Bedford Institute of Oceanography

HOME

BIO REVIEW '84

Canada

The Bedford Institute of Oceanography (BIO) is the principal oceanographic institution in Canada; it is operated within the framework of several federal government departments; its staff, therefore, are public servants.

BIO facilities (buildings, ships, computers, library, workshops, etc.) are operated by the Department of Fisheries and Oceans, through its Director-General, Ocean Science and Surveys (Atlantic). The principal laboratories and departments are:

Department of Fisheries and Oceans (DFO)
- Canadian Hydrographic Service (Atlantic Region)
- Atlantic Oceanographic Laboratory
- Marine Ecology Laboratory
- Marine Fish Division

Department of Energy, Mines and Resources (DEMR)
- Atlantic Geoscience Centre

Department of the Environment (DOE)
- Seabird Research Unit

BIO operates a fleet of three research vessels, together with several smaller craft. The two larger scientific ships, *Hudson* and *Baffin*, have global capability, extremely long endurance, and are Lloyds Ice Class I vessels able to work throughout the Canadian Arctic.

BIO has four objectives:

(1) To perform fundamental long-term research in all fields of the marine sciences (and to act as the principal Canadian repository of expertise).
(2) To perform shorter-term applied research in response to present national needs, and to advise on the management of our marine environment including its fisheries and offshore hydrocarbon resources.
(3) To perform necessary surveys and cartographic work to ensure a supply of suitable navigational charts for the region from George's Bank to the Northwest Passage in the Canadian Arctic.
(4) To respond with all relevant expertise and assistance to any major marine emergency within the same region

W.D. Bowen - *Chief, Marine Fish Division, DFO*

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On the cover:

An engraving of "The Glacier of Sermiatsialik, Greenland" from:

Adams, William Henry Davenport. 1876. The Arctic World: Its Plants, Animals, and Natural Phenomena, with a Historical Sketch of Arctic Discovery down to the British Polar Expedition, 1875-76. London: T. Nelson & Sons: p. 129.

Climate change and variability is the theme of our *BIO Review* this year. The perennial ice cover in polar regions has a profound effect on our world's climate and, among oceanographic institutes, BIO is particularly active in carrying out research and survey work at high latitudes. Many of the examples of our climate-related work included herein are based on data collected on ship voyages to the Canadian Arctic and adjoining areas.

CLIMATE change and variability

In the southern winter of 1982, unusually strong southerly winds developed in the Tasman Sea extending from southern New Zealand nearly to the equator. These winds were the first evidence of the global weather disasters of the two subsequent years. They initiated unusual westerlies in the tropical Pacific that then led to the strongest El Niño of the century; soon we read and heard of floods and storms in California and western South America, droughts in southern Africa, Indonesia, and China, and failure of the monsoon in India.

It also quickly became common knowledge that all these events, which cost many lives and hundreds of millions of dollars in property damage, were in some way caused by a major change in ocean circulation in the tropical Pacific, itself connected with global changes in our weather patterns. If it did not become a household word, at least very many people now knew about El Niño and its consequences. Here in eastern Canada, 1982-1983 became known as the winter-that-wasn't with quite important consequences for energy-consumption, and a lot of frustrated skiers. For the first time in decades, the coastal deserts of Peru were carpeted with flowers.

Since 1982, the ocean science community has been hard at work trying to piece together exactly what did happen. As well as being the most important event of its kind this century, it was also the best studied because both oceanographers and meteorologists have had El Niño studies as an important part of their agenda for several decades now. It is clear today that, associated with the events in the tropical Pacific, anomalous conditions in the ocean existed as far away as the Gulf of Alaska and over much of the Atlantic.

Not only was the changed pattern of ocean circulation associated with changed weather patterns, but it also had important consequences for life in the ocean and for fisheries resources. Sea lions and marine iguanas suffered in the Galapagos, seabirds failed to breed on many Pacific islands, and the great fisheries of the Humboldt Current suffered yet another major change: anchovy, sardine, scallop, and bonito fisheries were all affected, for better or worse, and in several parts of the ocean distant from the eastern Pacific accounts are beginning to accumulate of northerly or southerly shifts in species' ranges.

Perhaps coincidentally, perhaps because we were all sensitized by these events to the possibility of instabilities in our environment, public awareness began to grow during the same period about a much longer term process likely to change the global climate: unlike El Niño, this change will be caused by us. Again, the 'greenhouse effect' is not yet a household word, but it is already well known by many people that our industrial, agricultural, and transportation industries have directly contributed to increasing concentrations of carbon dioxide in the atmosphere in the last century since the start of the industrial revolution; we expect this apparently irreversible trend will raise global temperatures over the next century enough to shift climatic and agricultural regions, modify sea level, and wreak other havoc.

As with the El Niño phenomena, it is now widely understood by the general public that the ocean has an important role to play in determining how fast the 'greenhouse effect' will change our climate: to an important extent, the rapidity with which the ocean absorbs carbon dioxide from the atmosphere, either by simple solution or by incorporation in the marine food chain, will determine how rapidly this gas and others, which also trap heat in the atmosphere, will in fact build up.

Now firmly in the public consciousness, this array of problems has preoccupied meteorologists and

Alan Longhurst.

oceanographers for at least a century. About 100 years ago, the meteorological service of India began seeking statistical correlations between failure of the Indian monsoon, causing the catastrophic famine of 1877, and other indices of weather - such as surface air pressure in distant parts of the Indo-Pacific region. By the early 1900s, the Director-General of Observatories for India, Gilbert Walker, had in fact discovered the basic mechanism that drives El-Niño events. We now know that part of the global El-Niño event is often drought - or failure of the monsoon - in the Indian subcontinent. In a listing of the occurrence of El Niño in the historical record, it is no surprise to find that of 1877-1878 listed as one of the 14 greatest of the last 200 years.

What has all this to do with Canada, and Canadian oceanography? If you are a farmer in southern Saskatchewan in the great dry summer of 1984, you may wonder if what you are suffering, and what may well drive you off your land before the year is out, was predictable so that you could have so ordered your farm business as to ease the shock. If you are an inshore fisherman off Nova Scotia during the same summer, you may well wonder if the plague of southern dogfish, useless to market yet preventing your normal fishing, are brought by changes in ocean circulation this year and - if so - could the event have been predicted? You may not know that what ails you may have its roots in processes studied and beginning to be understood by oceanographers, including those of your Department of Fisheries and Oceans, but you know that something is wrong.

It seemed natural, then, in place of the regional survey to which we expected to devote our *BIO Review '84,* instead to devote it to discussing some of the ways this Institute is, and has been, studying the difficult scientific problems that have to be solved before we can usefully and operationally predict the kinds of events that plagued us in 1982-1983, or that we expect to influence the lives of our children. BIO does not have a climate research programme as an organizational component of its work: rather, the problems of variability in the marine environment are studied as components of almost all oceanographic, some geological, and some hydrographic projects.

The range of climate-related activities at BIO is very large, from studies of how, and how fast, carbon dioxide passes between air and sea water at the surface of the ocean to the consequences of between-year differences in arctic ice cover for shipping in the Northwest Passage. The variability of ancient climates as recorded in the strata in cores of deep-sea sediments is studied by geologists, and the influence of between-year variability on the reproduction of fish stocks in the Northeast Atlantic is studied by biologists. Staff of BIO are active in planning for various components of the national and international climate research programmes that are very actively being put together in response to our new perceptions of how ocean variability impacts on our national economy Some projects actually produce long-term data, on inshore seawater temperatures and coastal sea levels for instance, which will serve as basic information about changes as they occur. Other programmes, such as a routine trans-Atlantic temperature section from Halifax to Europe, will soon be initiated to provide some Canadian content to such data being collected actively by many nations.

The individual contributions in this *Review* are not intended comprehensively to cover all climate-related work at BIO; for this, the reader is referred to our regular list of individual project descriptions of all of our activities. The principal descriptive chapters provide only a selected sampler of the whole.

The final chapters of *BIO Review '84* comprise our now familiar annual survey of relevant information about the Institute: publications, voyages, research and survey projects are all listed, as are the statistics of some of the facilities available at the Institute.

It is no coincidence that our *Review* this year contains a note on the 1984 Huntsman Award presentation to an oceanographer who has been investigating our planet's paleoclimates and who spoke at the award ceremonies on how analysis of these past climates is useful in interpreting present-day changes and predicting the likely future changes in our climate.

- *A.R. Longhurst*
Director-General
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HUNTSMAN AWARD RECIPIENTS

Wolfgang Berger.

Reuben Lasker.

Dr. Wolfgang Berger of the Scripps Institution of Oceanography was the 1984 recipient of the A.G. Huntsman Medal for Excellence in the Marine Sciences. He was recognized for his contributions to the understanding of the carbonate preservation and dissolution cycles in deep-sea sediments. Dr. Berger developed the concept of the lysocline, a level or ocean depth at which the rate of solution of calcium carbonate just exceeds its combined rate of deposition and precipitation. He described how the lysocline varied in the past and related these variations to changes in global climate.

Dr. Reuben Lasker of the National Marine Fisheries Service at La Jolla, California, received the 1983 Huntsman Medal for his sustained research into the problem of the 'critical period' in larval fish and the determination of year-class strengths. Over 15 years, Dr. Lasker and his colleagues used both experimental and field observations to elucidate the mechanism that determines year-class strength in the California anchovy population.

The A.G. Huntsman Award honours those who have had and continue to have a significant influence on the course of marine scientific thought. Established by the Bedford Institute of Oceanography and supported by the petroleum industry, government, and fisheries- and ocean-related industries, the award honours the memory of Archibald G. Huntsman (1883-1972), a pioneer of Canadian oceanography and fisheries biology. Nominations for the award come from the entire Canadian community of marine scientists. Past recipients include Christopher J.R. Garrett, Ramon Margale,. Dan P. McKenzie, Henry M. Stommel, and J. Tuzo Wilson. The award is presented annually in one of three categories (except in its inaugural year, 1980. when recipients were honoured in all categories): marine geosciences, physical and chemical oceanography, and marine biology.

Paleoclimatology – past states of the ocean

The oceans as we know them are dominated by water only a few degrees above the freezing point. Today, the polar seas are partly ice-covered, and a very thin layer of warm water lies above their cold interior: in tropical seas, only a few hundred metres below the surface, the water temperature approaches that of the Labrador Sea in summer. But, the oceans have not always been so. For long periods during the Paleozoic and Mesozoic eras, the polar seas were almost as warm as the Gulf Stream off eastern Canada is now, there were no ice caps, and the then-tropical oceans resembled the Red Sea. Over much shorter time periods, at the peak of the most recent glaciations, the oceans were even colder than today, the extent of warm surface water was much less, and enough water was bound up in the polar ice caps that sea level was as much as 100 m below today's stand.

Climatic changes appear to be mediated by a variety of mechanisms, but perhaps most importantly by the amount of carbon dioxide in the atmosphere. By reducing the earth's outgoing radiation, this gas effectively makes our planet a 'greenhouse' whose temperature will rise as more radiation arrives from the sun. This appears to be the driving force on both long- and short-term time scales, and it is itself determined by the balance - still very improperly understood - between those forces that release the gas into the atmosphere such as volcanic activity, the decay of forest biomass, and the alteration of the ocean ecosystem and those forces that remove it such as the weathering of new mountain chains and the accumulation of biomass as coal or oil.

Faced with the problem of predicting where the clearly observable present-day rise in atmospheric carbon dioxide will take our global climate - both in the atmosphere and oceans - the reaction of the ocean to past changes is our chief guide. Both at BIO and at other major ocean science institutes, we are probing the history of the oceans to try to understand how these mechanisms actually caused the changes we know occurred. From such studies we can hope to learn how rapidly changes can occur, whether the new climate will be highly or slightly variable, and where sea level is likely to stand on our grandchildren's seashores. What follows are two examples of this line of research.

Climate and the geologic record

C.T. Schafer, P.J. Mudie, and J.N. Smith

Proxy signals of past climate conditions can be derived from textural evidence in marine sediments on a scale of years and from lithological and paleontological evidence on a scale of thousands to millions of years.

Climate research at the Atlantic Geoscience Centre (AGC) is concerned with interpreting indirect climatic information imprinted on the geological record. Instrumental data necessary for predicting the local impact of hemisphere-wide climate variations have been recorded in Canada for only about the last 100 y. These data reveal the links between interannual or seasonal changes in weather and variations in atmospheric circulation, but they cover too short a span to identify longer term, low frequency changes. For example, to make a quantitative study of climate variations that take place over 50 y intervals, a record ten times as long (i.e., 500 to 1000 y) is required. The evaluation of extreme events like storms requires even longer records in order to reliably estimate their probability of recurrence. The proxy signals imprinted in the geological record are one of the few sources of long records of climate information in Canada. These signals are in the form of marine microfossil and fossil pollen abundances, and in the grain-size characteristics of discrete sediment layers that occur in core samples (see first figure). Working with proxy signals from locations throughout the country can help unravel the effect of recent global climate variations on the different parts of Canada's landmass, flora, and marine environments, and permit us to assess the impact of long-term climatic changes on local conditions.

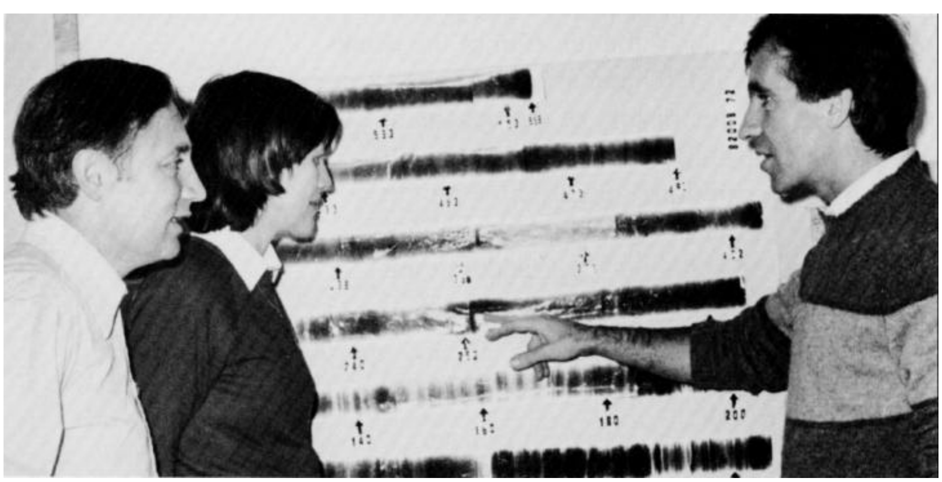
A paleohydrologic study presently underway in the Saguenay fjord, Quebec, is aimed primarily at describing the variations in climate that modulated the spring river-discharge intensity of the Saguenay River before the 20th century. Investigation of sediments deposited during the 20th century in a basin near the head of the fjord has shown a direct relationship between the proportion of coarse sediment particles deposited each year during the 20th century and the intensity of the annual spring freshet of the river. One major factor controlling the intensity of the freshet is the precipitation that accumulated as snow during the previous winter. Studies of the relationship between snow cover, an important factor in the Canadian climate story, and air temperature suggest that relatively warm moist air flowing northward into Canada over snow about 15 cm deep loses its heat by conduction, and cools by 4-5°C per day. Similarly, warming during the early spring months is usually most rapid when snow cover is minimal or absent.

Interpretation of the proxy climate record for the Saguenay area depends on accurate dating of subsamples from cores that contain a 400-y-long record of sediment deposition. Geochronological investigations have been undertaken using the naturally-occurring radionuclide. Pb-210, whose half-life of 22 y makes this isotope an appropriate radioactive tracer for sediment dating over the past 100-150 y (see second figure). Radionuclides such as Cs-137 and Pu-239 and 240, introduced into the environment initially as a result of nuclear weapons' tests in the late forties, can also be used as time-stratigraphic markers to date specific horizons in recent sediments. Once the core has been dated precisely using radionuclide tracers, other documented anthropogenic or natural phenomena are employed to extend the dating methodology back in time.

The precise dating of distinctive textural changes observed in older sediments. and knowledge of the river discharge rates required to produce these changes, provide one means of reconstructing a proxy historical record of winter precipitation and temperature in the Saguenay area over the past few hundred years.

Analysis of many core samples from the Saguenay fjord reveals a general relationship between the modal grain size of sediment layers and the magnitude of the annual-maximum mean-monthly river discharge. One such relationship was established in the following manner. The grain size distribution of the sand fraction was measured in 2-cm thick sediment intervals that were dated to the nearest year using the Pb-210 method. The historical record of river discharge was then compared to determine the maximum mean-monthly discharge during the year of deposition of each associated sediment interval. This discharge level was plotted against the modal diameter of the sand for each sediment interval (see third figure). The plot suggests a direct relationship between modal sediment size and river discharge: thus, the deposition of comparatively coarse sand particles near the head of the fjord increases as the annual-maximum mean-monthly river-discharge level increases. Samples containing clay pellets identify sediment inputs that are associated with landslides. and/or with anthropogenic activities such as excavation of dam sites along the main channel of the Saguenay River during the first half of the 20th century.

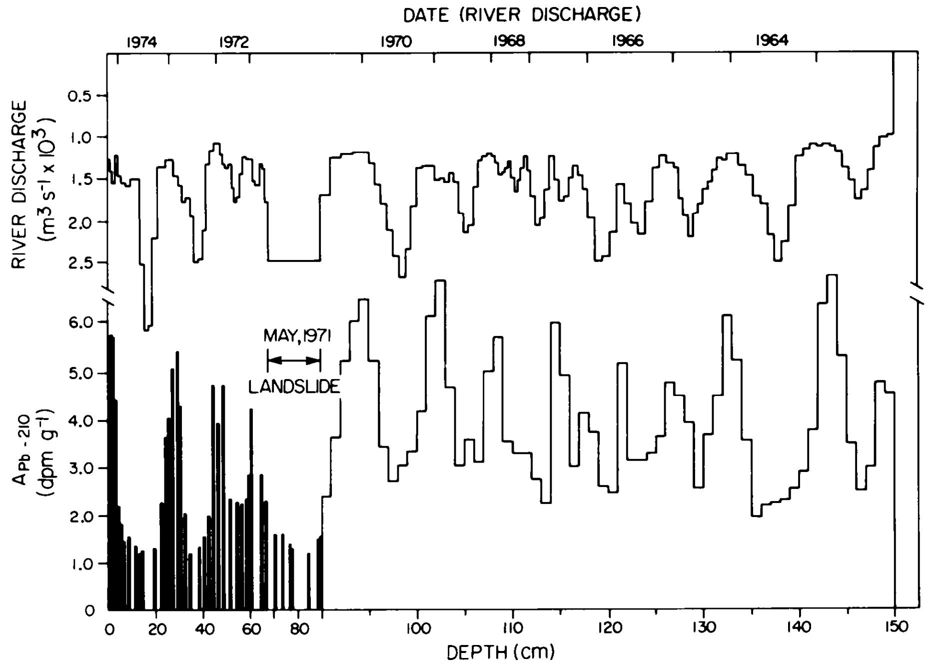
The longer term climatic variations that are reflected by the major glacial and interglacial intervals observed in the



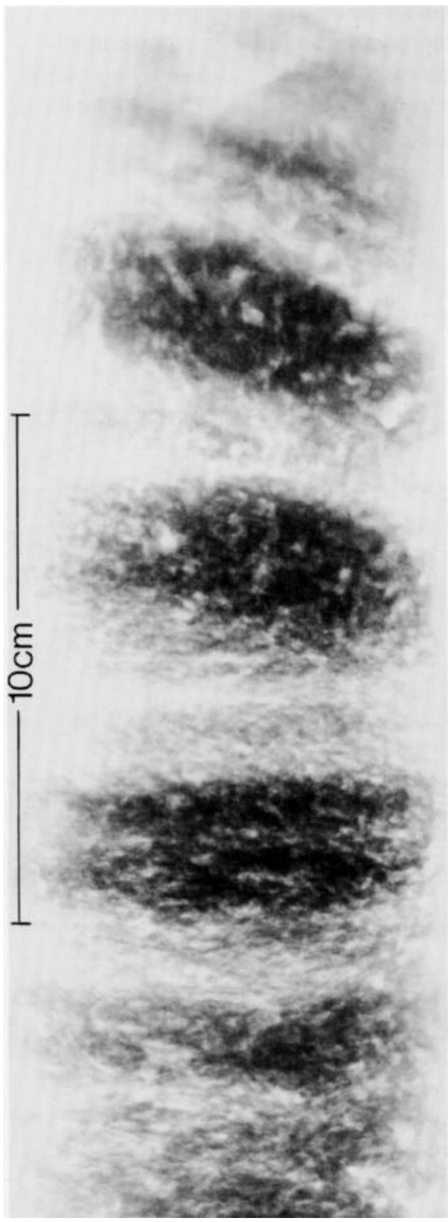
Charles Schafer, Peta Mudie, and John Smith examine X-ray photographs of sediment cores.

North American geologic record pose several important questions for paleoclimatologists. Of current interest is the timing of changes in oceans, ice sheets, and atmosphere during the approach to a glacial climatic stage. Scientists agree that a global data base is required to assess the tempo of these changes and to understand the changes in large-scale atmospheric circulation reflected in the proxy record contained in marine sediments.

Deep-sea sediments provide long



Pb-210 activities and river discharge intensity plotted as a function of core depth and year of deposition in a core (3111) collected near the head of the Saguenay fjord. The Pb-210 is associated with fine sediment particles and its activity level at a particular depth interval of the core is proportional to the time of deposition of the associated sediment layer.



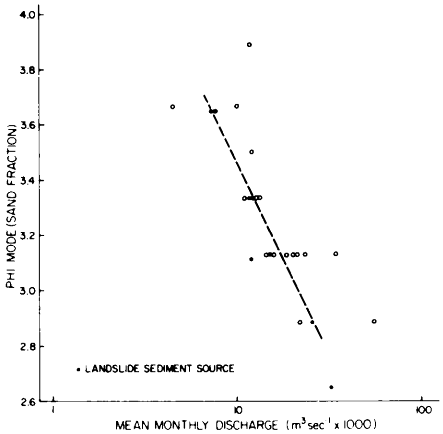
An X-ray photograph of a sediment core showing annual deposits of comparatively coarse sediment (the dark layers) that are carried into a basin near the head of the Saguenay fjord during the annual spring freshet.

(100,000 to 750,000 y). continuous records of oceanographic responses to climatic change. Proxy climatic data are derived from fossil plankton, such as foraminifera, coccoliths, and diatoms, which make up the bulk of the sediments. Statistical analysis of the plankton deposited at the seabed, in a sampling grid extending from the tropics to the polar regions, shows that the fossils record modern surface- and bottom-water temperature conditions with an accuracy of about 1°C. If it is assumed that the temperature response of the fossil plankton has not changed significantly in one million years, then temperature-calibrated modern fossil data can be applied to the long sediment records in order to obtain graphs of ocean temperature changes for prehistoric times, including the last ice age when most of Canada was covered by an ice sheet l-3 km thick.

The method, known as paleoecological transfer function analysis, has been used successfully by the international CLIMAP Project (Climate/Long-range Investigation Mapping and Prediction) to construct synoptic maps of ocean circulation in the North Atlantic during the last glacial interval (18,000 y ago), and during the transition to interglacial conditions. which have existed for about the past 10,000 y. CLIMAPdata show that the Gulf Stream off Greenland was about 1600 km further south during the ice-age maximum when summer ocean surface water around Iceland was 7°C colder than at present.

Changes of this magnitude could have a major effect on ocean productivity and climate in eastern Canada. In 1982, therefore, a study was started at AGC and Dalhousie University to analyze the proxy climatic record in sediments from deep basins on continental shelves off Labrador, Newfoundland, and Nova Scotia. Paleoecological transfer functions have been obtained for a 20,000 y record off Hamilton Inlet, Central Labrador (see fourth figure). These data show that: (1) the summer temperature of the Labrador Current was only about 2-4°C lower at the glacial maximum; (2) bottom water was about 1°C higher than at present during the warmest interglacial interval, about 7000 to 3000 y ago; and (3) there has been an average temperature decrease of 1-2°C during the past 3000 y.

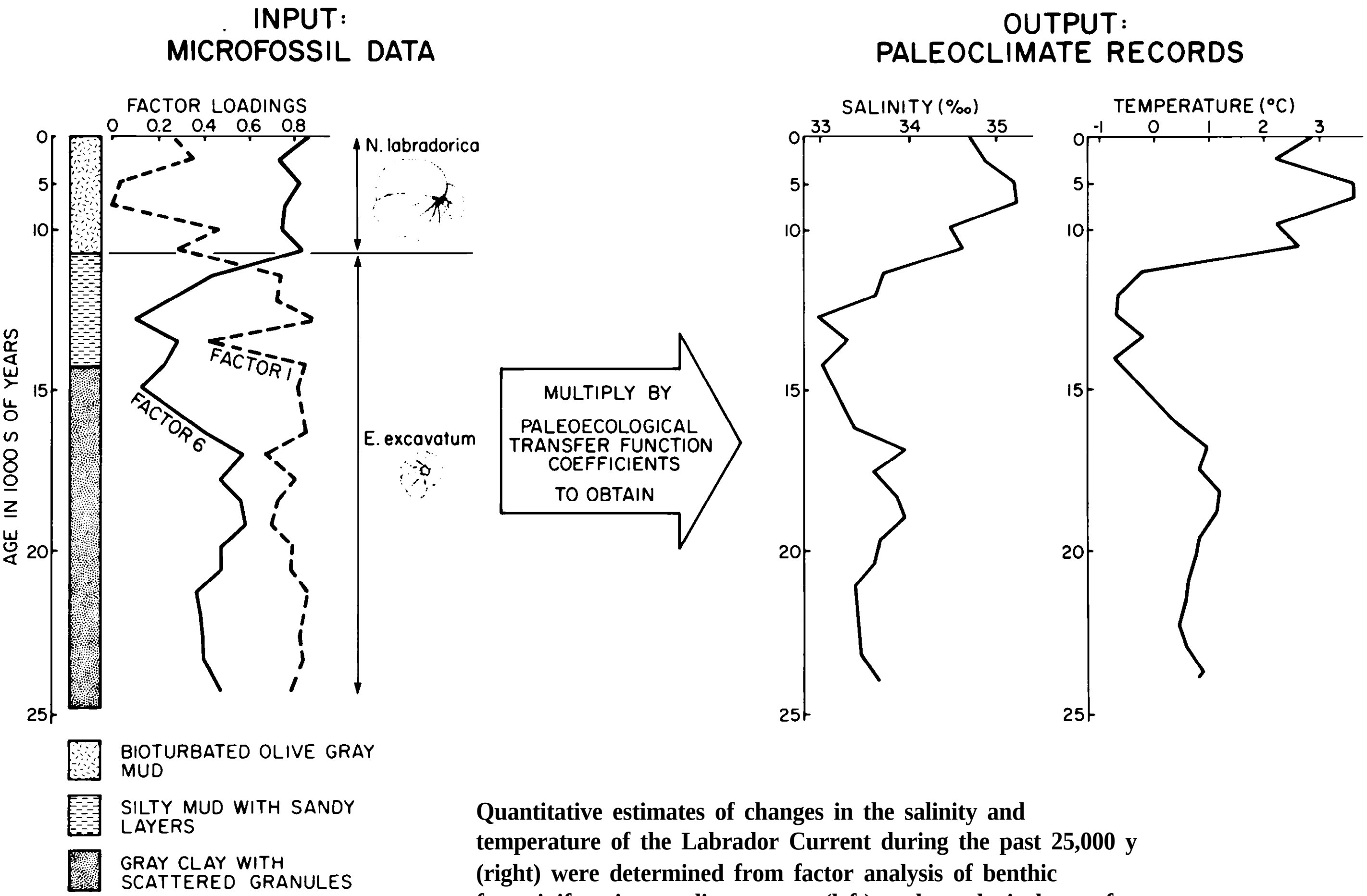
In order to specify the ocean-atmosphere temperature relations that characterize the onset of an ice age, however, it is necessary to examine proxy climatic records that span several glacial-interglacial transitions (i.e.. that provide a continuous record for at least the past 350,000 y). Therefore, we are now studying cores from Davis Strait that



The modal grain diameter of suspended sediments increases in direct proportion to river discharge intensity because relatively coarse sediments are carried in suspension farther offshore during the spring freshet before settling to the bottom of the fjord basin.

contain a 300,000 y sediment record. Abundances of fossil foraminifera and dinoflagellates are being used to analyze the history of ocean temperature and productivity; pollen assemblages from these cores are also being analyzed to obtain proxy data that reflect climate change and wind trajectories over the North American continent. Initial results indicate that the northern Labrador Sea was warmer than at present during earlier glacial stages due to a stronger northward advection of southern cyclonic air masses along the margins of expanding ice sheets over Greenland and Canada. This circulation pattern also explains the increased moisture required to maintain rapid ice-sheet growth.

The slow sedimentation rates (2.5 cm/ 1000 y) observed in cores from Davis Strait do not allow us to define the characteristic features of climatic conditions during the onset of glaciation because sediment mixing by bioturbating organisms and from other causes limits the resolution of proxy climatic signals to between 2000 and 5000 y. Therefore, we are now pursuing various means of deep drilling to obtain long geological records from ocean areas with high sedimentation rates in which the effects of bioturbation are substantially reduced. In the summer and fall of 1985, the Ocean Drilling Program is scheduled to drill several long (500 m) boreholes in the Labrador Sea basin. Cores from these holes should provide geological samples that will improve the resolution of proxy climatic records for eastern Canada and thus extend the paleoclimatic record back at least three million years.

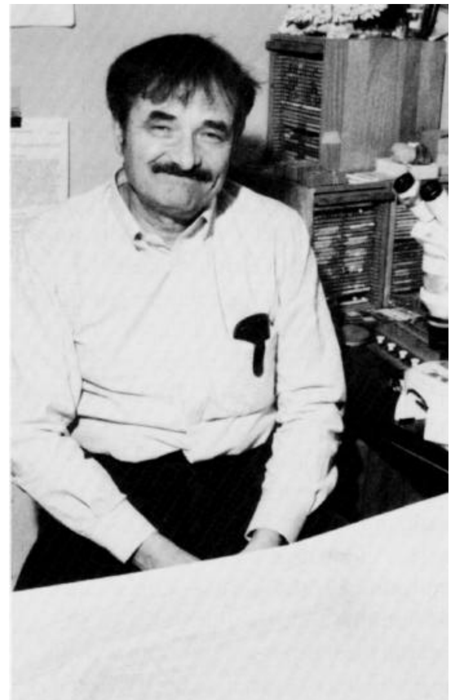


Quantitative estimates of changes in the salinity and temperature of the Labrador Current during the past 25,000 y (right) were determined from factor analysis of benthic foraminifera in a sediment core (left): paleoecological transfer functions describe the relation between modern foraminifera *(e.g., Nonion labradorica, E. excavatum)* and present seawater temperature/salinity.

Paleoclimatic models from fossil records: A case history in Lake Melville, southeastern Labrador

G. Vilks

Evidence of the fluctuations in the glacial and postglacial conditions in the Lake Melville area is preserved in the local sediments. Early fluctuations were due to an influx of glacial meltwater, later ones to shallowing of sill depths at the entrance to the lake.



Gus Vilks.

Building paleoclimatic models from fossil faunas is a developing science whose aim is to improve our knowledge of past climates, age dating, and prediction of climate change. Stable isotope ratios, such as the $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios in foraminiferal carbonates. have been successfully used in studying offshore sediments and transfer functions have been calculated so as to statistically estimate paleotemperatures and paleosalinities from microfossil assemblages in sediment cores. In marginal marine environments such as Lake Melville, which is not a true lake at all, the offshore methods are not always applicable, and we are still trying to establish their usefulness. Along the zone of land-sea interactions, major environmental changes have a tendency to fluctuate to greater extremes than regional and global changes. Therefore, a framework of ^{14}C ages is often the only way to correlate nearshore, offshore, and global paleoclimatic events reliably. Insufficient amounts of carbon are available for conventional dating methods in our area and so ^{14}C ages are too few to make accurate correlations. The newly developed mass spectrometer method for reliable ^{14}C dating can handle samples 100 times smaller and promises to overcome this shortcoming soon.

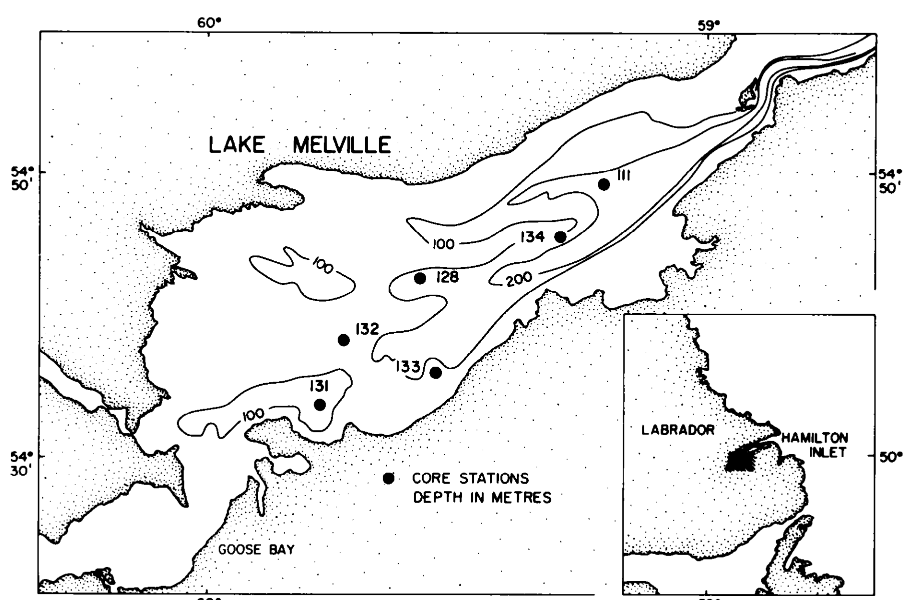
In Lake Melville, foraminifera are useful for paleo-oceanographic/paleoclimatic studies once their ecology is sufficiently understood. Then a particular species assemblage found in subsurface sediment can be linked, for example, to its most likely paleosalinity range, which could be linked to the Labrador Current and thus to a possible paleo-oceanographic/paleoclimatic setting that existed during the time when the foraminifers were living on the sea floor.

