SCIENCE SCREENING COMMITTEE

In order to increase the transparency of its logistics support allocation process, the Polar Continental Shelf Project (PCSP) Advisory Board, at its fall meeting in 1992, approved the creation of a Scientific Screening Committee. It comprises university-based researchers from across the country. Members represent the major scientific disciplines and have extensive experience in the Arctic, as well as a solid knowledge of PCSP's operations. Membership is based on a three-year rotation.

In setting up the Committee it was made clear that:

> *"PCSP will never be able to base its decisions regarding support exclusively on the scientific merits of the various projects. Unavoidably, logistics considerations will have to be taken into account. We do recognize the need for a review of applications for support particularly for those initiated from outside of Canadian government departments. The scientific screening system will ensure that applications are reviewed fairly and equitably; it will also make the review-of-applications process more transparent for all users."*

In addition to the *Application for Logistics Support (Form 11)*: applicants from Canadian universities and non-Canadian and non-government organizations must **also** complete the ***"Application for Support: University-based, Non-Canadian or Independent Researcher(s)"***; applicants undertaking traditional knowledge programs must also complete the ***"Application for Support: Traditional Knowledge Program"***.

Only the information provided in these latter two forms will be used by the Scientific Screening Committee to review applications and make its recommendations on whether PCSP should consider support to these projects.

Evaluation Criteria:

The committee's evaluation is based on:

- the clarity of the project's objectives and its feasibility
- the applicant(s)'s scientific productivity based on the record of publications for the past five years, and,
- in the case of university programs, the involvement of students. The Committee may consult other scientists if required.

The recommendations of the Scientific Screening Committee are submitted to the Director of Polar Shelf. These recommendations are an essential part of allocation decisions in which scientific merit is considered, along with resource availability and ultimately logistics feasibility.

A summary of comments by the Scientific Screening Committee is sent in writing to each affected applicant after the Committee has deliberated and PCSP has completed its planning for the year.

Project: _________
(for PCSP use only)

2007 - APPLICATION FOR SUPPORT
UNIVERSITY-BASED, NON-CANADIAN OR INDEPENDENT RESEARCHER(S)

POLAR CONTINENTAL SHELF PROJECT
615 Booth Street, Room 487
Ottawa, Ontario K1A 0E9
Tel: (613) 947-1650 Fax: (613) 947-1611

Note: Please use min. 10 point font - handwritten copies will not be accepted.

This application is for a: collaborative project □ or individual project □ (Please check one)

(Those involved in integrated projects with a number of collaborators are encouraged to submit a group collaborative application.)

Project Title: **THE DYNAMIC RESPONSE OF ARCTIC GLACIERS TO GLOBAL WARMING: A CANADIAN CONTRIBUTION TO INTERNATIONAL POLAR YEAR PROJECT *GLACIODYN* (IPY 30)**

Principal Investigator (if graduate student, clearly identify supervisor and provide supervisor's CV): **Martin Sharp**
Status of Principal Investigator (professor [indicate status: assistant, full, associate, adjunct], graduate student, independent): **Full Professor and Chair**

University/Agency: **Alberta** Department**: Earth and Atmospheric Sciences**

Protection of health and safety of personnel: Please complete Appendix 1 attached

Project Support : Please list all annual grants and scholarships, or other in-kind or financial support **(*no acronyms please*)**

Source:	**NSERC IPY Special Research Opportunity**	Pending □	**Granted X**
	U.Alberta, Faculty of Science Chair's Support Funds	Pending □	**Granted X**

Others involved in the project (attach list if necessary):

Name: **Jeff Kavanaugh** Affiliation: **University of Alberta**
Name: **Luke Copland** Affiliation: **University of Ottawa**
Name: **Lev Tarasov** Affiliation: **Memorial University of Newfoundland**
Name: **Sarah Boon** Affiliation: **University of Northern British Columbia**

Students involved in the project (doctorate, masters, undergrad):

Name:	Year*	Degree/Date of completion**
Faye Wyatt (Alberta)	**1**	**M.Sc 2008**
Christine Dow (Alberta)	**1**	**M.Sc. 2008**
Tyler Sylvestre (U.Ottawa)	**0**	**M.Sc 2009**
Student Assistant (UNBC)		
Student Assistant (MUN)		

Anticipated dates of field work:____

* Indicate which year in the project the upcoming field season would be, e.g., 1st of 2 or, 3rd of 3.
**Indicate degree student is seeking and year of completion.

Publications: * Indicates PCSP supported work; Bold indicates student author

Please provide year of PhD or academic appointment, along with a list of your peer-reviewed publications and those of any members of your project (the most recent publications first) **for the past 5 years only**. (Please indicate PCSP project number(s) where applicable.) A maximum of **one page per person** is allowed for group applications. Only **one page** will be accepted for applications from individuals.

