instruments moored in 1998 and 1 trap moored in 1997 were recovered and over 75 sampling stations were carried out. In addition in 1999, careful preparation made possible a call of the ship to the Grise Fjord (Canada) and Qaanaaq (Greenland) communities. During the visits, the Community was invited onboard to see for themselves the work of the scientists and to discuss with them. The information provided during the visits resolved some concerns that the local populations may have had about the impact of the scientific operations on the region. These activities also increased the awareness of local people about the importance of the research in a context of climate change and the potential benefits to their Community.

The spectacular success of the NOW field program reflects months of careful preparation by scientists and professionals all over the world. Our success is also, in large part, attributable to the extraordinary competence and enthusiastic support of the Polar Continental Shelf Project in Resolute and to the officers and crew of the CCGS Louis S. St-Laurent and Pierre Radisson. From August 1997 to October 1999, the different teams have logged 169 days of shiptime in the North Water (190 days at sea when including voyages to and from the area). Overall, this represents 6543 scientist-day at sea, not including the field work of our teams at Cape Hershel, Coburg Island and Hakluyt Island.

3. Preliminary results

Obviously, the gigantic volume of samples and data collected during the three expeditions will take many years to digest. However, the main dynamics of the North Water ecosystem are already emerging. Among several preliminary results of significance:

1) Once the ice bridge forms in Nares Strait, the strong northerly winds (30–70 knots) prevailing in April and May drive the ice cover southward and away from the Canadian coast while the upwelling of warm water and warmer air temperature help melt the ice cover on the Greenland side. The two mechanisms could be linked, the upwelling on the eastern side being fuelled by the wind induced North-South flux on the western side. A surprising and spectacular observation: the North Water can open in less than 24 hours.

2) Above-freezing near-surface temperatures were recorded as early as April in the eastern part of the polynya, consistent with the hypothesis that sensible heat processes (both oceanic and radiative) contributed to the melting of the ice cover along the Greenland Coast.

3) The intense primary production starts as early as April in the North Water, immediately fuelling the reproduction of large herbivorous copepods such as *Calanus glacialis*. By comparison, the onset of the phytoplankton bloom and reproduction of *Calanus glacialis* does not occurs until July in nearby Barrow Strait. The algal biomass measured in the polynya are as high as the highest ever measured in the ocean. In agreement with the predictions of the central hypothesis, the algal bloom starts along the Greenland coast and propagates West to the Canadian side.

4) Data from sediment traps moored in August 1997 and recovered in July 1998 indicate that a strong vertical flux of organic matter persists from June to November, reflecting at least 5 months of plankton production. Elsewhere in the Arctic, the season of plankton production typically last less than 2 months.

4. The future

The exceptional data set obtained on the physic, biology and biogeochemistry of the North Water represents one of the most comprehensive studies ever of an Arctic marine ecosystem. The presentation and synthesis of this data is being achieved through international workshops and special sessions at international conferences (ASLO-AGU, January 2000, San Antonio; Sea-Ice Symposium, February 2000, Mombetsu; this symposium, February 2000, Tokyo; ASLO, Copenhagen, June 2000) and upcoming special issues of Atmosphere & Ocean and Deep-Sea Research.

All the while, participants in the Network are planning a new initiative to pursue the international collaboration and apply the Network's complementary expertise to the study of the changing Arctic Ocean. The emerging CASES (Canadian Arctic Shelf Exchange Study) is an international program to understand and model the response of the Canadian Arctic shelf ecosystem to atmospheric, oceanic and continental forcing, in the present context of warming of the Arctic. CASES is providing a unique opportunity to study the large Cape Bathurst polynya that is part of the circum-arctic system of flaw lead polynyas that characterise Arctic shelves and play a central role in the dynamics of the Arctic ice sheet and the formation of Arctic deep water. Accordingly, at its last meeting in January 2000 in San Antonio, the Steering Committee of the IAPP has decided that CASES would constitute phase III of the IAPP.

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