I study foraminifera in Lake Melville sediments to infer changes in paleoenvironment during the last 10,000 y. a time span when continental glaciers retreated from southeastern Labrador in response to major changes in climate and oceanography

Lake Melville, a fjord on the southeastern Labrador coast, contains up to 300 m of unconsolidated deposits (Grant, 1975). Sediments in piston cores show a series of well-defined lithologic and faunal boundaries that reflect changes in marine environments and sedimentary processes from the late glacial to recent times. Thus we see sedimentary structures that were formed along the last glacial ice margins and faunas that were living during the early postglacial marine maximum and during the Holocene changes in sea level. The preserved marine record of fossils and sediment lithology can provide proxy information on major changes in paleoclimate.

Studies of terrain and soils around Lake Melville suggest a complex history of glacial-deglacial events (Fulton and Hogdson, 1979). To the north of Lake Melville, the Late Wisconsinan ice extended to the sea; to the south, the Mealy Mountains may have obstructed some of the seaward flow and the ice may have stopped short of the present shoreline (Rogerson, 1977). Drawdown may have taken place in the Lake Melville Basin, which most likely acted as a calving bay for the glacial ice.

Since deglaciation, relative sea level has changed as a result of isostatic rebound of the terrain. The initial marine flooding was followed by sea-level regression at faster



Location map of Lake Melville showing its bathymetry and the core stations occupied.

rates inland than at the coastline. Thus, the deposits of the marine maximum are found 150 m above the present datum at Goose Bay and 120 m above that at the Narrows (Andrews, 1973).

The salinity and temperature of the water in Lake Melville are a function of river run-off and the marine contribution from the Labrador Sea. During August, the warm and fresh river water is present as a thin surface layer almost throughout the Lake, but during October the surface cooling promotes mixing. The shallow channel leading to the Lake prevents the entrance of relatively saline and cold subsurface waters into the Lake and, as a result, the bottom waters of Lake Melville are less saline than waters at corresponding depths outside it. Because of the relatively low bottom salinities, the exchange of water in the basin is at least annual. Thus, the dissolved oxygen in bottom water of Lake Melville is at the level of saturation.

The sediments collected in piston cores are basically olive brown muds that become silty to sandy towards the bottom of the cores. The fine sediment structures are best seen in x-radiographs taken through longitudinally split cores. The most prominent and diagnostic features are the bioturbated surface layers underlain by laminated sediments towards the bottom. The laminae are due to fine layers of slightly coarser sediment. Within the bioturbated zone, x-radiographs also show pyritized structures of biogenic origin and worm burrows. Dropstones are pebbles that have been released by melting sea ice and occasionally show evidence of having sunk through layers of mud. The gas fissures of Core 111 formed after the cores were collected and are most likely due to methane gas coming out of solution.

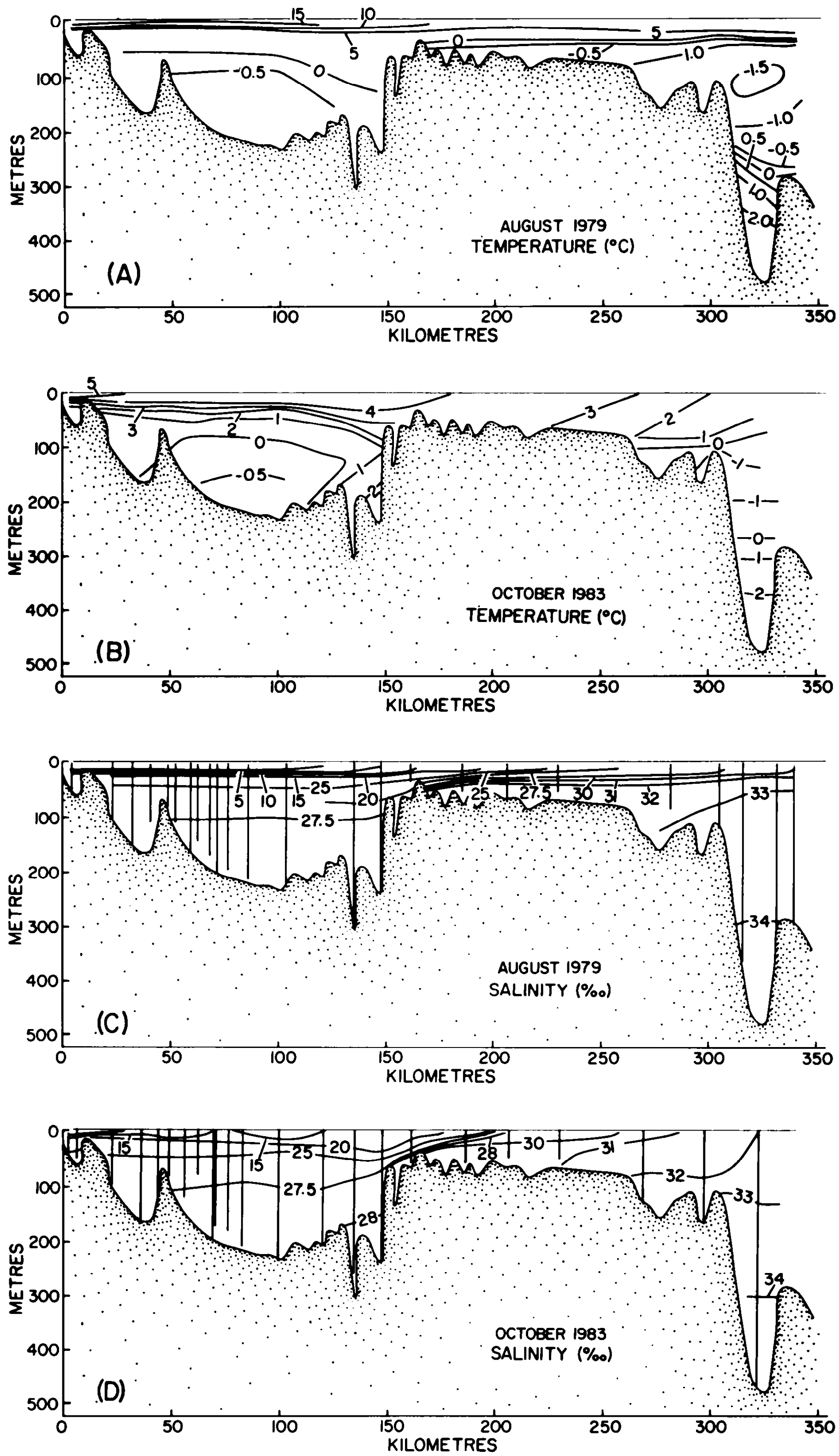
The presence of foraminifera in sediment cores is closely related to x-ray stratigraphy. Foraminifera are common only in the bioturbated zone of the cores and occur in small numbers or are totally absent from the sharply laminated sediments (third figure). Basically two types of foraminifera are present in the fossiliferous zone. The upper layers of the cores are dominated by agglutinated species below which there is a zone dominated by calcareous species. A few molluscan shells are also found in the bioturbated zone in addition to evidence of other macrobenthos, such as worm burrows.

Faunal changes in sediment cores strongly suggest major changes in the marine environment through time. Pollen profiles in Core 111 and ^{13}C dates of organic matter indicate average sedimentation rates on the order of 2 m per 1000 y in the deep basins (Vilks and Mudie, 1983) and less than 1 m per 1000 y on the ridges. Since all sample intervals were 5 cm thick, the time resolution in each sample is not better than about 25 y in the basins and 50-100 y on the ridges.

Foraminifera are directly affected by water salinity and temperature, availability of food through primary and secondary production rates, and dissolved oxygen. Sediment sources in combination with sedimentary environment govern the type of sediment available as substratum (e.g., some species prefer muddy sediments and others sandy). These primary factors are linked to a series of secondary factors that eventually lead to the climate.

Foraminifera living on the sea floor at the present time are adjusted to the bottom

The Narrows lead into Lake Melville in southeastern Labrador. The lake, which is tidal, has a maximum width of 32 km and contains generally deep waters comparatively free of shoals except in the western part of the main section.



Temperature and salinity profiles in Hamilton Inlet, Labrador.

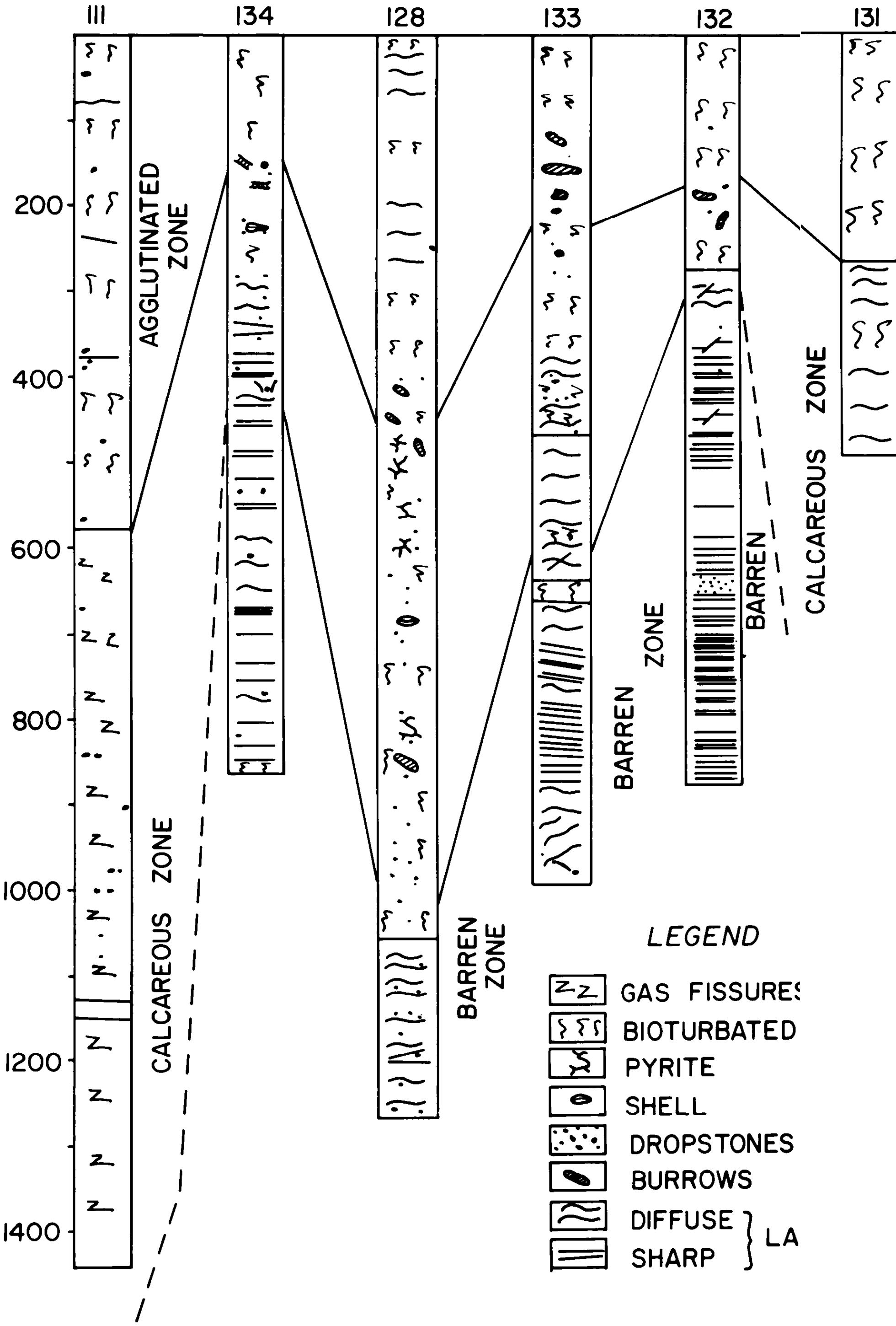
salinity of 28 parts per thousand, the temperature of 0.5°C, and the mainly muddy sediment. The average freshwater influx through river run-off is 58 km^3/y; dissolved oxygen levels in the bottom water are between 7-8 ml per litre; and sea ice is present from November until May. The minimum water depth in the channel, which is 2.8 km wide and 22 km long, is 30 m. Any major changes in these primary factors would lead to changes in foraminiferal assemblages on the sea floor.

Studies of foraminiferal ecology in estuarine environments suggest that salinity is one of the important factors influencing the distribution of species. In the most thoroughly studied core, 111, the eurysaline cold-water agglutinated species at the surface are replaced by calcareous species about 400 cm downcore. The calcareous interval contains an upper faunal zone dominated by *Islandiella helenae* and a lower zone dominated by *Elphidium excavatum f. clavata.* A paleosalinity range of 32-34 parts per thousand was estimated for the *I. helenae* zone on the basis of the known salinity tolerance ranges of species within the zone (Vilks and Mudie, 1983; Mudie, *et al.,* 1984). These same studies suggest a warmer paleotemperature range of between 0°-2°C. The *I. helenae* zone is between 5000 BP and 8000 BP old.

Higher bottom salinities could be due to: (1) greater paleosill depths at the entrance to Lake Melville; (2) lower volumes of fresh water added to the system; (3) saltier water entering the Lake; or a combination of the three alternatives. Pollen profiles in Core 111 do not suggest an extensive dry period since deglaciation; thus, reduced run-off is unlikely. Raised marine deposits at certain areas around the Lake and in the Narrows indicate greater paleodepths in Lake Melville and in the Narrows. Since the sill surface is in the pycnocline, slight changes in its depths will determine the type of water entering the Lake from outside. Deepening of the sill, and thus widening of the channel. will allow the entrance of more saline water in addition to reducing tidal mixing. Thus, higher paleosalinities could easily be explained by a deeper channel without changing the characteristics of the inner shelf Labrador Current.

The paleosalinities of the *E. excavatum f. clavata* zone towards the bottom of the core are 31-33 parts per thousand. a lower range than for the *I. helenae* zone of the younger sediments. The extrapolated ^{14}C age for the top of the *E. excavatum* zone is about 8000 y BP and within the time of the early postglacial marine maximum in Hamilton Inlet. The sill depth may then have been close to 130 m and if the estuarine circulation were similar to the present, bottom salinities should have been in the order of 33-34 parts per thousand. The predicted lower paleosalinities indicate that fresher water from glacial run-off may have been present at greater depths in the Hamilton Inlet area.

Elphidium excavatum f. clavat is present in recent sediments in a variety of environments ranging from estuaries to



The stratigraphy in Lake Melville sediment cores as determined from examination of X-ray photographs.

continental slopes. In older sediments off Eastern Canada and Scandinavia, the species is persistently dominant in late glacial deposits and is one of the major species found in sediments facing a tidewater glacier in Spitzbergen. There is, therefore, a distinct possibility that the *E. excavatum* zone found in all cores collected in Lake Melville represents a distal glacial margin environment during the time when glaciers were melting in the uplands to the west of Lake Melville.

Below the zone of the distal glacial sediments are laminated sediments devoid of faunal remains. These may have been deposited in a proximal glacial environment dominated by the presence of glacial ice and large volumes of glacial meltwater. Below the sampling depth of piston corers, the high resolution Huntec deep tow seismic profiles also show stratified sediments that lie on top of acoustic structures interpreted as tills.

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Ocean circulation and climate change - The North Atlantic Ocean

As the global climate changes either naturally on various time-scales or as the carbon-dioxide 'greenhouse' effect begins to bite, the consequences will not simply be a uniform warming, with all other weather patterns remaining as we know them today. The global wind patterns will shift their location and climate belts marked by certain levels of rainfall will shift not only north and south, but also east and west.

Such changes can be predicted with a degree of certainty already, but we are very far from being able to do the same thing for the changes in ocean-current patterns that will undoubtedly also occur. Yet such are probably the most important effects: what if, for instance, the Gulf Stream departs from the North American coast not at Cape Hatteras, but at Cape Cod or Nantuckett Shoals, which is certainly not impossible? How will it then impact on the coastline and continental shelf of eastern Canada'? Will it strengthen or weaken the transport of cold arctic water along our coasts by the Labrador Current?

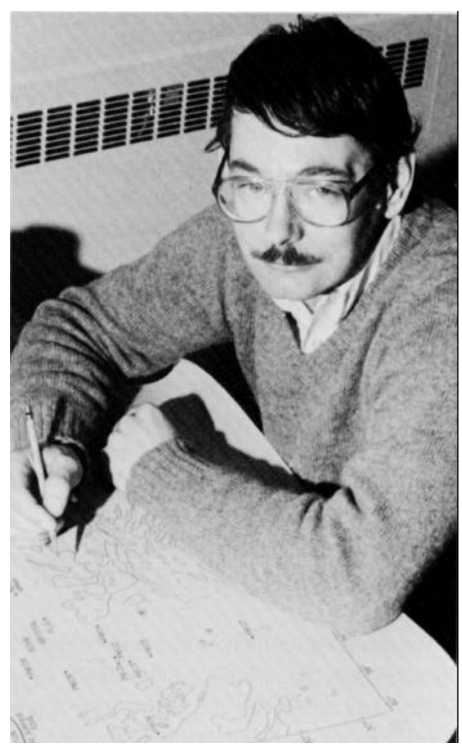
These are the kinds of questions to which the three studies discussed in this chapter are addressed.

Gulf Stream studies

R.M. Hendry

The Gulf Stream exerts a major influence on the climate of the North Atlantic Ocean and adjacent land areas by transporting large amounts of heat poleward. Understanding the dynamics of this system is an important goal of present-day physical oceanographic research.

The Gulf Stream is a major feature of the world ocean circulation. Beginning with the Florida Current off the southeast coast of the United States, it grows into the eastward flowing Gulf Stream proper south of Nova Scotia, and rounds the Grand Banks to continue as the North Atlantic Current flowing across the northern North Atlantic Ocean towards Europe. To the physical oceanographer, the Gulf Stream is a fascinating dynamical puzzle. It is a mid-ocean jet with water transport equal to 10,000 St. Lawrence Rivers, constantly twisting and meandering as it goes, casting off eddies that entrain up to 15,000 km^{-3} of water and can persist for months or even years. To the climatologist, the Gulf Stream is the northern and western boundary of an immense pool of warm water that is a source of heat and moisture for the overlying atmosphere and plays a vital role in determining the regional climate. Changes in the position of this boundary and changes in the temperature of the warm pool will inevitably be reflected in changes in the regional climate. A long-term goal of the physical oceanographer studying the Gulf Stream

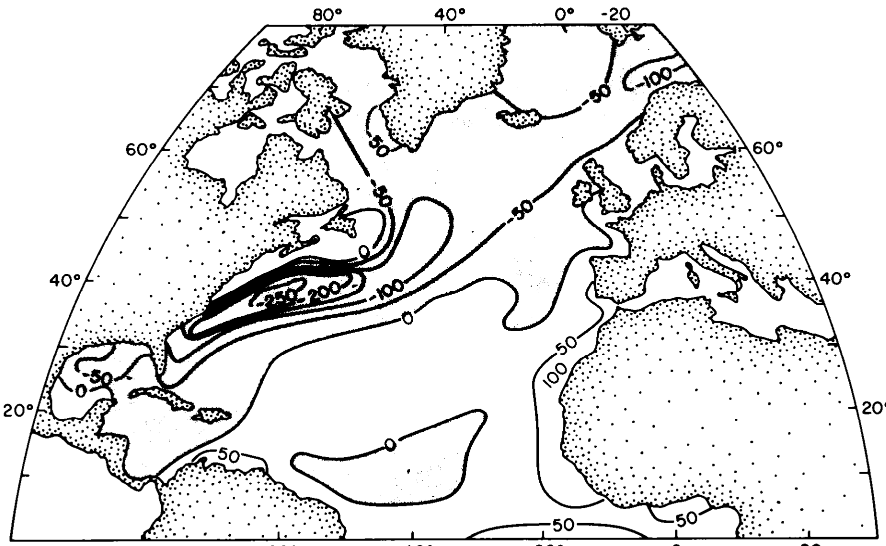


Ross Hendry.

to understand the dynamics of the system so as to be able to predict such changes.

According to Professor Henry Stommel in his well-known monograph "The Gulf Stream", the first mention of this major current system comes from Ponce de Leon who encountered the Florida Current in 1513 in the course of his exploration of the New World. It was relatively familiar to American mariners in 1770 when Benjamin Franklin, then Deputy Postmaster General for the American Colonies, had a chart prepared showing the course of the Gulf Stream to encourage mail packets from England to New England to avoid the strong eastward currents in the Stream and thus speed their passage. As late as 1942, Sverdrup could write in his classic oceanographic textbook that most meteorologists of the day neglected the effect of ocean currents such as the Gulf Stream in transporting heat from lower to higher latitudes. Sverdrup himself showed by example that oceanic transports could be significant in some regions, but he felt that the atmosphere played the dominant role in the overall process. In fact, modern studies have shown that the ocean circulation is vital in the global climate system, actually carrying more heat poleward in tropical latitudes than the atmospheric circulation itself.

We can refer to the first figure to begin a discussion of the influence of the Gulf Stream and ocean circulation in general on the climate of the North Atlantic Ocean and adjacent land areas. This figure shows the net heat transfer from the atmosphere to the North Atlantic Ocean averaged over the annual cycle. South of approximately 30°N. relatively cool surface waters gain heat from the overlying air as well as from the direct influence of the sun. North of 30°N, in a broad band running northeast from the Gulf of Mexico all the way to the Norwegian Sea, the ocean releases heat to the atmosphere over an annual cycle. This transfer is partly sensible heat, or energy associated with molecular motions, but the dominant component is the latent heat of evaporation associated with the change of state from liquid ocean water to water vapour picked up by the moving air. The two areas of greatest oceanic heat loss are found just east of the United States near 35°N and just east of Newfoundland near 45°N. where relatively cool and dry winds blowing off the North American continent first encounter the warmer ocean waters. The maximum rate of heat transfer found is about 250 Wm^{-2} of ocean surface. By comparison, the annual mean surplus of radiation from the sun at the surface of the earth near the equator, after allowing for reflection of incoming short wave radiation and long wave back radiation, is only about 150 Wm^{-2}.



The net heat transfer from the atmosphere to the North Atlantic Ocean over the annual cycle. Contours are in watts per square metre.

The heat energy absorbed by the atmosphere over the mid-latitude North Atlantic is carried to the east by the prevailing westerly winds and helps shape the temperate climate of northwestern Europe. Most of the heat must be released by condensation and subsequent precipitation of the water vapour carried by the winds, giving a somewhat damp climate to these European countries as an unavoidable companion of their moderate annual range of temperature.

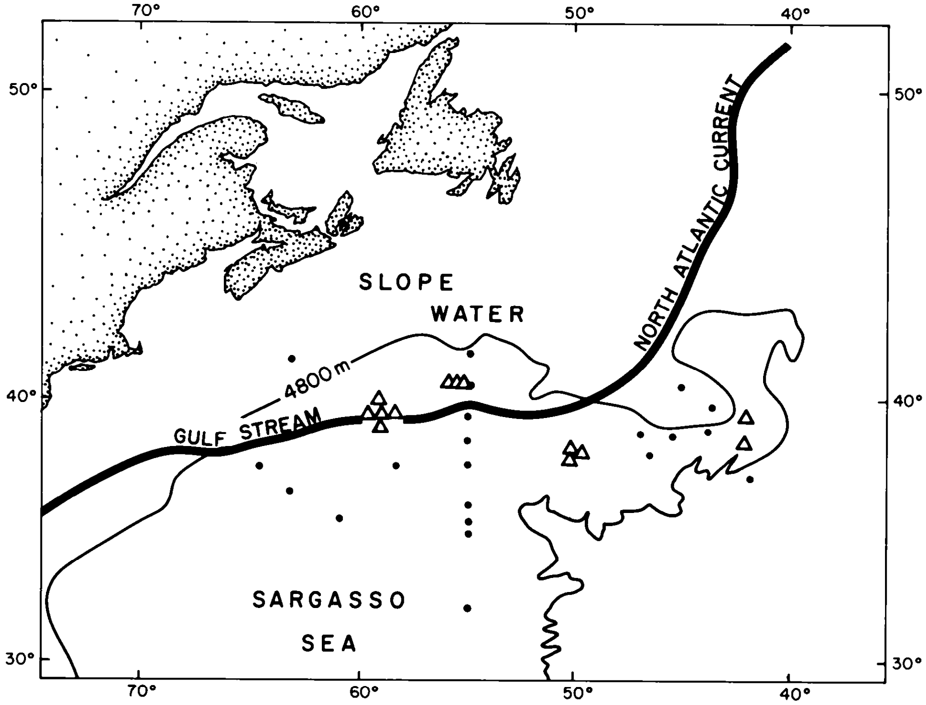
Referring again to the first figure, the ocean waters immediately adjacent to northwestern Europe release relatively small amounts of heat to the atmosphere compared to the areas near the North American coast, and the ocean-wide atmospheric circulation is a vital link in this coupled regional climate system. The Gulf Stream does not really bathe the shores of Europe as is sometimes naively suggested. Some readers might wonder why Canadian oceanographers should be so concerned with the climate of Europe, but it must be recognized that the study of large-scale ocean and atmospheric circulation is truly an international effort. Japanese oceanographers studying a similar system of large air-sea heat exchange associated with the Kuroshio Current in the western Pacific Ocean are contributing to the understanding of factors shaping the maritime climate of coastal British Columbia! To return to the basic theme of this article, just what is the role of the Gulf Stream in this large-scale process and how can fluctuations in ocean currents change our climate?

A moment's thought will make it clear that if certain areas in the North Atlantic are losing great quantities of heat to the atmosphere without cooling drastically, then heat must also be being supplied to these areas from some other source. Ocean currents accomplish this by transporting heat from tropical regions that enjoy a net surplus of solar energy input over a year. The maximum average poleward heat transfer by ocean currents in the North Atlantic has been estimated at about 3×10^{15}W near 20°N. just at the upstream end of the Gulf Stream System. The poleward ocean heat-transport decreases to the north as the ocean-borne heat is released to the atmosphere. The Gulf Stream, and its continuation as the North Atlantic Current, carry relatively warm waters to the north. In a steady state, an equal southward transport of water must occur somewhere in the ocean to maintain mass continuity. A net heat transport results because the southward flowing currents generally carry cooler water than the northward flowing currents. One component of the return flow is the cold Labrador Current, which flows southward down the eastern coast of Canada. Other return flows take place at abyssal depths. The three-dimensional structure of the North Atlantic circulation is the focus of study for oceanographers from many nations. The dynamical balances that control the circulation and maintain the distinctive warm-water gyres associated with the Gulf Stream and the North Atlantic Current are only partly understood. Specific mechanisms by which oceanic heat-transport is accomplished are also being actively studied. One question still to be answered is the importance of time-dependent ocean eddies in the large-scale transport of heat.

The warm Gulf Stream currents are important in determining ocean conditions in Eastern Canadian waters as well as in shaping the large-scale patterns of climate. An economically important region called the Slope Water is found north of the Gulf Stream between eastern continental North America and the Grand Banks. This Slope Water is formed mainly of a mixture of warm water from the Sargasso Sea south of the Gulf Stream and cold Labrador Current water. It is separated from the warmer waters to the south by the Gulf Stream itself, which acts as a dynamical but partly permeable boundary. We will return to the Slope Water in the concluding paragraph.

The Atlantic Oceanographic Laboratory has been and continues to be involved in the international effort to understand the physics of deep-ocean circulation, and has expended a considerable effort in studies of the Gulf Stream System. The second figure shows the locations of some of the moorings instrumented with current and temperature sensors that have been deployed in such studies by the Atlantic Oceanographic Laboratory over the past decade. Several of the individual experiments were conducted in co-operation with scientists at the Woods Hole Oceanographic Institution and some of their mooring positions are also indicated in the figure to give an idea of the scope of the combined effort. Many of these studies have been frankly exploratory in nature, designed to answer very basic questions.

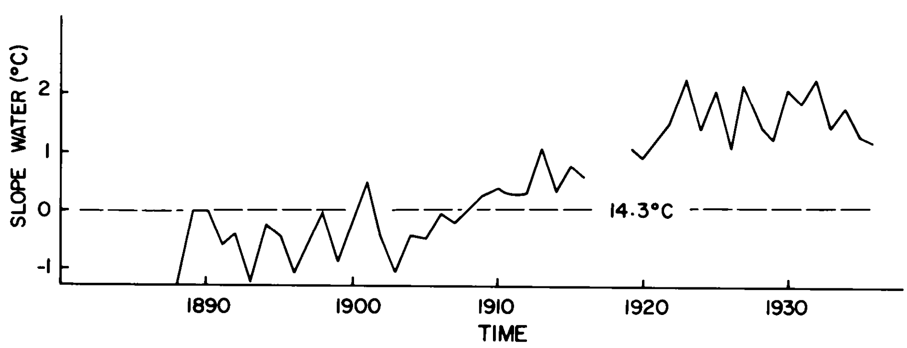
How energetic are Gulf Stream eddies at different locations? We have helped to map out the answer to this question by showing that the current fluctuations decrease in magnitude but have longer temporal periods on moving downstream in the system. How do the currents change with depth in the Gulf Stream'? A two-year



Instrumented moorings deployed by the Atlantic Oceanographic Laboratory (△) to study the Gulf Stream. Also shown are some of the moorings deployed by the Woods Hole Oceanographic Institution (•) for the same purpose.

study begun in 1983 is seeking the answer to this very question. How important are cut-off Gulf Stream rings in transferring heat across the Stream between the warm Sargasso Sea and the cooler Slope Water with its Labrador Current influence? There are hints that such processes may be a very significant part of the total transfer, but the final answer has yet to be found.

In the introductory remarks, I mentioned the possibility of climate change. The third figure gives an example of the type of long-term variability actually observed in the North Atlantic Ocean. It shows the trend in annual mean sea-surface temperature during the first part of the present century in a 5° by 5° square centred in the Slope Water south of Nova Scotia and Newfoundland. There is convincing evidence of a net warming of these waters by at least 2°C over the 40 y of data. Explanations for this phenomenon are largely speculative, but one suggestion is that the warming was due to increased mixing with warm water from the Sargasso Sea as a result of more frequent and energetic meandering and eddy production by the Gulf Stream. The Stream itself is driven by the large-scale North Atlantic wind system. Changes in sea-surface temperature and the resulting changes in air-sea heat exchange affect the large-scale atmospheric circulation. The resulting feedback loop is typical of the entire global



Time series of annual sea temperature anomalies (°C) in the Slope Water south of Nova Scotia (40-45°N, 55-60°W). (After Bjerknes, J.B. 1964. Atlantic air-sea interaction. *In Advances in Geophysics 10:* p. 36.)

climate system. By seeking to understand the fundamental dynamics of the Gulf Stream and its eddies, we hope to contribute to the eventual understanding of this complicated system.

Towards a world climate research programme

F.W. Dobson and S.D. Smith

As a result of our participation in the "CAGE" study of the feasibility of measuring the poleward heat transport of the North Atlantic Ocean, we are investigating the accuracy of extant formulae for estimating sea-surface heat exchanges. We have found substantial discrepancies between our results and established wisdom; this promises an exciting future for the World Climate Research Programmes.

Fred Dobson and Stuart Smith.

The World Climate Research Programme, established in 1980 by the World Meteorological Organization, is designed to investigate the variability of the earth's climate on three time scales: roughly speaking, months, years, and decades. The goal is to explain and eventually predict the variations. The oceans are involved at all three time scales: they store heat locally on a monthly time scale; year-to-year variability in sea-surface temperature and oceanic heat-storage rate is the immediate cause of the El Niño events; and it is the ability of the great ocean currents plus global exchange processes that will, over the long term, determine the response of our climate system to man-made changes in the carbon-dioxide content of the atmosphere (the 'greenhouse' effect). The international efforts now getting underway are reflected in some BIO research programmes.

Clarifying the roles of the atmosphere and the ocean and the many ways in which they interact is crucial if progress is to be made in the modelling and eventual prediction of the earth's climate. We begin by describing an internationally sponsored investigation of the feasibility of making an accurate measurement of the amount of heat carried poleward annually by the North Atlantic Ocean (the CAGE study). We then outline our current work, much of which resulted from the CAGE study, and finish by describing the 'state of the art' in climate-scale air-sea interaction research, and ramifications for the upcoming World Climate Research Programme.

In June 1980, the Committee on Climate Change in the Ocean set up a small group, which included one of us (Dobson), to report on the feasibility of making an important measurement: the amount of heat annually transported poleward by the North Atlantic Ocean, to an accuracy of 20%. The idea was to surround the ocean, theoretically, with a 'Cage', measure all the heat entering and leaving the sides and top of the cage, and thus discover how much heat was being transported by the ocean within.

This heat transport had already been estimated by three different techniques. First, in 1974 Andrew Bunker estimated the amount of heat transferred annually through the surface of the North Atlantic using empirical formulae relating the air-sea heat transfers to quantities such as wind speed, air-sea temperature differences, humidity, and cloud cover from millions of archived ship-reports. The heat given up annually by the North Atlantic Ocean to the atmosphere (relatively little heat leaks into the Arctic Ocean) must be made up by poleward transfer within the ocean. Bunker's estimate was 1.1×10^{15} W (one petawatt), equivalent to the output of one 300 MW power station every nautical mile along the equator, from one side of the Atlantic to the other!

Second, in 1976 Abraham Oort and Thomas Vonder Haar used a variant of the 'Cage' idea: they estimated, for 10° latitude bands, the heat entering the top of the atmosphere from satellite-based solar radiation measurements, the heat transported poleward in the atmosphere from archived radiosonde-measurements of wind, temperature, and humidity, and the rate at which heat is stored by the ocean from archived sea-temperature data. Knowing that the system is in equilibrium (we are not warming up or cooling down measurably, over long time-averages), they obtained a poleward transfer of 2.2×10^{15} W by the North Atlantic and North Pacific combined, which seems to be in reasonable agreement with Bunker's result, if it is assumed that the Atlantic transports half of the total.

Third, in 1980 Harry Bryden and Mindy Hall used oceanographic data only. Noting that the depth-averaged ocean temperatures along 24°N (roughly Miami to Dakar) remained very constant everywhere on the line, and knowing the amount of heat transported poleward across 24°N by the Gulf Stream as it flows through the Florida Strait, they estimated from the heat balance at that latitude that the ocean gives up 1.1×10^{15} W to the atmosphere, a figure close to that computed by Bunker.

The Committee on Climate Change in the Ocean believed there was a good chance that, given updated and more accurate formulae for computing the heat transported through the sea surface from ships' meteorological observations, given more accurate and carefully planned-satellite measurements of the incoming solar radiation and reasonable augmentations of the existing WMO radiosonde and sea-temperature reporting networks, and given some oceanographic work at 24°N specifically tuned to measure poleward oceanic heat transport (Bryden and Hall used existing data), it should be possible to measure the poleward transport of heat by the North Atlantic Ocean to

± 20%. when averaged over a five-year period.