Martin Sharp: Full Professor, Appointed 1993.

*__D.Burgess__. 2006. Ice Dynamics and Recent Geometric Changes of the Devon Island Ice Cap, Nunavut, Canada. Ph.D thesis, University of Alberta.

*__L.Wang.__ 2006. Satellite Remote Sensing of Snow Cover and Snowmelt in the Arctic. Ph.D thesis. University of Alberta

*S.Marshall, M.J.Sharp, **D.O. Burgess**, and **F.Anslow**. Surface temperature lapse rate variability on the Prince of Wales Icefield, Ellesmere Island, Canada: Implications for regional-scale downscaling of temperature. *International Journal of Climatology.* Accepted July 4, 2006.

*__R.G.Bingham__, P.W.Nienow, M.J.Sharp and **L.Copland**. 2006. Hydrology and dynamics of a polythermal (mostly cold) High Arctic glacier. *Earth Surface Processes and Landforms* **31**:1463-1479.

*__M.Bhatia__, M.Sharp and J.M.Foght. 2006. Distinct bacterial communities exist beneath a high Arctic polythermal glacier. *Applied and Environmental Microbiology* **72**, 5838-5845.

*__J.Barker__, M.Sharp, S. Fitzsimons and R.J.Turner. 2006. Organic carbon abundance and dynamics in glacier systems. *Arctic, Antarctic and Alpine Research* **38***,* 163-172.

*__D.Burgess,__ M. Sharp, D.Mair, J.Dowdeswell and T.Benham.2005. Flow dynamics and iceberg calving rates of the Devon Ice Cap, Nunavut, Canada. *Journal of Glaciology* **51**, 219-230.

*__R.G.Bingham__, P.W.Nienow, M.Sharp and **S.Boon**. 2005. Subglacial drainage processes at a High-Arctic polythermal valley glacier. *Journal of Glaciology* **51**, 15-24.

*__L. Wang,__ M. Sharp, B. Rivard, S.J. Marshall, and **D. Burgess**. 2005. Melt Season Duration on Canadian Arctic Ice Caps, 2000-2004. *Geophysical Research Letters* **32**, L19502, doi:10.1029/2005GL023962.

*__M. Skidmore__, S.P. Anderson, M. Sharp, J.M. Foght, and B. Lanoil. 2005. Comparison of microbial community composition in two subglacial environments reveals a possible role for microbes in chemical weathering processes. *Applied and Environmental Microbiology* **71**, 6986-6997.

M. Lafreniere and M. Sharp. 2005. A comparison of solute fluxes and sources from glacial and nonglacial catchments over contrasting melt seasons. *Hydrological Processes* **19,** 2991-3012**.**

L.Wang, M.Sharp, R.Brown, C.Derksen and B.Rivard. 2005. Evaluation of spring snow-covered area depletion in the Canadian Arctic from NOAA snow charts. *Remote Sensing of Environment* **95**, 453-463.

*V. St.Louis, M.Sharp and 8 others **(including 3 students)**. 2005. Some Sources and Sinks of Monomethyl and Inorganic Mercury on Ellesmere Island in the Canadian High Arctic. *Env. Sci.Tech.* **39**, 2686-2701.

*__M.Skidmore,__ M. Sharp and M.Tranter. 2004. Fractionation of carbon isotopes during the weathering of carbonates in glaciated catchments: implications for detection of microbial CO_2: I. Kinetic effects during the initial phases of dissolution in laboratory experiments. *Geochimica et Cosmochimica Acta* **68**, 4309–4317.

*__D. Burgess,__ and M.Sharp. 2004. Recent changes in areal extent of the Devon Island Ice Cap, Nunavut, Canada. *Arctic, Antarctic and Alpine Research* **36**, 261-271.

*J.A. Dowdeswell, T.J. Benham, M.R. Gorman, **D. Burgess,** and M. Sharp**.** 2004. Form and flow of the Devon Island Ice Cap, Canadian Arctic. *Journal of Geophysical Research, Earth Surface***,** 109**,** F02002, doi:10.1029/2003JF000095.

*__L.Copland__, M.Sharp, P.Nienow and **R.Bingham**. 2003. The distribution of basal motion beneath a high Arctic polythermal glacier. *Journal of Glaciology* **49,** 407-414.

*__L.Copland,__ M.Sharp, and P.Nienow. 2003. Links between short-term velocity variations and the subglacial hydrology of a polythermal glacier. *Journal of Glaciology* **49**, 337-348.

