NATO-Russia Advanced Research Workshop (May 8-10, 2008)
40th International Liège Colloquium on Ocean Dynamics (May 5-7, 2008)
INFLUENCE OF CLIMATE CHANGE ON THE CHANGING ARCTIC AND SUB-ARCTC CONDITIONS[1]

Terms of Reference:

The on-going transformation of the Arctic ecosystem. The Intergovernmental Panel on Climate Change (IPCC) anticipates that, by the end of the 21^{st} century, global average temperature could increase by as much as 5.8 C^{o}. Yet, recent studies indicate that the climate models used by the IPCC may underestimate future global warming because feedback mechanisms that release additional greenhouse gases, such as accelerated microbial decomposition in soils and changes in surface ocean chemistry, are not factored in (http://sciencenow.sciencemag.org/cgi/content/full/2006/526/1?rss=1).

In the Arctic, satellite observations confirm the warming of the lower atmosphere predicted by models and show that the sea-ice cover is disappearing faster than expected by the most pessimistic climate scenarios. Since the early seventies, the summer central ice pack has lost 6% of its surface per decade, shrinking from 7.5 to less than 6 million sq km. A linear extrapolation of this trend forecasts that the Arctic Ocean will be nearly free of ice during the summer sometime around 2080 (ACIA, 2005). However, spectacular reductions in summer sea-ice extent from 2002 to 2006 suggest that the shrinking of the sea ice cover is accelerating, perhaps in response to a reduction in albedo as the area of open water expands (http://nsidc.org/news/press/2006_seaiceminimum/20060816_arcticseaicenews.html). Taking into account this albedo feedback in numerical simulations brings the complete summer melt of the central ice pack forward to 2040 (Holland et al. 2006). Even more alarming, the rate of decrease of arctic sea ice *volume*, especially during the last several years, may have been about twice faster than that of ice *extent* as determined from satellite data. Based on the modeled sea-ice volume trend the Arctic Ocean could actually be free of ice in summer before 2020 (Maslowski et al. 2005). All studies indicate that melting is accelerating and scientists cannot identify any natural feedback that could eventually slow down the process. The current trend may propel the Arctic Ocean into a seasonally ice-free state not seen for over a million years.

Meanwhile, glaciers all over the world are regressing. Of particular concern, the thick ice sheet over Greenland shows increasing signs of destabilization. Based on satellite observations (e.g. the Gravity Recovery and Climate Experiment satellite), estimates of the annual losses reach as much as 240 billions tons of water annually. Although time series of

[1] The modification of the title from "Oceanography and surveillance of the rapidly changing Arctic and Sub-Arctic" has been made on NATO's request and accepted by the Organizing Committee.

NATO OTAN
This workshop is supported by: The NATO Science for Peace and Security Programme

observations are short, evidence accumulates that the Greenland ice sheet is loosing an increasing amount of mass to the ocean. Furthermore, the speed at which Greenland's glaciers flow to the sea has doubled since 1996, most likely in response to the lubrication of the rock bed by melt water percolating through the ice sheet. Based on climate models, the 2004 Arctic Climate Impact Assessment and the US National Center for Atmospheric Research (NCAR), predict that local warming in Greenland will exceed 3 degrees Celsius during this century. Such warming would lead to a complete melt of the Greenland Inlandsis over several centuries. Since most of the Inlandsis is above the ocean, its complete melt would result in a 7-m increase in sea level. In the nearer term, the expected doubling of the rate of sea-level rise over the present century will have immediate consequences that coastal managers, real estate developers, and insurance companies would be wise to consider
(see http://www.realclimate.org/index.php/archives/2006/03/catastrophic-sea-level-rise-more-evidence-from-the-ice-sheets/).

Reduced ice cover and the concomitant reduction, or even absence, of sea-ice melt will lead to weaker stratification and hence the potential for increased vertical mixing and primary production in the peripheral Arctic Ocean basin. Thus, over the next several decades, a progressive reduction of the sea-ice cover and a warming of the surface layer of Arctic seas could be beneficial to the highly specialized pelagic fauna of the Arctic by relaxing the extreme conditions that have been prevailing over recent evolutionary times. For example, the relatively good present condition of 11 of the 13 Polar bear populations in the Canadian Arctic, could reflect some general increase in the frequency of leads that make seals available to them, and /or an improvement of the biological productivity that sustain the production of seals. Similarly, the production of calves by gray whales increases with the duration of the ice-free season on their feeding grounds in the Bering Sea and, initially at least, a lighter sea-ice regime should favour the reproduction of this species. In general, this bolstering of the pelagic ecosystem is expected to occur at the expanse of the benthos.