The ‘Cage’ Group studied the issue with some care. Their conclusions were startling and disconcerting: of the three techniques proposed for determining the meridional heat flux, only the oceanographic determination appeared feasible.

The estimation of the transport of heat through the sea surface was deemed the least accurate with errors of 30-50%. The budget technique pioneered by Oort and Vonder Haar was investigated using newly obtained more accurate satellite data, the best available meteorological data set, and the best current numerical forecast model. The global heat transport budget showed unexplained yearly imbalances in Eurasia of ±40 Wm^{-2} (±20% in the North Atlantic is 10 Wm^{-2}). For the oceanographic technique, new ways of estimating the heat transport were attempted, a new programme was undertaken for measuring the heat transport of the Gulf Stream, and a study of how best to estimate heat storage in the entire ocean showed it could be done with seven lines of expendable temperature probes, dropped every 175 km by merchant ships on regular runs five times per year, and reaching depths of 1200 m. Another major finding was that the heat transport appears to vary by less than 20% of its mean value from year to year. On the basis of this evidence, the CCO decided that the ‘Cage’ experiment would not be pursued as an entity; rather, those parts that appeared feasible would be done one by one as part of the World Ocean Circulation Experiment.

Having dedicated large parts of our careers to upgrading the formulae for vertical heat transport through the sea surface, we were challenged by the CAGE findings to determine and, when possible, reduce the error bounds of each of the formulae. Heat is transported through the sea surface by four different means:

(1) Incoming solar radiation (heats the sea surface);

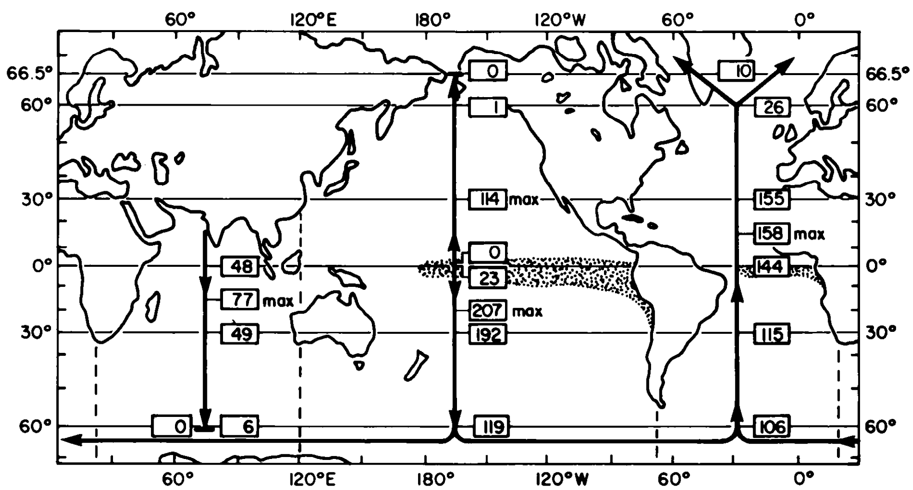
(2) Infrared radiation (cools the sea surface);

(3) Turbulent heat transport (heats or cools the surface depending on whether the air is warmer or cooler than the sea; wind-speed dependent); and

(4) Turbulent water-vapour transport (usually cools the sea surface; wind-speed dependent).

Our first efforts (Smith, 1981) centred on a careful review of our own measurements, and of the literature, to tabulate evaporation and heat transport using the best formulae. These transports were typically 20-30% less than Bunker’s values.

We compared (Dobson) meteorological measurements by trained observers with calibrated instruments on Ocean Weather Stations against the same quantities reported by non-professional observers on ships within 2° in latitude and longitude of the Ocean Weather Stations. The passing ships produced identical climatologies; the worst error was a 6% underestimate of total cloud amount.



Oceanic heat transport (in units of 10^{13} W) from Hastenrath (1980). The dashed lines show how the southern ocean was divided: the stippled areas indicated regions of maximum export of heat by ocean currents.

We tested existing formulae against 15-20 y time-series of solar radiation measurements at Ocean Weather Stations P in the North Pacific, at A, I, J, and K in the eastern North Atlantic, and at Sable Island, N.S. The most widely used formula (Bunker for instance used it), developed in Russia by Budyko and Berliand, estimates clear-sky radiant heat input to within 2%, but underestimates solar heating on cloudy days by 30% or more. Other less well known formulae do better, but we decided to optimize the procedure to model the observations with formulae that allow for what we regard to be the important physics. We can model the mean solar radiation to within about 5%, and we cannot do better because the radiometers used presently on the weatherships are no better!

We know already that the infrared radiation formula used by Budyko overestimates the rate of cooling of the ocean by as much as 30% in tropical regions. We hope that others will join us in the search for a better formula.

Our recently published study of the local heat budget at Ocean Weather Station *Bravo,* in the middle of the Labrador Sea (Smith and Dobson, 1984) shows that Bunker’s method overestimates the net cooling of the sea surface by about 50%. By comparing the incoming heat with the rate of storage of heat at *Bravo,* using oceanographic data originally studied by John Lazier, we estimated how much heat was moved into or out of the region by ocean currents. From month to month, the amount of heat stored differed wildly from that crossing the surface, while over the long term the amounts were roughly equal. Since the oceanography of the area indicates little movement of heat, the conclusion is not inconsistent with our versions of the heat transport formulae.

One of our colleagues, Professor L. Hasse of the University of Kiel in West Germany, and a student have acquired what was still available of Bunker’s computed monthly averages of the various meteorological variables in the North Atlantic, and they are re-computing, with the most modem formulae, the distribution of the heat transports through the sea surface over time and space. We have discussed the formulae with them, and reached general agreement on which to use. (Theirs are not exactly the same as ours - what two scientists will agree - but they are close.) Even before the work is completed, it is clear that the Bunker estimate of 10^{15} W for the mean annual poleward transport of heat by the North Atlantic across 24°N is too high. The question is: by how much? Our guess is about 50%. Because most existing estimates, by whatever technique, give about 10^{15} W, the new results will call all the old ones into question.

Calling the results into question for a well-studied ocean like the North Atlantic is a matter of great concern to those who wish to understand the global climate system and eventually to predict it. The accompanying figure, from a paper by Stefan Hastenrath (1980), indicates how the heat transport of the various oceans is interconnected, with the North Atlantic being a major contributor. Rearranging the balance to fit a new, smaller estimate for the North Atlantic heat transport will not be a simple matter. Since the ocean and atmosphere are strongly coupled, the atmospheric contribution to the poleward transport of heat must also be reconsidered. The resolution of the resulting arguments will not be easy; we believe our surface heating formulae are correct now at least to within 20%. The science of climate-scale air-sea interaction promises to be an exciting one over the next few years.

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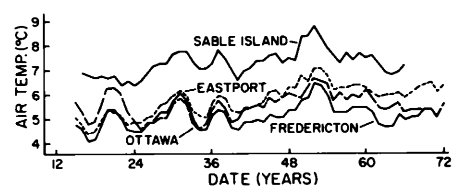
Sea-surface temperature trends and patterns in the Northwest Atlantic

R.W. Trites

Studies of sea-surface temperature in the northwest Atlantic reveal both year-to-year and decadal-scale changes. Evidence is mounting that the large-scale meteorology is of primary importance in producing the observed variability.

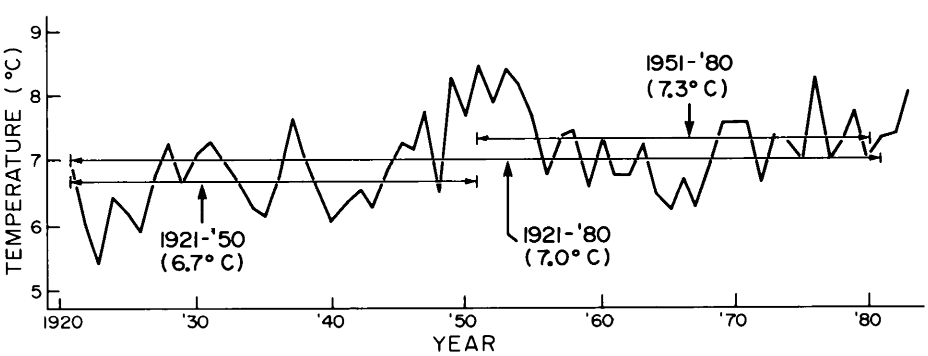
The twice-daily observations of sea-surface temperature (SST) begun in 1921 at St. Andrews, New Brunswick, are the longest continuous series of water temperature data for one site along the Canadian Atlantic coast. Annual mean temperatures for 1921 to 1983 as compared to the 7°C average for the total period were below normal from the early twenties to the mid forties; from about 1945 to 1960, values were above the 60-y mean. Subsequently no clear trends are apparent. On a 30-y basis, the 1951 to 1980 period was 0.6°C warmer than the 1921 to 1950 period. The rather large year-to-year variations in temperature revealed in the records (up to 1.8°C) make up a sizable fraction of the maximum change (2.7°C) between the coldest year, 1923, and the warmest, 1951.

The water temperature at any given coastal site is the result of both local processes (heat exchange across the sea surface and mixing) and advection operating on a range of geographic scales. For any given month (or even year), temperature anomalies at sampling sites separated by as little as a few tens of kilometres may be of different magnitude and sign. When averaged over several years, however, the mean anomalies usually become comparable. In fact, there is evidence mounting that large-scale processes operate over distances of perhaps several thousand kilometres to produce coherent temperature shifts.



Plots of 3-year equally weighted means of the annual air-temperature averages at Eastport, Maine; Fredericton, New Brunswick; Ottawa, Ontario; and Sable Island, Nova Scotia.

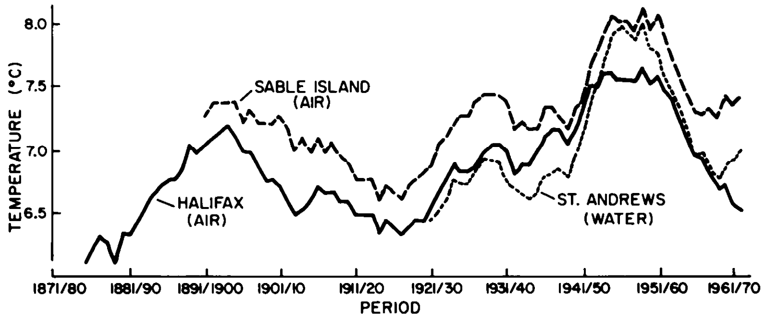
To appreciate the geographic scale of these longer term temperature changes, it is useful to study air temperatures first because they have been more often recorded and at more sites than water temperatures. Doing so, one finds that year-to-year variability in air temperature is correlated over relatively wide geographic areas. For example, the relatively close correlation between the 3-y running means of the annual averages of air temperature for Ottawa, Fredericton, Eastport, and Sable Island is readily apparent. Similarly,



Mean annual sea-surface temperature at St. Andrews, New Brunswick, from 1921 to 1983. The annual average for the total period is 7°C.

the correlation between air and coastal water temperatures is usually good when running means over several years are used.

For the Northwest Atlantic as a whole, the largest SST data base is derived principally from records of the intake temperature of the cooling water on merchant vessels; these temperatures are reported in radio weather messages to shore stations and in log books transmitted to the National Climatic Center in North Carolina. When analyzed in quadrangles of one-degree latitude and longitude, this



Surface water temperature at St. Andrews, New Brunswick, and air temperatures at Sable Island and Halifax, Nova Scotia. Ten-year moving averages of the annual mean temperatures are credited to the last year of the period.

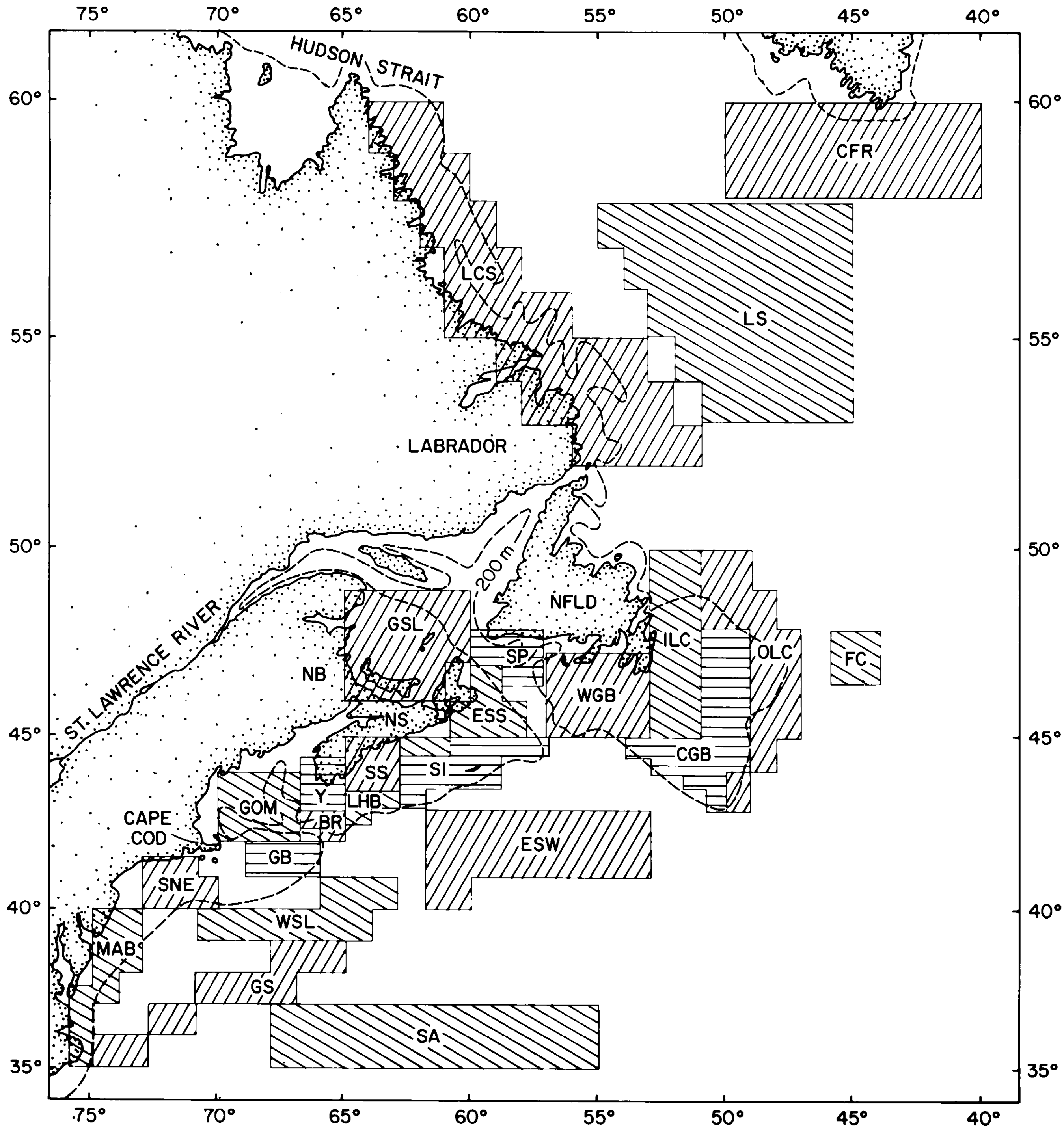
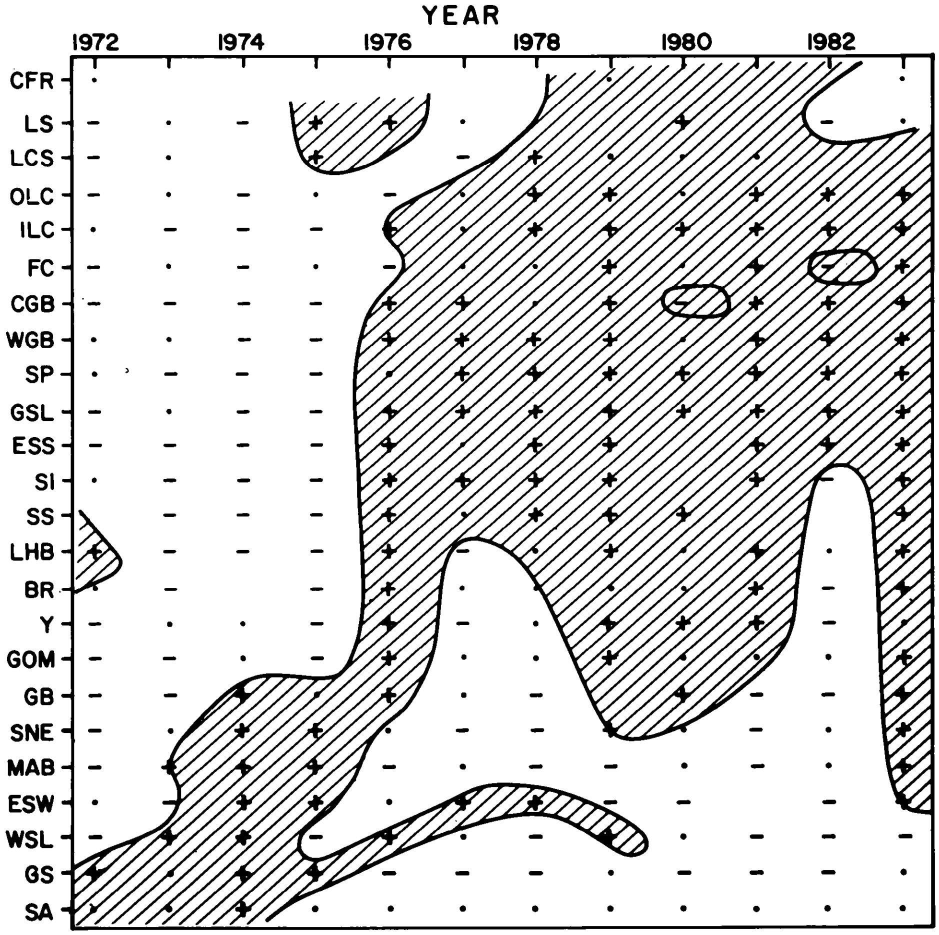
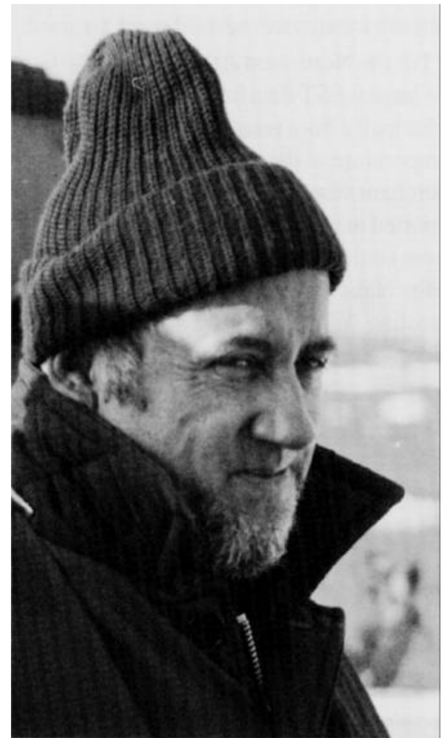


Chart showing the areas over which sea-surface observations have been averaged monthly.



The distribution of annual sea surface temperature anomalies from 1972 to 1983 by subarea (see previous chart) relative to the means for the 1972-1980 base period. (A '+' or a '-' symbol represents an anomaly that exceeds 0.15°C: a ' • ' symbol represents an anomaly with a magnitude of less than 0.15°C.) Only anomalies exceeding 0.15°C have been used in constructing the contours.



Ron Trites.

data base typically displays relatively high spatial and temporal variability. Undoubtedly, some of this variability is real but some is the result of undersampling. However, large-scale coherence and shifts can be identified by grouping the data for the Northwest Atlantic into a number of subareas, which coincide with fishing banks or with major water masses (e.g., the Labrador Current, Gulf Stream, Sargasso Sea). A time-space plot of annual sea-surface temperature anomalies in the 1972 to 1983 period is reasonably constant usually over 1000 to 20 km for several years. From 1972 to 1975, the northern and shelf waters from the Labrador coast to the Gulf of Maine were relatively cold, while the temperatures of the southern and offshore Gulf Stream and Sargasso Sea were above normal. In 1976, the situation appears to have been in the process of reversing. From 1977 to 1983, annual mean temperatures were usually above normal in the northern regions and below-normal in the southern. The largest positive anomalies for the 12-y period occurred in 1983 in the Grand Banks - Scotian Shelf region.

Not surprisingly there are good indications that the sea-surface temperature anomaly pattern and the large-scale meteorology (air temperature and pressure patterns) are closely linked. It is noteworthy that during 1982 and 1983, the strongest El Niño Southern Oscillation (ENSO) in over 100 y was recorded. El Niño refers to anomalously warm water in the eastern tropical Pacific but has been shown recently to be part of a much larger ocean-atmosphere interaction. The effects are felt almost worldwide and it appears likely that the anomalous sea-level atmospheric pressure pattern over the North Atlantic is at least partially related to the atmospheric response associated with the El Niño event, but the nature of any relationship needs further research.

The influence of the Arctic

The global thermal machine that determines our climate, and whose variability is the subject of this Review, acts principally to redistribute heat - received mostly at the surface of the planet in the tropics - over the whole planetary surface into the pattern of warm and cold areas with which we are all familiar, and which drive our industry, agriculture, and forestry.

It is the redistribution of heat that drives the wind systems, both at the surface and at high altitudes, and the surface and deep currents of the oceans. In eastern Canada and in the North Atlantic Ocean, the transport of heat to high latitudes by warm surface currents of the ocean, and the return of cold water southwards from the arctic, either at the surface as the Labrador Current or at depth from the centres of formation of deep water in the Labrador and Norwegian seas, dominates these processes. Variability in this heat transport affects not only the arctic itself, and life there, but also the oceanography of the whole region, and is the subject of the studies we discuss in this chapter.

Arctic run-off in the North Atlantic Ocean

J.R.N. Lazier

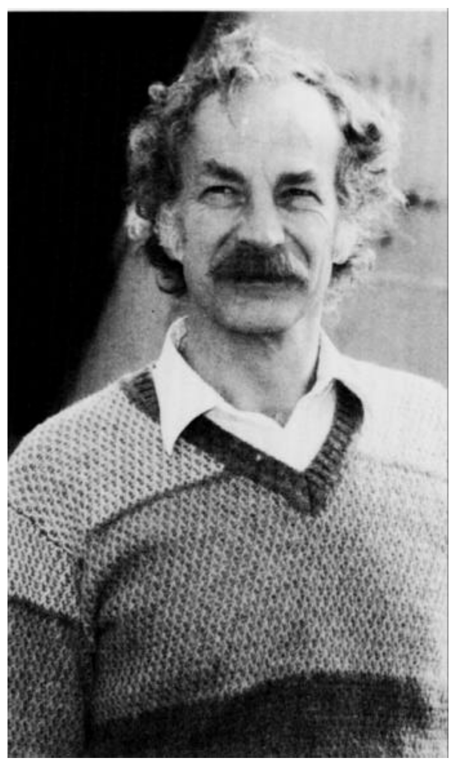
Freshwater run-off in the Arctic helps control important physical processes in the North Atlantic Ocean such as winter-time convection in the Labrardor Sea and transport in the boundary currents. Two programmes designed to investigate the freshwater's role are described.

The 80,000 or so tons of fresh water that make their way every second into the North Atlantic Ocean from the large Arctic rivers in Canada and the USSR such as the MacKenzie and Yenisey significantly influence the climate and structure of the ocean.

During the past few years. we have begun to discover some of the highlights of this association. We first learned of the role of fresh water in the winter mixing by convection down into the ocean that occurs in the Labrador Sea, then we saw how changes from year to year in the freshwater flow can control the depth of this convection, and now we are working to detail how the water gets into the middle of the ocean so we can better understand how the processes work and interact with each other.

Fresh water enters the ocean as river run-off, rain, snow, or melted ice. It then mixes into the ocean waters, which are about 3.5% salt. The fresh water doesn't stay completely fresh but gradually becomes saltier and may be traced in the ocean as flows of water with less salt than the open ocean water.

The Arctic is the freshest of the worlds' oceans, partly because it receives the outflows from the large Arctic rivers and partly because the permanent ice cover prevents evaporation of fresh water out of the ocean. Arctic water comes into the North Atlantic through the Canadian

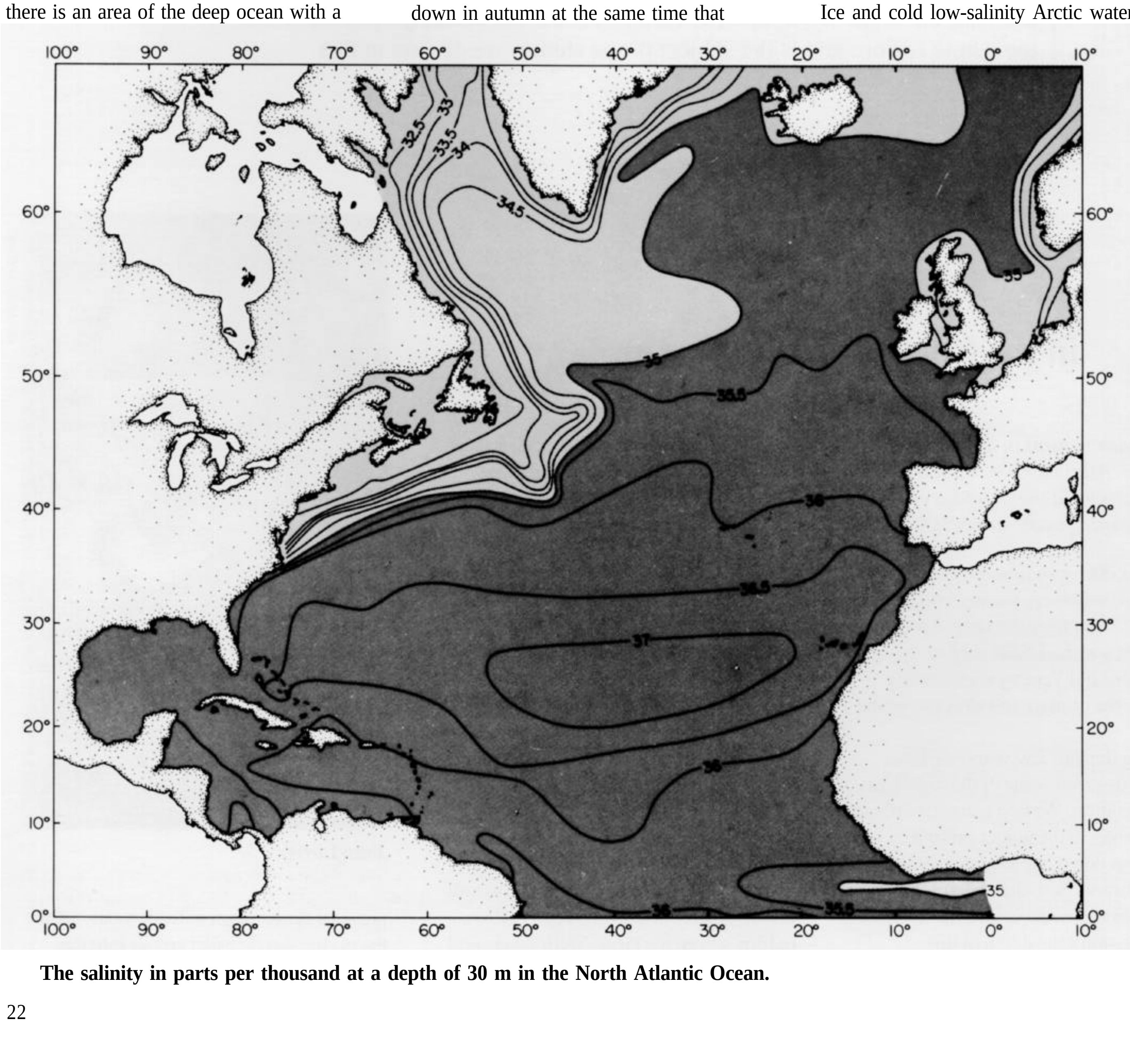


John Lazier.

Archipelago and Denmark Strait between Greenland and Iceland. A smaller contribution of fresh water also comes from Hudson Bay through Hudson Strait.

The influence of the fresher Arctic water in the North Atlantic is illustrated in the map of salinity at 30-m depth shown in the first figure. Next to Greenland, Baffin Island, and Labrador are bands of low salinity water (less than 33.0 ppt or 3.3% salt) marking the southward flows of the Arctic water in the East- and West-Greenland, Baffin-Island and Labrador currents. The effect of the outflow from the St. Lawrence River is also evident in the low salinity water in the Gulf of St. Lawrence and seaward of Nova Scotia. The highest salinities due to high evaporation rates are found in the middle of the ocean at the latitude of southern Florida. In the middle of the Labrador Sea. south of Greenland and east of Labrador, there is an area of the deep ocean with a lower salinity than anywhere else. This is the flow that is important to the Labrador Sea.

The influence of this flow on the climate of the ocean was first realized when the data from the Ocean Weather Ship *Bravo* were examined. This ship was stationed at 56°30’N, 51°W in the middle of the Labrador Sea between 1945 and 1974, and collected oceanographic data for the final ten years. The salinity at various depths at the *Bravo* position is shown for the ten years in the second figure. The bottom line represents the salinity near the surface and, because the lines never cross, the lowest salinity is always at the surface. Every year this line shows the salinity decreasing in summer and increasing in winter- the annual cycle. The summer decrease occurs because of the spring and summer increase in run-off and ice melt, while the increase in winter comes when the run-off slows down in autumn at the same time that cooling and more violent storms stir the low salinity water down into the water column and bring higher salinity water up near the surface. The climatic signal in these salinity values is the change to lower values, in addition to the annual signal, from the late sixties to early seventies. This change at *Bravo* was one manifestation of a widespread phenomenon that shortened the growing season in England in the late sixties and put more ice than usual north of Iceland: the effects are still being observed in, for example, the mid-North Atlantic at the 1500-m depth. The reason for the salinity decrease was traced by Dickson *et al.* (1975) to an abnormally high atmospheric pressure system that remained over Greenland for a number of years. Air moves clockwise around high pressure regions and in this case produced abnormally strong and persistent winds south along the east coast of Greenland. Ice and cold low-salinity Arctic water were



The salinity in parts per thousand at a depth of 30 m in the North Atlantic Ocean.

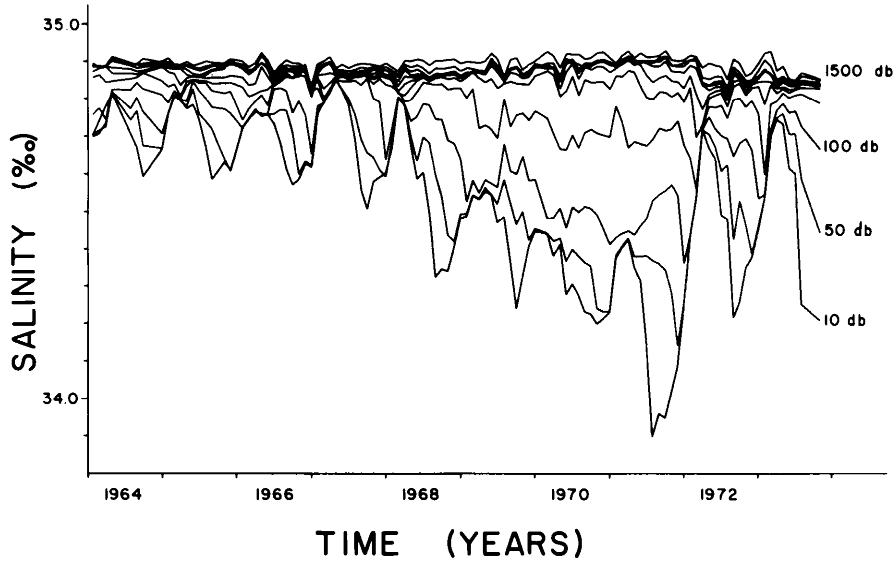
thereby forced south of Denmark Strait in larger quantities.

In the middle of the Labrador Sea, the layer of abnormally fresh water made the water column abnormally stable in the late sixties thereby increasing the heat loss required to convectively mix the water to a given depth. This is an important consideration because the Labrador Sea is one of the few places in the world where the water is overturned in winter to great depths via convection. This is how some of the deep waters are created or renewed in the ocean. In an exceptionally cold year, such as 1976, the water can be mixed down to 2000 m but in mild years, such as 1969 or 1970, extra fresh water adds buoyancy to the surface layer and the mixed layer may only get to a depth of 200 m. This difference in depth of winter mixing can be roughly deduced from the salinity plot (second figure). In winter, the water is homogeneous at depth if the figure's lines run together. If they stay apart, there is still a salinity gradient with depth. The end of the mild winters that seemed to accompany the abnormally low salinity water ended abruptly in the severe winter of 1971-1972. Convection proceeded that year to 1500 m and probably beyond.

To recap, an abnormally high atmospheric pressure over Greenland produced higher than normal winds south along the east coast of Greenland, which forced more Arctic water into the Atlantic than usual. This Arctic water, characterized by a lower salinity than the Atlantic, created a low buoyancy cap on top of the Labrador Sea, which helped to reduce the depth to which deep convection occurred in the winters of 1969-1971.

A large climatic signal such as this is of great interest in itself because it shows what changes do occur and illustrates some of the important connections between the physical processes in the ocean. Understanding this chain of events and the magnitude of its impacts will be a very powerful economic tool.

Now that one significant change in the ocean climate has been observed, it is important to know how often such phenomena occur, what if any effect they have on the atmospheric climate, and what effect they have on the Newfoundland fisheries. To look a bit further, a programme was begun in 1978 to monitor the flow of the Labrador Current near Hamilton Bank, Labrador. The current meters used to measure water velocity for 9 to 12 months at a time are moored at three positions: one at the 1000 m isobath in the fastest part of the current and the other two in the shallower water to the west of the Bank. Because icebergs are numerous in the area, the meters are near the bottom or no shallower than 500 m, which is too bad because the strongest part of the current is near the surface, and probably any significant changes from one year to the next will be observed with greatest amplitude near the surface.



The monthly averages of salinity for 11 depths at station *Bravo* from 1964 to 1973.