*__R.Bingham,__ P.Nienow, and M.Sharp. 2003. Intra-annual and intra-seasonal flow dynamics of a high Arctic polythermal valley glacier**.** *Annals of Glaciology* **37**, 181-188.

*__S. Boon__ and M.Sharp. 2003. The role of hydrologically-driven ice fracture in drainage system evolution on an Arctic glacier. *Geophysical Research Letters* **30,** doi:10.1029/2003GL018034. (4pp)

*__L.Copland,__ M.Sharp, and J.Dowdeswell. 2003. The distribution and flow characteristics of surge-type glaciers in the Canadian high Arctic. *Annals of Glaciology* **36**, 73-81.

*__S.Boon__, M.Sharp and P.Nienow. 2003. Impact of an extreme melt event on the runoff and hydrology of a high Arctic glacier**.** *Hydrological Processes* **17**, 1051-1072**.**

*M.Sharp, **M.Skidmore**, and P.Nienow. 2002. Seasonal and spatial variations in the chemistry of a high Arctic supraglacial snowcover. *Journal of Glaciology* **48,** 149-158.

*__L.Copland__ and M.Sharp. 2001. Mapping thermal and hydrological conditions beneath a polythermal glacier using radio echo sounding. *Journal of Glaciology* **47**, 232-242.

Jeff Kavanaugh: Assistant Professor, Appointed 2005

Kavanaugh, J. L. and G. K. C. Clarke. 2006. Discrimination of the flow law for subglacial sediment using in situ measurements and an interpretation model. *Journal of Geophysical Research*, *Earth Surface*, 111, F01002, doi:10.1029/2005JF000346.

Kavanaugh, J. L. and K. M. Cuffey. 2003. Space and time variation of $\delta^{18}O$ and δD in Antarctic precipitation revisited. *Global Biogeochemical Cycles*, 17(1), 1017, doi:10.1029/2002GB001910.

Kavanaugh, J. L. and K. M. Cuffey. 2002. Generalized view of source-region effects on δD and deuterium excess of ice sheet precipitation. *Annals of Glaciology*, 35, 111-117.

Kavanaugh, J. L. and G. K. C. Clarke. 2001. Abrupt glacier motion and reorganization of basal shear stress following the establishment of a connected drainage system. *Journal of Glaciology*, 47(158), 472-480.

Kavanaugh, J. L. and G. K. C. Clarke. 2000. Evidence for extreme pressure pulses in the subglacial water system. *Journal of Glaciology*, 46(153), 206-212.

Luke Copland: Ph.D 2001 Assistant Professor, Appointed 2006

Glasser, N., Goodsell, B., **Copland, L**. and Lawson, W. 2006. Debris characteristics and ice-shelf dynamics in the ablation region of the McMurdo Ice Shelf, Antarctica. *Journal of Glaciology*, **52**(177), 223-234.

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Bishop, M.P., Olsenholler, J.A, Shroder, J.F., Barry, R.G., Raup, B.H., Bush, A., Copland, L**.**, Dwyer, J.L., Fountain, A.G., Haeberli, W., Kaab, A., Paul, F., Hall, D.K., Kargel, J.S., Molnia, B., Trabant, D. and Wessels, R. 2004. Global Land-Ice Measurements from Space (GLIMS): remote sensing and GIS investigations of the Earth's cryosphere. *Geocarto International*, **19**(2), 57-84.

***Copland, L**., Sharp, M. and Dowdeswell, J. 2003. The distribution and flow characteristics of surge-type glaciers in the Canadian High Arctic. *Annals of Glaciology*, **36**, 73-81.

***Copland, L.**, Sharp, M., Nienow, P. and **Bingham, R.** 2003. The distribution of basal motion beneath a High Arctic polythermal glacier. *Journal of Glaciology*, **49**(166), 407-414.

***Copland, L.**, Sharp, M. and Nienow, P. 2003. Links between short-term velocity variations and the subglacial hydrology of a predominantly cold polythermal glacier. *Journal of Glaciology*, **49**(166), 337-348.

*Sharp, M., **Copland, L.**, **Filbert, K., Burgess, D.** and **Williamson, S.** 2003. Recent changes in the extent and volume of Canadian Arctic glaciers. *Glaciological Data Report GD-32, Papers and Recommendations: Snow Watch 2002 Workshop and Workshop on Assessing Global Glacier Recession*. National Snow and Ice Data Center, Boulder, USA, p. 73-75.

***Copland, L.** and Sharp, M. 2001. Mapping thermal and hydrological conditions beneath a polythermal glacier with radio-echo sounding. *Journal of Glaciology*, **47**(157), 232-242.