However, in the longer term and perhaps by the end of this century, the continued shrinking of the sea-ice habitat could spell population reductions for ice-adapted Arctic specialists, and their replacement by boreal and temperate generalists moving into the Arctic Basin from the Atlantic and the Pacific. In the Beaufort Sea and in NW Hudson Bay where the ice-free season has lengthened most, significant losses of body weight and reduced reproductive success in local populations of seals and polar bears have been linked to a lengthening of the ice-free season. In Hudson Bay, a shift in the diet of thick-billed murres from an arctic fish assemblage dominated by Arctic cod to a boreal assemblage dominated by capelin has been linked to the lengthening of the ice-free season. In the Pacific sector of the Arctic, the recent warming trend has favoured the salmon fisheries of Alaska, and Pacific salmon species have been recorded further east in the Arctic basin than ever. In the Bering Sea, the limit between the distributions of the walleye

Pollock and the Arctic cod shifts longitudinally with interannual fluctuations in the southward penetration of sea-ice, and a similar situation is suspected between Arctic cod and Atlantic cod in the Atlantic sector of the Arctic Ocean. Hence, a reduction of the winter sea ice extent is expected to bring a rapid transition on Arctic shelves from an Arctic cod-dominated ecosystem to a walleye Pollock-dominated ecosystem in the Pacific Sector and an Atlantic cod/capelin-dominated ecosystem in the Atlantic Sector.

Socio-economically, the Arctic is undergoing nothing less than a historic rush for virgin territory and mineral resources worth hundreds of billions of dollars. Even before the Polar ice began to thin, countries were pushing into the frigid Barents Sea, lured by undersea oil and gas fields and emboldened by spectacular advances in technology. Now, as the shrinking and thinning of the sea-ice cover make access easier, exploration and exploitation are likely to move progressively farther north. The Polar Thaw is beginning to unlock other treasures: lucrative shipping routes including the fabled Northwest Passage; new destinations for cruise ships; and potentially important commercial fisheries.

Impacts on sub-arctic and temperate seas. The Barents Sea, Iceland and Greenland waters, the Newfoundland/Labrador Shelf, the Bering Sea, the Oyashio Shelf, and the Sea of Okhotsk are among the regions that support some of the most important fisheries in the Northern Hemisphere. These shelves are located at the southern extreme of seasonal sea ice cover, and thus are likely to be highly sensitive to variations in sea ice regime as sea ice forces the timing, amount and fate of primary production and the survival of larval fish. Already, evidence of a northward migration of southern assemblages in response to a shift in ocean climate is accumulating. In the North Atlantic and North Pacific Oceans in recent years, major changes in phytoplankton and zooplankton stocks and the abundance and productivity of commercially important groundfish, marine mammals and seabirds have been correlated to temporal shifts in physical forcing. The analysis of long-term records of zooplankton collected automatically from commercial ships crossing the North Atlantic indicates that from 1960 to 1999, warm-water copepods have moved North by as much as 10^o of latitude with a concomitant reduction in the abundance of cold-water species which, presumably, have been displaced towards the Arctic Basin. Climate-related northward shifts in the distribution of North Sea fish species have paralleled the northward migration of copepods. Until recently, northern Bering Sea ecosystems were characterized by extensive seasonal sea ice cover, high water column and sediment carbon production, and tight pelagic-benthic coupling of organic production. New research published in *Science* (March 2006) shows that these ecosystems are shifting away from these characteristics. The colonization of new rivers by pink salmon is just one of many changes in fish and crab stocks that appear linked to retreating sea ice and warming waters in the Chukchi Sea and, farther south, the Bering Sea. The changes are important because the Bering Sea is rich with pollock, salmon, halibut and crab, already yielding nearly half of America's seafood catch and a third of Russia's. In a 2002 report for the United States Navy on climate change and the Arctic Ocean, the Arctic Research Commission concluded that species were moving north through the Bering Strait. Snow crabs, for example, appear to be moving away from Alaska, north and west toward Russia, as the sea ice retreats. The valuable fishery could eventually move entirely out of American waters, some federal fisheries scientists said. Therefore, climate warming is likely to bring extensive fishing activity to the Arctic, particularly in the Barents Sea and Beaufort-Chuckchi region where commercial operations have been minimal in the past.