A number of equipment problems have been encountered in this program, the strangest being the very high and unexpected rates of corrosion in the middle of the Labrador Current that caused the loss of four instruments. Two of these were eventually recovered with good data: one in Ireland and one in the Azores. Icebergs and/or fishing trawlers have taken another three moorings but by changing the mooring design, using improved equipment, and trying to moor in the 'safe' spots, the success rate was greatly improved.

The data so far show many interesting features such as a seasonal change in the strength of the main part of the current, and unexplained midwinter surges in flow over the inner shelf, but it is probably too early to know if we are observing any significant climate changes. Meantime, a lot is being learned about the weekly to seasonal changes in the temperature, salinity, and velocity, and consequently our understanding of the processes that control and change the current is increased.

The renewal of the water filling the top 500 m or so of the Labrador Sea is another process currently being investigated at BIO. We are reasonably certain all this water is created by mixing some Labrador Current water and some Gulf Stream water together, but how or where this mixing occurs is still unknown. The most likely area seems to be east and northeast of Flemish Cap where water from the Labrador Current flows off the shallow continental shelves toward the north just to the west at the strong northerly flow of the most northerly branch of the Gulf Stream. The Labrador water, cold and relatively fresh beside the warm salty water from the south, makes for larger horizontal gradients of temperature and salinity throughout the area. Mixing or stirring is more likely in areas of large horizontal gradients than in areas of small gradients partly because these regions are more energetic with large horizontal and vertical velocity gradients associated with the large temperature and salinity gradients. The large horizontal velocity gradients often become unstable, breaking the frontal regions up into smaller eddies that tend to stir the different water types together. By mapping the temperature and salinity in the area, and by analysing paths of satellite-tracked drifters and water-velocity data, the processes that cause the waters to mix before they move into the middle of the Labrador Sea are being understood a little better.

In summary, one intriguing climatic signal has been found in the salinity values (which decreased in the late sixties) of the middle of the Labrador Sea. This low salinity layer helped to limit the depth of deep convective mixing in winter and slightly altered the temperature and salinity characteristics of the upper waters of the Labrador Sea. Two field programmes are presently underway to further our understanding of the processes that bring Arctic water south, mix it with the southern waters, and cause changes in the heat or salt content from one year to the next.

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Sea ice as an indicator of climate change

G. Symonds

Fluctuations in sea-ice extent recorded from 1963 to I969 are closely correlated to contemporaneous variations in both atmosphere and ocean. Also, the presence of sea ice increases atmospheric and possibly oceanic variability. Thus, sea ice has both a passive and an active effect on local and global climate.

Graham Symonds.

From global glaciations to local year-to-year fluctuations, sea-ice extent is a sensitive indicator of climate variability. This sensitivity is enhanced through atmosphere-ice-ocean interactions whereby sea ice responds to climate fluctuations and can in turn feed back to influence climate variability. Understanding the factors affecting the distribution of sea ice can therefore provide some insights into factors affecting climate variability.

The general circulation of the atmosphere is driven by the global distribution of heat absorbed by the atmosphere. In general the amount of heat absorbed depends on: (1) the amount of solar radiation incident on the upper atmosphere; (2) the composition of the atmosphere; and (3) the reflective and absorption characteristics of the earth's surface.

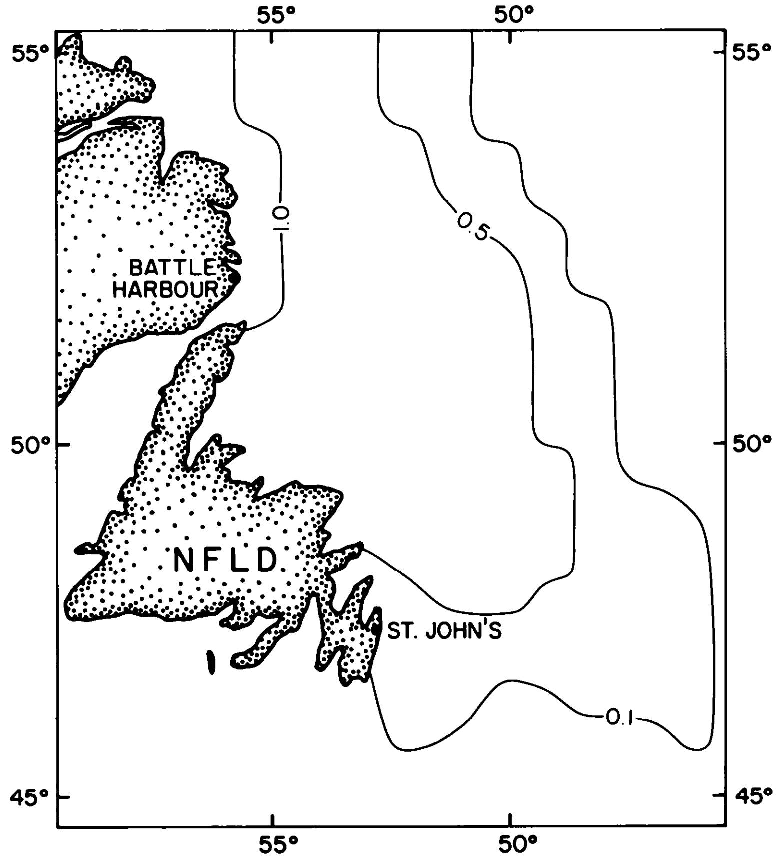
The atmosphere readily allows short-wave radiation (solar energy) to pass through it to be absorbed or reflected at the earth's surface. The energy absorbed is radiated back into the atmosphere as long-wave radiation, the main source of heat for the atmosphere. A measure of the amount of energy absorbed and hence the heating of the earth is provided by the albedo of the surface-the ratio of reflected to incident short-wave radiation. The albedo lies between zero and one and the higher the albedo, the higher the reflectivity and the lower the absorption. For flat ground and rock it is 0.12-0.15, for snow and ice 0.70 - 0.80. The high albedo of snow and ice leads to the positive feedback mechanism through which a global decrease in temperature will cause an increase in ice extent, which in turn decreases temperature even more (due to the higher albedo of ice), and thus further increases ice extent. Similarly, with increasing temperatures and decreasing ice coverage, the associated decrease in albedo leads to further warming. In addition to the albedo effect, ice also effectively insulates the atmosphere from the ocean. By transporting heat from low latitudes, the oceans provide a significant source of heat to polar regions. The presence or absence of ice significantly affects the ocean-atmosphere heat flux and surface air temperatures.

During the winter months, Arctic sea-ice covers an area of approximately 14×10^6 km^2 while in the summer the coverage is reduced to 7×10^6 km^2. In the northern hemisphere 7×10^6 km^2 of ocean are alternatively ice covered and ice free during the course of a year. In addition to the seasonal cycle over one year, the area covered by ice may vary by 0.3×10^6 km^2 over time scales of 10 y. These figures are based on an average over the period 1953-1977 (Walsh and Johnson, 1979). Over geological time, the extent of sea ice has varied from extreme glaciations extending as far south as 40°N to entirely ice-free periods. Fluctuations in sea-ice extent are one result of the complex air-sea-ice interaction processes and are inherently coupled with climatic variations.

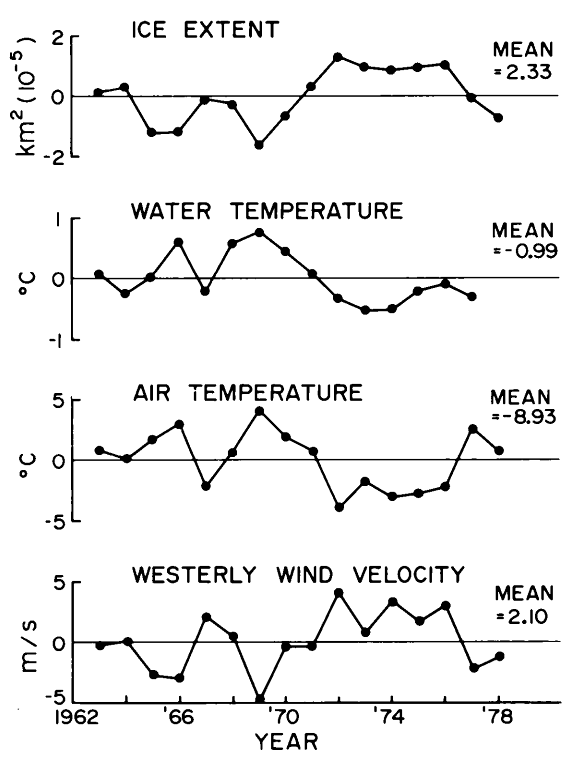
In the northern hemisphere today, the regions where the ice cover varies greatly from winter to summer and from year to year are the seas adjacent to the Arctic Ocean. In the Greenland and Labrador seas, Baffin Bay, and Davis Strait, the Arctic outflow transports sea ice and low-salinity surface water southward along the eastern coasts of Greenland, Baffin Island, and Labrador. Because of this surface outflow of water near the freezing point, sea ice forms in winter throughout this area yet melts and retreats in summer because of the strong solar heating at these latitudes. A similar low-salinity surface-layer allows ice to grow southward within the Bering Sea. However, in the Barents Sea north of Norway there is an inflow into the Arctic Ocean of warm salty Atlantic water, which replaces the outflow of cold low-salinity water from the Arctic. This provides a source of heat at these high latitudes that keeps parts of the Barents Sea ice free throughout the year, and melts ice over much of the rest of the area in summer. Thus, ocean currents play a large role in determining ice distribution in the northern hemisphere.

The extent of ice in any season in these marginal seas varies from year to year. When such variations persist over a number of years and over a large area, they may play a significant role in modifying the global climate. While their global effects are still speculative, regional changes in ice distributions have had profound effects on the climate of adjacent coastal areas as well as on the local fisheries. The first figure shows the distribution of sea ice off Labrador and Newfoundland for March averaged over the period 1963-1978. The 0.5 contour represents the limit of the region covered by ice for at least 50% of the period 1963-1978. This region represents the average conditions for Labrador and Newfoundland. Also shown in the figure are the minimum and maximum extremes for March (indicated by the 1.0 and 0.1 contours respectively). During summer. the region shown in the figure is entirely ice free. The fluctuations in sea ice extent, both seasonally and year to year, can be expected to affect the local climate and in turn reflect large-scale climatic variations.

The atmosphere-ice-ocean coupling is illustrated in the second figure. At the top is a time series of departures from the mean, or anomalies, for ice extent off Newfoundland and Labrador during March from 1963-1978. Below this is the anomaly of water temperature in March averaged over the upper 200 m of the water column at station 27 just off St. John's. Newfoundland (see first figure). Also shown are the anomalies of air temperature and westerly wind velocities in the vicinity of Battle Harbour, Labrador (see first figure). Obvious similarities exist between each of the four series shown in the second figure. Warmer than normal water temperatures are associated with below normal ice extent and vice-versa. Both the air temperature and water temperature vary in much the same way in spite of their spatial separation and the fact that the water temperature is averaged over the upper 200 m of the ocean. The variation in ice extent with both air and water temperatures is as one might expect while the variation with westerly wind requires some explanation. Firstly, a westerly wind blows cold air from the Canadian interior into the Labrador Sea; hence the inverse relationship with air temperature as shown in the second figure. Secondly, the combination of increased wind speed and cold temperatures increases the air-sea heat flux and lowers the water temperature, which makes conditions more conducive to ice formation. Finally, the westerly wind moves the ice offshore (approximately 30°



Sea-ice extent for March expressed as the probability of occurrence of ice determined from the period 1963 to 1978. Mean, minimum, and maximum extents are represented by the 0.5, 1.0, and 0.1 contours, respectively.



March anomalies of ice extent (top) measured as the area covered by ice in the region shown in the first figure. Corresponding anomalies of water column temperature, air temperature, and westerly geostrophic wind illustrate atmosphere-ice-ocean coupling.

to the right of the wind direction) thus increasing the offshore extent of ice and at the same time producing areas of open water along the coast where new ice may form.

In addition to having important local implications there is evidence that the variability shown in the second figure occurs on a much larger climate scale. At Ocean Weather Ship *Bravo,* in the centre of the Labrador Sea, the same signal in temperature and salinity has been observed (Lazier, 1980), which indicates variability on a scale that includes the Labrador Sea. Other evidence in the literature suggests that the variability shown in the second figure may be associated with large-scale fluctuations in atmospheric circulation affecting Greenland and Northern Europe (Dickson *et al.,* 1975). Greater than normal sea-ice extent in the Norwegian-Greenland Seas has been related to an intensification in a high pressure cell over Greenland and an associated increase in the northerly wind component. In turn, heavy ice years in the Norwegian-Greenland Sea tend to be associated with light years in Baffin Bay/Davis Strait. Furthermore, it has been well documented that winter temperatures tend to be low over northern Europe when they are high over Greenland and the Canadian Arctic, and vice-versa (Van Loon and Rogers, 1978). This temperature pattern has been associated with well-defined pressure anomalies over most of the northern hemisphere.

The fundamental outstanding problem is to separate cause from effect. The preceding discussion has illustrated the coupling and feedback processes involved in atmosphere-ice-ocean interaction, but has given no indication as to what the driving mechanisms are and what the response is to these processes. An understanding of these processes is necessary before we can hope to predict both local and global variations in climate and how this climate might be modified by man's intervention. Identifying the major driving mechanisms is the subject of ongoing research within the Atlantic Oceanographic Laboratory.

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Climatic change and the exploration of the Canadian Arctic by sea

A.J. Kerr and K. MacDonald

Looking back over a thousand years of exploration of the Canadian Arctic it appears that complex geography has had as much to do with the movement of sea ice as have climatic changes. This is not to say that climatic research is not an essential feature in developing economic marine transportation as the Soviets have shown in developing their Northern Sea Route over the last 50 years.

Much of the early exploration of our Canadian Arctic was carried out by sea and, although air transportation has now largely replaced travel by ship and dog sled, an ability to move ships freely through Arctic waters remains important to Canada. Obviously, sea ice significantly inhibits the movement of ships in polar regions with rough weather and even icebergs being less important. Sea-ice cover is to some extent influenced by climatic trends, both year-to-year and longer term. It is important, therefore, that we develop an understanding of how variability of sea-ice cover has affected Arctic navigation in the past and may do so in the future.

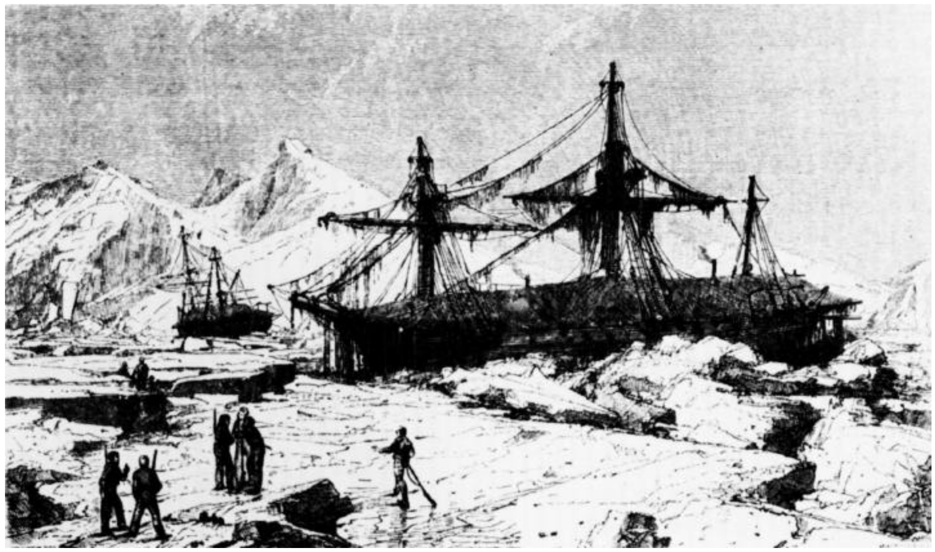
Today in the Arctic we are interested in the possibility of exporting large reserves of oil and natural gas, and already ore is being shipped from mines well above the Arctic Circle. The epic voyages of the supertanker *Manhattan* through the Northwest Passage in 1969 and the Soviet *Arktika* to the North Pole in 1977 demonstrated that very large ships can travel in ice-infested waters throughout the whole year. However, the environmental impact of the traffic and the design of the ships are not fully worked out. In addressing these concerns we must not only provide answers for today but must predict the situation in the future when the climate may be different. In particular, we must attempt to predict the presence of ice

Adam Kerr and Kirk MacDonald.

and whether it will pose an increasing difficulty to the exploitation and exportation of hydrocarbons.

Can we relate periods of climatic change in the past with what we know of the history of arctic navigation? As early as 330 B.C., Pypheus, a Greek navigator-astronomer, sailed from near the present-day Marseilles out into the Atlantic and then northwards to a frozen ocean where his exploration was halted. This voyage occurred during a period of climatic deterioration with cool moist conditions but since neither Pypheus nor we know just where he was stopped by ice, we can say no more than that this appears to be the earliest recorded arctic voyage. However. we do know that the period 950-1200 A. D. was relatively warm and that this clearly had a very significant effect on the movement of people into Iceland and Greenland and subsequently into the Canadian Arctic. It was during this period that those hardy seafarers, the Vikings, first found their way to Iceland, then to southern and southwestern Greenland, and finally across the northwestern Atlantic to Baffin Island, the Labrador Coast, and to at least one settlement in Newfoundland. From the sagas and archaeological evidence we know that southwest Greenland at that time was fertile and there were many farms. Most importantly for us, regular trade was carried out between Greenland and Norway that later became impossible due to the presence of sea ice around Iceland. During this period, when Norse adventurers travelled freely to the northeastern shores of North America, sea ice must have retreated well to the north in Baffin Bay.

From about 1200 onwards the climate of the northern hemisphere progressively deteriorated, culminating in the period 1650-1750, the “Little Ice Age”. There was an increase in the amount of sea ice in the northern Atlantic, and particularly around Greenland and Iceland, resulting in the abandonment of the shipping routes from Greenland to Europe from the early fifteenth century until the 1720s and the eventual death of the Norse colonies. The sea-ice situation around Iceland was particularly serious at the end of the sixteenth century. However, it was at the very peak of this period (1576-1578) that Martin Frobisher, an Elizabethan navigator, made his voyages to the bay named after him in southern Baffin Island. John Davis, another Elizabethan sailor, managed to penetrate north of 70° latitude into Baffin Bay in 1587. His track up the west coast of Greenland and then west across Baffin Bay indicates that the infamous “middle pack”, an area of heavy pack ice in the northern part of the bay well known to later navigators, barred his way further north. In 1616, Henry Baffin made a remarkable circumnavigation of the bay named after him, a voyage that was only matched by John Ross, who followed in his footsteps two centuries later. Thus at the very nadir of the Little Ice Age, European sailing ships were able to make their first recorded penetration of this eastern archipelago.



This engraving depicts Edward Parry’s ships, the *Hecla* and *Fury*, wintering at Winter Island in 1819-1820. *(From:* Adams, W.H.D. 1876. The Arctic World: Its Plants, Animals, and Natural Phenomena with a Historical Sketch of Arctic discovery down to the British Polar Expedition, 1875-76. London: T. Nelson & Sons.)

The latter half of the Little Ice Age was not a period of significant exploration by sea in the Canadian Arctic, though apparently the four voyages made into Hudson Bay then were not unduly impeded by ice. At the end of the eighteenth century there were considerable fluctuations in temperature in northern Europe with a period of relative cold extending into the first half of the nineteenth century. This was significant in terms of Arctic exploration because it coincided with the British Navy’s great interest in this part of the world. In 1818, John Ross made a major voyage of discovery into northern Baffin Bay. On board with him as officers were men who later would become famous: Edward Parry, John Franklin. George Back, Edward Sabine. and James Clark Ross. Ross failed to recognize the entrance to Lancaster Sound and it was left to his second-in-command, Lieutenant Parry, to make a year later that truly most remarkable of Arctic voyages across the length of Parry channel to Winter Harbour on Melville Island. The success of this voyage indicates that low temperatures at least as recorded in northern Europe are not necessarily a good criterion for heavy ice cover in the Canadian Arctic island channels. Parry’s voyage was followed not long after by the ill-fated Franklin voyage and the many voyages that searched for him subsequently. Franklin’s ships we now know were beset by heavy ice in Peel Sound, but this was not related to unusual ice or climatic conditions. Heavy ice accumulations in Parry Channel tend to press southward through the channels to the south becoming at times heavily consolidated and even barring the passage of modern icebreakers.

The final decades of the nineteenth century saw another cold spell in northern Europe that did not let up until after 1910, so Amundsen’s first transit of the Northwest Passage in the little sailing vessel *Gjoa* from 1903-1906 may be attributed perhaps to sheer persistence. as well as skill in avoiding ice. Certainly, Joseph Bernier aboard the *Arctic* in 1910-1911 did not find ice conditions light: he met heavy packs in Barrow Strait and. although he did manage to reach southwest Melville Island, he found - like almost all explorers before and after him - that

M'Clure Strait was impenetrable.

Unusually warm summer temperatures dominated the northern hemisphere from the 1920s to the 1940s, perhaps the warmest era since that of the Norse explorers: some writers have related the successful transits of the RCMP vessel *St. Roche* to this climatic change, but this relationship can be questioned. The warming trend faltered in the fifties, a time of considerable shipping activity in Arctic waters. A major component of this expanded activity was the establishment of the Dewline. While warming trends may have been a bonus, the use of powerful icebreakers guaranteed the success of these operations. The voyage of the *Manhattan*, particularly its transit of the Northwest Passage in 1969, contributed another element to icebreaking technology by reinforcing the arguments about using mass to break up ice in congested channels. It became clear that very large vessels, suitably strengthened and powered, could force their way through almost any kind of ice condition. Nonetheless, the *Manhattan*, even with the escort of the *John A. MacDonald* and *Louis St. Laurent.* Canada's largest icebreakers, could not penetrate the multiyear polar ice of M'Clure Strait.

In the last decade in spite of one or two particularly severe ice years such as the summer of 1972, some yachts and passenger vessels have made remarkable voyages right through the Northwest Passage. Because average temperatures apparently declined during this period, these voyages are all the more remarkable. The availability of detailed ice reconnaissance and short-term forecasts (a few days) was certainly a powerful factor in these arctic navigations.

Apart from the influence of major climatic trends the presence of ice appears to be controlled as much by complex geography as by variations in winter temperature. The overall pattern of summer ice distribution is well known, but short-term movements are often difficult to predict.

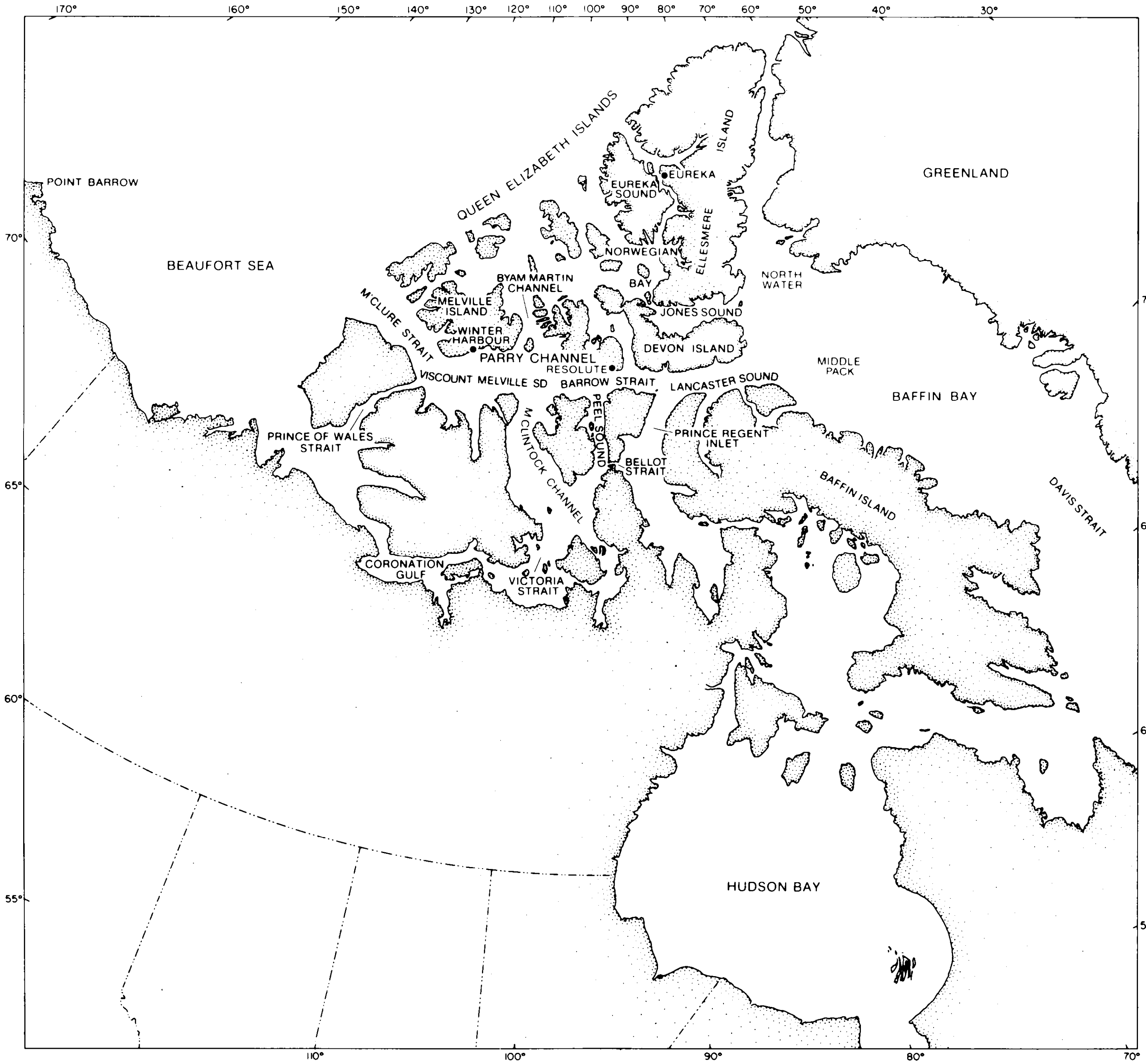
In Baffin Bay, a tongue of open water extends up the west coast of Greenland and during the summer links up with the open North Water in the northern part of the bay. The latter feature is the most extensive polynya in the Canadian Arctic. On the western side of the bay. the ice tends to accumulate as the "middle pack". an area that proved extremely hazardous to the whalers during the last century. In Lancaster Sound, open water extends westwards during the summer from the North Water as far as Barrow Strait. To the north of Devon Island, the open water during the summer extends into Jones Sound and in most summers it extends further up the west side of Ellesmere Island across Norwegian Bay and into Eureka Sound.

CSS *Hudson* steams through ice in Viscount Melville Sound during its circumnavigation of the Americas in 1970.

To the north and west lie the Queen Elizabeth Islands, where ice seldom breaks up in the summer and the channels are usually inaccessible even to today's icebreakers. Resolute, because of its relatively easy access at the western end of Lancaster Sound, has become a central shipping point while Eureka has become the northernmost station regularly served by Coast Guard icebreakers. In contrast to the well-developed ports and even towns that exist on the Greenland coast, the coast of Baffin Island is hazardous and frequently beset by ice. To go westwards from Resolute, the mariner has two choices: to continue westwards via Viscount Melville Sound and Prince of Wales Strait into the Beaufort Sea, or to proceed southwards through Prince Regent Inlet or Peel Sound and thence through Victoria Strait and Coronation Gulf into the Beaufort Sea. The northern of these two routes is deeper and is the only route that would be available to supertankers, but it is an area of heavy multiyear ice forced down through M'Clure Strait. The southern route is usually easier with respect to ice, but it is relatively shallow.

The presence of ice in either the northern or southern routes to the west cannot be attributed solely to climatic changes, although an abnormally cold summer will undoubtedly slow the break-up. In a normal year, one-year ice in Viscount Melville Sound will break up and the southward setting currents through Byam Martin Channel and McDougall Sound will give open water along the north side. This was the open lead which allowed Parry, Bernier, and later explorers to reach Melville Island. If the summer becomes warmer than usual, the ice in the Queen Elizabeth Islands to the north will break up and heavy multiyear ice will move south to block Viscount Melville Sound. Some of this may drift even further south, block M'Clintock channel completely, and make navigation through Peel Sound difficult if not impossible. On these occasions ships with shallow enough drafts will take a route through Prince Regent Inlet and then through Bellot Strait. A particularly devastating set of circumstances can occur when after a warmer than usual summer there is a cold winter that freezes the multiyear ice solidly into the new ice across Viscount Melville Sound.

The Beaufort Sea is probably directly influenced by climatic trends as anomalously low temperatures extend the limits of the Arctic Ocean pack ice. Point Barrow is the key to unlock the Beaufort Sea to ships that have not wintered in, as an extension of the Arctic pack may seal off the Beaufort Sea completely by grounding against Point Barrow. The situation in the Beaufort Sea is similar to that faced in 1983 by the Soviets on their Northern Sea Route when many ships, including icebreakers. were trapped by ice. It was the need to understand climatic fluctuations on this route that led them to initiate a major program of research on the Arctic Ocean



The Canadian Arctic showing the major locations discussed in the text.

sea ice in the 1930s. Evidently, there is still much to be learned.

Since the establishment of the Polar Continental Shelf Project in 1958, Canada also has paid more attention to increasing its scientific knowledge of the Arctic. However, it was the search for hydrocarbons in the Arctic islands and the Beaufort Sea that focussed our attention on ice dynamics. Practical problems of the day include not only the study of ice applied to the needs of shipping but also to such problems as the construction of ice platforms from which to operate drilling rigs. Clearly, long-term climatic trends are a factor that must be considered in many of these studies and research in that area is of great importance for future Canadian developments in the North.

Biological feedback and effects

Until very recently our concerns with biology related to climate change were restricted entirely to the consequences that climate variability might have on our fisheries resources and wildlife. Today, our concerns are widening as we and other research groups come increasingly to understand that, even with regard to such processes as the balance of carbon dioxide between atmosphere and ocean, we cannot view the oceans simply as physical and chemical systems.

We now understand, from our studies of past oceans, that the ocean's plants and animals play a key role in determining how oceans mediate climate change. The studies reviewed in this chapter address themselves to the consequences for animals of climate change in the ocean, but also to the manner in which ocean plants may cause the changes to occur in particular ways.

Carbon dioxide and the biological cycle of the ocean

A.R. Longhurst, W.G. Harrison, and T. Platt

The growth of planktonic marine plants may play an important role in controlling the amount of atmospheric carbon dioxide, and hence the 'greenhouse effect', yet our level of understanding of the processes of plant production in the ocean is inadequate to quantify this role.

International concern that increasing amounts of carbon dioxide in the atmosphere may cause significant changes in the global climate during the next century is based on observations that levels have risen over the last 120 y by about 20%. Considerable disagreement exists about how this happened, and a global mass budget for carbon dioxide still has many major uncertainties - perhaps especially on the role of the ocean as a sink for atmospheric carbon dioxide (e.g., Hobbie *et al.,* 1984; Walsh, 1984).

A very recent analysis of air trapped in glacial ice from Greenland has given the startling result that atmospheric carbon-dioxide concentrations apparently doubled (or were reduced to one half) over periods of only a couple of hundred years about 30,000-40,000 y ago (Oeschger *et al.,* 1983). It is hard to see how such rapid changes, which must have modified the climate, could be due to the mechanisms that we now think we understand: there must have been a feedback mechanism between the upper ocean and the atmosphere other than by simple physical processes. A possible mechanism is through production of plant material by photosynthesis of phytoplankton in the lighted zone of the ocean, which causes a 'biological pump' to transfer carbon dioxide from the upper ocean to the deep-ocean sediments by the fall-out of plant material whether digested or not. Analysis of this mechanism immediately brings one up against a set of much bigger problems: the global, biochemical cycling not only of carbon but also of nitrogen, phosphorus, and oxygen.

Unfortunately, we do not know as much as we need to about these cycles in the ocean. Worse, it now seems that we do not know as much as we previously thought. Understanding the biogeochemical cycle of an element requires a knowledge of how much there is, how it is distributed among its different forms (organically bound, ionic, gaseous, and so on), and the rates of change among the various forms.

One of the most important geochemical processes for carbon is that associated with photosynthesis, by which carbon dioxide is converted to carbohydrate with a corresponding release of molecular oxygen. There has been little agreement about the rate of this process in the ocean. In addressing this basic question, the Marine Ecology Laboratory is trying to make a contribution to understanding world climate and the 'greenhouse' problem.

It used to be thought (see tabulation in Platt and Subba Rao, 1975) that the average rate of photosynthesis by phytoplankton in the open ocean was 50-100 g carbon m^{-2} y^{-1} based on a compilation of data from experiments that used radioactively labelled carbon dioxide. Towards the end of the seventies, these figures began to be challenged (see Kerr, 1983); some investigators now suggest that the annual photosynthetic production figures for the open ocean be increased by a factor of 5, or even 10, revisions that if valid are of considerable significance in understanding the 'greenhouse' effect.

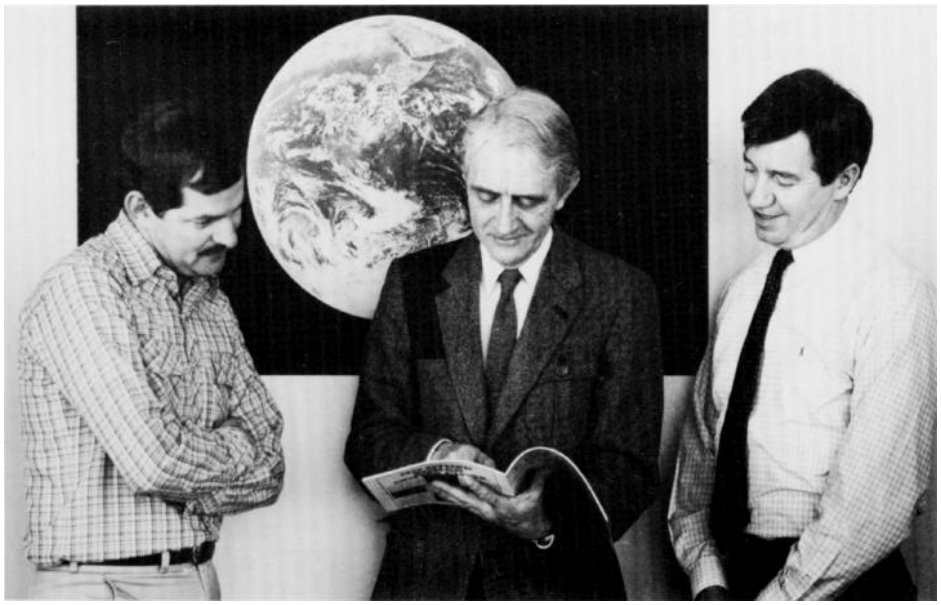
One line of evidence that has been used in support of this argument is based on the summer accumulation of oxygen below the pycnocline (Shulenberger and Reid, 1981). Oxygen is evolved in photosynthesis, but its concentration in the ocean's surface layer is usually adjusted by exchange with the atmosphere. Diffusion of oxygen from below the mixed layer into the atmosphere is impeded by the pycnocline so that a subsurface oxygen maximum is developed, which represents the cumulative primary production since the pycnocline was formed.

