The International Polar Year
Circumpolar Flaw Lead (CFL) System Study

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Section 1. Project Description and Research Workplan

Introduction: The World expects confirmation of global warming first and strongest in the polar regions of our planet (IPCC, 2004, ACIA, 2005). Climate change has immediate implications for the sustainability of northern communities and the health and well-being of individuals and their economies. Creative responses based on sound research, shared knowledge and the engagement of people at all levels is required to meet this critical challenge. Technologically and scientifically advanced nations have a particular responsibility to understand the nature and impacts of these changes in order to prepare appropriate policies for adaptation. Observations indicate that the Arctic Ocean and its peripheral seas are presently warming. The extent of Arctic sea ice has shrunk at an average annual rate of over 70,000 km^2 per year since 1979 (Barber et al. 2005). Five of the minimum extent years have occurred since 1998, with 2005 being the minimum on instrumental record. The thickness of the multiyear ice has also decreased by about 40% over the past 30 years (Lui et al. 2004). Recent studies have documented variations in the Northern Annular Mode and associated surface atmospheric pressure fields (Thompson and Wallace 1998). The resulting strengthening of westerly winds has increased the influx of warm Atlantic water into the Arctic basin (e.g., Polyakov et al. 2005), has deflected eastward the freshwater plumes of the several large rivers, and has increased the export of sea ice through the transpolar drift (Kwok et al. 2002). The freshwater on the continental shelves normally forms a shield between the ice and the underlying warm Atlantic water. The eastward advection of this shield has allowed contact between the ice and the invading Atlantic waters enhancing sea-ice melt (Polyakov et al. 2005). In the Canada Basin, the Beaufort Sea Gyre also affects reduction of sea ice and formation of the circumpolar flaw lead (CFL). Recent results (Lukovich and Barber, 2005) show that the reversal of the Beaufort Gyre, triggered by increased cyclogenesis over the Canada Basin (Zhang et al. 2003), has increased in frequency since 1990, thereby affecting both sea-ice aerial extent and dynamics. The complexities of sea-ice response to changing oceanic and atmospheric forcing, and the subsequent response of the marine ecosystem to this change, are key motivating principals for the International Polar Year (IPY) and for this CFL system study.

The circumpolar flaw lead (CFL) is a perennial characteristic of the central Arctic. The Flaw Lead Polynya system is formed when the central pack (which is mobile) moves away from coastal fast ice, opening a flaw lead that occurs throughout the winter season. The flaw lead is circumpolar, with recurrent and interconnected polynyas forming in the Norwegian, Icelandic, North American and Siberian sectors of the circumpolar arctic (Barber and Massom, 2006). Due to a reduced ice cover these regions are exceedingly sensitive to physical forcing from both the atmosphere and ocean and provide a unique laboratory from which we can gain insights into the changing polar marine ecosystem. Oceanographically the high ice production in the flaw lead system contributes significantly to brine fluxes from the continental shelves into the deep basins (Martin et al. 1995). These fluxes drive biogeochemical fluxes on and off the continental shelves and control many aspects of gas and mass fluxes across the ocean-sea ice-atmosphere (OSA) interface. Meteorologically we expect the flaw lead system to play a central role in the steering of cyclones within the area; we also expect that the connection to the central pack portends a large scale teleconnection to hemispheric scale pressure patterns such as the Arctic Oscillation (e.g., Dmitrenko et al. 2005). Biologically the CFL preconditions the shelves to be productive portions of the marine ecosystem with the early availability of light and increased availability of nutrients through advection and upwelling at the shelf break. We expect ecosystem-wide enhancements to productivity in these areas, sustained for longer periods throughout the annual cycle. These expectations are supported by early use of the flaw lead by apex predators such as birds, beluga, bowhead and polar bears.

Study Area and Sampling Strategy: Although the CFL is hemispheric in scale, we propose to focus on the Canadian component near Banks Island, NT. The study area is typified by the recurrent thin ice/open water in the flaw lead and adjacent formation of fast ice > 150 cm in winter thickness. We discovered an ideal location for the CFL study while conducting the CASES program, as summarized in detail in 'Relationship to other funding' and Figure 1. Ice thickness (in the flaw lead) in the mid-winter ranges from open water to < 30 cm making this an ideal location to study physical-biological coupling. The field study would require the over-wintering of the NGCC *Amundsen* beginning in October, 2007, and continuing through July, 2008. Surveys of the flaw lead would be conducted as ice forms from the northern limit of the pack ice and from the landfast ice in the south. Details of the typical growth cycle are well known and have been published elsewhere (Barber and Hanesiak, 2004). The size of the study area would decrease as the ice encroaches on the flaw lead until January when the ship would enter into the landfast ice located immediately adjacent to the flaw lead, south of Banks Island (Figure 1). An ice camp would be established using the infrastructure of parcols, snow machines, snowcat, etc., from the *Amundsen* pool of equipment. Temporal measurements will be emphasized at the ice camp, while spatial measurements will be emphasized during the flaw lead sampling via the *Amundsen*. On regular intervals (montly to bi-weekly) we plan to take the *Amundsen* from her 'landfast harbour' and conduct a 1-2 day survey of the evolving flaw lead system. The extent of the survey would be determined by the extent of the flaw lead but is expected to range from 10,000 km^2 (January) to 80,000 km^2 (June). A corridor between the fast ice harbour and the flaw lead would be maintained by the icebreaker throughout the winter. A fuel barge would be moored near the flaw lead (e.g., in Summer Harbour) for refueling of the *Amundsen*. Once ponds form (likely in mid-June), the ice camp would be disassembled and the study would proceed with continuous sampling from the *Amundsen* to the end of July, 2008.

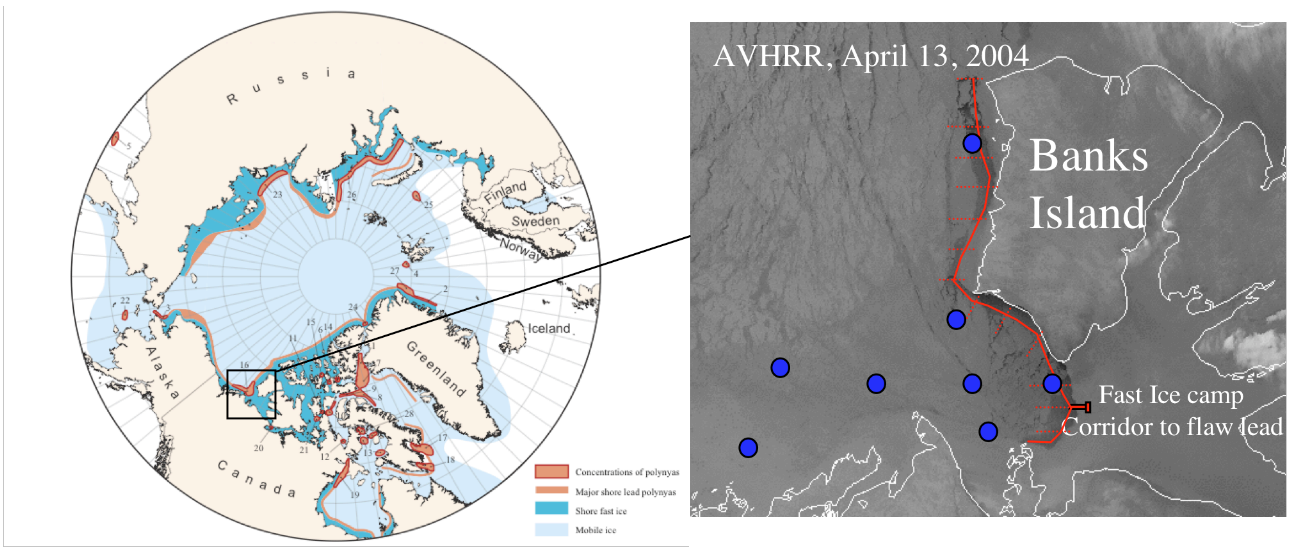

Figure 1. CFL study area showing the circumpolar flaw lead system (left), proposed sampling transects (line), location of the fast ice camp, and observatory locations (blue dots).