Gordon, S., Sharp, M., Hubbard, B., Willis, I., Smart, C., **Copland, L.**, Harbor, J., and Ketterling, B. 2001. Borehole drainage and its implications for the investigation of glacier hydrology: experiences from Haut Glacier d'Arolla, Switzerland. *Hydrological Processes*, **15**, 797-813.

Kieffer, H., Kargel, J., Barry, R., Bindschadler, R., Bishop, M., Mckinnon, D., Ohmura, A., Raup, B., Antoninetti, M., Bamber, J., Braun, M., Brown, I., Cohen, D., Copland, L., DueHagen, J., Engeset, R., Fitzharris, B., Fujita, K., Haeberli, W., Hagen, J.O., Hall, D., Hoelzle, M., Johansson, M., Kaab, A., Koenig, M., Konobalov, V., Maisch, M., Paul, F., Rau, F., Reeh, N., Rignot, E., Rivera, A., Wildt, M., Scambos, T., Schaper, J., Scharfen, G., Shroder, J., Solomina, O., Thompson, D., van der Veen, K., Wohlleben, T. and Young, N. 2000. New eyes in the sky measure glaciers and ice sheets. *Eos*, *Transactions, American Geophysical Union*, **81**(24), 265 & 270-271.

Shroder, J., Bishop, M., Copland, L. and Sloan, V. 2000. Debris-covered glaciers and rock glaciers in the Nanga Parbat Himalaya, Pakistan. *Geografiska Annaler*, **82A**, 17-31.

***Copland, L.** and Sharp, M. 2000. Radio-echo sounding determination of polythermal glacier hydrology. In: *Eighth International Conference on Ground Penetrating Radar*. Noon, D., Stickley, G.F., Longstaff, D. (eds.). SPIE Vol. **4084**, 59-64.

Sarah Boon, Ph.D 2005; Assistant Professor, Appointed 2005

*Bingham, R.G.; Nienow, P.W.; Sharp, M.J.; **Boon, S.** 2005. Subglacial drainage processes at a High-Arctic polythermal valley glacier. *Journal of Glaciology* 51(172): 15-24.

***Boon, S.** and M. Sharp. 2003. The role of hydrologically-driven ice fracture in drainage system evolution on an Arctic glacier. *Geophysical Research Letters* **30**(18), DOI: 10.1029/2003GL018034.

***Boon, S.**; Sharp, M.J.; Nienow, P.W. 2003. Impact of an extreme melt event on the hydrology and runoff of a high Arctic glacier. *Hydrological Processes* **17**(6): 1051-1072.

Lev Tarasov: Assistant Professor and Canada Research Chair (Tier 2), Appointed 2007

W. R. Peltier, L. Tarasov, G. Vettoretti and L. P. Solheim. In press. Climate Dynamics in Deep Time: Modelling the "Snowball Bifurcation" and Assessing the Plausibility of its Occurrence, in *Multidisciplinary Studies Exploring Extreme Proterozoic Environmental Conditions*, American Geophysical Union.

L. Tarasov and W. R. Peltier. 2006. A calibrated deglacial drainage chronology for the North American continent: Evidence of an Arctic trigger for the Younger Dryas. *Quaternary Science Reviews* **25**, 659-688.

L. Tarasov and W.R. Peltier. 2005. Arctic freshwater forcing of the Younger Dryas cold reversal. *Nature* **435**, 662-665.

L. Tarasov and W.R. Peltier. 2004. A geophysically constrained large ensemble analysis of the deglacial history of the North American ice sheet complex. *Quaternary Science Reviews* **23**, 359-388.

L. Tarasov and W.R. Peltier. 2003. Greenland glacial history, borehole constraints and Eemian extent, *Journal of Geophysical Research* **108** (B3), 2124-2143.

L. Tarasov and W.R. Peltier. 2002. Greenland glacial history and local geodynamic consequences. *Geophysical Journal International* **150**, 198-229.

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S.J. Marshall, L. Tarasov, G.K.C. Clarke and W.R. Peltier. 2000. Glaciology of Ice Age cycles: Physical processes and modelling challenges. *Canadian Journal of Earth Sciences* **37**, 769-793.

Payne, A. J. and 10 others. 2000. Results from the EISMINT model intercomparison: the effects of thermomechanical coupling. *Journal of Glaciology* **46**, 227-238.

Scientific Discipline:

Biological □ **Earth Sciences X** Physical/Atmospheric □ Social/Human □ Environment □ Other □

Theme: **Glaciology**

Project Description: *(min. 10 point font)*

Use this and the next page **only** to provide a succinct project description that gives reviewers a meaningful overview of your research project. Please identify the research problem, the project objectives, and methods. Please also identify where graduate students will be involved. **If support was given in a previous year for this project, the description must include a progress report of results achieved to date.** Group projects may use up to one additional page for each principal investigator (maximum of three additional pages).