A comparison was made in the central gyre of the North Pacific Ocean between this technique and the instantaneous fixation of carbon dioxide as measured by the ^{14}C method at the depth of the subsurface oxygen maximum. Unfortunately, the two methods measure processes on vastly different scales of time and space (Platt *et* al., 1984). The ^{14}C method measures photosynthesis at a particular depth over the time required to do the experiment (not more than 24 h). The oxygen accumulation method has an intrinsic time scale of about 100 days, for which the corresponding space scale is about 1×10^6m.

Further possible problems with the comparison have been discussed by Platt (1984). Among the more important is sampling variability in ^{14}C measurements. When small-scale variability in the amplitude of the subsurface oxygen maximum is considered, the purported discrepancy between the oxygen and carbon fluxes becomes much less certain.

Another recent study relevant to the open-ocean production problem is that of Williams *et al.* (1983), who compared the evolution of oxygen with the fixation of carbon dioxide in independent measurements on the same sample. Here the time-scales of the two methods were much better matched and gave similar results. Nonetheless, interpreting the apparent agreements between the short-term oxygen and carbon fluxes as evidence that both are accurate may be an oversimplification of a complex problem (Smith *et al.,* 1984).

Because the surface layer of the ocean can exchange gaseous components with the atmosphere, it has been suggested that increasing levels of carbon dioxide in the atmosphere due to man, which have received so much attention in the control of world climate, will modify the carbon cycle in the ocean, in particular that part of the cycle associated with photosynthesis (e.g., Holm-Hansen, 1982). But photosynthesis in the ocean is apparently almost never limited by availability of carbon. Other essential elements, especially nitrogen, are in very much smaller supply and more likely to limit photosynthesis.



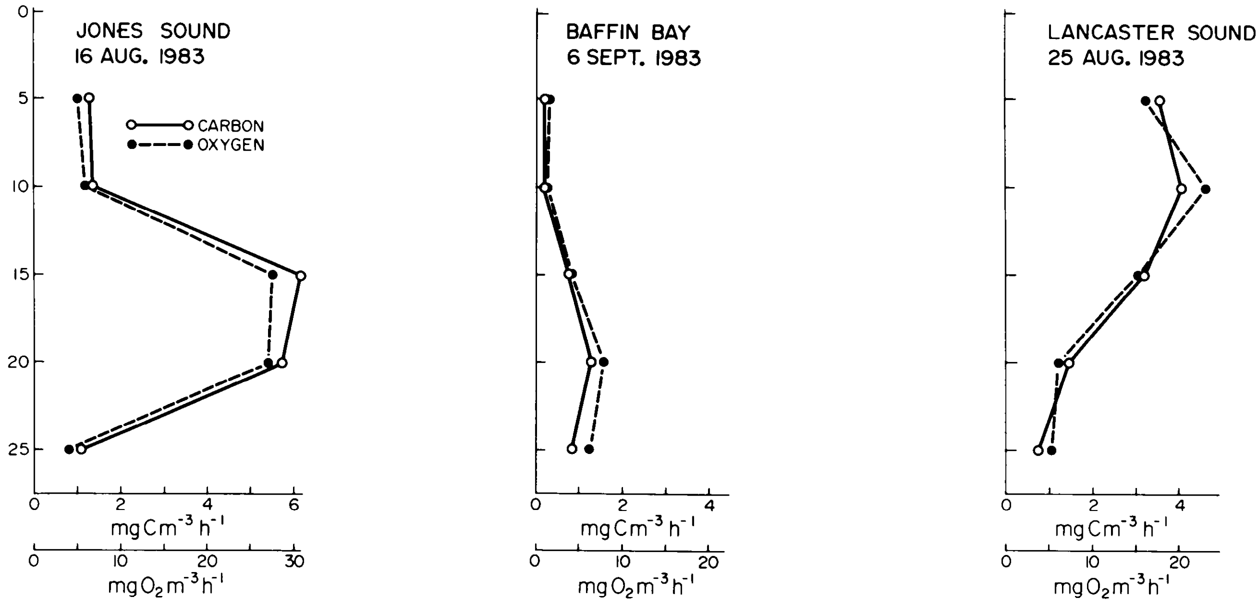
Glen Harrison, Alan Longhurst, and Trevor Platt.

The absolute level of primary productivity in the ocean is, in fact, thought to be limited by the rate at which nitrogen can be supplied from the abyssal reservoir. This has been termed 'new' production in contrast with productivity maintained by biological recycling of organically-bound nitrogen in the upper ocean or 'regenerated' production (Dugdale and Goering, 1967). Much as with the controversy surrounding ^{14}C measurements, attempts at quantifying 'new' and 'regenerated' production using nitrogen tracers have come under similar criticism (e.g., Harrison, 1983). and much is still unclear regarding the biochemical nitrogen cycle and how it affects primary production (Harrison. 1982). Notwithstanding these problems, increasing the availability of carbon atoms in the surface of the ocean or in the atmosphere above it, unless complemented with a suitable increase in availability of nitrogen atoms, will have no direct effect on the biological production cycle.

It has been suggested that the flux of nitrogen from the abyss, and thus 'new' production, must be generally balanced by a flux of carbon associated with organic particles sedimenting from the surface layer (Eppley and Peterson, 1979). This has led to considerable interest in the results obtained from sediment traps designed to intercept these particles as they fall. Such measurements are showing, (e.g. Billet *et al.*, 1983) that the rate of sedimentation (and by implication the rate of photosynthesis) is by no means as constant in time as was previously supposed.

Intermittency appears to be characteristic of ocean productivity, as it is of so many ocean properties. Until this variability is fully described and understood, our picture of ocean productivity will be incomplete. The present picture, derived from extrapolations of isolated measurements as if intermittency were not the rule, is far from adequate. It may turn out that the most cost-effective way to monitor and characterize variability in ocean productivity is through a global network of sediment traps.

In some of the more remote areas of the world's oceans, new measurements of photosynthesis are changing old ideas that were based on little data. This is certainly true in Arctic waters (Subba Rao and Platt, in press) where we now believe that annual primary production is more than an order of magnitude higher than estimated ten years ago. During a CSS *Hudson* voyage in August 1983 to Jones Sound in the Canadian Arctic. we measured more



Primary production rates during the development and decline of a photoplankton 'bloom' in Jones Sound, eastern Canadian Arctic. Carbon and oxygen productivities are shown.

primary production in one day than had previously been thought to occur in the Arctic basin in one year (see figure). A large part of the reason for this is that Arctic productivity is strongly seasonal, and ignoring this can produce a very distorted picture.

A similar conclusion can be reached by examining nitrogen cycles, as was done recently in the Antarctic by Jennings *et al.* (1984). They inferred, from the seasonal depletion of nitrate, a rate of primary production four times higher than previous estimates from isolated ^{14}C experiments. They attributed the discrepancy not to a fundamental inadequacy of the ^{14}C method but rather to the difficulties of extrapolating results over space and time in an intensely intermittent system.

Thus our understanding of the oceanic carbon dioxide cycle, perhaps intimately linked with the atmospheric cycle and therefore with the question of climate change, is now developing in a way that admits of higher levels of plant production in the ocean than was previously thought possible. Where this new understanding, to which various MEL research projects have contributed significantly over the last few years, will lead us is still hard to see. It is remarkable that after so many years of study, we are still unable to approach a simple global mass budget for carbon-dioxide cycling that satisfactorily accounts for what we know of biological processes in the ocean. As the inexorable rise of carbon dioxide and other 'greenhouse' gases in the atmosphere continues to be observed by our monitoring stations, biological oceanographers will increasingly be under pressure to develop international programmes to address the issue. Indeed, such are planned already by the Committee for Climate Changes in the Ocean of SCOR and WMO, and the Marine Ecology Laboratory expects to continue to be intimately involved in this activity in the coming years.

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Climate, freshwater run-off, and fisheries

K. F. Drinkwater

Effects of freshwater run-off on the physical characteristics of the continental shelf waters of eastern Canada extend thousands of kilometres from where the rivers enter the sea. They can in turn influence the survival of certain fish in their early life stages. Thus, there are correlations between fish abundance and river run-off: examples from the Gulf of St. Lawrence, Gulf of Maine, and Labrador Shelf are discussed.

Ken Drinkwater.

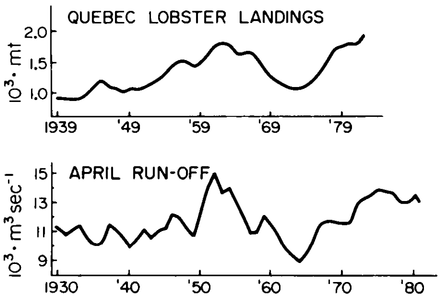
Marine fish populations respond to changes in ocean climate. These can be rather dramatic as in the case of the tenfold decrease in the anchovy catches off Peru following the cessation of upwelling caused by the El Niño event in 1972 or the threefold increase in cod catches off western Greenland following the warming trend in the fifties. Changes in climate can bring about shifts in geographical distributions such as the alternation of North Sea herring between the coasts of Norway and Sweden during warm and cold periods, respectively. The influence of the physical environment on the fish and shellfish populations in the northeast Atlantic has been the subject of several investigations (e.g., ICNAF. 1965) with sea temperatures the climatic factor most often considered. For example, during colder than normal years the number of cod caught on Georges Bank increases (Martin and Kohler, 1965) but Gulf of Maine lobster catches decrease (Dow, 1969; Flowers and Saila, 1972). Over the last decade scientists from the Marine Ecology Laboratory have been studying the role of freshwater run-off on the major commercial species off eastern Canada. This article briefly describes some of the important findings from that research.

Sutcliffe (1972) in a study of a small embayment along Nova Scotia's Atlantic coast observed a direct correspondence between fluctuations in the amount of local freshwater run-off and the rate of primary production. Lacking adequate statistics from the embayment for testing long-term relationships he turned his attention to the Gulf of St. Lawrence. Not only are there long time series records for the Gulf but the freshwater run-off is very large. The St. Lawrence River system alone discharges 424 km^3/y of freshwater. a quantity greater than the sum of the entire run-off (353 km^3/y) along the eastern coast of the United States from the Canadian boundary to the southern tip of Florida (Sutcliffe *et al.,* 1976). The influence of the St. Lawrence discharge is traceable throughout the Gulf of St. Lawrence onto the Scotian Shelf and as far south as the Gulf of Maine (Sutcliffe *et al.,* 1976). Year-to-year changes in the freshwater discharge or its seasonal pattern can produce measurable effects on the salinity and stratification of the waters downstream. For example, the summer salinities in the surface waters of the Magdalen Shallows are determined by the spring run-off from the St. Lawrence River (Lauzier, 1957).

Sutcliffe (1972) investigated the relationship between fish abundance and St. Lawrence River discharge. Quebec landings of halibut, haddock, soft-shell clams, and lobster were all found to be positively correlated with the annual run-off. The maximum correlation coefficients occur when the fish lags the river discharge. The lag time in years is species dependent and is approximately equal to the age at maturity (i.e., the age it enters the fishery). This indicates that run-off affects the fish's first year of life and is consistent with other biological studies that suggest fish abundance is determined in the egg and larval stages. Sutcliffe argued further that, if the St. Lawrence River is primarily influencing the first year of life, then higher correlations may result if run-off at critical months is used rather than annual means. This was subsequently shown to be correct with the spring discharge correlating most closely with the lagged fish abundance (Sutcliffe, 1973). The similarity in the lobster landings and April run-off is shown in the first figure. As a result of the lag times between river discharge and fish, predictions of fish catch can be made from the correlations with run-off (Sheldon *et al.,* 1982).

It was originally thought that increased freshwater discharge causes nutrient enrichment of the surface layers through estuarine circulation and mixing (Sutcliffe, 1973). The excess nutrients then lead to increased biological production that enhances larval fish survival. Later studies showed that an important effect of increased freshwater flow is to intensify stratification downstream, which causes greater heat retention near the surface (G. Bugden, personal communication). This, in part, accounts for the close resemblance between St. Lawrence River run-off and coastal sea-surface temperature records (Sutcliffe *et al.,* 1976).

The physical effects of the freshwater discharge from the St. Lawrence River are not limited to the Gulf of St. Lawrence but extend beyond to the Scotian Shelf and the Gulf of Maine (Sutcliffe *et al.,* 1976). Therefore, investigations into the possible effects of the St. Lawrence River on Gulf of Maine fish stocks were undertaken. Catches of 10 out of 15 commercial marine species of fish and shellfish in the Gulf of Maine showed significant correlation with the St. Lawrence River run-off (Sutcliffe ***et*** *al.,* 1977). As in the Gulf of St. Lawrence, maximum correlations occurred when the fish was lagged by a time approximately matching its age at commercial size. While over half of the species in the Gulf of Maine were positively correlated with run-off, four species were negatively correlated. Fish abundance was also related

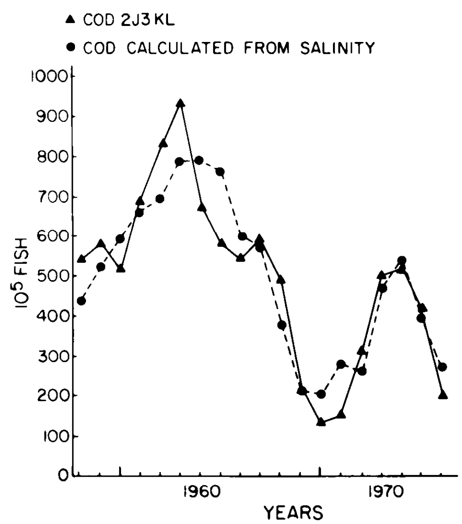


Three-year running means of the Quebec lobster landings and the combined April river discharge from the St. Lawrence, Ottawa and Saguenay Rivers.

to coastal sea-surface temperatures, a result that is not surprising given the high correlation between the sea-surface temperatures and the river discharge. The positively correlated species are generally considered to be near the northern limit of their distributional range, while on the other hand many of the negatively correlated species are near their southern limit. If temperatures are warm then it is good for the warm-water species but not so good for the cold-water species.

Having observed the large geographic area over which the effects of St. Lawrence River are felt, Sutcliffe and coworkers investigated another important source of freshwater in eastern Canada - the run-off into Hudson Bay. The total freshwater discharge into Hudson Bay and James Bay is 523 km^3/y (Prinsenberg, 1980), an amount even larger than that of the St. Lawrence system. The peak monthly mean discharge in June can be traced as a salinity minimum down the Labrador Shelf, onto the Grand Banks (Sutcliffe *et al.,* 1983), and apparently onto the southern Newfoundland Shelf (Petrie and Anderson, 1983). Sutcliffe *et al.* (1983) also related the abundance of Atlantic cod stocks on the southern Labrador Shelf and northern Newfoundland shelf to changes in surface-layer salinity (see second figure). The correlations between cod and salinity are positive indicating high salinity (i.e. low run-off) promotes cod production. They argue that tidally-generated mixing within Hudson Strait increases the nutrients and the salinity in the surface waters. These waters are carried by the residual circulation onto the northern Labrador Shelf where the nutrients promote primary production. In the time required for a food chain to develop, the water is advected southward by the Labrador Current; this explains the southward increase in fish concentrations along the Labrador Shelf. In years of high freshwater-outflow from Hudson Bay, the increased stratification suppresses mixing, which reduces nutrients and lowers the salinity of the water on the Labrador Shelf; less food is then available to the cod.

Future research will be directed towards a further understanding of the actual mechanisms linking fish with run-off. These will include studies on the role of freshwater discharge on the physical oceanography of the continental shelves off Canada's east coast as well as continuing to relate environmental fluctuations to changes in fish abundance.



The measured abundance of Atlantic cod in southern Labrador and northern Newfoundland and the abundance calculated from correlations with salinities.

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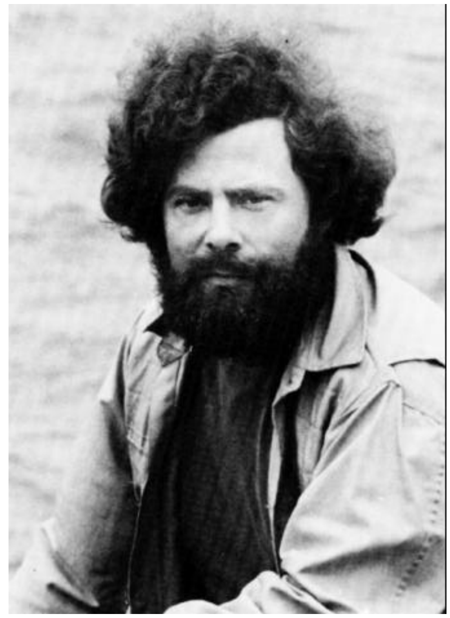
Breeding of Arctic seabirds in unusual ice years: The Thick-billed Murre *Uria lomvia* in 1978*

D.N. Nettleship, T.R. Birkhead, and A.J. Gaston

Unusually severe ice conditions in Lancaster Sound during 1978 resulted in Thick-billed Murres breeding three weeks later than normal: smaller eggs and chicks were produced, parental behaviour was abnormal, fledging success declined, and almost all chicks were lost immediately after fledging.



David Nettleship.

Total reproductive failure among seabirds is unusual, particularly among species breeding in temperate or arctic regions (Belopol'skii, 1957; Freuchen and Salomonsen, 1958; Salomonsen, 1972). Here we present, for the first time, a detailed account of the effect of unusually severe ice conditions on the breeding of Thick-billed Murres *Uria lomvia.*

The study was conducted in 1978 at Prince Leopold Island at the western end of Lancaster Sound, N. W.T., with some additional observations near Cape Hay, Bylot Island, and at Cambridge Point, Coburg Island. Between 86,000 and 160,000 pairs of Thick-billed Murres breed at these colonies (see first figure). Detailed records of ice conditions in the region have been kept since the late forties, and in all previous years ice in Lancaster Sound (west to Prince Leopold Island) has remained open or broken up and moved out during the spring or summer, usually by late April. In 1978, however, Prince Leopold Island remained ice-locked, and Lancaster Sound was choked with large ice-pans throughout the summer. Cape Hay was near the ice edge in 1978, and Coburg Island was ice-free throughout the 1978 breeding season. We compared features of the breeding biology of Thick-billed Murres at Prince Leopold Island in 1978 with data from 1975/1977 when ice conditions were relatively normal (Gaston and Nettleship, 1981) and fell within the averages shown in the first figure. All results in the text refer to Prince Leopold Island unless otherwise stated.

The median egg-laying date in 1978 (18 July) was approximately 18 days later than in 1975-1977 (see second figure). Mean laying dates differed significantly ($P<0.001$) between years, and laying in 1978 was significantly later ($P<0.05$) than in any previous year. Counts of the total number of eggs laid on four study plots showed that at least 97% of the 1975-1977 population bred in 1978. The timing of breeding at Cape Hay in 1978 was similar to that at Prince Leopold Island; extrapolating from a small sample (n = 63) of hatching dates, the median laying date at Cape Hay was 20 July

Thick-billed Murres produced relatively small eggs in 1978 in comparison with previous years. Mean egg volumes differed significantly between years ($F_{3,446}$ = 15.6, $P<0.001$). In 1975 and 1976 volumes were not significantly different, nor were those in 1977 and 1978 (all other pair-wise comparisons were: Duncan's Multiple Range Test, $P<0.05$). In addition there were no significant differences in egg volume between Prince Leopold Island, Cape Hay, and Cambridge Point in 1978 (the size of breeding adults did not differ between these colonies). This indicates that environmental conditions had very far reaching effects on food availability, and were not restricted to birds breeding at Prince Leopold Island.

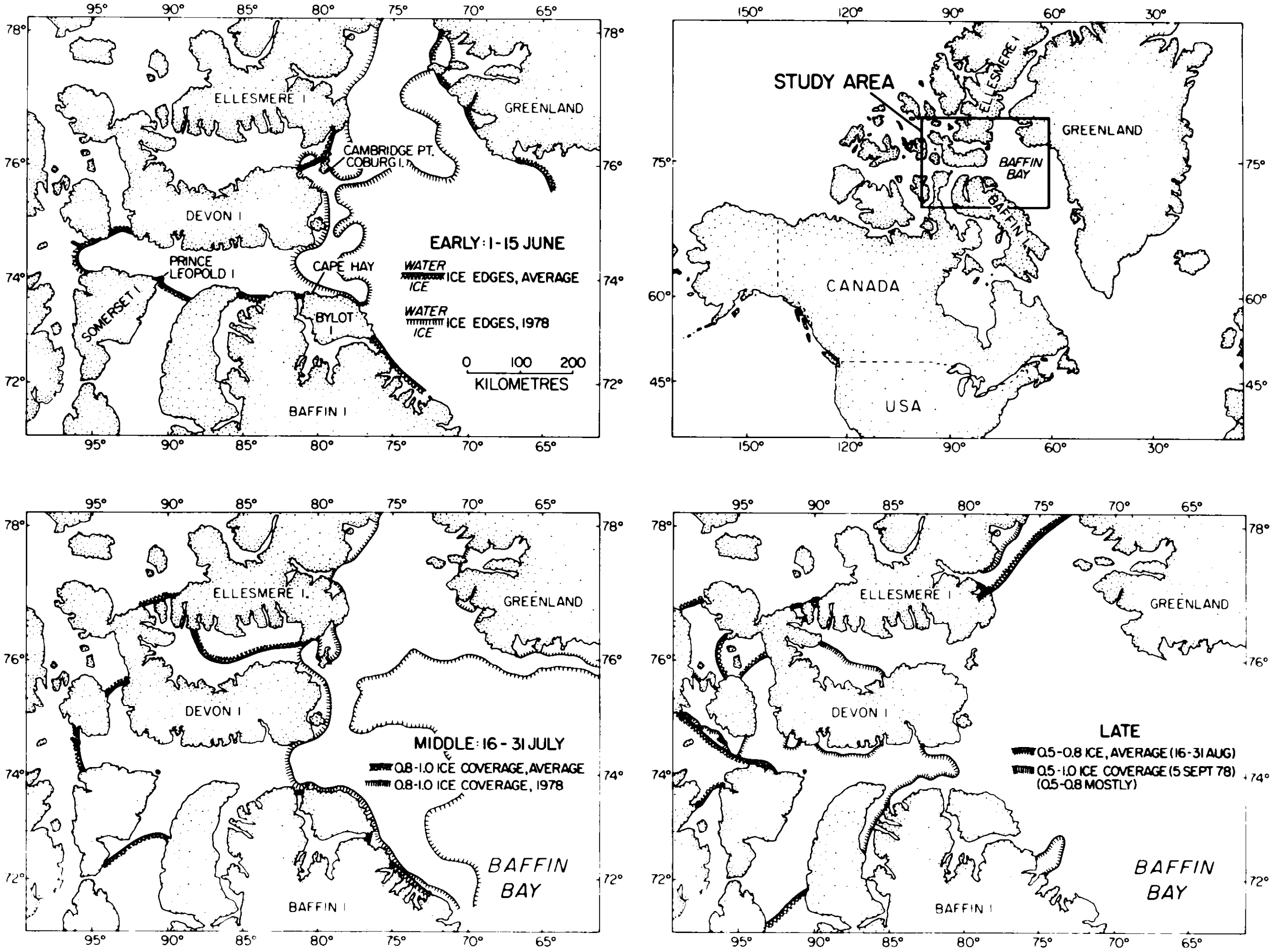
The mean egg volume at Prince Leopold Island in 1978 was not significantly different from that in 1977 when laying was significantly later than in 1975 or 1976, although the difference in median laying dates was only four days (Gaston and Nettleship, 1981). This suggests, first, that there might be a minimum viable egg volume of about 78-80 cm^3 for Thick-billed Murres in Lancaster Sound populations. Second, it suggests that there may be a trade-off between egg-volume and timing of breeding, so that the birds minimize the delay in laying by producing smaller eggs. In 1978 feeding conditions during the period of egg formation must have been considerably worse than in 1977 since it took 18 days longer than normal to accumulate sufficient food reserves to produce even minimum-sized eggs.

Body weights of adult murres during the incubation period were not significantly lower in 1978 than in other years, and incubation proceeded normally in 1978, with the mean incubation period (32.1 days) similar to that in previous years (Gaston and Nettleship, 1981).

Chick growth rates were lower in 1978 than in previous years. The mean weight of two-day old chicks in 1978 was 66.0 g ± 1.72S.E. (n=21), 8% lower than in 1975-1977 (70.8 - 72.2 g). By day 14 the percentage difference in mean weights between 1978 and previous years had increased to 17% (1978: 155.7 g, 1975-1977: 204.5-221.5g). These differences could be due to chicks hatching from relatively small eggs in 1978, a reduction in calorific intake, or increased energy consumption due to changes in brooding attentiveness of the adults or to differences in air temperature. Mean air temperatures during the chick-rearing period were slightly lower in 1978 [1] and, in marked contrast to previous years (Gaston and Nettleship, 1981) and other studies (Birkhead, 1976), some adult murres left

* This investigation is associated with the program 'Studies on northern seabirds'. Seabird Research Unit, Canadian Wildlife Service. Environment Canada (Report No. 184).

[1] Ambient temperatures were recorded each day at 0700 and 1900 local time, and the mean values determined. The chick-rearing period was here defined as from the start of hatching through to the median fledging date. Averagedaily temperatures: 1975: + 2.5°C. 1976: +0.7°C. 1977: + 2.5°C. and 1978: -1.0C.



Distribution and concentration of ice in Lancaster Sound and vicinity in normal years and in 1978: hatched lines show boundaries between ice and water areas (double hatched: normal years; single hatched: 1978). Early-shows locations of fast ice edges (1.0 or 10/10 ice cover). Middle-shows areas of close pack ice (0.8 or 8/10 ice cover) to compact or consolidated pack ice (1.0 or 10/10 ice cover). Late-shows areas of open pack ice in 1978.

their chicks unattended for up to four hours at a time, especially towards the end of the season. Despite these marked differences in growth patterns and behaviour, the mean duration of the chick-rearing period (2 I days) did not differ between years. In a very late season on the Murman coast (Kola Peninsula, U.S.S.R.), some adult murres abandoned eggs and chicks after most chicks had fledged (Kartashev, 1960).

The breeding success of about 350 pairs of Thick-billed Murres was monitored in each of the four years: the proportion of eggs that hatched in 1978 (81.4%) was similar to l975-1977 (82.5 - 86.3%). but the proportion of young that survived to fledge in 1978 (81.8%) was low compared with 1975-1977 (90.9-91.9%): (combining data for 1975-1977: X^2_1 = 21.2, P<0.001). In 1978 several chicks were found dead at their sites, apparently due to starvation. No deaths from starvation were suspected in earlier years (Gaston and Nettleship, 1981). Breeding success was lower in 1978 (66.6%) than in any preceding year (74.9-79.3%). Evidence from fledging weights suggested that young murres in 1978 fledged at about 20% below normal weight (Gaston and Nettleship, 1981). Although there are no data on the subsequent survival of murre chicks, it seems likely that very light chicks would have less chance of surviving than average or heavy chicks (Perrins *et al.,* 1973).

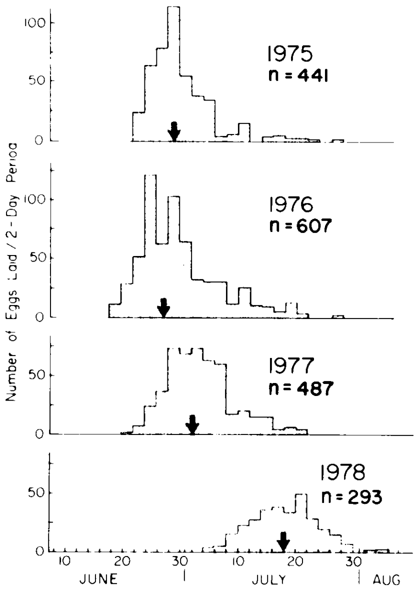
Fledging chicks and their accompanying adults from Prince Leopold Island swim east out of Lancaster Sound. and then south to southwest Greenland where they overwinter. In 1978 fledging did not proceed normally, and adults attempted to encourage chicks less than 15 days old (i.e.. below the minimum fledging age) to Hedge. During fledging most chicks managed to alight in open water between pans of ice which encompassed the island. Chicks appeared to have some degree of control over their descent and actively avoided the ice. Fledging chicks and adults were confronted with approximately 300 km of heavy ice concentration including enormous ice floes (5-10 km across). which separated them from open water near the entrance to Lancaster Sound. Adults and chicks started to walk over the ice, but virtually all chicks perished as a result of exhaustion and/or exposure, and it seems likely that no chicks from Prince Leopold Island survived in 1978. At Cape Hay and Coburg Island, ice cover was much less, so most chicks probably fledged successfully. However, if they also Hedged at very low body weights as a result of breeding late, it seems likely that post-Hedging survival would be low.

The long-term effect of one year’s reproductive failure on the numbers of Thick-billed Murres must be considered in

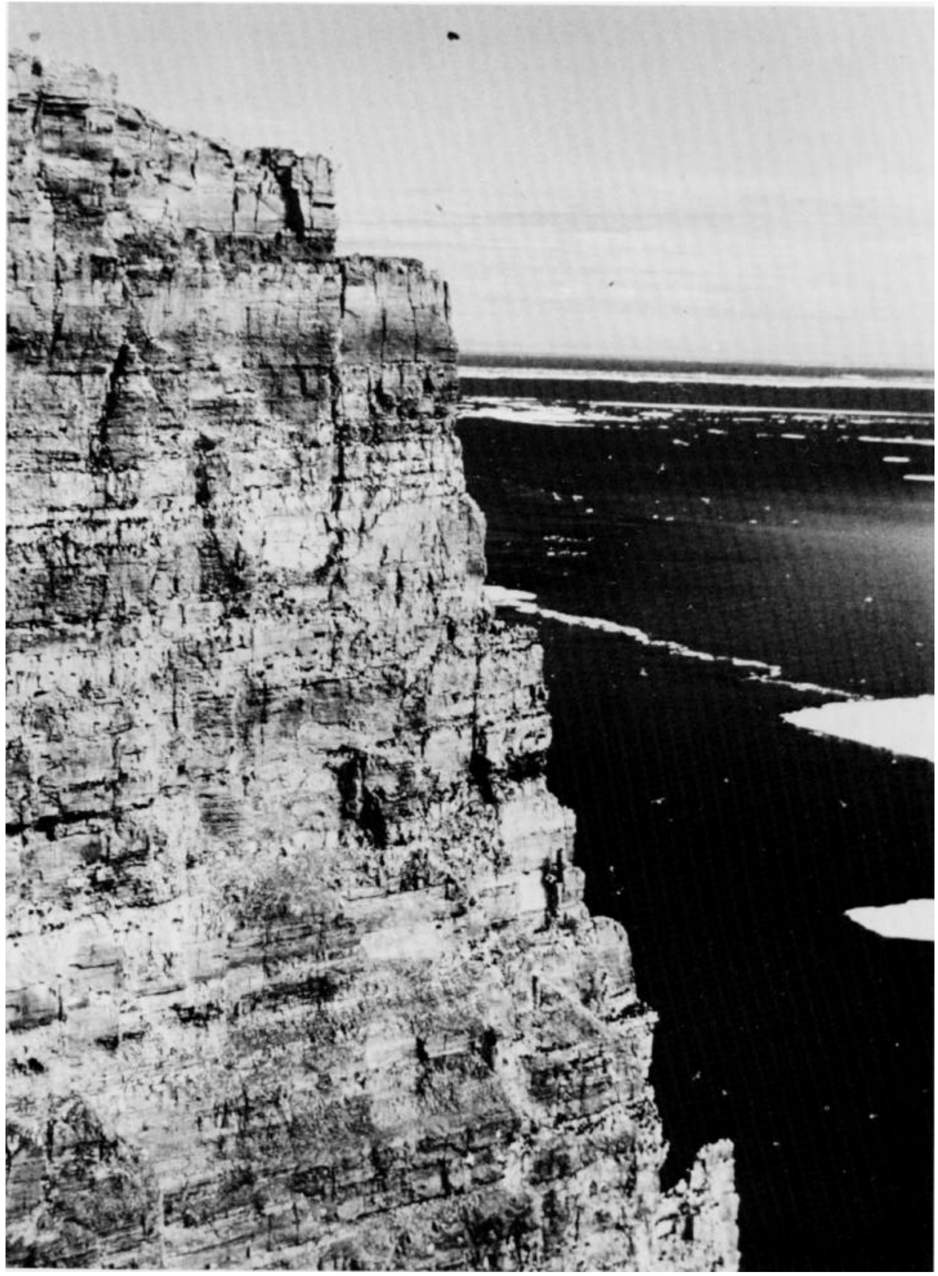
Thick-billed Murres on section of east cliffs at Prince Leopold Island, August 1978, showing density of breeding birds and characteristics of the rock ledge habitat.

Thick-billed Murre and egg, a sea-cliff colonially breeding arctic seabird.

relation to their population dynamics. Thick-billed Murres exhibit low adult mortality with a breeding life of at least 10 y and delayed onset of breeding (probably commencing in the 5th year) and low annual productivity (Birkhead and Hudson, 1977). However, a decrease in productivity or juvenile survival in one year will have only a minor effect on subsequent population size (Wooler and Coulson, 1977), particularly if juvenile mortality is density dependent. Thus, low productivity one year may be offset by increased juvenile survival in the next. On the other hand, even a small increase in adult mortality is likely to have a substantial and long-lasting effect on population size. For example, a species with a 95% annual adult survival rate need only suffer a 5% decrease in survival to double its mortality rate. This means that seabird populations can readily withstand a 'natural disaster' such as the 1978 ice and associated climatic conditions, which affects only productivity, because their life-history pattern has evolved to cope with such events. They are, however, much less likely to recover from any factor (such as oil pollution, gill-netting, and hunting) that increases adult mortality. Of all seabirds breeding in Lancaster Sound, Thick-billed Murres are especially vulnerable to increased adult mortality, through man's activities in arctic regions. Already, salmon gill-net fishing off southwest Greenland (the wintering area for most of the Lancaster Sound Thick-billed Murre population) has caused massive mortality (Tull *et al.*, 1972; Nettleship, 1977). Now, in addition, there is the threat of oil pollution as a result of offshore drilling (Milne and Smiley, 1978) and tanker transport.