<u>**Science Objectives:**</u> We propose a study with three integrated components: a) a field study, b) an observatory, and c) a modeling study. This triumvirate will integrate a series of testable hypotheses designed to examine the importance of climate processes, which are changing the nature of the flaw lead system in the northern hemisphere, and the effect of these changes on marine ecosystem processes, contaminant transport, fluxes of nutrients and biogenic carbon, and exchange of greenhouses gases across the ocean-sea ice-atmosphere interface. The CFL project will contrast and compare the early opening (late closing) of the flaw lead area against that of the adjacent fast ice. This contrast will focus on the oceanic and atmospheric forcing of the ice cover in these two regions and describe how these physical processes moderate biogeochemical processes within the Arctic marine ecosystem. The science teams will collaborate on addressing a pair of interconnected hypotheses:

1) Climate variability/change affects the timing and extent of the flaw lead system through predictable oceanic and atmospheric forcing which will result in increased ecosystem productivity and carbon cycling.

2) Climate variability/change affects the adjacent fast ice ecosystem by controlling the timing of snow precipitation and formation/decay of sea ice which in turn dictates the contributions of sympagic versus pelagic production to carbon cycling.

The short term objectives of this project are to develop a unique dataset of the physical controls of marine ecosystem productivity in the circumpolar flaw lead, to use these data to improve physically based models of atmospheric, sea-ice and oceanic processes, and to develop improved modeling approaches to predict biophysical processes within the Arctic marine system. The long term objectives are to use these findings to affect policy decisions regarding ocean management, climate impacts and adaptation in this region of Canada's Arctic. Through connections within our Pan-AME full proposal to IPY we expect to describe the climate change impacts in this region relative to others in the circumpolar Artic. The findings expected from this research will have direct relevance to northern residents. A better understanding of the marine environment will assist hunters and trappers whose families rely on wildlife for subsistence and cultural survival. Those with extensive local knowledge of the environment in this region will be invited to help scientists verify and interpret findings and observations. Though it can be challenging to "translate" discrete scientific data and findings into common language, a key objective of this project is to develop the tools that will enable us to identify our shared interests early in the process, in preparation for sharing our strengths and knowledge for mutual understanding over the life of the study and beyond. We structure our work into ten multidisciplinary science teams. Each of these teams is led by a Canadian PI, with several other investigators collaborating within each team. We plan to support 40 graduate students from Canada and at least 40 from the 12 different foreign countries collaborating within the CFL. This makes the CFL project one of the largest Canadian projects ever conducted and a major proposal within the IPY.

Team 1: Physical Oceanography (Gratton)
Introduction: We will examine the physical processes responsible for water mass exchange and circulation between the flaw lead, the Canada Basin and the continental shelf. Selected research questions include: 1) what is the role of Mackenzie freshwater on ocean water mass circulation; 2) how do Pacific and Atlantic water masses move between the Canada Basin and shelf; and 3) what is the role of brine convection versus ice-edge upwelling and turbulent mixing in the flaw lead and the oceanic mixed layer? Answers to these questions are needed in order to develop more accurate predictive models for nutrient supply, sediment transport and overall biological productivity of the shelf. An understanding of the interaction of water masses within the flaw lead is particularly lacking for the winter months due to an absence of historical data.

Rationale: The basic surface circulation in the offshore region of the Beaufort Sea is dominated by the anticyclonic Beaufort Gyre (Coachman and Aagaard 1974). Below the surface waters, however, the flow reverses to cyclonic, forming the Beaufort Undercurrent (Aagaard 1984). This flow moves waters of both Pacific and Atlantic origin eastward along the continental margin (Coachman & Barnes, 1961) and provides an offshore source of nutrients to shelf waters (Macdonald et al. 1987). The oceanography of the shelf can be divided into four different periods. During winter when the sea is ice-covered, wind effects are diminished and density-driven flows due to brine release are possible (Melling and Lewis 1982). In the flaw lead, we can expect much enhanced ice formation, brine rejection and wind effects compared to the surrounding area. Break-up begins in spring (late April) in the Mackenzie River. Between mid-May and June, the river discharge peaks and latent heat from the river may advance ice melt by as much as two months on the shelf. During summer, inflows from the Mackenzie River dominate surface property distributions of the Mackenzie Shelf. Freeze-up begins in early to mid-October, but is affected by shelf pre-conditioning (Melling 1993). The summer ice melt and the wind dictate the balance of fresh and saltwater in the first meters of the water column. Of equal importance to biology on the shelf is the annual runoff cycle, because it supplies nutrients, sediments, and plankton; influences circulation; and modifies upper layer density stratification (an important control on primary production). Finally, preliminary CASES results from the same region suggest that tidal variability within the Neap-Spring cycle may have a major impact on the stability of the under-ice surface mixed layer.

Methods: Rosette measurements will provide biophysical variables every 3-12 h while the ship is stationary at the ice camp and while in transit within the flaw lead. A minimum of twelve 13-h hourly (or half-hourly, personnel permitting, to capture internal waves) sampling blitzes, i.e. two in each leg, will help us document the local Neap-Spring tidal variability. Ship-based profiling will be supplemented with moving vessel profiling (MVP) for salinity, temperature, fluorescence and dissolved oxygen to investigate the nature of fronts and regional scale structure associate with the flaw lead. The *Amundsen* will visit the flaw lead once each 7 days to conduct a survey throughout the expanse of ice that is < 30cm thick. This sampling will constitute 'first ever' ship-based measurements throughout the annual cycle in the flaw lead system. Mooring locations have been set as part of the ArcticNet and JWACS programs (Figure 1) and will be utilized in combination with historical data to investigate shelf basin exchange processes at both the flaw lead and ice camp sites. INRS-ETE has submitted a CFI proposal for a CTD-equipped AUV (Autonomous Underwater Vehicle), among other equipment. If funded, the AUV will be run under the ice from open water to obtain unique cross-self CTD sections. The role of turbulent mixing in the mixed layer will be assessed by collecting profiles of temperature microstructure at the ice camp and in the flaw lead with a *Self-Contained Autonomous Micro-Profiler* and/or shear measurements with a *Vertical Microstructure Profiler*. These profiles will provide estimates of the vertical turbulence heat fluxes, as well as the turbulent kinetic energy dissipation rate.

Team 2: Ocean-Sea Ice-Atmosphere Processes (Barber)

Abstract: Reductions in sea-ice concentration, aerial extent and thickness are very pronounced in the southern Beaufort Sea (Serreze et al. 2004). Team 2 will examine how the sea ice acts to moderate fluxes of mass, gas and energy across the ocean-sea ice-atmosphere (OSA) interface, and how these processes scale from the local to hemispheric over the annual cycle. Selected research questions include: 1) how does the early opening and thin ice of the flaw lead affect the ocean surface mixed layer and adjacent fast ice thermodynamics; 2) how is radiative exchange moderated by oceanic and atmospheric forcing of the flaw lead; and 3) how does the evolution of the flaw lead effect mass and energy exchange with the atmosphere and how far does the effect propagate vertically and horizontally?

Rationale: The circumpolar flaw lead is an excellent laboratory to study the scaling of oceanic and atmospheric forcing of sea ice. Recent results show that the circumpolar flaw lead responds to hemispheric forcing of the Beaufort Sea Gyre and the Transpolar drift (Dmitrenko et al. 2005; Lukovich and Barber, 2005). The circulation of the central arctic pack away from the landfast ice, over the continental shelves, occurs both along the North American and Siberian sectors of the Arctic (Carmack et al. 2006). This pattern means that the flaw lead system is, at least initially, forced by hemispheric pressure patterns and surface flow associated with teleconnections such as the Arctic Oscillation (AO). At the regional scale, cyclones gain energy over the flaw lead system and tend to 'steer' along these features. Momentum and moisture fluxes associated with these cyclones are a key determinant in how the snow/sea-ice system evolves thermodynamically and radiatively. A growing body of evidence indicates that the flaw lead responds to ocean heat fluxes upwelled at the shelf break. The nature of this upwelling also appears to be very sensitive to the location of ice edges relative to the shelf break (e.g., Carmack and Thompson, 2003). At the local scale the differences in ice thickness will control the temperature gradients and the associated proportions of brine in ice and ice in the snow/sea-ice matrix. This means that conductive, radiative and mass fluxes will be quite different between the flaw lead and adjacent fast ice.