A major conclusion emerging from these observations is that seemingly small shifts in the long-term mean values of atmospheric variables, at least when compared to their interannual variability, may result in major changes in the distribution and productivity of fish populations. To anticipate the impacts of these changes on sub-arctic and temperate regions, we need to understand the oceanographic and atmospheric processes controlling the transport of heat, salt, nutrients and plankton by the currents flowing to and from the Arctic through sub-arctic and temperate seas. In particular, long-term changes in climate regime will bring changes in the number, intensity, and trajectories of storms. Fewer and weaker winter storms could reduce vertical mixing, thereby producing a shallower mixed layer and lower nutrient concentrations at the end of winter, prior to the spring bloom. Lower nutrient stocks in spring will impact primary production and the entire food web up to first-feeding fish larvae. Alternatively, reduced ice coverage would increase winter mixing and enhance nutrient renewal in the surface layer of Arctic and sub-arctic seas. A change in the number an/or strength of summer storms may also impact post spring bloom primary production by affecting cloud cover, light, sea surface temperature and primary production.

The issue of sovereignty and security in the Arctic. The United Nations Convention on the Law of the Sea (UNCLOS) has set a deadline in 2010 to countries that wish to claim national jurisdiction to marine areas adjacent to their territories, based on the extent of their continental shelf. With only a fraction of the overall bathymetry of the Arctic Ocean ever surveyed by icebreakers or nuclear submarines, Russia, Canada, Denmark, Norway and the United States are rushing to map the geological structure (bottom and sub-bottom physiography) of their Arctic shelves. (The three other Arctic nations, Iceland, Sweden and Finland, do not have a coast on the Arctic Ocean.) Claims for expanded territory are being formulated in every region of the world, but the Arctic Ocean is where experts foresee many conflicts as the potential boundaries of the five nations converge to the Pole, somewhat the way sections of an orange meet at the stem. In 2001, Russia claimed nearly half of the Arctic Ocean, a claim that was rejected by the international commission for lack of sound data. Russia now hopes that the recent expedition of its research ship *Akademik Fyodorov* to the North Pole will yield geological data supporting its request. Denmark and Canada are conducting a joint effort to chart the Arctic Ocean north of Greenland and Ellesmere. Denmark is particularly interested in proving that a 1600-km undersea mountain range, the Lomonosov Ridge, is linked geologically to Greenland, a semiautonomous Danish territory. Such a link would buttress Denmark's claim to the

North Pole. Canada could also claim a huge area of the Arctic Ocean and then face challenges from the other Arctic nations. The United States is petitioning for a swath of the Arctic seabed larger than California. Two other arctic conflicts concern Canada – in the east, Hans Island between Greenland and Ellesmere is a bone of contention with Denmark. The stake is strategic for the control of sea-borne trade and the exploitation of petrol and gas resources. Rivalry is high in the western arctic where as much as a quarter of the world's oil and gas reserves could be situated, and where an old dispute persists about the frontier between the United States and Canada in the Beaufort Sea. Issues are similar at the convergence of the Canadian, Alaskan, and Russian shelves in the High Arctic where large underwater oil and gas fields may exist.

The thawing of the Arctic Ocean will create the so-called Arctic Bridge, a shipping route with Arctic countries' ports as the logical terminals. The potential advantages of maritime short-cuts across the top of the world could be immense. For example, shipping from Murmansk to mid-continental North America by the classical route through the St. Lawrence Seaway and the Great Lakes to Thunder Bay, in western Ontario, typically takes 17 days. The voyage from Murmansk to Churchill is 8 days under good ice conditions, and from Churchill, rail links run through Manitoba, the American Midwest and points south all the way to Monterrey, Mexico. Murmansk is also the starting point of the once very active Northern Sea Route that stretches nearly 5600 kilometres to the rich nickel mines at Norilsk and to the newly established Arctic colonies at Dikson, Khatanga, Tiksi and Pevek before reaching the Bering Sea. Most importantly, the opening of Northern Sea Routes, either through the Siberian Arctic or the Northwest Passage in the Canadian Archipelago, would drastically shorten (40%) the transit of goods and raw materials between northeast Asia and Europe and between Northeast Asia and northeast North America.

By opening the poorly chartered waters of the coastal Arctic to shipping, lighter ice conditions and a longer ice-free season will drastically increase the risks of catastrophic oil spills and introduction of exotic species. Conditions for offshore oil and gas exploration and production will also improve, again increasing risks of spills. Oil pollution is particularly concerning as impacts on the low-diversity, low-resilience, vertebrate-dominated, arctic marine food web are essentially unknown (AMAP 1998). At about 40 900 m^3, the Exxon Valdez spill in sub-arctic Prince Williams Sound in 1989 ranked 54th by volume among the major oil spills surveyed in 1993. Yet, the remoteness of the impacted area complicated the cleaning operations and costs soared in the billions of dollars. The costs of mopping up a major spill in remote, ice-infested, and cold areas of the Canadian and Siberian Arctic are bound to be staggering.