Egg-laying dates of Thick-billed Murres at Prince Leopold Island in four seasons. The heavy arrow indicates the median laying date. Studies for 1975-1977 commenced on 18 May, 7 May, and 1 June, respectively; studies in 1978 were initiated on 21 July once the unusual ice conditions in Lancaster Sound were identified and reported. Laying dates for 1978 were extrapolated from hatching dates using the mean incubation period (32 days) derived from the 1975-1977 data.



Thick-billed Murre breeding habitat - top of cliffs at Prince Leopold Island.

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Charts and Publications

CHART PRODUCTION

The Atlantic Region of the Canadian Hydrographic Service has a cartographic staff of 25, with the responsibility for 433 navigational charts covering the region from the Bay of Fundy to Prince of Wales Strait in the Arctic.

During 1983, 5 new charts, 3 standard new editions, 25 new editions for Loran C and/or Decca, 7 chart correction patches, and 43 Notices to Mariners were produced by C.H.S. Atlantic. In addition to this, 21 new editions for Loran C were also produced in the Atlantic Region by commercial contract. Our headquarters office produced for the region 4 new charts, 21 new editions (primarily to incorporate the new 1 ALA buoyage system), and 30 reprints. For the first time in the Atlantic Region, 14 charts were printed by contract in Halifax, N.S.

New Charts

4000 Gulf of Maine to Baffin Bay
4006 Newfoundland to Bermuda
4245 Yarmouth Harbour and Approaches
4277 Great Bras d'Or, St. Andrews Channel
4843 Head of St. Mary's Bay
5044 Cape Harrison to Dog Island
5045 Dog Islands to Cape Makkovik
7540 Bridport Inlet and Approaches
7552 Bellot Strait and Approaches

New Editions and Reprints

4001 Gulf of Maine to Strait of Belle Isle
4010 Bay of Fundy Inner Portion
4011 Approaches to Bay of Fundy
4013 Halifax to Sydney
4015 Sydney to Saint Pierre
4016 Saint Pierre to Saint John's
4017 Cape Race to Cape Freels
4021 Pointe Armour to Cape Whittle
4022 Cabot Strait and Approaches
4023 Northumberland Strait
4128 Approaches to Saint John Harbour
4154C Nactaquac Dam to Newbourg Junction
4145.1 Nactaquac Dam to Newbourg Junction
4145.2 Nactaquac Dam to Newbourg Junction
4275 St. Peters Bay
4319 Saint John Harbour and Approaches
4343 Friar Roads
4384 Pearl Island to Cape LaHave
4399 Parrsboro Harbour and Approaches
4403 East Point to Cape Bear
4462 St. Georges Bay
4463 Cheticamp to Cape Mabou
4464 Cheticamp to Cape St. Lawrence
4519 Maiden Arm, Spring Inlet and Approaches
4520 Orange Bay to Cape Bonavista
4530 Hamilton Sound, Eastern Portion
4544 Deer and St. James Harbours
4545 Smith and Random Sounds, Eastern Portion
4575 Cape Boyle to Renews Harbour
4577 Old Perlican and Winterton to Hearts Content
4598 Bay of Exploits Sheet IV North-East
4599 Little Bay Island to League Point
4611 Grand Bank and Approaches
4622 Cape St. Marys to Argentia Harbour
4624 Long Island to St. Lawrence Harbour
4625 Burin Peninsula to Saint Pierre
4626 Saint Pierre and Miquelon
4635 Cape Ray to LaPoile Bay
4700 Belle Isle to Resolution Island
4703 White Point to Corbet Island
4716 Chateau Bay
4730 Nain to Domino Point
4731 Strait of Belle Isle to Domino Run
4745 White Point to Sandy Island
4771 Eclipse Harbour to Cape White Handkerchief
4775 Nain to Saglek Bay
4776 Saglek Bay to Buttons Island
5001 Labrador Sea
5150 White Bear Island to Ragged Island
5251 Payne Bay and Approaches
5391 Douglas Harbour and Approaches
7011 Hudson Strait to Grønland
7053 Padloping Island to Clyde Inlet
7065 Mill Island to Winter Island
7126 Culbertson Island to Frobisher
7127 Koojeese Inlet and Approaches
7170 Exeter Bay and Approaches
7217 Scott Inlet to Pond Inlet
7302 Lady Ann Strait to Smith Sound
7404 Frozen Strait, Lyon Inlet and Approaches
7430 Repulse Bay, Harbour Island to Talon Bay
7455 Igloolik and Approaches
7465 Frustration Bay and Approaches
7930 Hell Gate and Cardigan Strait
7950 Jones Sound, Norwegian Bay and Queens Channel
7954 Cape Stallworthy to Cape Discovery
8005 Georges Bank
8007 Halifax to Sable Island
8008 Banquereau and Misaine Banks
8009 Grand Banks of Newfoundland
8010 Grand Banks (Southern Portion)
8011 Grand Banks (Northern Portion)
8012 Flemish Pass
8013 Flemish Cap
8014 Grand Banks (North-East Portion)
8015 Funk Island and Approaches
8046 Button Island to Cod Islands
8047 Cod Island to Cape Harrison
8048 Cape Harrison to St. Michael Bay
8049 St. Michael Bay to Gray Island

Large Corrections (Patches)

4637 Burgeo and Ramea Island
4703 White Point to Corbet Island
4744 Approaches to Spotted Island Harbour
4745 White Point to Sandy Island
4910 Miramichi
5133 Domino Point to Cape North

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We present below an alphabetical listing by author of BIO publications for 1983. Articles published in scientific and hydrographic journals, books, conference proceedings, and various series of technical reports are included. For further information on any publication listed here please contact: Publication Services, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2.

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1983 Ship Voyages*

C.S.S. HUDSON

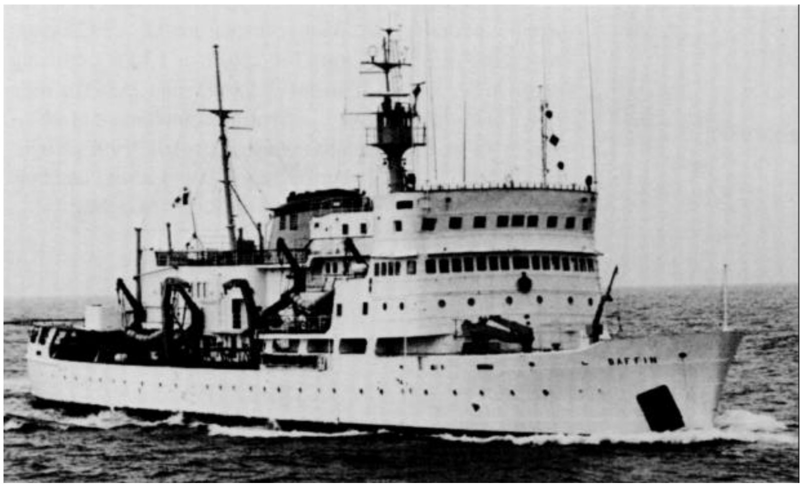
- The C.S.S. *Hudson* is a diesel-electric driven ship designed and used for multidisciplinary oceanographic research. The ship is owned and operated by the federal Department of Fisheries and Oceans.

- Principal Statistics-Lloyds Ice Class I hull . . . built in 1963 . . . 90.4 m overall length . . . 15.3 m overall beam . . . 6.3 m maximum draft . . . 4870 tonne displacement . . . 3721 gross registered tons . . . 17 knot full speed . . . 13 knot cruising speed in Sea State 3 . . . 80 day endurance and 23,000 n. mile range at cruising speed . . . scientific complement of 26 . . . 205 m^2 of space in four laboratories . . . two HP 1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . four survey launches

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-002	Apr. 6 to 23	T. Platt, MEL	Scotian Shelf/Sargasso Sea	Series of biological oceanographic observations on the pelagic ecosystem at an oligotrophic station
83-007	Apr. 23 to May 2	P.J. Ryall, Dalhousie Univ.	St. Georges, Bermuda	Deep water tests of rock core drill: sediment sampling; recover and deploy moorings; obtain box core samples
83-009	May 4 to 30	R.M. Hendry, AOL	Bermuda to Halifax	Deploy current meter moorings; CTD survey; heat flow measurements; navigation tests; collect rain samples for pollution studies
83-017 Phase I	Jun. 7 to 21	K.S. Manchester, AGC	Scotian Shelf Laurentian Fan Grand Banks	Test new deep tow equipment. CHIRP sonar system, CTD. and gravimeters; sediment sampling: acoustic survey; deploy current meter moorings; recovery and deployment of OBSs
Phase II	Jun. 22 to Jul. 5	B.D. Loncarevic, AGC	Same	Same
83-019	Jul. 8 to 15	G. B. Fader, AGC	Bedford Basin. Scotian Shelf and Slope	Test Seabed II mapping system: sidescan sonar survey; seabed sediment sampling
83-021	Jul. 28 to Aug. 6	J.R. Lazier, AOL	Hamilton Bank	Recover and deploy moorings: CTD survey

* Abbreviations used here include: *AGC* Atlantic Geoscience Centre: *AOL* Atlantic Oceanographic Laboratory; *CHS* Canadian Hydrographic Service; *DFO* Department of Fisheries and Oceans: *FESD* Fisheries Environmental Sciences Division: *GIROQ* Groupe interuniversitaire de recherches ockanographiques du *Québec; IMPD* Invertebrates and Marine Plants Division; *NAFO* Northwest Atlantic Fisheries Organization: *NSRF* Nova Scotia Research Foundation.

83-023	Aug. 6 to Sep. 17	T. Platt, MEL	Eastern Arctic. north of Hudson Strait	Study biological oceanography of Arctic
83-028	Sep. 19 to Oct. 5	J.P. Syvitski, AGC	Baffin Island fjords	Climatology. sediment dynamics. animal-sediment relationships. and other studies
83-030	Oct. 5 to 26	G. Vilks, AGC	Labrador Shelf. Lake Melville	Sediment sampling and seismic surveys; chemical study of petroleum related substances
83-033	Oct. 28 to Nov. 7	G. Vilks, AGC	Northeast Labrador Shelf, Grand Banks	Study paleoecology and stratigraphy of Quaternary sediments, and sediment stability
83-036	Nov. 9 to Dec. 7	J.R. Lazier, AOL	Hamilton Bank	Replace moorings; CTD surveying; obtain Batfish sections; Polar Front survey
83-043	Dec. 7 to 13	A.E. Hay, Memorial Univ.	Fortune Bay. Baie d'Espoir. and Hermitage Channel, Nfld.	CTD survey; deploy current meters; heat flow measurements; obtain gravity cores



C.S.S. BAFFIN

- The C.S.S. *Baffin* is a diesel driven shipdesigned for hydrographic surveying but also used for general oceanography. The ship is owned and operated by the federal Department of Fisheries and Oceans.

- Principal Statistics- Lloyds Ice Class I hull . . . built in 1956 . . .87 m overall length . . . 15 m moulded beam . . . 5.7m maximum draft . . . 4986 tonne displacement . . . 15.5 knot full speed . . . 10 knot cruising speed in Sea State 3 . . . 76 day endurance and 18,000 n. mile range at cruising speed . . . complement of 29 hydrographic staff... drafting. plotting. and laboratory spaces provided . . . two HP 1000 computer systems . . . heliport and hangar . . . twin screws and bow thruster for position holding . . . six survey launches

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-008	May 2 to Oct. 28	V. J. Gaudet, CHS	Trinity Bay, Belle Isle Strait, Nfld.: Jones Sound. NWT	Standard navigational charting
83-035	Nov. 3 to 28	G. W. Henderson, CHS	SW Nova Scotia	Multidisciplinary data collection for map production
83-042	Dec. 1 to 7	A.K. Malone, CHS	Scotian Shelf area	Testing DOLPHIN. transducers. oceanographic winch. and launch lifting hooks

The NOAA ship Whiting sails out to sea after paying a courtesy call to BIO.

C.S.S. DAWSON

- The C.S.S. *Dawson* is a diesel-driven ship designed and used for multidisciplinary oceanographic research, hydrographic surveying, and handling of moorings in deep and shallow water. The ship is owned and operated by the federal Department of Fisheries and Oceans.

- Principal Statistics - built in 1967 . . . 64.5 m overall length . . . 12 m moulded beam . . . 4.9 m maximum draft . . . 1940 tonne displacement . . . 1311 gross registered tons . . . 14 knot full speed . . . 10 knot cruising speed in Sea State 3 . . . 45 day endurance and 11,000 n. mile range at cruising speed . . . scientific complement of 13 . . . 87.3 m^2 of space in four laboratories . . . computer suite provided . . . twin screws and bow thruster for position holding . . . one survey launch

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-001	Apr. 5 to 12	PC. Smith, AOL	SW Nova Scotia Shelf/ Browns Bank	Recover Cape Sable moorings; deploy Browns Bank moorings; carry out dispersion study; hydrographic surveying
83-003	Apr. 12 to 18	J.N. Smith, AOL	Point Lepreau/ Bay of Fundy	Collect samples for laboratory radioactivity analysis
83-006	Apr. 20 to May 3	D.D. Sameoto, MEL	Scotian Shelf	Test new sampling equipment; conduct acoustic/light experiment; collect zooplankton/ micronekton samples
83-010				
Phase I	May 17 to 18	R. Hall, Dalhousie Univ.	Scotian Shelf	Identification of acoustic reflectors
Phase II	May 18 to 23	T. Chriss, D. Huntley Dalhousie Univ.	Emerald Basin area	Testing and collecting bottom turbulence data with new instrumentation system; marine copepod measurements; bottom stereophotography
83-012	May 5 to 13	D.E.T. Bidgood, NSRF	Scotian Shelf and Slope	High resolution seismic surveying; core sampling
83-014	Jun. 2 to 21	H.G. Miller, Memorial Univ.	Nfld. Coast	Physical and biological oceanography; underwater gravity mapping; surficial geology; seabird observations
83-018	Jun. 22 to Jul. 5	S.D. Smith, AOL	Strait of Belle Isle	Collect data for a computer model of iceberg drift; current measurements; test "penetrometer" sediment corer
83-020	May 23 to 30	K.T. Frank, MEL	NAFO Division 4X	ichthyoplankton survey (SW Nova Scotia Fishery Ecology Program)
83-022				
Phase I	Aug. 2 to 5	I. Reid, AGC	Mouth of Laurentian Channel	Grand Banks microseismicity experiment (recovery of OBSs)
Phase II	Aug. 5 to 9	L. Legendre, GIROQ	Northwest Gulf	General oceanography
Phase III	Aug. 12 to 19	N. Silverberg, GIROQ	Gulf of St. Lawrence	Sampling for biogeochemical evaluation of the benthic boundary layer
83-024	Aug. 19 to 30	J.A. Elliott, AOL	Edge of Scotian Shelf	Study the generation of high amplitude internal waves
83-026				
Phase I	Jul. 7 to 12	C.L. Amos, AGC	Scotian Shelf area	Seismic surveying and coring for sediment studies

Phase II	Jul. 12 to 16	K.T. Frank, MEL	NAFO Division 4X	Ichthyoplankton survey and zooplankton studies (SW Nova Scotia Fishery Ecology Program)
83-027	Sep. 26 to Oct. 10	D. Huntley, T. Chriss, Dalhousie Univ.	Emerald Basin off N.S.	Test. and gather data with, new bottom turbulence instrumentation; stereophotography of bottom roughness
83-029	Sep.7 to 21	R.M. Hendry, AOL	Gulf Stream	CTD survey; acoustic profiling; water sampling
83-031	Oct. 11 to 20	D.L. McKeown, AOL	Scotian Shelf/Slope; Emerald and Western banks	Test Ametek current profiler and Datasonics multifrequency back scatter systems
83-032	Oct. 24 to 29	N.S. Oakey, AOL	Edge of Scotian Shelf	Test Epsonde to 1000 m; study turbulent mixing in mixed layer; study surface energy, heat flux, and wave generation
83-034	Nov. 2 to 11	PC. Smith, AOL	Browns Bank off N.S.	Recover and redeploy moorings; dispersion studies; WAVEC directional-buoy testing; hydrographic survey
83-037 Phase I	Nov. 14 to 21	K.T. Frank, MEL	NAFO Division 4X, (primarily Browns Bank)	Ichthyoplankton survey and zooplankton studies (SW Nova Scotia Fishery Ecology Program)
Phase II	Nov. 21 to 28	P. Schwinghamer, MEL	SW Nova Scotia	Biological sampling of bottom; test benthic camera system; respiration experiments on benthic organisms
83-038	Nov. 30 to Dec. 7	G.L. Budgen, AOL	Gulf of St. Lawrence	Quantify heat content and density distribution for seasonal ice forecasting; nutrient and oxygen sampling; satellite buoy deployment.
83-039	Dec. 10 to 15	K.S. Manchester, AGC	St. Margaret's Bay, N.S.	Test Nordco underwater coring system; collect nearshore geological samples for mapping

C.S.S. MAXWELL

- The C.S.S. *Maxwell* is a diesel-driven ship designed and used for inshore hydrographic surveying. The ship is owned and operated by the federal Department of Fisheries and Oceans.

- Principal Statistics - built in 1962 . . . 35 m overall length . . . 7.6 m moulded beam . . . 2.1 m maximum draft . . . 270 tonne displacement . . . 262 gross registered tons . . . 12.2 knot full speed . . . 10 knot cruising speed in Sea State 2 . . . 10 day endurance and 2400 n. mile range at cruising speed . . . scientific complement of 7 . . . drafting and plotting facilities . . . two survey launches

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-004	Apr. 15 to May 2	B.D. Loncarevic, AGC	Mahone Bay, N.S.	Evaluation of KSS-30 gravimeter
83-011 Phase I	May 9 to Jun. 10	E.J. Comeau, CHS	St. Mary's Bay, N.S.	Standard navigational charting
Phase II	Jun. 14 to Oct. 28	E.J. Comeau, CHS	Trinity Bay, Nfld.	Standard navigational charting
83-04 I	Nov. 8 to 30	R.M. Eaton, CHS	Mahone Bay, N.S.	Evaluations of navigational systems

NAVICULA

- The *Navicula* is a wooden-hulled fishing vessel owned and operated by the federal Department of Fisheries and Oceans and used for research in biological oceanography.

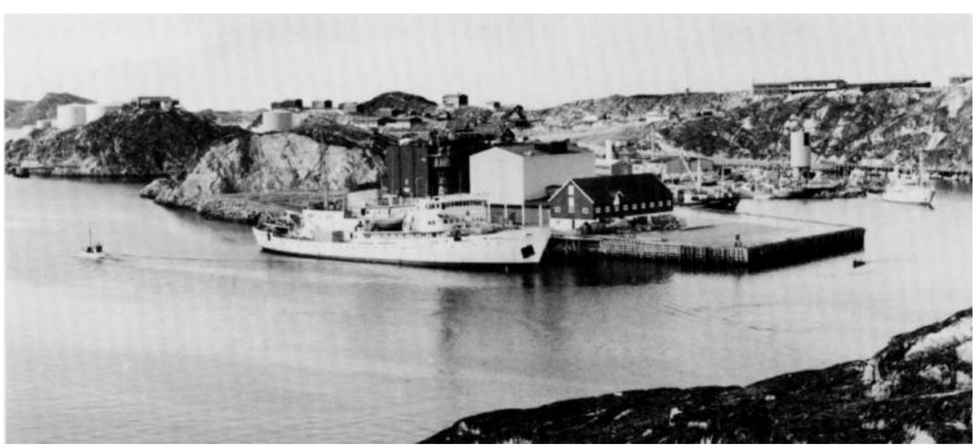
- Principal Statistics - built in 1968 . . . 19.8 m overall length . . . 5.5 m moulded beam . . . 110 ton displacement . . . 78 gross registered tons

VOYAGE YEAR - NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-005	Apr. 18 to May 27 Sep. 6 to Oct. 28	D. Blaney, CHS	Nova Scotia Coast; Northumberland Strait	Chart revision; range surveys
83-015	Jul. 23 to 30 Aug. 25 to 30	G.A. Packman, Environment Canada	Strait of Canso; Chedabucto Bay: Sydney Harbour. N.S.	Sediment studies related to ocean dumping
83-016	Jun. 2 to Aug. 23	T.C. Lambert, MEL	St. Georges Bay. N.S.	Ichthyoplankton survey

OTHER VOYAGES

VOYAGE YEAR - NUMBER & VESSEL	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
83-025 M.V. *Sigma-T*	Jun. 17 to Sep. 19	G.C.H. Harding, MEL	St. Margaret's Bay	Larval lobster survey
83-013 M.V. Quest	May 25 to Jun. 7	C.E. Keen, AGC	Continental Margin southwest of the Grand Banks; Laurentian Channel/ Fan	Deploy OBSs; collect data from OBS stations and seismic reflection system; system assessment

NOTE: The Atlantic Region of the Canadian Hydrographic Service also had the use of the CCGS *John A. McDonald* on a non-dedicated basis and the CCGS *Labrador* on a dedicated basis (Aug. 13 to Oct. 5) primarily for survey work in the Arctic.



LADY HAMMOND

- The *Lady Hammond.* a converted fishing trawler. is chartered by the Department of Fisheries and Oceans from Northlake Shipping Ltd. and used specifically for fisheries research. Its main user is the Marine Fish Division. which has components at BIO and in St. Andrews, N.B. Except as otherwise noted below in the remainder of this chapter. "officers in charge" are affiliated with the Marine Fish Division.

- Principal Statistics-built in 1972 . . . 54 m overall length . . . 11 m overall beam . . . 5.5 m maximum draft . . . 306 gross registered tons . . . 13.5 knot maximum speed . . . 12 knot cruising speed

VOYAGE NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
H088. H089	Jan 6 to 18	R. Mahon/M. Buzeta	NAFO Div. 4X	Groundfish survey. SW Nova Scotia Fishery Ecology Program
H090	Jan. 29 to Feb. 5	J. Reid	Bedford and Emerald basins	MININESS gear trials
H091	Feb. 8 to 20	P. Hurley	NAFO Div. 4X	Broadscale survey. SW Nova Scotia Fishery Ecology Program
H092	Feb. 21 to 26	P. Hurley, T. Koslow. Dalhousie Univ.	NAFO Div. 4X	Process studies. SW Nova Scotia Fishery Ecology Program
H093	Mar. 5 to 17	M. Fowler	NAFO Div. 4X	Broadscale survey, SW Nova Scotia Fishery Ecology Program
H094. H095	Mar. 21 to Apr. 15	S. Scott. N. McFarlane	Scotian Shelf, Bay of Fundy	Spring groundfish survey
H096	Apr. 20 to 28	P. Hurley, T. Koslow. Dalhousie Univ.	NAFO Div. 4X	Process studies, SW Nova Scotia Fisheries Ecology Program
H097	May 4 to 14	J. Reid	NAFO Div. 4X	Broadscale distribution survey. SW Nova Scotia Fishery Ecology Program
H098	May 19 to 29	P. Hurley, T. Koslow. Dalhousie Univ.	NAFO Div. 4X	Process studies. SW Nova Scotia Fishery Ecology Program
H099	Jun. 1 to 14	P. Hurley	NAFO Div. 4X	Broadscale distribution survey. SW Nova Scotia Fishery Ecology Program
H100	Jun. 16 to Jul. 4	J. Anderson. DFO Nfld.	NAFO Div. 4N	Ichthyoplankton survey
H101. H102. H103	Jul. 8 to 29	P. Perley, G. White	NAFO Div. 4V, 4W, and 4X	Comparative fishing with M . V. *Needler*
H104	Aug. 1 to 12	P. Koeller	NAFO Div. 4X	Juvenile haddock survey
H105	Aug. 15 to 17	J. Pringle, IMPD	St. Margaret's Bay and approaches	Lobster survey
H106	Sep. 3 to 15	D. Gascon. DFO Quebec	NAFO Div. 4R	Cod tagging
H107 H108	Sep. 23 to Nov. 6	P. Rubec. DFO Gulf Region	NAFO Div. 4R and 4S	Shrimp and redfish abundance survey
H109	Nov. 15 to 21	J. Reid	Bedford Basin	MININESS gear trials
H110	Nov. 24 to Dec. 8	J. McGlade	NW Atlantic	Pollock survey

E.E. PRINCE

- The *E.E. Prince* is a steel stern trawler used for fisheries research. and experimental and exploratory fishing. The ship is owned and operated by the federal Department of Fisheries and Oceans.

- Principal Statistics- built in 1966 . . . 39.9 m overall length . . . 8.2 m overall beam . . . 3.6 m maximum draft . . . 421 ton displacement . . . 406 gross registered tons

VOYAGE NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
P282	Jan. 7 to 25	U. Buerkle	Chedabucto Bay	Herring-acoustics survey
P283	Feb. 4 to 11	M. Etter, IMPD	Roseway Bank	Shrimpdistribution and abundance
P284	Feb. 15 to 23	L. Dickie, MEL	NAFO Div. 4T	ECOLOG testing
P285	Mar. 3 to 7	M. Strong	Emerald Basin	Pollock collection for meristic and electrophoretic studies
P286	Mar. 9 to 11	C. Morrison, FESD	Halifax Harbour	Live fish collection
P287	Mar. 15 to 27	G. Boutilier	Bay of Fundy	Larval herring survey
P288	Apr. 6 to 21	P. Hurley	NAFO Div. 4X	Broadscale distribution survey, SW Nova Scotia Fishery Ecology Program
P289	May 6 to 13	M. Etter, IMPD	NAFO Subdiv. 4Vn	Shrimp distribution and abundance
P290	May 16 to 26	G. Robert, IMPD	Middle. Western. and Browns banks; German and Lurcher shoals	Stock assessment survey on deep sea scallops
P291	Jun. 4 to 17	W. Squires, DFO Nfld.	NAFO Div. 3L	Snow crab survey
P292	Jun. 20	B. Mercille, DFO Gulf Region	NAFO Div. 4T and Subdiv. 4Vn	Mackerel egg and larval survey
P293	Jul. 11 to 22	J. Pringle, IMPD	Scotian Shelf	Lobster larval survey
P294	Aug. 1 to 26	G. Robert, IMPD	Georges Bank	Lobster larval survey
P295	Aug. 29 to Sep. 2	J. Reid	NAFO Div. 4X	MININESS gear trials
P296	Sep. 6 to 30	D. Clay, DFO Gulf Region	NAFO Div. 4T	Groundfish survey
P297	Oct. 18 to 26	L. Dickie, MEL	Bancaro Bank	ECOLOG testing
P298	Oct. 31 to Nov. 14	M. Power	Bay of Fundy	Herring survey
P299	Nov. 18 to 24	M. Etter, IMPD	Scotian Shelf	Shrimp survey

CO-OPERATIVE VOYAGES

During 1983, the Marine Fish Division participated in co-operative voyages aboard the USSR's research vessel *Let Kievu* (abbreviated as LK below)

VOYAGE NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
LK01 LK02	Oct. 17 to Nov. 24	B. Wood, M. Strong	Scotian Shelf	Comparative juvenile silver hake survey

M.V. ALFRED NEEDLER

- The *M.V.Alfred W.H. Needler* is a diesel-driven shipowned and operated by the federal Department of Fisheries and Oceans. and used for fisheries research.

- Principal Statistics- built in 1982 . . . 50.3 m overall length . . . 10.9 m beam . . . 925.03 gross registered tons . . . complement of 10 scientific staff . . . equipped with up-to-date communication systems, electronics, navigational aids, research equipment, and fishing gear.

VOYAGE NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
N007	Jan. 7 to 17	G. Winters	St. Pierre Bank	Assessment of scallop stocks
N008	Jan. 28 to Mar. 2	T. Rowell (IMPD) E. Dawe	Halifax to Jacksonville, Florida	Distribution of larval and juvenile *Illex* along the axis of the Gulf Stream
N009	Apr. 22 to May 8	J. Baird, DFO Nfld.	NAFO Subdiv. 3Ps and 3Pn	Groundfish survey
N010	May 25 to Jun. 4	K. Waiwood	NAFO Division 4X	Groundfish survey (SW Nova Scotia Fishery Ecology Program)
N011	Jun. 20 to 30	P.Koeller	SW Nova Scotia	Juvenile haddock survey
N012. N013. N014	Jul. 5 to 29	P. Koeller	Scotian Shelf, Bay of Fundy	Standard groundfish survey
N015	Aug. 3 to Sep. 9	R. Mahon	NAFO Division 4X	Groundfish survey (SW Nova Scotia Fishery Ecology Program)
N016	Sep. 12 to 29	J. Young. IMPD	Scotian Shelf	Distribution of squid
N017. N018	Oct. 3 to 27	S. Smith/K. Waiwood	Scotian Shelf	Fall groundfish survey
N019	Oct. 31 to Nov. 9	D. Waldron	Scotian Shelf	Silver hake stock discrimination
N020	Nov. 16 to 30	W.D. Smith	Banquereau Bank	Redfish inventory

VOYAGES ABOARD THE CHARTERED VESSEL *J.L. HART*

VOYAGE NUMBER	VOYAGE DATES	OFFICER IN CHARGE	AREA OF OPERATION	VOYAGE OBJECTIVES
0S01	Aug. 2 to 27	M. Power, J.S. Scott	Sable Island. LaHave-Browns banks	Juvenile haddock survey, comparative day-night fishing
	Mar. 31 to Apr. 9	W. Smith	NAFO Div. 4X	Haddock tagging
	Jul. 11 to 20	U. Buerkle	Bay of Fundy	Herring-acoustics survey

Organization and Staff

BIO is a research institute of the Government of Canada operated by the Department of Fisheries and Oceans (DFO), both on its own behalf and for the other federal departments that maintain laboratories and groups at the Institute. Research, facilities, and services are co-ordinated by a series of special and general committees.

BIO also houses the office of the Northwest Atlantic Fisheries Organization (Executive Secretary- Captain J.C.E. Cardoso); the analytical laboratories of the Department of the Environment's (DOE) Environmental Protection Service (Dr. H. S. Samant); and the Atlantic regional office of the Canada Oil and Gas Lands Administration of the Department of Energy, Mines and Resources (DEMR). In leased accommodation at BIO are the following marine-science related private companies: Huntec Ltd., Wycove Systems Ltd., and Franklin Computers Ltd.

We present below the major groups at BIO together with their managers and a list of Institute staff as at July 1984. Telephone numbers are included in the first list: note that Nova Scotia's area code is 902 and the BIO exchange is 426. In the staff list, the group or division for which an individual works is given in abbreviated form following his/her name: the abbreviations used are defined in the list of major groups immediately below.