Methods: Measurements at the landfast ice station will include automated weather stations collecting gas, mass and energy fluxes over the evolving fast ice surface (Papakyriakou et al. 2005). A meteorological program will examine vertical profiles of temperature, humidity and wind vectors with rawindsonde launches. Cloud radiative forcing will be measured with an all-sky camera, ceilometer and water vapour profiling with an atmospheric water vapour radiometer (Minnett et al. 2005). Temperature probes will be installed to collect gradients in temperature between the upper ocean, through the ice and snow, into the atmosphere. Microstructure properties for snow and sea ice will be extracted and processed aboard the *Amundsen* cold lab following the approaches of Barber et al. (1993). Snow distribution will be measured daily and variogram models fit to these distributions (Iacozza and Barber, 2001). Ship-based observations will duplicate the same suite of variables but will also include radiative exchange within the upper surface and measurements of surface hydrography driven by growth and decay of sea ice using a 6-m launch ('skippy boat') deployed from the *Amundsen*. The met station, CTD profiling (seabird 19+), and vertical estimates of optical extinction (profiling spectral radiometer) from the 'skippy boat' allow for detailed measurements of the surface mixed layer away from the influence of the *Amundsen*. An EM induction and Ground Penetration Radar (GPR) system will be used to estimate mass balance of sea ice across the fast ice, flaw lead, and offshore pack ice gradient throughout the annual cycle. This mass balance sampling will also include characteristics of ice surface roughness relative to snow catchment within the study area. A remote sensing program will use surface-based microwave radiometers (19, 37 and 89GHz), scatterometers (5.3 GHz, fully polarimetric), thermal infrared radiometers (9-11 μm), and hyperspectral optical radiometers (0.38-1.1 μm), operating at the ice camp and aboard the *Amundsen*, coupled with the climate station and geophysical properties to calibrate in situ measurements to various satellite system, including AMSR, SSM/I, Radarsat II, ENVISAT, MODIS, MERIS and ASTER. The remote sensing program will work closely with the Canadian Ice Service and NASA to validate/calibration the new Canadian Radarsat II system over a wide range of ice types and thermodynamic states.

Team 3: Light, Nutrients and Primary Production (Gosselin)

Abstract: Atmospheric, oceanic and hydrologic forcing of sea-ice extent will dictate the overall seasonal production of phytoplankton in the flaw lead and adjacent fast ice. Once the ice cover is removed, the timing of water column stabilization will determine the onset of the phytoplankton bloom, the duration of the biological production season and the final stage reached by phytoplankton succession. Selected research questions include: 1) how do the landfast and flaw lead regions differ in the timing and rates of primary production; 2) is the phytoplankton community composition and structure different between these two regions; and 3) is biological production in these regions limited by light and/or nutrients?

Rationale: Phytoplankton and ice algae are the main sources of primary production in coastal arctic waters (Horner and Schrader 1982). On the Canadian Shelf of the Beaufort Sea, the timing and intensity of the phytoplankton summer bloom are strongly affected by the dynamics of the sea ice and water column stratification (Arrigo and van Dijken 2004). Data collected during the CASES program on the Mackenzie Shelf–Franklin Bay region indicate that the phytoplankton abundance was low and chlorophyll *a* biomass near the limit of detection in winter, with unknown estimates for the flaw lead region. Nano- and picoflagellates (0.8- to 20-µm diameter cells) were the most abundant autotrophs in the water column along with some diatoms. Low cell numbers, low chlorophyll *a*, and weak primary production persisted until the ice break up in June. Algal cells were found in sea ice from the time it formed in the fall and were generally scattered throughout the ice layer, with microflagellates numerically dominant but diatoms making up the bulk of the biomass. In the spring, ice algae were represented mainly by pennate diatoms, which dominated in both number and biomass and were responsible for two-thirds of the total primary production, as previously reported in the nearshore regions of the western Beaufort Sea (Horner and Schrader 1982). Hsiao et al. (1977) studied the phytoplankton species composition, abundance, biomass and production from both open water and ice stations in the southern Beaufort Sea (69–71.2°N; 130–138.5°W) during three consecutive summers (July-August). Phytoplankton biomass and production generally decreased with increasing distance from shore and the Mackenzie River mouth. This pattern was attributed primarily to higher nutrient concentrations and warmer temperatures in coastal waters. On the Mackenzie Shelf, total primary production (P_T) and new production (P_{new}), the part of P_T fuelled by allochthonous nutrients (mainly NO_3), were estimated at 12 and 8 g C m^{-2} y^{-1}, respectively (Carmack et al. 2004). On the inner shelf, the dirty landfast ice and turbid surface waters limited primary production most of the year. On the outer shelf, reduced water turbidity and enhanced stratification by ice melt and solar heating favour microalgal growth from early spring to summer, depending on the timing of the opening of the flaw lead system (Arrigo and van Dijken 2004, Carmack et al. 2004). In years of early opening of the flaw lead, primary production could be limited by nutrient supply sooner in the season. This study will greatly improve our understanding of the processes controlling the timing, magnitude and composition of the phytoplankton bloom in the flaw lead polynya.

Methods: Team 3 will establish measurement programs both at the ice camp and aboard the *Amundsen* as it conducts surveys in the flaw lead. Core variables will include irradiance (spectral UV and PAR), nutrients (NO_3, NO_2, NH_4, PO_4, and $Si(OH)_4$, in collaboration with Team 7), and size-fractionated chlorophyll *a*. Nutrients and microalgal variables will be determined in the sea ice and at 7 optical depths over the euphotic zone (100, 50, 30, 15, 5, 1, and 0.1% of surface irradiance), 75 and 100 m, every additional 100-m intervals and 10 m above the bottom. Nutrients, chlorophyll *a* (chl *a*), and particulate organic carbon (POC) and nitrogen (PON) will be determined using the JGOFS Core Measurement Protocols (JGOFS 1996) with appropriate modifications. Production of POC and dissolved organic carbon (DOC) by microalgae will be estimated with the ^{14}C-assimilation method as described in Gosselin et al. (1997). All samples for the determination of chl *a* biomass and production will be size-fractionated at the 5-µm threshold (polycarbonate filters, post-incubation for rate measurements). Photosynthesis efficiency will be determined using pulse-amplitude-modulated (PAM) fluorescence methods (Kashino et al. 2002). In order to supply information for the estimation of primary production from remote sensing and for modeling purposes, photosynthesis vs. irradiance parameters (Babin et al. 1994), microalgal specific absorption (Tassan and Ferrari 2002), and inherent optical properties of the seawater and its dissolved organic material will be determined (NASA's Ocean Optics Protocols). The flow of organic matter through ice meiofauna will be determined using stable and radioactive isotope techniques. Cell enumeration will be done under an inverted microscope for large algae (> 5 µm, sedimented subsamples), and using an epifluorescence microscope for small cells (subsamples collected on black filters, mounted on a slide). The distinction between autotrophs and heterotrophs will be based on the fluorescence of autotrophic cells. Microscopic cell counts will be complemented by flow cytometry analyses that characterize particles according to their optical features (fluorescence and light scatter) and that is more efficient than microscopy for small cells, by high performance liquid chromatography (HPLC) analyses of algal pigments (Zapata et al. 2000), by tests of cell viability (Agustí and Sanchez 2002), by gas chromatographic analyses of highly branched isoprenoids, a specific tracer of some diatom genera (e.g., *Haslea* spp.; Belt et al. 2001), and by way of DNA community fingerprinting, clone libraries, fluorescence in situ hybridiszation and quantitative polymerase chain reaction to identify and estimate the abundance of small cryptic flagellates (Diez et al. 2001, Not et al. 2005, Zhu et al. 2005).

Team 4: Pelagic and Benthic Foodwebs (Fortier)

Abstract: By affecting primary production and zooplankton community structure and abundance, sea ice dynamics govern interannual variability in the trophic and vertical fluxes of carbon. We expect zooplankton assemblages and these fluxes to differ between the flaw lead and the adjacent fast ice, leading to differences in benthos. Pertinent research questions include: 1) How does pelagic-benthic coupling varies in and out of the CFL? 2) How do pelagic (0+) Arctic cod recruit to their ice habitat in the fall and winter? 3) What is the annual cycle of distribution of fish and marine mammals in the CFL region, including the shelf break? 4) Are the abundance and diversity of the epi- and endo-benthos superior in the flaw lead polynya compared to the rest of the shelf?