Note: Extra space used as project has 5 investigators. New project so no progress report included.

Background

The committee will note that I have submitted two applications for PCSP support this year. This application is for a new project funded by the NSERC IPY Special Research Opportunity, while the other is for my ongoing research program on thickness changes of the Devon Island ice cap. Since 4 students have already embarked upon research projects under the umbrella of the latter project, it is critical that the decision about whether or not PCSP should support the IPY project should not affect the ability of these students to complete their programs. Hence, I have submitted separate applications for the 2 projects, even though some work on the Belcher Glacier is envisaged in both applications. I should explain that while I did submit a budget for PCSP logistic support as part of my application to the NSERC IPY program, NSERC provided no funds for this purpose even though they funded the rest of the project in full.

Introduction

IPY 30 (Glaciodyn) is led by Professors J.Oerlemans (Utrecht) and J-O Hagen (Oslo), and promoted by the International Arctic Science Committee (IASC) Working Group on Arctic Glaciology. It's goal is to investigate the role of ice dynamics in the response of Arctic glaciers and ice caps to global warming, with a view to improving our ability to predict future changes and their impact on global sea level and fluxes of fresh water to the ocean. To arrive at more accurate predictions, IPY Glaciodyn proposes to study the dynamics of Arctic glaciers and develop new tools to deal with their dynamic response. The inclusion of ice dynamics in predictive models would represent a significant advance over what was done in the Arctic Climate Impact Assessment (ACIA), where a simple approach was taken to estimate the runoff from all glaciers in the Arctic for a set of climate-change scenarios. Changes in the surface mass balance were calculated without dealing with the fact that glacier geometries will change as climate warms. It was also assumed that the rate of iceberg production at calving fronts would not change. Within *Glaciodyn*, special attention will be given to tidewater glaciers, which lose significant mass by iceberg calving. The goal is to look carefully at the interaction between surface processes and dynamics (e.g. the influence of meltwater supply on ice velocities and consequently calving rates). In a warming world the thermal regimes of some glaciers will transform from cold to polythermal, or from polythermal to temperate. It is proposed to study the effect of such transitions on glacier dynamics and rates of adjustment of glacier geometry. *Model development* will be conducted in parallel with the observational programs. Modelling will deal with processes acting on both the smaller scale (e.g. parameterization of the calving process) and the larger scale (e.g. global dynamics of tidewater glaciers, response to climate change).

The Canadian contribution to *Glaciodyn* will focus on the Belcher Glacier drainage basin in the northeast sector of the Devon Island ice cap, Nunavut. **One motivation for this initiative is to engage the Canadian glaciological community in a common effort to tackle a major problem in Arctic Glaciology**. The project will involve an intensive field and remote sensing study of the mass balance, hydrology and dynamics of the glacier, linked to the development and validation of a state of the art, high order coupled model of ice flow dynamics and glacier hydrology. The scientific goal is to develop and validate a high-resolution thermo-mechanically coupled mass balance-hydrology-dynamics model that will be used to investigate the dynamics of the Belcher Glacier under current conditions and to explore its likely response to future climate change scenarios. Through the experiments proposed, we will evaluate the impact of changes in hydrology, ice flow dynamics, and calving rates on the rate and magnitude of the glacier's response to climate forcing. The field and remote sensing investigations that we propose will allow us to constrain the 3-D geometry of the glacier, estimate the time-space evolution of surface meltwater production and runoff across the glacier surface and into the glacier, characterize the surface velocity and strain rate fields and their temporal variability at high spatial resolution, and quantify the mass loss by iceberg calving and its temporal variability. Through modeling, we will be able to explore the force balance of the glacier, its variation over time, and its simulated evolution in response to climate warming. This study will be a major contribution to the work of *Glaciodyn*, providing a new state of the art model and characterization of the dynamics and evolution of a system at the cold end of the spectrum of Arctic glacier systems. The modelling will be a joint venture between **Lev Tarasov** (whole ice cap modeling and tidewater calving dynamics), **Shawn Marshall** (Calgary; nested higher order model of outlet glacier dynamics) and **Gwenn Flowers** (Simon Fraser University; glacier hydrological model to be coupled to the model of outlet glacier dynamics). Neither Marshall nor Flowers will be involved in the proposed fieldwork, but the fieldwork is critical to the success of the modeling effort. Remote Sensing studies will be conducted in the labs of **Martin Sharp** and **Luke Copland**.