OCEAN SCIENCE AND SURVEYS, ATLANTIC (DFO)

A.R. Longhurst
DG - Director-General 3492

[redacted]

OID - Ocean Information Division
H.B. Nicholls, Head 3246

Public Relations
C.E.Murray,Manager 3251
BIOMAIL Officer
B.Bennett 3698

MS - Management Services
G.C. Bowdridge, Manager 6166

Administrative Services
M.C. Bond, Chief. 7060
Financial Services
E. Pottie, Chief 7060
Materiel Management Services
R.J. Stacey, Chief 3487

P - Personnel Services
J.C. Feetham, Manager. 2366

AOL - Atlantic Oceanographic Laboratory
G.T. Needler, Director 7456

AOL - 1. Chemical Oceanography
J.M.Bewers,Head 2371
AOL - 2. Coastal Oceanography
C.S. Mason, Head. 3857
AOL - 3. Metrology
D.L. McKeown, Head. 3489
AOL - 4. Ocean Circulation
J.A. Elliott, Head 2502

CHS - Canadian Hydrographic Service (Atlantic Region)
A.J. Kerr, Director. 3497

CHS - 1. Field Surveys
T.B. Smith, Head 2432
CHS - 2. Chart Production
S. Weston, Head 2432
CHS - 3. Hydrographic Development
R.G. Burke, Head 3657
CHS - 4, Navigation
R.M. Eaton, Head 2572
CHS - 5. Planning and Records
R.C. Lewis, Head 2477
CHS- 6. Tidal
S.T. Grant, Head 3846

MEL - Marine Ecology Laboratory
K.H. Mann, Director 3696

MEL - 1. Biological Oceanography
T.C. Platt, Head 3793
MEL - 2. Environmental Quality
R.F. Addison, Head. 3279
MEL - 3. Fisheries Oceanography
S.R.Kerr,Head. 3792

IF - Institute Facilities
R.L.G. Gilbert, Manager 3681

IF - 1. Ships
J. Parsons, Head 7292
IF - 2. Engineering Services
D.F. Dinn, Head 3700
IF - 3. Computing Services
D.M. Porteous, Head 2452
IF - 4. Library Services
J.E. Sutherland, Head 3675
IF - 5. Publication Services
M.P. Latremouille, Head 5947

ATLANTIC FISHERIES SERVICE, MARITIMES (DFO)

[redacted]

MFD - Marine Fish Division
W.D. Bowen, Chief. 8390

CAFSAC - Canadian Atlantic Fisheries Scientific Advisoy Committee - Secretariat
D.Geddes 8390

CANADIAN WILDLIFE SERVICE (DOE)

[redacted]

SRU - Seabird Research Unit
D.N. Nettleship, Head 3274

GEOLOGICAL SURVEY OF CANADA (DEMR)

[redacted]

AGC - Atlantic Geoscience Centre
M.J. Keen, Director. 2367

AGC - 1. Administration
C.Racine, Head 2111
AGC - 2. Eastern Petroleum Geology
G.L. Williams, Head 2730
AGC - 3. Environmental Marine Geology
D.J.W. Piper, Head 7730
AGC - 4. Program Support
K.S. Manchester, Head 3411
AGC - 5. Regional Reconnaissance
C.E.Keen, Head 3448

STAFF LISTING

ABRIEL, James *AOL-1*
ACKER, Queenie *MS*
ADAMS, Al *IF-1*
ADDISON, Richard *MEL-2*
AHERN, Patrick *MEL-2*
ALLEN, Lorraine *MEL-3*
AMIRAULT, Byron *AOL-1*
AMOS, Carl *AGC-3*
ANDERSON, Bob *AOL-4*
ANDERSON, Debbie *MS*
ANDERSON, George *MS*
ANNAND, Christine *MFD*
ANNING, Jeff *MEL-1*
ARCHER, Barbara *OID*
ARCHIBALD, Chris *MS*
ARMITAGE, Fred *IF-2*
ARMSTRONG, Nancy *MFD*
ASCOLI, *Piero AGC-2*
ASPREY, Ken *AGC-3*
ATKINSON, *Karen AOL-2*
ATKINSON, Tony *AGC-4*
AVERY, Mike *AGC-2*
AVEY, David *Baffin*
AWALT, Garon *IF-2*

Jackie Dale,

BACKMAN, Earl *Dawson*
BAKER, Lloyd *IF-1*
BARSS, Sedley *AGC-2*
BASDEN, Kelly *IF-1*
BASTIEN, Robert *IF-3*
BATES, Steve *MEL-1*
BEALS, Carol *CHS*
BEANLANDS, Brian *AOL-3*
BEANLANDS, Diane *MFD*
BEAVER, Darrell *AGC-4*
BECK, Brian *MFD*
BECK, Vince *IF-3*
BELANGER, Roger *IF-5*
BELL, Bill *Dawson*
BELLEFONTAINE, Larry *AOL-2*
BELLEFONTAINE, Linda *MS*
BENNETT, Andrew *AOL-3*
BENNETT, Rick *Navicula*
BERKELEY, Tom *CHS-3*
BEST, Neville *Hudson*
BETLEM, Jan *AOL-3*
BEWERS, Michael *AOL-1*
BLAKENEY, Claudia *AGC-3*
BLANCHARD, Elaine *MS*
BLANEY, Dave *CHS-1*
BLASCO, Steve *AGC-3*
BONANG, Faye *MS*
BONANG, Linda *MS*

BOND, Murray *MS*
BOUDREAU, Gerry *AOL-4*
BOUDREAU, Henri *CHS-1*
BOUDREAU, Paul *MEL-3*
BOWDRIDGE, Gordon *MS*
BOWEN, Don *MFD*
BOWEN, Eileen *MS*
BOWMAN, Garnet *CHS-1*
BOWSER, Mike *IF-2*
BOYCE, Rick *AOL-2*
BOYCE, Austin *AGC-4*
BRANTON, Bob *MFD*
BRINE, Doug *IF-3*
BRODIE, Paul *MEL-3*
BROWN, Dick *SRU*
BUCKLEY, Dale *AGC-3*
BUGDEN, Gary *AOL-2*
BURGESS, Frank *CHS-1*
BURHOE, Meg *MS*
BURKE, Robert *CHS-3*
BURKE, Walter *CHS-1*

CALDWELL, Glen *IF-2*
CAMERON, Ralph *CHS-1*
CAMERON, Rose *MS*
CAMPANA, Steve *MFD*
CAMPBELL, Paul *AGC-3*
CARR, Judy *MFD*
CARSON, Bruce *AOL-4*
CASEY, Deborah *IF-3*
CASHIN, EImo *IF-1*
CASSIVI, Roger *AOL-3*
CAVERHILL, Carla *MEL-1*
CHAMBERLAIN, Duncan *IF-1*
CHAPMAN, Borden *AGC-4*
CHARLTON, Beverly *MFD*
CHENIER, Marcel *CHS-2*
CHIN-YEE, Mark *IF-2*
CLARKE, Allyn *AOL-4*
CLARKE, Tom *IF-2*
CLATTENBURG, Donald *AGC-3*
CLIFF, John *Baffin*
CLOTHIER, Rodney *Baffin*
COADY, Vernon *AGC-4*
COCHRANE, Norman *AOL-3*
COLE, Flona *AGC-3*
COLFORD, Brian *MS*
COLLIER, Kathie *AOL-3*
COLLINS, Gary *IF-3*
COMEAU, Ernest *CHS-1*
CONNOLLY, *Gerald AOL-3*
CONOVER, Bob *MEL- I*
CONRAD, Bruce *Hudson*
CONRAD, David *AOL-1*
COOK, Gary *AGC-2*
COOKE, Gary *IF-2*
COSGROVE, Art *IF-5*
COSTELLO, Gerard *CHS-1*
COTA, Glenn *MEL-1*

Jeff McRuer,

Bert Bennett,

COURNOYER, Jean *IF-2*
COX, Brian *Baffin*
CRANFORD, Peter *MEL-2*
CRANSTON, Ray *AGC-3*
CRAWFORD, Keith *CHS-Z*
CREWE, Norman *AOL-1*
CRILLEY, Bernard *AGC-2*
CRONK, Suzanne *AGC-5*
CROWE, Hubert *Hudson*
CRUX Elizabeth *CHS-2*
CUNNINGHAM, Carl *AOL-1*
CUNNINGHAM, John *CHS*
CURRIE, Randy *IF-3*
CUTHBERT, Jim *IF-3*

DAGNALL, Joyce *SRU*
DALE, Carla *MFD*
DALE, Jackie *MEL*
DALZIEL, John *AOL-/*
DANIELS, Marilyn *IF-4*
D'APOLLONIA, Steve *AGC-3*
DAS, Paddy *Baffin*
DAVIES, Ed *AGC-2*
DEASE, Ann *MS*
DEASE, Gerry *IF-2*
DeLONG, Bob *IF-2*
DEMONT, Leaman *IF-2*
DENNIS, Pat *AGC-1*
D'ENTREMONT, Paul *AOL-2*
DEONARINE, Bhan *AGC-3*
DESCHENES, Mary Jean *IF-3*
DESSUREAULT, Jean-Guy *AOL-3*
DICKIE, Lloyd *MEL-3*
DICKIE, Paul *MEL-1*
DICKINSON, Ross *Dawson*
DINN, Donald *IF-2*
DOBSON, Des *AOL-2*
DOBSON, Fred *AOL-4*
DOLLIMOUNT, Ray *Hudson*
DOWD, Dick *MEL-3*
DRINKWATER, Ken *MEL-3*
DUFFY, Sean *CHS-1*
DUGAS, Theresa *CAFCAS*
DUNBRACK, Stu *CHS-1*
DUNPHY, Paul *AOL-4*
DURVASULA, Rao *MEL-1*

EATON, Mike *CHS-4*
EDMONDS, Roy *MEL*
EDWARDS, Bob *P*
EISENER, Don *IF-2*
ELLIOTT, Jim *AOL-4*
ELLIS, Kathy *AOL-1*
ETTER, Jim *IF-2*

FADER, Gordon *AGC-5*
FAHIE, Ted *IF-2*
FANNING, Paul *MFD*

FAULKNER, Pat *MS*
FEETHAM, Jim *P*
FENERTY, Norman *IF-5*
FENN, Guy *AGC-4*
FERGUSON, Carol *IF-1*
FERGUSON John *CHS-1*
FINDLEY, Bill *IF-1*
FITZGERALD, Bob *AGC-3*
FLEMING, Dave *CHS-2*
FODA, Azmeralda *MEL-2*
FOOTE, Tom *AOL-2*
FORBES, Donald *AGC-3*
FORBES, Steve *CHS-3*
FOWLER, George *AOL-3*
FRANK, Ken *MEL-3*
FRASER, Brian *MEL-1*
FRASER, Jack *Maxwell*
FRASER, Shardlyn *P*
FREEMAN, Button *MFD*
FREEMAN, Ken *MEL-3*
FRICKER, Aubrey *AGC-4*
FRIIS, Mike *MS*
FRIZZLE, Doug *CHS-2*
FROBEL, David *AGC-3*
FROST, Jim *MEL-3*
FULLERTON, Anne *MEL-3*

GALLANT, Celesta *MS*
GALLANT, Roger *IF-2*
GALLIOTT, Jim *AOL-2*
GAMMON, Gary *MS*
GAUDET, Victor *CHS-1*
GEDDES, Dianne *CAFSAC*
GIDNEY, Betty *CHS-2*
GILBERT, Reg *IF*

Keeping things together,

GILROY, Dave *IF-2*
GIROUARD, Paul *AGC-5*
GLAZEBROOK, Sherman *AOL-4*
GOODWIN, Winston *IF-2*
GOODYEAR, Julian *CHS-1*
GORDON, Don *MEL-2*
GORVEATT, Mike *AGC-4*
GRADSTEIN, Felix *AGC-2*
GRANT, Al *AGC-2*
GRANT, Gary *AGC-2*
GRANT, Steve *CHS-6*
GREENBERG, David *AOL-2*
GREGORY, Don *AOL-4*
GREGORY, Doug *AOL-2*

GREIFENEDER, Bruno *AOL-4*
GUILDERSON, Joan *DG*
GUILBAULT, Jean-Pierre *AGC-3*

HAASE, Bob *CHS-1*
HACQUEBARD, Peter *AGC-2*
HALE, Ken *IF-5*
HALLIDAY, James *IF-1*
HALLIDAY, Ralph *MFD*
HALVERSON, George *IF-2*
HAMILTON, Jim *AOL-3*
HAMILTON, Phyllis *CHS-6*
HANTZIS, Alex *CHS-2*
HARDING, Gareth *MEL-2*
HARDY, Iris *AGC-5*
HARGRAVE, Barry *MEL-2*
HANKINSON, Doug *Baffin*
HARMES, Bob *AGC-3*
HARRIS, Cynthia *MFD*
HARRIS, Jerry *Dawsonn*
HARRIS, Leslie *MEL-1*
HARRISON, Glen *MEL-1*
HARTLING, Bert *AOL-2*
HARVEY, David *AOL-3*
HAYDEN, Helen *AOL-2*
HAYES, Terry *AGC-1*
HEAD, Erica *MEL-1*
HEFFLER, Dave *AGC-4*
HEMPHILL, Milt *CHS-1*
HENDERSON, Gary *CHS-1*
HENDERSON, Terry *AGC-1*
HENDRY, Ross *AOL-4*
HENDSBEE, Dave *AOL-4*
HENNEBERRY, Andy *MEL-2*
HEPWORTH, Deborah *CHS-2*
HERMAN, Alex *AOL-3*
HILL, Phil *AGC-3*
HILLIER, Blair *AGC-4*
HILTZ, Ray *AOL-1*
HILTZ, Sharon *MS*
HINDS, Jim *Hudson*
HODGSON, Mark *MEL-1*
HOFFER, Darrell *AGC-5*
HOGANSON, Joan *MS*
HOLLAND, Len *Dawson*
HOLMES, Wayne *IF-2*

Sheila MacHattie.

HORNE, Ed *MEL-1*
HORNE, Jack *IF-2*
HOUSSER, Debbie *AGC-5*
HOWIE, Bob *AGC-2*
HUBLEY, Susan *AGC-4*
HUGHES, David *CHS-1*
HUGHES, Mike *AGC-4*
HUNTER, Leamond *CHS-2*
HURLEY, Peter *MFD*

IRWIN, Brian *MEL-1*

JACKSON, Art *AGC-2*
JACKSON, Ruth *AGC-5*
JAMIESON, Steve *P*
JANSA, Lubomir *AGC-2*
JARVIS, Lawrence *Hudson*

Ken Freeman.

JAY, Malcolm *CHS-2*
JENNEX, Rita *MS*
JODREY, Fred *AGC-4*
JOHN, Paulette *MS*
JOHNSON, Sue *SRU*
JOHNSTON, Larry *AGC-4*
JOLLIMORE, Shirley *IF-4*
JONES, Peter *AOL-1*
JONES, Roger *CHS-2*
JORDAN, Francis *AOL-2*
JOSENHANS, Heiner *AGC-5*

KARG, Marlene *IF-3*
KAVANAUGH, Anita *IF-4*
KAY, William *AGC-5*
KEARNEY, Carl *Dawson*
KEDDY, Lil *MS*
KEEN, Charlotte *AGC-5*
KEEN, Mike *AGC*
KEENAN, Pat *AOL-2*
KEIZER, Paul *MEL-2*
KELLY, Bruce *IF-2*
KEPKAY, Paul *MEL-2*
KERR, Adam *CHS*
KERR, Steve *MEL-3*
KIERSTEAD, Linda *SRU*
KING, Donna *MFD*
KING, Graeme *CHS-5*
KING, Rollie *IF-1*
KNOX, Don *AOL-3*
KOELLER, Peter *MFD*
KRANCK, Kate *AOL-2*

LAKE, Diana *MS*
LAKE, Paul *AGC-2*
LAMBERT, Tim *MEL-3*
LAMPLUGH, Mike *CHS-1*
LANDRY, Marilyn *MEL-1*
LANGILLE, Neil *Navicula*
LAPIERRE, Mike *IF-2*
LAPIERRE, Richard *IF-1*
LAROSE, Jim *CHS-2*

LARSEN, Ejnar *MEL-1*
LATREMOUILLE, Michael *IF-5*
LAWRENCE, Don *AOL-2*
LAZIER, John *AOL-4*
LeBLANC, Bill *AGC-3*
LeBLANC, Cliff *Maxwell*
LeBLANC, Paul *IF-2*
LEJEUNE, Diane *MS*
LEJEUNE, Hans *MS*
LEONARD, Jim *AOL-1*
LEVY, Eric *AOL-1*
LEWIS, Mary *MEL-1*
LEWIS, Mike *AGC-3*
LEWIS, Reg *CHS-5*
LI, Bill *MEL-1*
LISCHENSKI, Ed *CHS-2*
LITTLE, Betty *P*
LIVELY, Bob *AOL-2*
LOCK, Stan *Baffin*
LOCK, Tony *SRU*
LOCKE, Don *AGC-4*
LOCKYER, Roy *Hudson*
LODER, John *AOL-4*
LONCAREVIC, Bosko *AGC-5*
LONGHURST, Alan *DC*
LORING, Douglas *AOL-1*
LUTLEY, Judy *MS*
LUTWICK, Graham *CHS-6*

MacDONALD, Al *MEL-1*
MacDONALD, Barry *MS*
MacDONALD, Gerry *IF-2*
MacDONALD, Kirk *CHS-5*
MacDONALD, Rose *CHS-2*
MacGOWAN, Bruce *CHS-1*
MacHATTIE, George *IF-2*
MacHATTIE, Sheila *P*
MacISAAC, Mary *MFD*
MacKAY, Bob *Hudson*
MacLAREN, Florence *P*
MacLAREN, Oswald *AOL-3*
MacLAUGHLIN, John *IF-2*
MacLEAN, Brian *AGC-5*
MacLEAN, Carleton *Baffin*
MacLEOD, Grant *CHS-2*
MacMILLAN, Bill *AGC-2*
MacMILLAN, Linda *CHS-1*
MACE, Pamela *MFD*
MACNAB, Ron *AGC-5*
MAHON, Robin *MFD*
MALLET, Andre *MEL-3*
MALONE, Kent *CHS-1*
MANCHESTER, Keith *AGC-4*
MANN, Ken *MEL*
MARTELL, Jim *MS*
MARTIN, Bud *MS*
MARTIN, Harold *Dawson*
MASON, Clive *AOL-2*

Ray Hiltz.

MASON, Ralph *MS*
MATTHEWS, Benny *Dawson*
MATTHEWS, Gordon *Hudson*
MAUGER, Fred *Hudson*
MAZERALL, Anne *IF-4*
McALPINE, Don *AGC-2*
MCCARTHY, Cathy *AGC-2*
MCCARTHY, Paul *CHS-1*
McCORRISTON, Bert *CHS-2*
MacFARLENE, Andrew *SRU*
McGINN, Pete *CHS-6*
McGLADE, Jacquie *MFD*
McKEOWN, Dave *AOL-3*
McMILLAN, Jim *MFD*

Herman Varma.

MCNEIL, Beverley *CHS*
McRUER, Jeff *MEL-3*
MEHLMAN, Rick *CHS-1*
MEIN, John *Baffin*
MEISNER, Patsy *CHS-2*
MELBOURNE, Ron *CHS-2*
MIDDLETON, Cecilia *AGC-3*
MILLER, Bob *AGC-5*
MILLER, Frank *CHS-2*
MILLETT, David *Baffin*
MILLIGAN, Tim *AOL-2*
MILNE, *Mary AGC-2*
MITCHELL, Carol *AGC-2*
MITCHELL, Michel *AOL-3*
MOFFATT, John *AOL-1*
MOORE, Bill *IF-1*
MORAN, Kate *AGC-3*
MUDIE, Peta *AGC-3*
MUISE, Fred *IF-2*
MUISE, Laura *MS*
MURPHY, Bob *AGC-4*
MURRAY, Ed *OID*
MYRA, Valerie *MFD*
MYERS, Steven *IF-1*

NEEDLER, George *AOL*
NELSON, Rick *AOL-1*
NETTLESHIP, David *SRU*
NEU, Hans *AOL-2*
NICHOLLS, Brian *OID*
NICHOLS, Brian *AGC-5*
NICHOLSON, Dale *CHS- 1*
NICKERSON, Bruce *AOL-3*
NICKERSON, Carol *MS*
NICOLL, Michael *IF-1*
NIELSEN, Jes *AGC-4*
NORTON, Neil *Baffin*

OAKEY, Neil *AOL-4*
O'BOY LE, Bob *MFD*
O'NEIL, John *AOL-4*
O'REILLY, Charles *CHS-6*
O'ROURKE, Mike *IF-2*
ORR, Ann *MEL-3*

PALMER, Nick *CHS-2*
PALMER. Richard *CHS-1*
PARANJAPE. Madhu *MEL-1*
PARNELL, Cheryl *AGC-1*
PARROTT, Russell *AGC-3*
PARSONS, Art *IF-2*
PATON, Jim *MS*
PEER, Don *MEL-2*
PELLERINE, Danny *IF-1*
PENNELL, Charles *Hudson*
PERROTTE, Roland *CHS-2*
PETERSON, Ingrid *AOL-4*
PETRIE, Brian *AOL-2*
PETRIE, Liam *MEL-3*
PHILLIPS, Georgina *MEL-2*
PHILLIPS, Ted AOL-3
PIETRZAK, Robert *CHS-5*
PI PER, David *AGC-3*
PLATT, Trevor *MEL-1*
POCKLINGTON, Roger *AOL-1*
POLSON, Carl *IF-2*
PORTEOUS, Dave *IF-3*
PORTER, Cathy *AOL-4*
POTTIE, Dennis *AOL-1*
POTTIE, Ed *MS*
POWROZ, William *Dawson*
POZDNEKOFF, Peter *AOL-4*
PRIME, Wayne *AGC-4*
PRINSENBERG, Simon *AOL-2*
PRITCHARD, John *AOL-2*
PROCTOR, Wally *AOL-3*
PROUSE, Nick *MEL-2*
PURDY, Phil *MS*

Jack Horne,

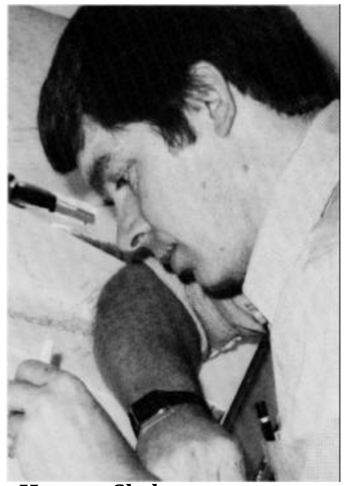
QUON, Charlie *AOL-4*

RACINE, Carol *AGC-1*
RAFUSE, Phil *Baffin*
RAIT, Sue *MS*
RANTALA, Reydo *AOL-1*
RASHID, Mohammed *AGC-3*
REED, Barry *Dawson*
REID, Ian *AGC-5*
REID, Jim *MFD*
REIMER, Dwight *MEL-3*
REINHARD, Harry *MS*
REINIGER, Bob *AOL-4*
REYNOLDS, Bill *Hudson*
RICHARD, Wayne *IF-3*
RIPPEY, Jim *Hudson*
RITCEY, Jack Baffin
ROBERTSON Kevin *AGC-3*
ROCKWELL, Gary *CHS-1*
RODGER, *Glen CHS-1*
ROOP, David *CHS-1*
ROSE, Charlie *IF-2*
ROSS, Charles *AOL-4*
ROSS, Jim *CHS-2*

ROSSE, Ray *MS*
ROZON, Chris *CHS-1*
RUDDERHAM, Dave *MEL-1*
RUMLEY, Betty *AOL-2*
RUSHTON, Laurie *MEL-1*
RUSHTON, Terry *IF*
RUXTON, Michael *CHS-1*
RYAN, Anne *CHS-1*

SABOWITZ, Norman *IF-4*
SADI, Jorge *Baffin*
SAMEOTO, Doug *MEL-1*
SANDSTROM, Hal *AOL-4*
SAUNDERS, Jo-Anne *IF-4*
SAVOY, Rachel1 *P*
SCHAFER, Charles *AGC-3*
SCHIPILOW, Catherine *CHS-2*
SCHUTZENMEIER, Marion *AOL-2*
SCHWARTZ, Bernie *IF-2*
SCHWINGHAMER, Peter *MEL-2*
SCOTNEY, Murray *AOL-2*
SEIBERT, Gerald *OID*
SHATFORD, Lester *AOL-3*
SHAY, Juanita *IF-2*
SHELDON, Ray *MEL-3*
SHERIN, Andy *AGC-4*
SHIH, Keh-Gong *AGC-5*
SHOTTON, Ross *MEL-3*
SILVERT, Bill *MEL-3*
SIMMONS, Carol *MEL-2*
SIMMS, Judy *AOL-1*
SIMON, Jim *MFD*
SIMPSON, Pat *MFD*
SINCLAIR, Alan *MFD*
SLADE, Harvey *IF-5*
SMITH, Alan *CHS-2*
SMITH, Burt *CHS-1*
SMITH, Bill *MFD*
SMITH, Fred *IF-1*
SMITH, John *AOL-1*
SMITH, John *MEL-1*
SMITH, Michelle *SRU*
SMITH, Peter *AOL-2*
SMITH, Steve *MFD*
SMITH, Stu *AOL-4*
SMITH, Sylvia *MEL*
SMITH, Ted *IF-1*
SPARKES, Roy *AGC-4*
SPENCER, Florence *AGC-1*
SPENCER, Sid *IF-2*
SPRINGETT, Joan *MS*
SRIVASTAVA, Shiri *AGC-5*
STEAD, Gordon *CHS-2*
STEELE, Trudi *AOL-4*
STEEVES, Gcorge *IF-2*
STEPANCZAK, Mike *AOL-3*
STEWART, Pat *AGC-1*
STILO, Carlos *Baffin*
STIRLING, Charles *CHS-1*
STOBO, Wayne *MFD*
STODDART, Stan *Hudson*
STOFFYN, Mark *AGC-3*
STOFFYN, Patricia *AGC-3*
STOLL, Hartmut *IF-2*
STRAIN, Peter *AOL-1*
STRUM, Loran *Hudson*
STUART, Al *IF-2*
STUIFBERGEN, Nick *CHS-4*
SUTHERLAND, Betty *IF-4*
SWIM, Minard *CHS-1*
SYMES, Jane *P*
SYMONDS, Graham *AOL-4*
SYVITSKI, James *AGC-3*

TAN, Francis *AOL-1*
TANG, Charles *AOL-2*
TAYLOR, Bill *IF-3*
TAYLOR, Bob *AGC-3*
TAYLOR, Gcorgc *MEL-3*



Harvey Slade,

TEE, Kim-Tai *AOL-4*
THOMAS, Frank *AGC-2*
TILLMAN, Betty *P*
TOLLIVER, Deloros *AGC-1*
TOMS, Elaine *IF-4*
TOPLISS, Brenda *AOL-2*
TOTTEN, Gary *IF-1*
TRITES, Ron *MEL-3*

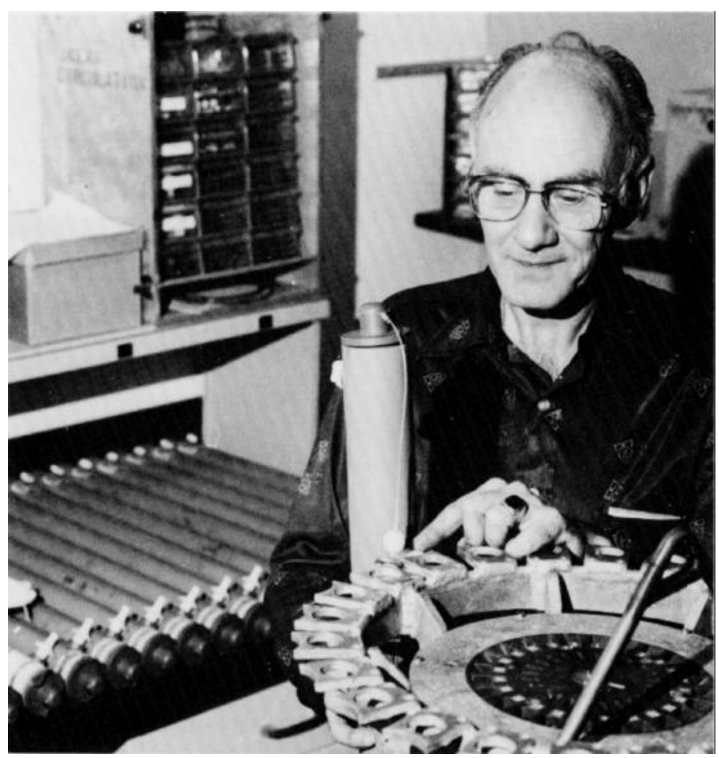
UNDERWOOD, Bob *IF-2*

VANDERMEULEN, John *MEL-2*
VARBEFF, Boris *IF-2*
VARMA, Herman *CHS-1*
VASS, Peter *MEL-2*
VAUGHAN, Betty *IF-2*
VERGE, Ed *AOL-2*
VETESE, Barb *AGC-1*
VEZINA, Guy *IF-2*
VILKS, Gus *AGC-3*
VINE, Dick *IF-2*

WADE, John *AGC-2*
WALDRON, Don *MFD*
WALKER, Bob *AOL-2*
WARD, Brian *IF-2*
WARDROPE, Dick *IF-2*
WARNELL, Margaret *IF-3*
WATSON, Nelson *MEL-1*
WEBBER, Shirley *MS*
WENTZELL, Cathy *P*
WESTHAVER, Don *IF-2*
WESTON, Sandra *CHS-2*
WHITE, George *MFD*
WHITE, Joe *MS*
WHITE, Keith *CHS-3*
WHITEWAY, Bill *AOL-3*
WHITMAN, John *AOL-3*
WIECHULA, Marek *IF-3*
WIELE, Heinz *IF-5*
WILE, Bruce *AOL-4*
WILLIAMS, Doug *MS*
WILLIAMS, Graham *AGC-2*
WILLIAMS, Pat *AOL*
WILLIS, Doug *EL-2*
WILSON, George *IF-1*
WILSON, Jim *IF-2*
WINTER, Danny *IF-2*
WINTERS, Gary *AGC-3*
WOOD, Bryan *FD*
WOODHAMS, Lofty *IF-2*
WOODSIDE, John *AGC-S*
WRIGHT, Dan *AOL-4*
WRIGHT, Morley *IF-2*
WTTEWAAL, Joan *IF-3*

YEATS, Phil *AOL-1*
YOULE, Gordon *AOL-3*
YOUNG, *Gerry MFD*
YOUNG, Scott *AOL-3*

ZEMLYAK, Frank *AOL-1*
ZEVENHUIZEN, John *AGC-5*
ZINCK Maurice *MFL-2*
ZWANENBURG, Kees *MFD*



Bruno Greifeneder.

Project Listing

We present below a listing of the projects (A,B,C, etc.) and individual investigations (1,2,3, etc.) being undertaken by the four major components of the Bedford Institute of Oceanography; the Atlantic Oceanographic Laboratory, Marine Ecology Laboratory, Atlantic Geoscience Centre, and Atlantic Region of the Canadian Hydrographic Service. The listing was current at the end of December 1983. For more information on these projects and those of other BIO components, feel free to write to Publication Services, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2.

ATLANTIC OCEANOGRAPHIC LABORATORY

A. SURFACE AND MIXED-LAYER OCEANOGRAPHY

1. Sea surface wind stress, heat flux, and evaporation *(S.D. Smith, R.J. Anderson, F.W. Dobson)*
2. Arctic polynya experiment *(S.D. Smith, R.J. Anderson)*
3. CO_2 exchange at the air-sea interface *(E.P. Jones, S.D. Smith)*
4. Surface heat flux at OWS Bravo *(S.D. Smith, F.W. Dobson, J.R.N. Lazier)*
5. Wave growth studies *(F.W. Dobson)*
6. Wave climate studies *(H.J.A. Neu)*
7. Oil trajectory analysis *(D.J. Lawrence, J.A. Elliott)*
8. Surface drifters *(D. Gregory)*
9. Iceberg drift track modelling *(S.D. Smith)*
10. Microstructure in the surface layers (N.S. *Oakey, J.A. Elliott)*
11. Near-surface velocity measurements (N.S. *Oakey)*
12. Comparison of long-term mean air-sea fluxes from historical data *(F. W. Dobson, S.D. Smith)*
13. Studies of the Labrador ice edge *(G. Symonds)*
14. Gulf of St. Lawrence ice studies *(G. Symonds, G.L. Bugden)*
15. Atmospheric Fluxes - MIZEX, the Marginal Ice Zone Experiment *(R.J. Anderson, S.D. Smith)*
16. Mean wind stress estimates from bulk aerodynamic formulas *(D. Wright, K. Thompson, R. F. Marsden)*
17. Fronts at the edge of Gulf Stream rings *(A.S. Bennett, D.J. Lawrence, C.L. Tang)*
18. Sea Ice Dynamics - MIZEX. the Marginal Ice Zone Experiment (G. *Symonds)*

B. LARGE-SCALE DEEP-SEA OCEANOGRAPHY

1. Labrador Sea water formation *(R.A. Clarke, N.S. Oakey, J.-C. Gascard)*
2. Dynamics of the Labrador Sea (C. *Quon, R.A. Clarke)*
3. Labrador Current variability *(A. Allen, R.A. Clarke)*
4. Age determination in Baffin Bay bottom water *(E.P. Jones, J.N. Smith, K. Ellis)*
5. Local-scale Gulf Stream variability *(R.M. Hendry, R.F. Reiniger)*
6. Gulf Stream extension experiment *(R.M. Hendry, R.F. Reiniger)*
7. Newfoundland Basin experiment *(R.A. Clarke, R.M. Hendry, A.R. Coote)*
8. Stability problems in GFD flows (C. *Quon)*
9. Northwest Atlantic atlases *(R.F. Reiniger, R.A. Clarke, R.M. Hendry, D. Gregory)*
10. Norwegian/Greenland sea experiment *(R.A. Clarke and others)*
11. Baseline hydrography and ocean heat flux *(R.M. Hendry)*
12. Polar front or North Atlantic current *(J.R.N. Lazier)*
13. Denmark Strait overflow *(C.K. Ross)*
14. Geochemical tracer studies (G.T. *Needler, D. Wright)*

C. CONTINENTAL SHELF AND PASSAGE DYNAMICS

1. Cape Sable experiment *(P.C. Smith, D. LeFaivre, K.-T. Tee. R.W. Trites)*
2. Shelf break experiment *(P.C. Smith, B.D. Petrie, J.P. Louis)*
3. Strait of Belle Isle *(B.D. Petrie, C. Garrett, B. Toulany, D.A. Greenberg)*
5. Tidally induced mixing *(J.A. Elliott, H. Sandstrom)*
6. Batfish internal waves *(A.S. Bennett)*
7. Dynamics of tidal rectification over submarine topography *(D. Wright, J. Loder)*
8. Dynamics of residual circulation in the Gulf of Maine *(D.A. Greenberg, J. Loder. P.C. Smith, D. Wright)*
9. Mixing and circulation on Georges Bank *(J. Loder, D. Wright)*
10. Circulation and dispersion on Browns Bank *(P.C. Smith)*

D. CONTINENTAL SHELF AND PASSAGE WATER-MASS AND TRANSPORT STUDIES

1. Labrador shelf and slope studies *(J.R.N. Lazier)*
2. Flemish Cap experiment *(C.K. Ross)*
3. Long-term monitoring of the Labrador Current at Hamilton Bank *(J.R.N. Lazier)*
4. Data archiving *(D. Gregory)*
5. Development of remote sensing facilities at the Atlantic Oceanographic Laboratory *(C.S. Mason, A.S. Bennett, B. Topliss)*
6. Oceanography of the Newfoundland continental shelf *(B.D. Petrie)*
7. Long-term temperature monitoring *(B.D. Petrie, D. Dobson)*
8. Eastern Arctic physical oceanography *(C.K. Ross)*
9. Water transport through and in the Northwest Passage *(S.J. Prinsenberg, B. Bennett)*

E. OCEANOGRAPHY OF ESTUARIES AND EMBAYMENTS

1. Saguenay fjord study *(G.H. Seibert)*
2. Northwestern Gulf of St. Lawrence *(C.L. Tang, A.S. Bennett)*
3. Gaspe Current studies *(C.L. Tang)*
4. Gulf of St. Lawrence frontal study *(C.L. Tang, A.S. Bennett)*
5. Seasonal and interannual variability in the Gulf of St. Lawrence *(G.L. Bugden)*
6. Laurentian Channel current measurements *(G.L. Bugden)*
7. The Gulf of St. Lawrence - Numerical modelling studies *(K.-T. Tee)*
8. Tidal and residual currents - 3-D modelling studies *(K.-T. Tee)*
9. Bay of Fundy tidal power - studies in physical oceanography *(D.A. Greenberg)*
10. Forced flows in the Strait of Canso *(D.J. Lawrence, D.A. Greenberg)*
11. Physical behaviour of particulate matter and sediments in the natural environment *(K. Kranck)*
12. Laboratory studies of particulate matter *(K. Kranck)*
13. Bottom drifters *(D. Gregory)*
14. Residual barotropic circulation in the Bay of Fundy and Gulf of Maine *(D.A. Greenberg)*
15. Suspended sediment modelling *(D.A. Greenberg, C.L. Amos)*
16. Winter processes in the Gulf of St. Lawrence *(G.L. Bugden)*
17. Modelling historical tides *(D.A. Greenberg. D. Scott, D. Grant)*
18. Storm surge *(D.A. Greenberg, T.S. Murty)*
19. Tidal and wind mixing in the Gulf of Maine *(D.A, Greenberg, J. Loder)*
20. Circulation and air/sea fluxes of Hudson Bay and James Bay *(S. Prinsenberg)*