Rationale. The CASES program has revealed a surprisingly active zooplankton-fish-mammal community on the inner shelf during the fall and winter months. Cluster analysis and non-metric multidimensional scaling of the zooplankton collected during the fall 2002 indicate distinct assemblages on the Mackenzie Shelf-Franklin Bay region, the Cape Bathurst Polynya and the Beaufort Slope (Darnis et al. 2006). Copepods were the main indicator species contributing to the discrimination of the three assemblages. Station depth and the duration of <50% ice cover in summer explained the distribution of the different assemblages. *Pseudocalanus sp.*, the main indicator species and the staple prey of the early larval stages of Arctic cod, was positively correlated to the duration of reduced ice cover (<50%), suggesting the predominance of the herbivorous food chain in the flaw lead. *Cyclopina sp*., *Microcalanus pygmaeus* and other species indicators of the offshore assemblages and the microbial food web were negatively correlated to the same variable. The on-going analysis of the 2003 CASES collections will enable us to test that these ice-dynamics-dependent assemblages also exist in spring and summer. But a critical missing piece in the puzzle is the winter distribution of the zooplankton, Arctic cod and mammals on the Shelf and at the shelf slope. For the first time ever, the CFL study will allow us to characterize these winter distributions and the ontogenetic vertical migrations of key species in relation to the slope of the Arctic continental shelf. In particular, our ambitious plan to sample juvenile (0+) Arctic cod as they recruit into different sea-ice types will provide unique information on the transition from epipelagic to sympagic life. Combined with the information on the particulate fecal flux across the shelf collected by the long-term sediment trap program of ArcticNet, the CFL study will enable us to achieve a circum-annual synthesis of the role of copepods and appendicularians in the modulation of the vertical POC flux across the Arctic Shelf. The annual availability of fisheries resources (fish and marine mammals) in the CFL region will be assessed in close collaboration with local Inuit communities. The characterization of the benthic meiofauna and epifauna in the flaw lead and under the land-fast ice will allow us to measure the effect of the ice regime on pelagic-benthic coupling.

Methods: At the landfast ice station mesozooplankton, fish larvae and their prey will be sampled using the double net towed by the half-track (Drolet et al. 1991). On the ship, the 3-frequency EK60 echo-sounder will be permanently operated to describe the seasonal evolution of the bulk vertical distribution of zooplankton and fish over the region that will be patrolled at regular intervals for the 9-mo duration of the CFL study. The acoustic survey will be complemented by synoptic assessment of abundance and vertical distribution over the predetermined station grid using the Hydrobios multiple-net sampler deployed in all ice conditions through the moon pool of the ship. At ice-free stations, the abundance and vertical distribution of Arctic cod pelagic 0+ will be determined with the BIONESS multi-net sampler. Sympagic 0+ and older fish are regularly observed wiggling out of or washed on ice floes overturned by the icebreaker. The air-boat will be deployed in the wake of the ship to collect these animals and characterize the type of ice they are associated with. The passive acoustic hydrophones carried by the ArcticNet moorings record the vocalization of marine mammals and will provide background information on the frequentation of the area by the different species over an annual cycle. The seasonal evolution of the epibenthic and endobenthic faunas will be characterized over the sampling grid using the epibenthic sledge and the box-core respectively. The ROV deployed from the moon pool will provide images of the undisturbed epibenthic assemblages. Our team is also making significant progress in the numerical modeling of the response of the arctic shelf ecosystem to variability and change in sea ice dynamics. The proposed CFL work will contribute crucial missing information on (1) the offshore ecosystem; (2) the recruitment of Arctic cod juveniles to sea-ice; and (3) pelagic-benthic coupling.

Team 5: Marine Mammals and Sea Birds (Ferguson)

Abstract: Team 5 will study the use of the flaw lead by marine mammals to overwinter, with emphasis on predator-prey interrelations between polar bears and ringed seals. A special component of the proposed research is an investigation into the chronology of flaw lead development during the spring as sea ice ameliorates and primary production cascades into the life processes of migrant marine mammals and bird predators. Pertinent research questions include: 1) what is the importance of flaw leads to overwinter survival of polar bears, ringed seals, and bearded seals; 2) what are the predator-prey interrelations between polar bear-ringed seal relative to flaw lead icescape; and 3) what is the importance of flaw lead chronology of production to spring arrival and feeding by migrant marine mammals and sea birds?

Rationale: Climate change, including rapid and drastic alterations in temperature regimes, substantially alters Arctic habitats with cascading effects on marine predators influencing distribution, abundance, behaviour, and genetic exchange of nearly all biological life, especially marine mammals and birds (Stirling and Derocher 1993). Arctic marine mammals and birds with their life history, behaviour, and feeding timed with the cyclical nature of the polar environment are highly specialized or dependent on a specific set of resources at specific times of the year (Heide-Jorgensen and Laidre 2004). The Arctic is characterized by large annual changes in temperature, light, primary production, yet the most defining feature is sea-ice formation and recession (Smetacek and Nicol 2005). The two most profound features of sea ice are the consistency of seasonal coverage and the inconsistency of temporal and spatial variability (Ferguson and Messier 1996; Gagnon and Gough 2005). Annual sea ice is manifested in the form of fast ice (ice attached to the land without cracks) or pack ice (loose offshore ice) subject to wind and currents, with separation demarcated by a flaw lead. Thus, marine mammals and birds rely on flaw leads; the consistency or lack of consistency of these leads impacts directly on individual fitness with population consequences (Stirling and Cleator 1981). Depending on the species, the physical structure of the flaw lead and associated sea ice acts either as a substrate or a barrier for marine mammals and birds. Arctic pinnipeds (i.e. ringed and bearded seals) rely heavily on the ice surrounding flaw leads as a platform for hauling out, whelping, foraging, and moulting (Smith and Stirling 1975; Smith and Hammill 1981). Polar bears rely on the fast ice and moving ice associated with flaw leads for hunting and denning during inclement weather (Stirling et al. 1999; Ferguson et a. 2000). In the case of cetaceans, sea ice generally excludes them from polynyas and flaw lead areas they would otherwise use, thus physically reducing habitat (Moore et al. 2000). However, all arctic cetaceans are adapted, specifically selecting moving pack ice for feeding and predator avoidance.

Methods: Aerial surveys by helicopter will be conducted b-weekly over the duration of the field program and continual acoustic monitoring (located on the CFL Observatories) across the flaw lead to estimate abundance as well as predator-prey interactions (polar bear-seals). Survey results will be coupled with physical parameters such as ice type, ice concentration, and sea-surface temperature, as well as biological parameters such as chlorophyll, zooplankton, and ecosystem structure. During the spring break-up a concentrated study of the chronology of cascading events will be monitored with special emphasis on development of trophic cascades associated with top marine mammal and bird predators. Here, we will monitor for a number of key species' their life history processes that include fitness measures associated with survival and reproduction. Proposed research includes analysis of ringed and bearded seal samples from around the coastline of the eastern Beaufort Seas. Body condition and reproductive data from contemporary (1992-present and ongoing) and historical collections (1971-1979 and 1987-1989) in the Beaufort region will be re-analyzed and included as part of this component. Dedicated, additional sampling will be undertaken in the autumn offshore of Tuktoyaktuk as part of this IPY study, which will augment existing and ongoing sampling of harvested animals at Holman and Sachs Harbour. We also plan to deploy geographic positioning system (GPS) radiocollars on adult polar bear females in each of 3 years. Deployment will allow simultaneous integration of data across the entire study area. Adult females accompanied by yearlings will be targeted since they will return to the ice, mate in the following spring, and can be followed to breeding areas. This study will provide detailed information of movement on the sea ice, movement interactions with climate events, timing of movement onto and off of the sea ice relative to ice condition, sea-ice habitat selection using resource selection functions, and habitat selected for maternity denning. GPS collars, a proven technology, will be used to provide frequent, precise on-ice locations. Some 50-100 polar bears will be captured and sampled each year to provide specimens for isotopic signatures, genomics, and fatty acids. The information on polar bear movements will be integrated with the distribution and movement of prey species and the analyses of the sample specimens collected.

Team 6: Gas Fluxes (Papakyriakou)

Abstract: Team 6 will examine rates and patterns of air-surface exchange, primarily of carbon gases, within the CFL domain. Research questions include: 1) What are the rates and associated variability of gas exchange across the atmosphere-surface (sea ice and seawater) interface; 2) What are the most important controls on the fluxes; and 3) How are the gas fluxes linked with and sea ice and upper ocean ecological and physical processes; and 4) What are the ramifications of surface gas exchange for regional carbon cycling?