Transport of toxic microalgae by ship ballast water increases the occurrence of paralytic, diarrheic, and amnesic poisoning of humans worldwide. The introduction of toxic microalgae in the Arctic is of particular concern since bivalves that concentrate the toxin are a common staple food of Northerners, and the toxicity of some common Atlantic species of algae (e.g. Alexandrium tamarense) reaches record levels at low temperatures.

The potential opening of the Northwest Passage is renewing challenges to Canadian sovereignty over the channels of the Arctic Archipelago. Canada has little choice but to re-affirm its right and duty to control navigation to limit the multiplication of the environmental disasters that are bound to occur in such treacherous waters. The costs of suitable navigational aids, charts, ports, satellite controls as well as pilot, ice-breaking and escort services in the remote Canadian Arctic will be large, but could generate major socio-economic opportunities, employment, and new capacity and expertise to Northerners.

Countries intend to defend their sovereignty in a region where expectations and cupidity are on the rise. Important litigations can be foreseen: for control of the sea as new strategic shipping routes open; for the exploitation of natural resources as prices of oil and gas increase; and as issues of environmental and national security develop with increasing traffic and new entry points to North America.

Climate and geophysical changes will liberate vast areas of ocean where oceanographic conditions have not yet been sampled, surveyed, documented, and modeled. The hydrodynamics, biogeochemistry and biology of these regions and their response to climate forcing are still largely unknown. In relation to the International Polar Year in 2007-2008, the European Commission highlights the following research priorities in polar regions: (i) world climate change; (ii) the Arctic Ice Cover Simulation Experiment (AICSEX) project, which has focused on the Arctic ice cap, its evolution and modeling; (iii) measurement of marine currents, temperature and salinity, carbon uptake, atmospheric circulation and pollution, as new data will be available from new ice free regions. Investigations in the Arctic Polar regions have a direct impact on the European Union and its citizens.

Justification and timing of the meeting. The above description of the transformation of the Arctic illustrates the urgency and magnitude of the challenge faced by the scientific community. This challenge amply justifies that scientists revisit the oceanography of the Arctic and sub-Arctic halfway through the International Polar Year (2007-2009). The NRARW is scheduled to take place in Liège immediately after the International Liege Colloquium on Ocean Dynamics. The Liège Colloquium is an annual open forum that attracts participants from all disciplines of oceanography (not only from Polar oceanography) and from all countries. The 40th Liège Colloquium will offer a tribune to the scientists of Arctic and Sub-arctic seas to present and compare state-of-the-art observations, models and forecasts and will be of general interest. The Advanced Research Workshop, on invitation only, will provide specialists the opportunity to collate and discuss their findings and expectations on the evolution of the Arctic/sub-arctic environmental and geopolitical situation. In particular, the ARW will bring together key players from several national and international Arctic research networks such as, for example, the Canadian ArcticNet (http://www.arcticnet-ulaval.ca/), the Norvegian ARCTOS (http://www.nfh.uit.no/arctos/), the Russian-USA NABOS (http://nabos.iarc.uaf.edu/) and the European DAMOCLES (http://www.damocles-eu.org/). We also expect, of course, a very strong participation from scientists involved in the International Polar Year. The penultimate goal of the ARW is to advance the development of pan-Arctic syntheses that will be of use to policy makers of the Arctic countries.

Organisational information:

The meeting is divided in two parts

(i) The 40th Liège Colloquium is organized aver three days (May 5-7) with key lectures, shorter communications and poster sessions – Participants are selected on the basis of an abstract submitted before December 2007. A registration fee of € 250 covers the costs of the inaugural reception on Monday 5, the official diner at the Château de Colonstère, the bus service from downtown hotels to the campus, the cost of publications of the proceedings (the papers presented at the Colloquium and/or the ARW will be published in a book by Springer and a special issue of JMS). The participants in the Colloquium are most welcome to participate in the ARW. There will be no additional registration fee for this participation.

(ii) The NATO –Russia ARW is organized over 2 ½ days (May 8-10) with invited key lectures and seminars with related short presentations, case studies analysis and discussions under invited chairpersons crosiers. Invited lecturers and chairpersons of the NATO ARW are heartily invited to attend both the Colloquium and the ARW (Actually, if they would prefer to address a larger audience and speak within the Colloquium, limiting their contribution to the ARW to chairing a seminar on their subject, this can be easily arranged). The registration fee to the Colloquium is not required for ARW invited lecturers and chairpersons.

NATO funds are available to reimburse the travel and living expenses of the ARW invited lecturers and chairpersons within the limits set by NATO i.e. travel by the shortest and most economic route and no extravagance in hotel booking. The invited lecturers who attend both the Colloquium and the ARW will receive a complementary subsidy for the extra nights.

NATO OTAN This workshop is supported by: The NATO Science for Peace and Security Programme