F. SENSOR DEVELOPMENT

1. Anemometers for drifting buoys *(J.-G. Dessureault)*
2. CTDs and associated sensors *(A.S. Bennett)*
3. Thermistor chains on drifting buoys *(G.A. Fowler, J.A. Elliott)*
4. Towed biological sensors *(A.W. Herman and others)*
5. The dynamics of primary and secondary production on the Scotian Shelf *(A.W. Herman, D.D. Sameoto, T.C. Platt)*
6. Vertical profiling biological sensors *(A.W. Herman, M. Mitchell, S. Young, E. Phillips)*
7. Zooplankton grazing and phytoplankton production dynamics *(A.W. Herman, A.R. Longhurst, D.D. Sameoto, T.C. Platt, W.G. Harrison)*
8. Measurement of zooplankton variability *(A.W. Herman, D.D. Sameoto)*
9. Real-time data acquisition *(A.S. Bennett)*

10. CTD sensor time-constant measurements *(A.S. Bennett)*
11. Moored biological sensors *(A.W. Herman, M. Mitchell, S. Young, E. Phillips)*
12. Satellite estimations of primary productivity *(B.J. Topliss)*
13. Optical properties of Canadian waters

G. SURVEY AND POSITIONING SYSTEM DEVELOPMENT
1. Bottom referenced acoustic positioning systems *(D.L. McKeown)*
2. Ship referenced acoustic positioning systems *(D L. McKeown)*
3. Multifrequency acoustic scanning of water column *(N.A. Cochrane)*
4. Digital echo sounding *(N.A. Cochrane)*
5. Doppler current profiler *(N.A. Cochrane)*

H. OCEANOGRAPHIC INSTRUMENT DEPLOYMENT
1. Engineering studies of stable platforms *(S.D. Smith, R.J. Anderson, R.G. Mills)*
2. Mooring system development *(G.A. Fowler, R.F. Reiniger, A.J. Hartling)*
3. Handling and operational techniques for instrument cable systems *(J.-G. Dessureault, R.F. Reiniger)*
4. Drill system improvement *(G.A. Fowler, P.F. Kingston, P.J.C. Ryall)*
5. In-situ sampling of suspended particulate matter *(D.L. McKeown, B. Beanlands, P.A. Yeats)*
6. Measurement of geotechnical properties *(G.A. Fowler)*

I. NEARSHORE AND ESTUARINE GEOCHEMISTRY
1. Estuarine and coastal trace metal geochemistry *(P.A. Yeats, D.H. Loring)*
2. Atmospheric input into the ocean *(P.A. Yeats, J.A. Dalziel)*
3. Sediment geochronology and geochemistry in the Saguenay Fjord *(J.N. Smith, K. Ellis)*
4. Sediment transport and bioturbation studies in the Bay of Fundy *(K. Ellis, J.N. Smith, D. Wildish)*
5. Organic composition of the St. Lawrence River *(R. Pocklington, F.C. Tan, D. Cossa. E. Degens)*
6. Physical-chemical controls of particulate heavy metals in a turbid tidal estuary *(D.H. Loring, A. Morris)*
7. CO_2 sinks in shelf and slope sediments *(R. Pocklington, E. Premuzic)*
8. Arctic and west coast fjords *(J.N. Smith, K. Ellis, C.T. Schafer, J.P.M. Syvitski)*
9. Chemical pathways of environmental degradation of oil *(E.M. Levy)*
10. Climate variability in fjords *(J.N. Smith, K. Ellis, C.T. Schafer)*
11. Plant degradation and coastal food web studies by stable isotope methods *(R. Stephenson, F.C. Tan, K.H. Mann)*
12. Isotope geochemistry of major world estuaries *(F.C. Tan, J.M. Edmond)*
13. Review of chemical oceanography in the Gulf of St. Lawrence *(J.M. Bewers)*

J. DEEP OCEAN MARINE CHEMISTRY
1. Nutrient regeneration processes in Baffin Bay *(E.P. Jones)*
2. The carbonate system and nutrients in Arctic regions *(E.P. Jones)*
3. Distribution of sea-ice meltwater in the Arctic *(F.C. Tan, P.M. Strain)*
4. Trace metal geochemistry in the North Atlantic *(P.A. Yeats, J.A. Dalziel)*
5. Sediment transport, deposition, and bioturbation studies on the Newfoundland slope *(J.N. Smith, K. Ellis, C.T. Schafer)*
6. Natural marine organic constituents *(R. Pocklington, J.D. Leonard)*
7. Paleoclimatic studies *(F.C. Tan, G. Vilks)*
8. Comparison of vertical distribution of trace metals in the North Atlantic and North Pacific oceans *(P.A. Yeats)*
9. Carbon isotope fractionation studies in marine phytoplankton *(F.C. Tan, P. Wangersky)*
10. Extraction, identification, and analysis of dissolved organic matter *(R. Pocklington, F.C. Tan, T. Fu)*
11. Radionuclide measurements in the Arctic *(J.N. Smith, K. Ellis, E.P. Jones)*
12. Chemistry of sea ice *(E.P. Jones)*
13. Carbon isotope studies on particulate and dissolved organic carbon in deep sea and coastal environments *(F.C. Tan, P. Strain)*

K. MARINE POLLUTION CHEMISTRY
1. Dissolved low molecular weight hydrocarbons in Baffin Bay *(E.M. Levy)*
2. Petroleum hydrocarbon components *(E.M. Levy)*
3. Petroleum residues in the eastern Canadian Arctic *(E.M. Levy)*
4. Large-scale oil pollution of the oceans *(E.M. Levy)*
5. Point Lepreau environmental monitoring program *(J.N. Smith, K. Ellis, G.L. Bugden, J.M. Bewers, D. Scarratt)*
6. Canadian marine analytical chemical standards *(J.M. Bewers, P.A. Yeats, J.A. Dalziel)*
7. International activities *(J.M. Bewers, E.M. Levy, D.H. Loring)*
8. Joint Canada/FRG caisson experiments on metal exchanges between aqueous and sedimentary phases *(D.H. Loring, R. Rantala)*
9. Marine emergencies *(E.M. Levy)*
10. Heavy metal contamination in a Greenland fjord *(D.H. Loring)*
11. Background levels of petroleum residues and low molecular weight hydrocarbons in the Labrador shelf and Hudson Strait regions *(E.M. Levy)*
12. Intercalibration for hydrocarbons in the water column and on the sea surface *(E.M. Levy)*
13. Petroleum pollution monitoring in the Gulf of St. Lawrence *(E.M. Levy)*

L. TECHNOLOGY TRANSFER
1. Seabed mosaics *(J.-G. Dessureault)*
2. Ocean data systems *(J.A. Elliott)*
3. Papa *(J.A. Elliott)*

MARINE ECOLOGY LABORATORY

A. PRIMARY PRODUCTION PROCESSES
1. Mathematical representation and parameterization of photosynthetic response to changes in light intensity *(T.C. Platt)*
2. Dependence of photosynthesis-light parameters on environmental conditions *(T.C. Platt and others)*
3. Significance and nature of aggregation and dispersion in phytoplankton production processes *(T.C. Platt)*
4. Physiology and biochemistry of enzymes of photosynthesis *(J.C. Smith, T.C. Platt)*
5. Growth rates and protein synthesis by phytoplankton in relation to light intensity *(W.K.W. Li and others)*
6. Respiration, nutrient uptake, and regeneration in natural phytoplankton populations *(W.G. Harrison and others)*
7. Physical oceanography of selected features in connection with marine ecological studies *(E.P.W. Horne, T.C. Platt)*
8. Physiology of marine micro-organisms *(W.K.W. Li)*
9. Patterns of phytoplankton photosynthesis assessed by radiocarbon distribution among cellular polymers and metabolites *(W.K.W. Li, T.C. Platt)*
10. Role of picoplankton in the marine ecosystem *(T.C. Platt and others)*
11. Biological oceanography of the Grand Banks *(E.P.W. Horne and others)*

B. SECONDARY PRODUCTION PROCESSES
1. Carbon and nitrogen utilization by zooplankton and factors controlling secondary production *(R.J. Conover)*
2. Ecology of microzooplankton in the Bedford Basin, Nova Scotia *(M.A. Paranjape)*
3. Development of profiling equipment (BIONESS and LHPR) for plankton and micronekton *(D.D. Sameoto)*
4. Use of acoustic techniques to measure distribution of plankton and ichthyoplankton *(D.D. Sameoto)*
5. Analysis of microdistribution of ichthyoplankton and zooplankton in upwelling ecosystems *(D.D. Sameoto)*
6. Nature and significance of vertical variability in zooplankton profiles *(A.R. Longhurst)*
7. Investigation of the biochemical composition of particulate organic matter in relation to digestion by zooplankton *(E. Head)*
8. Measurements of enzyme levels and their utility in estimating physiological rates and in determining physiological stages *(E. Head)*
9. BIOSTAT program: zooplankton and micronekton *(D.D. Sameoto)*
10. Feeding studies on zooplankton grown in an algal chemostat *(E. Head, R.J. Conover)*

C. ATLANTIC CONSHELF ECOLOGY
1. Scotian Shelf Resources and the Shelf Ichthyoplankton Program: data acquisition over large spatial and long temporal scales *(R.J. Conover)*
2. Seasonal cycles of abundance and distribution of microzooplankton on the Scotian Shelf *(M.A. Paranjape)*
3. Comparison of methods of calculation of secondary production estimates from zooplankton population data *(R.J. Conover)*
4. Significance of Yarmouth upwelling plankton production to the general productivity of Scotian Shelf fish stocks *(D.D. Sameoto)*
5. Vertical flux of living and nonliving particles in the water column and nutrient-gas exchange across the seawater-sediment boundary on the Scotian Shelf *(B.T. Hargrave, G.C.H. Harding)*
6. Comparative studies of functional structure of pelagic ecosystems *(A.R. Longhurst)*

D. EASTERN ARCTIC ECOLOGICAL STUDIES
1. Physiology, production, and distribution of marine phytoplankton *(T.C. Platt and others)*
2. Distribution, growth, production, and the role of diapause in Arctic zooplankton communities *(R.J. Conover and others)*
3. Zooplankton and micronekton of the eastern Arctic *(D.D. Sameoto)*
4. Arctic microzooplankton net samples *(D.D. Sameoto)*
5. Distribution and abundance of microzooplankton in the Arctic *(M.A. Paranjape)*
6. Eco-physiological aspects of marine bacterial processes *(W. K. W. Li)*
7. Studies of epontic communities in Barrow Strait, 1983 *(N. Watson and others)*

E. ECOLOGY OF FISHERIES PRODUCTION

1. Acoustic analysis of fish populations and development of survey methods *(L.M. Dickie and others)*
2. Genetic and environmental control of production parameters *(L.M. Dickie and others)*
3. Geographic variations of production parameter\ *(L.M. Dickie and others)*
4. Metabolism and growth of tishes *(S.R. Kcrr)*
5. Mathematical analysis of fish production systems *(W. L. Silvert)*
6. Size-structure spectrum of fish production *(S.R. Kerr and others)*
7. Plankton growth rate in relation to size and temperature *(R. W. Sheldon)*
8. Bioenergetics: Marine mammals *(P.F. Brodie)*
9. Feeding strategies and ecological impact of bivalve larvae *(C. Abou Debs)*
10. Mathematical analysis of fish population interactions *(S.R. Kerr, L.M. Dickie)*
11. Marine mammal - fisheries interactions *(P. Brodie)*
12. Grand Banks ecosystem models *(W.L. Silvert and others)*

F. ENVIRONMENTAL VARIABILITY EFFECTS: CLIMATIC AND ENVIRONMENTALCONTROL OF FISH POPULATION ABUNDANCE

1. Residual current patterns on the Canadian Atlantic continental shelf as revealed by drift bottles and seabed drifters *(R. W. Trites)*

At top, a large set of herring (~150 tons) is pumped aboard the purse seiner *Mattuna Mariner* over German Bank, southwest Nova Scotia. Below, a biologist samples and measures the catch from the chute behind her that transfers the fish to the holds of the ship.

2. Water type analyses for the NAFO areas *(R.W. Trites, K.F. Drinkwater)*
3. Effects of Hudson Bay outflow on the Labrador Shelf *(K.F. Drinkwater)*
4. Larval transport and diffusion studies *(R.W. Trites, T.W. Rowell)*
5. Current and transport in the George's Bank - southwest Nova Scotia region in relation to the inshore/offshore lobster problem *(R.W. Trites)*
6. Oil distribution in relation to winds and currents following the breakup of the Kurdistan *(R.W. Trites and others)*
7. Halifax Section historical data *(K.F. Drinkwater)*
8. Environmental variability -correlations and response scales *(R. W. Trites)*
9. Climatic variability in the NAFO areas *(R.W. Trites, K.F. Drinkwater)*
IO. Baffin Island fjords *(R.W. Trites)*

G. FISHERIES RECRUITMENT VARIABILITY

1. Steady-state model and transient features of the circulation of St. George's Bay *(K.F. Drinkwater)*
2. The distribution. abundance. and recruitment of lobster larvae and their relation to stock recruitment *(G.C.H. Harding and others)*
3. Seasonal variability of planktonic particle size spectrum *(G.C.H. Harding and others)*
4. Nutrition and growth of micro-. macro-. and ichthyoplankton *(R.W. Sheldon and others)*
5. Vertical movement of plankton, suspended matter. and dissolved nutrients in the water column *(G.C. H. Harding and others)*
6. Characterization of water masses by particle spectra *(R.W. Sheldon and others)*
7. Langmuir circulation and small scale distribution of plankton *(T. Lambert and others)*
8. Primary production dynamics *(K.F. Drinkwater and others)*
9. Coupling of pelagic and benthic production systems *(P. Schwinghamer and others)*
10. Instrument development for surveys of particle size distribution *(R.W. Sheldon)*
11. Trophic relationships in nearshore kelp communities *(K.H. Mann)*
12. Hydrography of the southern Gulf of St. Lawrence *(K.F. Drinkwater)*
13. Fish reproductive strategies *(T. Lambert)*
14. Recruitment of larval lobsters along southwest Nova Scotia. the Bay of Fundy. and the Gulf of Maine *(G.C.H. Harding and others)*
15. Fine-scale measurements of larval survival *(K.T. Frank)*
16. Dispersal strategies of marine fish larvae *(K.T. Frank)*
17. Broad-scale spatial coherence of reproductive success among discrete stocks of capelin *(K.T. Frank and others)*
IX Southwest Nova Scotia fisheries ecology - Benthic production processes *(P. Schwinghamer and others)*

H. SUBLETHALCONTAMINATION EFFECTS

1. MFO induction by PCBs and PCB replacements *(R.F. Addison)*
2. Organochlorines in seals *(R.F. Addison)*
3. Fate. metabolism. and effects of petroleum hydrocarbons in the marine environment *(J.H. Vandermeulen)*
4. Organochlorine dynamics in the marine pelagic ecosystem *(G.C.H. Harding, R.F. Addison)*
5. Transfer of metalloids through marine food chains *(J.H. Vandermeulen)*
6. Hazard assessment of "new" environmental contaminants *(R.F. Addison)*
7. "Calibration" of MFO systems in winter flounder as an 'effects' monitoring tool *(R.F. Addison)*

I. BAY OF FUNDY ECOLOGICAL STUDIES
1. Ice dynamics in the upper reaches of the Bay of Fundy *(D.C. Gordon Jr.)*
2. Water chemistry and primary production in the Bay of Fundy *(D.C. Gordon Jr. and others)*
3. Concentration. distribution, seasonal variation. and flux of inorganic nutrients and organic matter in shallow waters and intertidal sediments in the upper reaches of the Bay of Fundy *(D.C. Gordon Jr. and others)*
4. Intertidal primary production and respiration and the availability of sediment organic matter *(B.T. Hargrave and others)*
5. Microbial ecology of the Bay of Fundy *(L. Cammen. P. Schwinghamer)*
6. Subtidal benthic ecology of the Bay of Fundy *(P. Schwinghamer, D.L. Peer)*
7. Intertidal benthic ecology of the upper teaches of the Bay of Fundy *(P. Schwinghamer and others)*
8. Zooplankton studies in Cumberland Basin. N.S. *(N. Prouse)*
9. Production. export. and ecological importance of the Bay of Fundy saltmarshes *(D.C. Gordon and others)*
10. Modelling of Bay of Fundy ecosystems *(D.C. Gordon and others)*

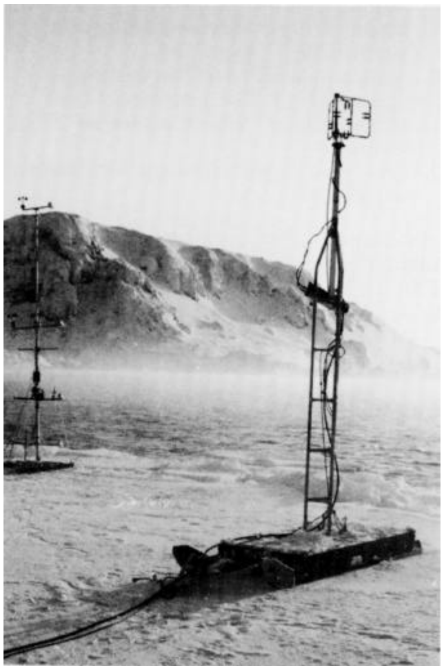
J. DEEP OCEAN ECOLOGY
1. Deep ocean benthic community studies *(P. Schwinghamer)*
2. Mobility of trace metals and radionuclides in sediments *(P. Kepkay)*
3. Activity of scavenging amphipods in transfer of materials in the deep ocean *(B.T. Hargrave)*
4. Vertical fluxes under the Arctic ice cap *(D.C. Gordon Jr. and others)*

ATLANTIC GEOSCIENCE CENTRE

A. COASTAL PROGRAM
1. Consulting advice on physical environmental problems in the coastal zone *(R.B. Taylor)*
2. Coastal morphology and sediment dynamics. southeast and east Cape Breton Island, N.S. *(R.B. Taylor)*
3. Morphology, sedimentology, and dynamics of Newfoundland coast *(D.L. Forbes)*
4. Coastal environments and processes in the Canadian Arctic Archipelago *(R.B. Taylor)*
5. Sediment dynamics and depositional processes in thecoastal zone *(D.L. Forbes)*
6. Beaufort Sea coast *(D.L. Forbes)*
7. Permafrost processes in Arctic beaches *(R.B. Taylor)*
8. Near-surface geology of the Arctic island channels *(D.J. W. Piper)*

B. COASTAL INLETS
1. The physical behaviour of suspended particulate matter in natural aqueous environments *(J.P.M. Syvitski)*
2. Sedimentology of fjords *(J.P.M. Syvitski)*
3. Landsat calibration for suspended sediment concentration in marine coastal environments *(C.L. Amos)*
4. Sediment dynamics - Head of the Bay of Fundy *(C.L. Amos)*
5. Geochemical transformations and reactions of organic compounds in Recent marine sediments *(M.A. Rashid)*
6. Ocean dumping consultation and study *(D.L. Forbes)*

C. CONTINENTAL SHELF
I. Ice scouring of continental shelves *(C.F.M. Lewis)*



Sonic anemeters set up near the polynya at Dundas Island (near Devon Island) to measure heat flux and wind speed.

2. Stability and transport of sediments on continental shelves *(C.L. Amos)*
3. Engineering geology of the Arctic shelf *(C.F.M. Lewis)*
4. Surficial geology and geomorphology. MacKenzie Bay/Continental Shelf *(S.M. Blasco)*

D. CONTINENTAL SLOPE
I. Quaternary geologic processes on continental slopes *(D.J.W. Piper)*

E. DEEP SEA
1. Environmental geology of the deep ocean *(D.E. Buckley)*
2. Surficial geology of the Lomonosov Ridge. Arctic Ocean *(S.M. Blasco)*
3. Facies models of modem turbidites *(D.J.W. Piper)*
4. Temporal and spatial variation of deep ocean currents in the western Labrador Sea *(C.T. Schafer)*

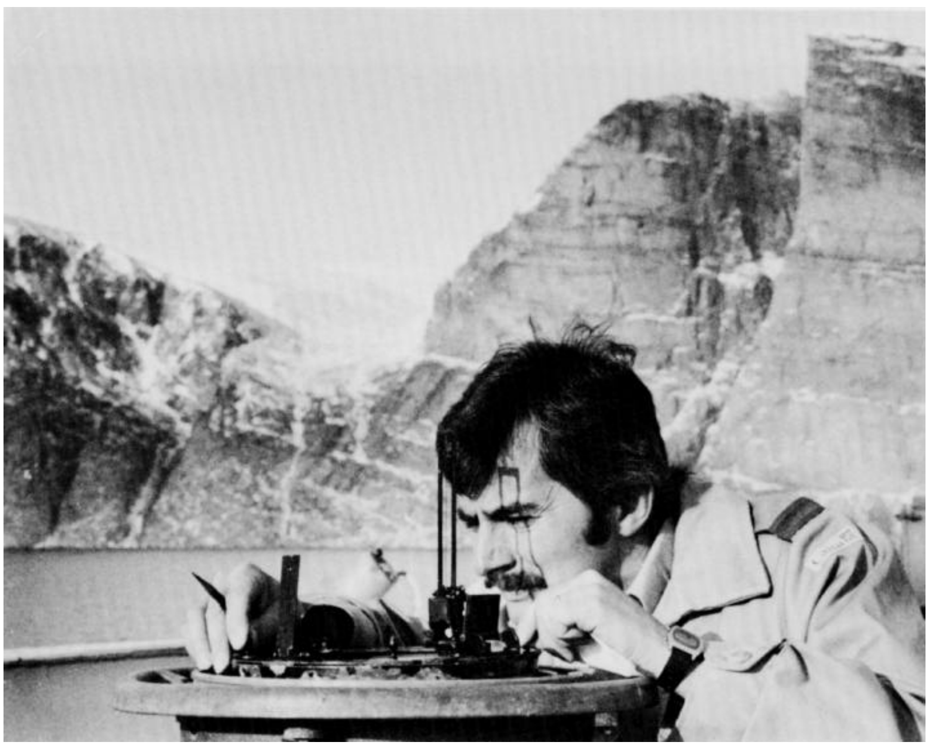
F. HOLOCENE
1. The Recent paleoclimatic and paleoecologic records in fjord sediments *(C.T. Schafer)*

G. PLEISTOCENE
1. Pleistocene-Holocene sedimentation in Hamilton Inlet and southeastern Labrador Shelf *(G. Vilks)*
2. Quantitative Quaternary paleoecology. eastern Canada *(P. Mudie)*

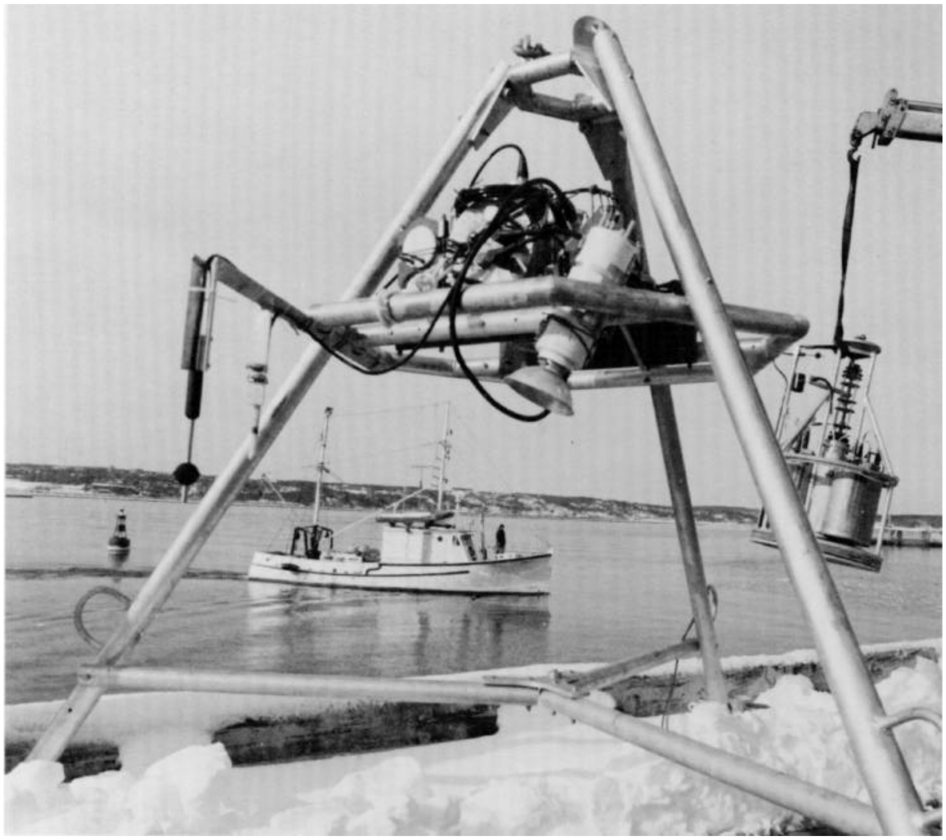
H. SURFICIAL SEDIMENTS AND BEDROCK MAPPING
1. Bedrock and surficial geology. Grand Banks and Scotian Shelf *(G.B. Fader)*
2. Eastern Baffin Island shelf bedrock and surficial geology mapping program *(B. MacLean)*
3. Surficial geology. geomorphology, and glaciology of the Labrador Sea *(H. Josenhans)*

I. REGIONAL GEOPHYSICAL SURVEYS
1. East coast offshore surveys *(R.F. Macnab)*
2. Evaluation of KSS-30 gravimeter *(B.D. Loncarevic)*
3. An earth science atlas of the continental margins of eastern Canada *(S.P. Srivastava)*
4. Arctic Ocean seismic refraction and related geophysical measurements *(H.R. Jackson)*

J. DEEP STRUCTURAL INVESTIGATIONS
1. Comparative studies of the continental margins of the Labrador Sea and of the North Atlantic *(S.P. Srivastava)*



Within sight of Baffin Island, Joseph Bray checks CSS *Hudson's* gyrocompass by measuring the sun's azimuth at noon.



The Sigma-T arriving at the BIO jetty.

2. Seismic studies of continental margins and ocean basins of the North Atlantic (LASE) *(I. Reid)*
3. Surficial geology and crustal structure of the Alpha Ridge. Arctic Ocean *(H.R. Jackson)*
4. Geology of the eastern margin of Canada and other parts of the Canadian offshore *(G.L. Williams)*
5. Seismicity studies of the eastern Canadian margins *(I. Reid)*

K. THEORETICAL MODELLING
1. Rift processes and the development of passive continental margins *(C.E. Keen)*

L. BASIN ANALYSIS AND PETROLEUM GEOLOGY
1. Regional subsurface geology of the Mesozoic and Cenozoic rocks of the Atlantic continental margin *(J.A. Wade)*
2. Geological interpretation of geophysical data as an aid to basin synthesis and hydrocarbon inventory *(A.C. Grant)*
3. Compilation of geoscientific data in the Upper Paleozoic basins of southeastern Canada *(R.D. Howie)*
4. Stratigraphy and sedimentology of the Mesozoic and Tertiary rocks of the Atlantic continental margin *(L.F. Jansa)*
5. Reconnaissance field study of the Mesozoic sequences outcropping on the Iberian Peninsula *(L.F. Jansa)*

M. RESOURCE APPRAISAL
1. Hydrocarbon inventory of the sedimentary basins of eastern Canada *(J.S. Bell)*
2. Rank and petrographic studies of coal and organic matter dispersed in sediments *(P.A. Hacquebard)*
3. Maturation studies *(J.S. Bell)*

N. BIOSTRATIGRAPHY
1. Identification and biostratigraphic interpretation of referred fossils *(S.M. Barss)*
2. Palynological zonation of the Carboniferous and Permian rocks of the Atlantic provinces. Gulf of St. Lawrence. and Northern Canada *(M.S. Barss)*
3. Biostratigraphy of the Atlantic and relevant areas *(E.H. Davies)*
4. Taxonomy. phylogeny, and ecology of palynomorphs *(E.H. Davies)*
5. DSDP dinoflagellates *(G.L. Williams)*
6. Biostratigraphic zonation (Foraminifera. Ostracoda) of the Mesozoic and Cenozoic rocks of the Atlantic shelf *(P. Ascoli)*
7. Biostratigraphic history of the Mesozoic-Cenozoic sediments of the Grand Banks. northeast Newfoundland. and Labrador shelves (based on Foraminifera and Ostracoda) *(F.M. Gradstein)*
8. Taxonomy, biostratigraphy, paleoecology, and paleobiogeography of agglutinated Foraminifera *(F.M. Gradstein)*
9. Biostratigraphic data-processing development *(M.S. Barss)*
10. Quaternary biostratigraphic methods for marine sediments *(G. Vilks)*

O. DATA BASES
1. Geological Survey of Canada representative on steering committee of the Kremp palynologic computer research project *(M.S. Barss)*
2. Information base-offshore east coast wells *(G.L. Williams)*
3. Data inventory *(I. Hardy)*

P. TECHNOLOGY DEVELOPMENT
1. Sediment dynamics monitor - RALPH *(D.E. Heffler)*
2. Development of Vibracorer/drill for geotechnical. geological. and engineering studies *(K.S. Manchester)*
3. Coastal information system development *(A. Fricker. D.L. Forbes)*
4. Development and implementation of cable handling and maintenance procedures *(K.S. Manchester)*

ATLANTIC REGION, CANADIAN HYDROGRAPHIC SERVICE

A. FIELD SURVEYS
1. Coastal and harbour surveys:
   Trinity Bay, Nfld. *(V. Gaudet, E.J. Comeau)*
   Jones Sound, N.W.T. *(M.G. Swim)*
   Strait of Belle Isle *(M.G. Swim)*
   St. Mary's Bay. N.S. *(E.J. Comeau)*
   Saint John Harbour. N.B. *(E.J. Comeau)*
   Liscomb. *N.S. (R. Mehlman)*
   Shediac. N.B. *(M. Lamplugh)*
   Richibucto. N.B. *(M. Lamplugh)*
   Hall Beach, N.W.T. *(M. Lamplugh)*
   Yarmouth, *N.S. (G.W. Henderson)*
   Fort Chimo. N. W.T. *(G. W. Henderson)*
2. Offshore Scotian Shelf *(G. W. Henderson)*
3. Revisory survey of Liscomb to Pictou. N.S. *(D.A. Blaney)*
4. Baffin Island reconnaissance *(G. Rodger)*
5. Horizontal control survey plots: Bonavista Bay. Nfld. *(K. Malone)*
   Eastern Shore. N.S. *(V. Gaudet)*
6. Miramichi River *(V. Gaudet)*
7. Halifax Harbour revisions *(V. Gaudet)*

A deep-sea camera is lowered over the side in an Arctic fjord.

B. TIDES, CURRENTS, AND WATER LEVELS

1. Operation of the Permanent Tides and Water Levels Gauging Network *(S.T. Grant, C.P. McGinn, G.B. Lutwick, P. Hamilton)*
2. Inspection and servicing of Arctic tide gauges *(G.B. Lutwick)*
3. Tidal and Current Surveys:
   Foxe Basin under contract to Dobrocky Seatech Ltd. *(S.T. Grant)*
   Labrador coast *(C.P. McGinn)*
4. Benchmark survey of Nova Scotia *(R. Palmer)*
5. Review and update of 1985 Tide Tables and Sailing Directions *(S.T. Grant, C. O'Reilly)*
6. Analysis of Miramichi cotidal chart accuracy *(S.T. Grant, C. O'Reilly)*
7. Ongoing support to CHS Field Surveys and Chart Production *(S.T. Grant, C. O'Reilly, C.P. McGinn, G.B. Lutwick, F. Carmichael, P. Hamilton)*

C. NAVIGATION

1. Loran-C calibrations in Atlantic Canada for large-scale charts *(R.M. Eaton)*
2. Loran-C error accuracy-enhancement for Atlantic Canada *(N. Stuifbergen)*
3. Syledis evaluations *(R.M. Eaton)*
4. Navstar evaluations *(R.M. Eaton)*
5. Upgrading BIONAV *(M. Ruxton)*
6. Development of electronic chart *(R.M. Eaton)*

D. CHART PRODUCTION

1. Production of 5 New Charts, 49 New Editions (46 Loran-C Charts), 7 Chart Amendment Patches, and the drafting of 43 Notices to Mariners *(R. Chapeskie. S. Weston, T.B. Smith)*

E. SAILING DIRECTIONS

1. Revisions to and the production of the Small Craft Guide, Saint John River, Third Edition *(R. Pietrzak)*

F. HYDROGRAPHIC DEVELOPMENT

1. Acquisition and implementation of a Navitronic vertical acoustic sweep system *(R.G. Burke, S.R. Forbes)*
2. Design specifications for dedicated sweep vessel *(R.G. Burke, S.R. Forbes)*
3. Data Management Study - a review of hydrographic data and of hardware and software systems to meet our requirements *(under contract to MacLaren Plansearch)*
4. Evaluation of an HP 7914 Disc Drive for shipboard applications *(H. Varma)*
5. Bathymetric interactive editing with a direct link *(H. Varma)*

G. RESEARCH AND DEVELOPMENT

1. ARCS - Development of an Autonomous Remotely Controlled Submersible to use in the Arctic under ice cover *(under contract to International Submarine Ltd.)*
2. DOLPHIN - Acquisition and evaluation of a remotely controlled survey vehicle running parallel sounding lines with a parent ship *(K. Malone)*
3. Automated Technique for Nautical Chart Conversion to Modem Formats -- carrying out computer-assisted cartographic techniques in converting obsolete charts to modem formats *(under contract to Marshall Macklin Monaghan)*

BIO

OPEN HOUSE

May 30 - June 3
1984

PHOTOS BY HEINZ WIELE.

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The BIOMAIL Office

BIO's Marine Advisory and Industrial Liaison Office, or BIOMAIL for short, is there to:

- assist in obtaining oceanographic information for you
- help you solve your problems with any aspect of oceanography
- smooth the transfer of our know-how to your company
- facilitate joint projects with BIO and industry
- bring the right people together for an expansion of oceanographic industry.

BIOMAIL's scope is not limited to local or Canadian aspects; we have access to global ocean information and expertise. The office is here to serve the interests of Canadian industry for the benefit of Canadian citizens.

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Fisheries and Oceans

Pêches et Océans

Energy, Mines and Resources

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Environment

Environnement