Rationale: The gaseous carbon cycles in polar waters are poorly known, particularly with regard to the role of sea ice. Limited observations of pCO2 in coastal Arctic waters, primarily from the North Water (Miller et al., 2002) and Northeast Water (Yager et al., 1995) studies, suggest that the surface waters in these areas are strongly undersaturated in the summer, thereby promoting large rates of CO2 uptake by the sea water – a factor of 4 greater than the global average for coastal oceans (Ducklow and McCallister, 2004). Annual net ecosystem exchange totals however assume a complete capping of the air-sea interface by sea ice, thereby dismissing outright the potential for atmospheric exchange between 4-6 months of the annual cycle. Further, in our budgeting, we do not consider the possibility that the Arctic coastal margins may house areas of significant heterotrophic production and release of CO2 associated with freshwater influx into the marine system (Borges, 2005). Recent direct measurements of the CO2 flux over sea ice using eddy correlation (Papakyriakou et al., 2004 and Semiletov et al., 2004) have shown that large amounts of CO2 are periodically exchanged between sea ice and the atmosphere, thereby discounting the sea ice capping hypothesis. Large downward fluxes have been observed during the winter and spring even when the surface waters below the ice are supersaturated, suggesting that the ice is not simply a passive conduit for gas, rather it is a site for processes actively driving the flux. These observations are supported by chamber measurements on both Arctic and Antarctic sea ice (Semiletov et al., 2004 and Delille et al., 2004). For each of the carbon species, causal relationships between the fluxes and sea ice (geophysics, chemistry and biology) have yet to be resolved. Fundamentally, we need to understand the nature of net ecosystem exchange of gaseous carbon during the ice-dominated period and to comprehend where in the ice the carbon is being stored, and in what form (abiotic vs. biotic). The role of sea ice in regional carbon budgeting will ultimately depend on whether or not the stored carbon is exported into the upper ocean upon ice melt, or immediately returned to the atmosphere

Methods: We propose an experimental program during both the mobile and ice camp phase of CFL. We will place an eddy covariance flux system for CO2 and gradient sampling arrays for both CO2 and CO on the bow of the ship to continually monitor vertical CO2 and CO fluxes over the open water and new and mature sea ice environments of the CFL domain. Micrometeorological flux measurements will be supported by chamber deployments using both an infrared gas analyzer and syringe sampling with subsequent concentration analysis (including CH4) by gas chromatograph. Bulk meteorology, the surface heat budget and on-track surface video will be monitored to place the gaseous carbon exchange in the context of surface ecological climatology. We will continuously monitor surface water pCO2, using an underway sensor mounted on the Amundsen's clean seawater supply, calibrated with discrete samples collected from the rosette. A separate flux tower will be deployed during the ice camp phase of the experiment, monitoring the evolution of the fluxes of heat and CO_2 at a place over the winter season and the spring to summer transition. Innovative techniques have been developed by members of our team to assess in-situ sea ice pCO_2 concentrations using surface and sack-hole chambers and silicone-based selectively permeable sampling tubes that will be frozen into growing ice. Static chambers will be sampled using both infrared gas analysers and syringes. This information will assist in the identification of the processes controlling the observed fluxes in the near surface atmospheric boundary layer. The gas measurements will be complemented by analyses of inorganic and organic carbon (alkalinity, total inorganic carbon, pH, pCO2, TOC, CO), and ecological parameters, including nitrogen, O2, and nutrients, productivity and accumulated biomass with other CFL teams from water samples and ice cores during the open-water and ice-dominated phases, respectively.

Team 7: Carbon and Nutrient Fluxes (Tremblay)

Abstract: Biogenic fluxes of carbon and nutrients in Arctic systems potentially determine the net effect of changing ice cover on food webs and the air-sea exchange of CO_2. The central objective of this team is to quantify and compare major fluxes over the annual cycle in the flaw lead and landfast ice regions. Research questions include: 1) what are the timing and magnitude of biogenic carbon and nutrient fluxes; 2) what are the roles of autotrophic and heterotrophic processes in the cycling of nutrients and carbon; and 3) what are the main pathways of carbon and nutrient flux? Team 7 will measure changes in the inorganic and organic pools of carbon and nutrients, stable isotopes, nutrient uptake, bacterial dynamics, and sinking fluxes and also estimate carbon demand by benthic fauna and the sediment. Complementary measurements by other teams will be synthesized and used to constrain budgets and pathways.

Rationale: The demise of sea ice is expected to bolster warming by decreasing the reflection of solar radiation into space and increasing the fugacity of oceanic CO_2. Concurrently, the greater penetration of sunlight and supply of nutrients by wind-driven upwelling and mixing in open waters should stimulate primary production, food web productivity and the vertical export of organic matter (Tremblay et al. 2006a). Vertical export fosters the storage of carbon in deep waters and the sediment, mitigating greenhouse warming (Feely et al. 2001). Assessing the net effect of these opposing responses requires a detailed investigation of elemental fluxes in relation to physical, chemical and biological processes in the CFL and under landfast ice. The pathways of carbon and nutrient flux should depend on the physical environment and the coupling between micro-algal production and heterotrophy (Michel et al. 1996). When grazing pressure is low, the direct sinking of ice algae, phytoplankton and aggregates are efficient routes to vertical export, promoting benthic production or the sequestration of C in the sediment. Pelagic herbivores contribute to vertical export when fast-sinking feces and housing material are released (Fortier et al. 1994; Wassmann 1998), but they essentially channel matter up the food web. This transfer promotes respiration, nutrient recycling, and leakage of dissolved inorganic carbon (DIC) (Tremblay et al. 2006b). These losses combine with lysis, microheterotrophy and bacterial respiration and hydrolysis of organic matter (Vetter and Deming 1994) to limit vertical fluxes, the efficiency of the biological CO_2 pump and the delivery of organic matter to the benthos (benthic-pelagic coupling) and the sediment.

Methods: The magnitude and stoichiometry of elemental fluxes and the mass balance between the different pools will be assessed by combining stock and rate measurements. Water-column measurements of the dissolved elemental pool will include the carbon system (DIC, alkalinity, pH and pCO_2), dissolved organic carbon (DOC) and nitrogen (DON) and the inorganic nutrients nitrate, nitrite, ammonium, phosphate and silicate (Grasshoff 1999). Changes in these elemental pools will be compared with measurements of gas flux, DIC photo-production and nitrogen uptake to assess new, regenerated and net production (Tremblay et al. 2002, idem 2006a). Nitrogen uptake will be estimated with the ^{15}N labelling method of Dugdale and Goering (1967) as modified by Tremblay et al. (2006b). Ancillary data on wind velocity, ice cover, currents and water mass provenances will be used to constrain forcing mechanisms. Particulates will be analyzed for biogenic silica (BSi; Ragueneau and Tréguer 1994), inorganic carbon (PIC) and particulate organic carbon (POC) and nitrogen (PON). Vertical fluxes will be estimated with the ^{234}Th method (Cochran et al. 1995), moored sediment traps and short-term traps (Knap et al. 1996) deployed in open water and under ice. Trap contents will be analysed for pigments, PIC, POC, PON and BSi. Large algal cells, zooplankton and faecal pellets will be enumerated and sized by microscopy. The stable isotopic C and N signature of sinking and suspended organic particulates will be used to determine their origin; i.e. river, bottom-ice or water column, growth conditions (e.g. nitrogen limited or not) and trophic position (Tremblay et al. 2006a). Carbon demand by the benthos and the sediment will be estimated with incubations (Grant et al. 2002). Microbial activity and extracellular enzymatic activity (Huston and Deming 2002) will be quantified in the ice, sinking material and at selected depths in the water column. Bacterial production and respiration will be measured using radioactive leucine incorporation (Smith and Azam 1992) and membrane-inlet mass spectroscopy (Kana et al 1994), respectively, to assess how the relative growth efficiency of the bacterial community changes over time and to estimate what fraction of the DOC pool fluxes through bacteria. Changes in the structure of the bacterial community will be investigated using the Biolog technique (Choi and Dobbs 1999). These changes are expected when the main source of C to the bacteria shifts from recycled materials to algal exudates.