The Belcher Glacier is the largest and fastest flowing (up to 300 m yr^{-1}) outlet of the ice cap, and it terminates in about 300m of tidewater. Flow stripes on the glacier surface suggest that flow is largely by basal sliding and/or bed deformation. Over the past 40 years, the glacier terminus has retreated by nearly 3 km, and the glacier has thinned along almost it's entire length at rates that are too high to attribute to changes in surface mass balance alone – so changes in flow dynamics are probably implicated in these changes. The glacier may be susceptible to hydrologically driven velocity variations, as it has a well-developed surface drainage system that includes major channels that are connected to both supraglacial and ice-marginal lakes and which sink into crevasse fields. The glacier bed lies below sea level in the lower 11 km of the glacier and reaches 400m below sea level in an over-deepened basin located 2-5.5 km from the terminus. Belcher Glacier accounts for approximately half the iceberg calving loss from the ice cap (~15% of the total mass loss) and its bed topography suggests that it's terminus region could become unstable in the event of further retreat. It is thus well suited for a targeted field, remote sensing, and model-based investigation of the coupling between surface mass balance, glacier hydrology, ice flow dynamics, and iceberg calving.

Model data requirements and integration with other project elements

The modeling requires data to constrain the glacier's geometry, velocity, and surface mass balance. Present-day surface and bed topography are first-order controls on ice and water flow. Centreline surface elevation profiles (from photogrammetry and airborne radar/laser surveys) already exist for the Belcher Glacier. Some information about ice thicknesses along the glacier centreline and across its terminus is available from airborne radar soundings by J Dowdeswell (2000) and W. Krabill (2006). Detailed mapping of the sea floor topography in front of the glacier was conducted during the 2006 cruise of the RCGS Amundsen. More extensive surveys of the surface and bed topography of the Belcher system will be conducted in 2007 and 2008 (**Kavanaugh and Dow (M.Sc)**), including cross-flow profiles and profiles across tributary junctions, which will be necessary in order to extend the modeling to two-and three-dimensions and for constraining upstream and tributary ice-flux boundary conditions. Surface velocities will be measured in the field and using remote sensing methods, which will provide an opportunity for both point- and large-scale comparisons between modeled and observed flow structure (**Sharp, Kavanaugh, Copland)**. Direct observations of iceberg calving mechanisms, iceberg characteristics, and calving rates will guide the development of a model of calving dynamics (**Tarasov).** Accumulation patterns will be constrained by snow pit surveys, 1GHz radar surveys and shallow (20 m) firn cores (**Copland and Sylvestre (M.Sc), Sharp**). Field investigations of surface melt and hydrology will be linked directly to the modelling of ice dynamics and englacial/subglacial hydrology **(Boon, Sharp, Wyatt (M.Sc))**. Results from these surveys will be used both to guide the model development (in choosing which processes to represent) and to evaluate model performance.

Radio-echo sounding of Belcher Glacier (Kavanaugh, Dow (M.Sc))

Measurements of ice thickness and surface elevation will be obtained in order to constrain the models of Belcher Glacier. Ice thickness and surface elevation data will be gathered by snowmobile-based ice-penetrating radar (IPR) and GPS surveys. Data will be recorded along a large number of transects, which will be oriented both parallel (1-3 transects at a given flow line distance) and transverse to flow (15-20 transects). In addition, transects will be measured across each tributary where it joins the Belcher Glacier. Ice thickness measurements will be obtained with the UHF ice-penetrating radar system developed by *Narod and Clarke*, which was specifically designed to sound the small polar glaciers and ice caps found in the Canadian Arctic. A single, compact (1.18 m long x 0.59 m wide x 0.30 high) antenna is used for both transmitting and receiving, resulting in a system that can be transported by Komatiq sled. Because this antenna is strongly directional, valley-wall echoes will be much reduced in comparison with VHF IPR systems. Ice sounding locations and surface elevation values will be determined using geodetic-quality Trimble R7 GPS receivers. Sub-decimeter positional accuracy of the radar soundings should be possible with this system. The ice thickness and surface elevation datasets obtained will be interpolated to develop digital elevation models (DEMs) of the Belcher Glacier surface and basal topographies. In addition, radar data will be used to determine the thermal and hydrological conditions at the bed of the glacier using residual bed reflection power techniques.