Team 8: Contaminants and aquatic marine ecosystem health (Stern)

Abstract: Arctic contaminants are ubiquitous, having arrived from global pathways in the oceans and atmosphere. Team 8 research questions include: 1) how does climate variability influence carbon and contaminant cycling in the circumpolar flaw lead system; 2) what effects do ocean structure and changes in sea ice have on the contaminant levels of mercury (Hg) and halogenated organic contaminants (HOCs) in aquatic marine biota; 3) does the flaw lead system provide a mechanism by which mercury depletion events (MDEs) can contribute significant amounts of Hg to the aquatic Arctic marine environment and how might this process be affected by climate warming; 4) how does air-sea exchange of HOCs respond to changing ice cover; 5) what is the relative contribution of HOCs and Hg to the Arctic from long-range atmospheric transport versus local air-water exchange and atmospheric chemistry and how might this change as a result of varying atmospheric flow patterns and decreased ice cover; 6) have Hg levels and food web structure been influenced by climate variations over the last century; and 7) what effect will climate variation and potentially increasing contaminant levels have on the health of fish and marine mammal population?

Rationale: Within the Arctic, mercury has become a focus of international research following the discovery of MDEs (Schroeder 1998; Lu 2001), together with high Hg concentrations in upper trophic level species such as seals, whales and polar bears (Lockhart 2005). Although it is clear that photo-chemically mediated MDEs remove gaseous Hg from the bottom km of the atmosphere after polar sunrise (Steffen 2005) and deposit it to surfaces in a reactive biologically available form (Lindberg 2002), the mechanisms and conditions that cause these MDEs remain unknown, as does whether MDEs actually result in increased loadings of Hg to aquatic systems (Kirk 2004; Stern 2005). The initiation of this reaction is postulated to occur right at the open leads, a source of reactive halogens such as BrO^-. The observation of up to 4-fold increases of Hg over the last two decades in marine mammal tissues (Lockhart 2005) poses a question of enormous significance to human and ecological health. Even though global emissions of Hg have been decreasing in North Amercia and Europe (Pacyna 2002) and even though the Arctic atmosphere shows no recent increasing or decreasing trend in Hg levels (Steffen 2005), the increasing trends of Hg in marine mammals suggest that something has been changing in the Arctic biogeochemical cycle of Hg and/or in the food web structure that conveys Hg and carbon to upper trophic level species (Stern 2005). Certainly, MDEs as a recent or recently enhanced phenomenon offer one explanation, but there are likely others linked to climate change and the alteration of hydrology, organic carbon cycling, and marine ecosystem structure in the Arctic (e.g., Macdonald 2005). As for other trace gases, exchange of HOCs between air and surface water is an important loading mechanism limited by ice cover. For example, increased volatilization of a-hexachlorocyclohexane (a-HCH) from the central Archipelago coincided with ice melt in the summer (Jantunen et al., 2005). Detailed studies of HOC exchange during CFL will enable us to predict changes in loadings accompanying a climate-driven loss of Arctic ice. The proposed IPY project of INCATPA (International IPY Proposal no. 327) will be investigating the amount of pollutants entering the Arctic from the Pacific rim. Air-monitoring studies of HOCs and Hg during CFL will provide information with regard to input of pollutants from the ocean to the atmosphere. By comparing these two sources, we can determine the relative contribution of pollutants to the Arctic from long-range transport (LRT) versus local air-water exchange and atmospheric chemistry. Incorporating air measurements of HOCs and Hg conducted under CFL and INCATPA into three-dimensional atmospheric transport models, as proposed under the INCATPA project, will provide insights into how future changes in atmospheric flow patterns and ice coverage will affect pollutant input into the Arctic. Beluga brain tissues will be analyzed for Hg so as to determine whether neurochemical parameters in beluga whales of the western Arctic are correlated to the increasing exposure. The ultimate objective will be to evaluate whether contaminants are negatively affecting the neurological health of Arctic marine mammals. CFL will provide the opportunity to study these processes in association with a changing sea-ice regime on a global scale.

Methods: To conduct the mercury studies, we propose to make the following measurements for total and methyl mercury in: 1) near-surface air (reactive, total and Hg on particles); 2) snow and ice cores; 3) vertical ocean water profiles (dissolved and particulate); 4) suspended and bottom sediments; and 5) benthic and pelagic food webs. Water column measurements of $d^{18}O$, salinity, and nutrients will be made in an effort to couple physical and biological processes. In addition to Hg, most abiotic samples will be analyzed for HOCs such as organochlorine pesticides, PCB, brominated flame retardants and fluorinated organic compounds. Two approaches are used to characterize current beluga foraging behaviour and diet: 1) a spatio-temporal approach to determine feeding regions and migratory paths using satellite telemetry; and 2) a biochemical approach to quantify seasonal diet by comparing stable isotopes and fatty acid signatures in beluga soft tissues with potential prey items. Together these will provide the geographical and trophic related sources of contaminant uptake. The variation in neurochemical parameters of beluga will be determined through the analysis of receptor densities and enzyme concentrations in brains collected from harvested belugas. The exposure of belugas to contaminants will be quantified by analyzing tissue samples for Hg and HOCs. The effect of contaminants on beluga neurochemistry will be tested statistically to determine whether variation in neurological parameters is explained by contaminant exposure. Historical trends, with decadal precision, of total Hg concentrations and stable C and N isotopes dating from the 1880s to the present will be determined on the teeth and hair of seals, beluga and polar bear utilizing Amundsen Gulf; samples will be come from museum collections, archeological sites and present-day harvests. Air-sea exchange of HOCs, focusing on HCHs, chlordanes, endosulfans and toxaphene, will be examined from paired measurements in air and surface water. Chemical signatures (proportions of isomers and enantiomers) will be employed to distinguish sea-derived compounds from those delivered through background air. Estimation of HOC fluxes should be possible by making use of the flux information for CO and CO_2 (Team 6). Continuous, weekly air measurements of persistent organic compounds (PCBs, organochlorines, brominated flame retardants and polycyclic aromatic hydrocarbons [PAHs]) will be conducted at the ice camp to generate data comparable to air-monitoring activities operated under INCATPA and long-term air-monitoring programs, such as the Arctic Monitoring and Assessment Programme (AMAP). Simultaneous air sampling of HOCs and Hg in the flaw lead and at Point Barrow, Alaska (INCATPA), Little Fox Lake, Yukon (INCATPA, AMAP), Whistler, British Columbia, and Alert, Nunavut (AMAP), coupled with measurements at source regions on the Pacific-rim (INCATPA), will allow for the characterization of localized air-water exchange/atmospheric chemistry at the flaw lead and long-range atmospheric input from source regions. Data from CFL will be used to support modeling efforts proposed under INCATPA to examine the potential influence of climate change on pollutant input into the Arctic.

Team 9: Modelling (Hanesiak)

Abstract: Polar science must evolve from an observation-centric, process studies oriented science, to one where models can realistically predict future conditions. Of particular relevance here is the continued development of 3-D ocean-sea ice-atmosphere models, regional climate models and coupled physical-biological models. Team 9 will utilize climate and biophysical state variables collected during the CFL project to validate model prediction of various ocean, sea-ice and atmospheric states over the seasonal evolution. Ecosystem measurements will be used to constrain biophysical models of the system with a particular emphasis on biogeochemical cycling and carbon cycling within the evolving circum-Arctic flaw lead system.

Rationale: The modelling team will organize around spatial and temporal scales as a structuring element for their work. Three scales will be investigated, each containing elements of both physical and biological modeling. The synoptic scale will focus attention on the hemispheric forcing of sea-ice dynamic and thermodynamic processes and estimate water circulation both in the deep basin and in exchanges between the Pacific, Arctic and Atlantic water masses. Part of the atmospheric analysis will focus on large scale teleconnections such as the Artic Oscillation (AO) and Pacific Decadal Oscillation (PDO) and on how these teleconnections affect ocean-sea ice-atmosphere processes at the synoptic scale. Biological models at the synoptic scale will focus on nutrient and light availability as a function of ocean circulation and sea-ice dynamics. At the regional scale the emphasis will be on detailed translation of biophysical, climate and ocean processes into a coupled biophysical model that can be tested with observational data. The team will examine aspects of eddy propagation along the shelf break regions of the flaw lead and study tracers of freshwater from the Mackenzie plume relative to observations from the *Amundsen* (Maslowski et al. 1999). Meteorologically, the team will model cyclonic systems and strong pressure gradient flows that can mix the upper layer of the ocean and affect the distribution of sea ice either through dynamical or thermodynamic processes. Blowing snow will be examined through regional 3-D and 1-D modeling and compared with process studies being conducted at the fast ice camp at the edge of the flaw lead. Clouds and estimation of cloud radiative forcing will also be modeled and validated with surface observations. The local scale will examine boundary layer processes and the complexities of both horizontal and vertical gradients. For example, a very strong surface control operates between areas of open water and adjacent fast ice edges. The boundary layer processes governing energy and mass exchange are driven by this surface heterogeneity. At this scale the team intends to use a one-dimensional column model with a principal focus on mass, gas and energy exchange over the heterogeneous domain of the flaw lead and adjacent fast ice.

Methods: The modeling team brings a series of well-developed models to the CFL study. The synoptic scale modeling will use the Naval Postgraduate School models (Maslowski et al. 2005). A high resolution version of the model (9 km) will be tested. Results suggest that a significant portion of the eddy kinetic energy field is accounted for in this model; in many regions it is 5-10 times greater than that simulated in the 18-km version (Zhang et al., 1999). In order to compare the modeled and actual eddy kinetic energy fields in the region quantitatively, obtaining field measurements at high spatial resolution, especially for ADCP and CTD data, is important. The team will also incorporate 3-4 numerical tracers to track pathways and modification of major arctic water masses (i.e. Pacific and Atlantic Water, river runoff, and meltwater). Regional atmospheric modelling will focus on the use of WRF and GEM-LAM models at the University of Manitoba. Testing of the regional models will rely upon near real-time radiosonde launches from the *Amundsen* and data from the climate stations both aboard the *Amundsen* and at the adjacent landfast ice camp. The models will be used to examine surface forcing in the region, particularly the representation of cyclogenesis and advection of cyclones passing through the region as well as boundary layer processes. Local scale models will focus principally on a new physical-biological coupled model being developed at Université Laval to examine forcing of the marine ecosystem. This model downscales a physical ocean-sea ice-atmosphere model and links it to a NPZD model and an individually based model (IBM) of the early life of Arctic cod. At the local scale the team will also use a 1-D blowing snow model (Dery and Yau, 1999) to examine blowing snow processes and a thermodynamic snow/sea-ice model (Hanesiak et al. 2001) that has been coupled to a radiative transfer model and sub-ice primary production model (Mundy et al. 2005).

Team 10: Traditional Knowledge (Smith/Meakin)

Abstract: Team 10 will build on an already established collaborative network including Inuvialuit management bodies, the Inuvialuit Settlement Region (ISR) communities, national Inuit organizations (ICC and ITK), and the science teams of the CFL. The Inuit Circumpolar Conference (Duane Smith, President) will take the lead of Team 10. The overarching goal of this Team will be to fully implement the notion of 'Two Ways of Knowing'. This concept seeks to integrate Traditional Knowledge held by members of the ISR with that of western science, held by the science teams of the CFL. Team 10 will conduct a number of activities to realize this 'Two ways of Knowing' philosophy: 1) Conducting a detailed Traditional Knowledge (TK) study in the communities surrounding the CFL study area (e.g., Holman, Paulatuk, Sachs and Tuk); 2) Leading the ICC Climate Change Impacts and Adaptation workshop held aboard the *Amundsen*; 3) working with the ongoing Community Based Monitoring (CBM) program; and 4) Providing guidance for the Circum-Arctic Inuit Youth 'Schools on Board' outreach program and participating in the other elements of the CFL outreach plan (e.g., media symposium, mentoring program, etc).

Rationale: Previous research within the Inuvialuit Settlement Region has shown that Inuvialuit are already experiencing the impacts of climate change, and they have much to contribute to our knowledge of its impacts on their culture and environment. A Traditional Knowledge (TK) study will be used to document Inuvialuit cultural knowledge and use of the sea ice (cultural icescape) and observations related to climate change. Team 10 will work with Inuvialuit to document their knowledge of the sea ice and the factors affecting sea ice change. The team will also examine aspects of how change in the sea ice affect marine resources and how

Inuvialuit will adapt or are adapting to such changes (resiliency). Examples of end products from the project include interview transcripts, a booklet on Inuvialuit terminology, a detailed report on the project written as a dissertation, education units for local schools, a non-technical report for the communities, and a book for Inuvialuit, scientists and general public that provides a comprehensive view of Inuvialuit knowledge and use of sea ice, climate change and adaptations for this region.

A community based monitoring (CBM) program will be used to engage communities within the research process. Given the vast geographic extent and sparse population of Canada's arctic, community based monitoring will of necessity be a long-term component of ecosystem based management in these regions. There is a regional need to develop expertise in applying this work in a cost-effective manner, in the often-inhospitable arctic environment, over an extended period of time. While the additional funding available under IPY is important to this work, even more important is the opportunity to collaborate and brainstorm with the dozens of other scientists who will be focusing on that same geographic area of interest. The ICC Climate Change Conference (held aboard the *Amundsen*) will also be managed through team 10. This conference will provide an opportunity for Inuit leaders to converge at the CFL study site, aboard the NGCC *Amundsen*, to explore evidence, impacts and adaptations to climate change following our philosophy of 'Two Ways of Knowing'. Team 10 will also participate in the Schools on Board programming, particularly within the Inuit-Youth program.

Methods: The objectives of the TK project are to work with Inuvialuit to document their knowledge of: a) the traditional uses of sea ice (e.g. hunting and fishing places, names areas, stories, travel routes); b) the physical nature of sea ice (e.g. seasonal formation, duration, degradation, types of ice); c) the factors affecting sea ice (e.g. climate, currents, tides); d) changes in the sea ice; e) how changes have affected them (more/fewer animals, problems with travel on the ice); and f) how Inuvialuit have coped with such changes in the past and present (i.e. resiliency). The project will take place in two communities, given budget and time limitations. The Inuvialuit Game Council (IGC) will help in the selection of which two communities are selected. During the initial community consultation tours we will work with the communities to see what structure they would like put in place to help guide the process, such as an advisory or steering committee. We will also work with them to develop a research protocol. Semi-directed interviews will be used to document knowledge of sea ice both in the communities and during multi-day trips to the sea ice. Interviews on the sea ice are essential to learning about it first hand and being able to take photographs of what is being discussed. The photographs can also serve as interview prompts during subsequent interviews, and can be used in the terminology list so that a word can be linked with an image. A terminology workshop will take place at the beginning of the project so that a list of Inuvialuktun words related to sea ice and climate change will be developed. This is essential for establishing a common frame of reference between Inuvialuit knowledge holders and both Inuvialuit and non-Inuvialuit research staff. Scientists from other CFL teams will participate in aspects of the traditional knowledge study such as helping to develop research questions and participating in interviews. Having the scientists and traditional knowledge holders work together will help build a bridge to enhanced communication.

The TK study is innovative in integrating an extensive amount of information from Inuvialuit archival oral histories that were collected from the 1950s to the early 1980s. The oral histories will provide; historical information on Inuvialuit observations and use of the sea ice, information used in developing interview questions, and for documenting relevant Inuvialuktun words for the terminology list (Hart and Amos 2004). An archival oral history working group is needed as most of the recordings contain a significant amount of old language no longer in common use and is therefore difficult to translate. A working group will be able to review the oral histories to clarify the meanings of many of the old words in Inuvialuktun, and to explain the context for their use. This allows us to be comfortable in adding those words and their definitions to the terminology list developed for the project. A training program for students will be developed to help participants begin to develop understanding of how research questions can be addressed through the use of traditional and scientific knowledge and the archival record. At least one trainee from each community will be involved in the entire process of doing the traditional knowledge research, including the development of a research protocol, doing background research, interviewing, working with interpreters and translators, and writing up results. They will participate in CFL team meetings in Winnipeg, and will also conduct archival research at the Northwest Territories Archives. They will work with a scientist to learn how scientific research is done. They will learn how to present the information gathered from the overall project by helping to develop educational units that can be used in local schools. The Prince of Wales Northern Heritage Centre, Government of the Northwest Territories is allowing CFL traditional knowledge staff to revise the training manual *Getting Started in Oral Traditions Research* (Hart 1995) for use with Inuvialuit students.