Surface velocity measurements on the Belcher Glacier (Sharp, Copland, Kavanaugh)

Field measurements of surface velocity will be made using 3 approaches: (i) Annual and seasonal mean velocities will be measured using static differential GPS for stakes on profiles across the main glacier and its major tributaries; (ii) high frequency measurements of horizontal and vertical velocities will be made using at least 6 geodetic grade GPS receivers at sites located up and down glacier from major water input points and in the region near the glacier terminus where tidal forcing may be significant. These measurements will allow us to identify any uplift events associated with meltwater penetration to the glacier bed and tidal signals; (iii) A wireless network of 15 GPS receivers will be established along the length of the glacier to provide high resolution, year-round measurements of surface velocities. This project was initiated in 2006 by **M.Sc student Brad Danielson.** It was planned independently of the IPY project and will go ahead regardless of whether or not PCSP can support the IPY project. The GPS velocity measurements will be used to: (i) derive the annually averaged surface velocity field along the glacier centreline; (ii) identify the time scales on which glacier velocity varies in different sections of the glacier; (iii) determine where short-term velocity events are initiated and whether/how they propagate in space; (iv) determine the relationship between velocity events, locations where surface meltwater enters the glacier, and the drainage of ice-marginal and supraglacial lakes; and (v) resolve the interactions between velocity responses to different (e.g. hydrological/tidal) forcings.

Calving Dynamics (Tarasov + Student)

Iceberg-calving analyses and model development will require seasonal measurements of calved ice-fluxes and sea-ice extent, seasonal marine temperature profiles near the calving margin, tidal range measurements, near margin bathymetry mapping, and measurements of crevasse density and depth at the marine terminus. We will use time-lapse photography to monitor the timing of major calving events and evaluate the sizes of bergs produced in each event. This will create the opportunity to explore linkages between variations in glacier velocity and iceberg calving events. The photography will provide information about sea ice abundance in front of the glacier, but we will supplement this with satellite observations (EnviSat ASAR Global Monitoring Mode (GMM)). We will install a pressure transducer in the fjord in front of the glacier to monitor tidal fluctuations in water level at the glacier surface. We obtained initial vertical temperature, salinity, and current profiles from the Belcher Glacier terminus during the 2006 cruise of the Amundsen and hope to repeat those in 2007 using a Zodiac. We will use a helicopter to access the terminal regions of the glacier to obtain video imagery of the crevassing in this area and to make local measurements of crevasse depth. We will obtain 4 sets of high resolution stereo *Ikonos* imagery of the terminus region in 2007 and 2008 to allow characterization of crevasse characteristics and crevasse development, determination of a detailed velocity field for this region using feature tracking techniques, and derivation of a high resolution digital elevation model for this section of the glacier that will not be readily accessible on the ground.

Surface Mass Balance and Runoff Generation (Boon, Sharp, Copland + Wyatt (M.Sc), Sylvestre (M.Sc) and 1 student)

For time-dependent simulations, the coupled hydrology-dynamics model will require modelling of the surface mass balance, which is a major driver of changes in glacier geometry. The mass balance model will also compute the magnitude and distribution of runoff production on the glacier under summer conditions, which is a critical input for the hydrology component of the model and for testing the hypothesis that changes in the rate of delivery of surface water to the glacier bed can result in major changes in the flow dynamics of the glacier. We therefore need to collect field data that can be used to drive and validate a mass balance model. Since long-term simulations will use output from climate reanalyses (such as ERA 40), or regional climate models, we also need to investigate how to downscale model output (temperature and precipitation) to the complex topography of the Belcher Glacier.

A surface mass balance model typically simulates 3 distinct processes: snow accumulation, surface melt, and internal refreezing. Accumulation can sometimes be specified from field measurements, but for longer-term simulations this is not possible. Climate model/reanalysis precipitation output is available at very coarse spatial resolution and has to be downscaled to the domain of the glacier model. This requires knowledge of the spatial pattern of snow accumulation across the glacier (which will be obtained from snow pits and 1 GHz radar surveys; **Copland and Sylvestre (M.Sc)**) and the relationship between modeled precipitation and the mean accumulation across the entire glacier. If these things are known then model outputs can be expressed as anomalies relative to a longer term mean and downscaling can be performed by calculating an anomaly in the glacier mean accumulation and local deviations from this mean. We plan to use both temperature index and energy balance models to simulate the melt component of mass balance. This requires the installation of two automatic weather stations on the glacier that will make a full suite of energy balance measurements and an array of Hobo air temperature loggers (mounted on GPS stakes) that will allow us to determine vertical lapse rates in surface air temperature and their temporal variability (**Sharp**). Ability to predict these lapse rates as a function of season and a parameter that can be easily obtained from climate model output (such as local 500 hPa geopotential height) is critical to successful downscaling of model-derived temperatures to the glacier domain. Previous work on Prince of Wales Icefield, Ellesmere Island, suggests that this approach has the potential to be successful. Internal freezing will be simulated using both physically based models and simple parameterizations of the fraction of surface melt that refreezes.