Section 2. Competence of Investigators and Collaborators

CFL Science Personnel: The Circumpolar Flaw Lead (CFL) system study marshals a significant subsector of Canada's capacity in polar marine science, integrates this national science expertise with international collaborators, and engages our northern partners in a focused large-scale IPY project meeting Canada's commitments to stewardship of our north. CFL has 53 co-applicants who come from 12 different universities, 4 regional departments, 4 DFO laboratories, Environment Canada (EC) and Natural Resources Canada (NRCAN). We also have 44 collaborators coming from 12 different countries (Russia, USA, France, Denmark, Germany, Poland, Japan, Spain, Norway, Belgium, UK and Sweden). These countries have developed reciprocal agreements with Canadian CFL team members to conduct research on programs funded through their national granting councils and together these teams make up the Pan-Arctic Marine Ecosystem (Pan-AME) full proposal of the international IPY (see IPY letters of endorsement). The CFL program builds upon, yet is distinct from, previous successful Canadian-led international research networks such as the North Open Water (NOW), the Canadian Arctic Shelf Exchange Study (CASES), the Joint Western Arctic Climate Study (JWACS), ArcticNet, the Western Arctic Community Based Monitoring Program (CBM), and international projects such as the Nansen and Amundsen Basin Observational Study (NABOS), the North East Water (NEW) study, the Surface Heat and Energy Balance of the Arctic (SHEBA), and the CABANERA project in Norway. We know of several other applications to the federal IPY program with a desire to partner with the CFL project. Additional teams can be accommodated aboard the *Amundsen* given the increased capacity that the ice camp brings to the CFL project (e.g., we have capacity for 40 science berths aboard the *Amundsen* and 10-15 in the ice camp for each 6-week leg of the CFL study).

Integration of the Research. The overarching framework for the CFL study is the concept of 'Two Ways of Knowing'. We first explored this relationship with ISR hunters, government and academic researchers at a workshop in Winnipeg in 2002 and have been working towards the type of large scale, highly integrated study as CFL ever since. The power of the concept is the recognition that Traditional Knowledge (TK) and Scientific Knowledge (SK) can be integrated to provide a more holistic representation of how the Arctic marine system will respond to climate change. The novelty of the CFL program lies within the highly integrated nature of this interdisciplinary approach to polar marine science, the excellence and track record of the research teams (see CV's), and the extensive partnerships between universities, government, northern peoples and the international science community. If funded, the CFL project will deliver an unprecedented level of detail on the physical and biological processes governing an important part of our Canadian Arctic marine system. It will be the first time ever that a research icebreaker has been able to conduct this level of detailed science anywhere within the circum-Arctic flaw lead system! Although we expect to see an enhanced functioning of the marine ecosystem, we need to understand the mechanisms and details through which this occurs. Given the current trend in arctic warming and concomitant reduction in sea ice, it is reasonable to suggest that the flaw lead serves as a bell-weather for near-future conditions. We will address this hypothesis as a contribution to the Canadian IPY initiative. The baseline data that will be collected will be the first ever for both the flaw lead and the adjacent fast ice region (since the fast ice camp will be within 1 km of the flaw lead). The project is also an evolution of almost two decades of multidisciplinary polar oceanography that culminated in the creation of the NGCC *Amundsen* as a new Canadian Research Icebreaker. The integration of the research occurs through the logistics of the CFL program. We bring together 97 scientists from around the world to study for each 42-day period (or leg) proposed as part of the CFL project. The ship sampling plan is conducted around a series of short, basic and full sampling station stops where data are collected by each of the science teams at the same location. This strategy means that physical measurements from the bottom of the ocean to the top of the atmosphere are co-located in space and time with biological measurements of all elements of the marine ecosystem. We integrate northerners into the scientific process by having members from the Inuvialuit Game Council (IGC) or designates from the community aboard the *Amundsen* during this period. These Inuvialuit provide assistance in sampling, guidance to science teams in areas where they have expertise, and a strong connection to traditional views through informal meetings with students and staff during the CFL program. The CFL Scientists also participate in the TK studies by accompanying team 10 researchers on community visits and participatory research programs. This approach to marine science has resulted in a significant improvement in our ability to study the Arctic marine ecosystem as a coupled physical-biological 'system'. The *Amundsen* is truly the Canadian 'jewel' of polar science as it provides the research integration required for a program of this scope and magnitude to occur. The *Amundsen*, along with the international science teams and indigenous participants, can and will deliver on innovations and explorations of this unique part of our Canadian High Arctic.

Excellence of Researchers: The CFL teams are led by Canadian University, Federal Government, or northern aboriginal leaders who each have proven track records in polar marine science (see personal data forms). The senior members of this group have led similar successful network expeditions in the North East Water (NEW), North Open Water (NOW), the Canadian Arctic Shelf Exchange Study (CASES), and the Joint Western Arctic Climate Study (JWACS), with some now involved in leadership roles within ArcticNet. This lineage of projects is testament to our ability to realize the scientific and field logistics of a project of this scope and magnitude and to deliver a significant international project to the Canadian IPY efforts. Professor Barber has extensive leadership experience in large interdisciplinary polar studies, with over 25 years of Arctic experience; thanks to his Canada Research Chair, he also has the available time and resources to manage a project of this stature. The Canadian co-lead of the CFL project is Dr. Gary Stern (Fisheries and Oceans Canada), who has over 20 years of experience working on the contaminants of Arctic Systems. Dr. Jody Deming is our international co-lead. She also has extensive experience managing large international research programs and continues to chair (since 2000) the International Arctic Polynya Program (IAPP) of the Arctic Ocean Science Board (AOSB). Each of the CFL team leads is an expert in his/her own areas of expertise and have well in excess of 100 years of collective experience in conducting Arctic System Science studies such as the CFL. The TK study will be lead by Ms. Elisa Hart, who has 15 years of experience working with the Inuvialuit cultural community in the ISR region. We have a healthy mix of young and established researchers with a very large cohort of students marshalled to contribute to the next generation of Arctic Marine System scientists.

Collaborators: Foreign collaborators have responded with a very strong showing to our call for participation in the CFL study (44 members from 12 countries). Some of these international partners have previous experience with our network approach by participating in either NEW, NOW, JWACS or CASES, while still others have heard of these opportunities and are joining our team for the first time. We have strong representation from a number of international countries that will come self-funded. We have also budgeted to bring 10 senior Russian scientists and 10 junior scientists to the Canadian Arctic to participate in the CFL project. The Otto-Schmidt laboratory in St. Petersburg has agreed to coordinate applications from Russia and to work with us in selecting a subset of the proposals to work in CFL (see letter of support). If funded by Canada this Russian team will dramatically improve our ties across the pole making for a truly circumpolar flaw lead study.

Why fund this proposal: We have lost over 2 million square kilometres of multiyear sea ice and at this rate we can expect a seasonally ice free arctic around 2050 (Barber et al. 2005). The thought that this condition (no sea ice in the summer) has not occurred on the planet Earth for at least 1 million years, is indeed cause for concern! Ecosystems are unable to adapt this quickly and the fate of temperate and tropical parts of our planet follow undoubtedly follow this bell-weather of change. Parts of this proposal were written (Sept'06) while aboard the *Kapitan Dranitsyn* (a Russian Icebreaker) travelling between northern Norway and the Laptev Sea (Siberian Arctic) collaborating with colleagues on the NABOS project. We transited well over two-thirds of the northern sea route encountering no ice; in fact, the ship had to travel several hundred kilometres north of the coast to find the remnants of the central pack. Having rounded the globe so quickly, we were struck by just how real is the concept of using the northern sea routes (i.e., NW and NE passages). The time is rapidly approaching when what was historically a dream of early European explorers will be a reality. For this, and all of the associated ecosystem, geopolitical and sovereignty reasons, the Government of Canada should be taking its responsibility to understand our northern regions with continued resolve. The circumpolar flaw lead (CFL) proposal brings together a pre-eminent team of polar scientists, merges them with a strong international cohort of collaborators, and integrates these teams fully with our northern peoples. The infrastructure required to undertake this challenging scientific adventure already exists thanks to recent investments by Canada (i.e., the NGCC *Amundsen* and her pool of scientific equipment). Canada has also produced the intellectual capital by investing in the university and government researchers required for CFL to be a success. The CFL team has the people, infrastructure, drive and experience required to make this proposal a resounding success. Our team is committed to leaving our science as a legacy of Canada's emerging prominence in polar marine science and integration of Traditional Knowledge, so that we are prepared when the world will routinely ply our northern waters.

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