Validation of model output will require stake-based measurements of surface melt, the changing density of residual snow cover, and the evolving temperature distribution within the snow and firn (**Boon**). QuikScat scatterometer data and EnviSat GMM data allow determination of the daily occurrence of surface melt across the ice cap and will be used to assess whether the model is predicting an appropriate spatial distribution of melt on a given day. Time-lapse cameras will be established to monitor the migration of the summer snowline, providing another means of validating model performance. Shallow ice cores will be used to measure the long-term mean net accumulation above the equilibrium line of the glacier. 20-m ice cores will be retrieved from sites along an elevation gradient above the equilibrium line (**Sharp**). All core sections will be weighed and measured in order to determine a density profile for each site. In situ ^{137}Cs gamma spectrometry will be used to detect the depth of the 1963 "bomb layer" (produced by the fallout from atmospheric thermonuclear weapons testing) in the boreholes from which each core was recovered. The mean net annual accumulation rate at each site will then be determined from the mass accumulated since 1963 (kg), the core cross-section (m^2) and the time elapsed since 1963 (yrs).

Mass balance models will simulate the production of surface runoff in each grid cell as the difference between surface melt and internal freezing at each time step. For the purposes of the hydrological model, this runoff needs to be routed across the glacier surface until it either leaves the glacier at its sides or terminus or penetrates the glacier interior via crevasses or moulins. The potential for storage in supraglacial or ice marginal lakes also needs to be considered, as such lakes are clearly visible on images of Belcher Glacier. We will use 1960 aerial photography and 1999 Landsat7 imagery to compile detailed maps of the surface drainage system of Belcher Glacier, highlighting major streams, lakes, and points where water appears to drain into the glacier. We will also map crevasse patterns so that we can explore the relationship between crevasse formation and the pattern of velocity and strain rates within the glacier (**Wyatt, M.Sc)**. It will be necessary to understand this relationship if we are to predict where crevasses will form during time-dependent simulations of the glacier and thus continually update the location of points where water can enter the glacier. We will use time-lapse photography to monitor the filling and drainage of supraglacial and ice marginal lakes. In addition, we will identify three major streams that sink into the glacier and monitor discharge through them using pressure transducers and a stage-discharge relationship developed using dye dilution techniques (**Boon**). This will allow us to validate model simulations of runoff inputs to the englacial drainage system.

I declare that this project will be carried out within the requirements of my institution and within environmental and ethical regulations.

Signature: ____________________________ Date: ____________________

APPENDIX 1

Protection of Health and Safety of Personnel

a) Who will be in the field (for the duration) and in charge of the field camp for this project this year?

Name: **At least one of Martin Sharp, Jeff Kavanaugh, Luke Copland or Sarah Boon will be in the field at any time**.

Affiliation: **University of Alberta (Sharp, Kavanaugh), Ottawa Copland), UNBC (Boon)**

Academic Level (must be at minimum 2nd year PhD): **All are academic staff (Assistant Professor or Full Professor)**

b) Years of Arctic field experience (must have at minimum 3 years working in the Arctic with at least two years' experience of running/helping run an Arctic Field camp): **Sharp (14 yrs + 1 in the Antarctic); Kavanaugh (yrs + ? in the Antarctic); Copland (4 yrs + 3 in the Antarctic); Boon (3 yrs)**

OR

If the above is not feasible, you must have a northern field assistant or guide in camp with your group at all times. If this is your preference, please identify who this will be:

Name: ____

Hired from (community): ______________________________________

Health- and Safety- Related Training

At minimum, one person (and preferably more than one) in this field camp at all times <u>must have</u> a valid basic (preferably advanced) first aid certification and CPR training. Please send PCSP a copy of first aid certificates held by any member of your field party. PCSP WILL NOT ALLOW ANY PARTIES INTO THE FIELD WITHOUT PROOF OF THE PROPER HEALTH AND SAFETY TRAINING.

Please list below all health- and safety-related training (e.g. PCSP recommends Arctic survival training for as many members of your group as possible) that members of this team have taken within the past two years:

Name	**Training Taken**	**Supplier**	**Completion date**
Copland	1st Aid + CPR (Standard and Wilderness)	Canadian Group for Emergency Training Inc	April 2006
Sharp, Copland, Boon and Kavanaugh all have valid Firearms Licenses			
Kavanaugh	1st Aid and CPR		April 2006

Boon, Sharp, Tarasov, Dow, Sylvestre and Wyatt will all renew First Aid certification prior to field season

Insurance

Is each member of your field party adequately and properly insured should search and rescues, medical evacuations or other emergency measures be required and/or expenses incurred?

Yes

I, as principal investigator and/or supervisor of this group, hereby verify all possible considerations and measures have taken into account and implemented to protect the health and safety of each and every individual involved in undertaking this program.

_______________________________ _______________

Signature of Principal Investigator Date

Signature of Supervisor (if different from above)
Date