Glacial Ice Hazards Working Group (GIHWG)

Report of the Inaugural Meeting

25 & 26 June 2015, at Carleton University

Photo taken late on 26 June 2015 showing 23 of 46 Participants in the Glacial Ice Hazards Working Group: (left to right) back row: Adrienne Tivy (CIS), Philippe Lamontagne (NRC), Carrie Young (PAL), John McClintock (Amec Foster Wheeler), Luc Desjardins (University of Ottawa), John Bennet (C-CORE Ottawa), Derek Mueller (Carleton University), Howard Edel (ASL Environmental), Greg Crocker (Ballicater/Carleton University), Wesley van Wychen (University of Ottawa), Brad DeYoung (Memorial University), Paul Pestieau (CIS), Des Power (C-CORE St John's), and Matt Arkett (CIS); middle row: Jack Chen (CIS), Hai Tran (CIS), Anna Crawford (Carleton University), Pat Barron (Oceans Ltd), Angela Cheng (CIS), Ron Saper (NRC), and Abby Dalton (University of Ottawa); front row: Marie-Andrée Giguère (Fednav) and Mike Hicks (International Ice Patrol).

How to cite: Glacial Ice Hazards Working Group (2016) Report of the Inaugural Meeting. Water and Ice Research Laboratory, Carleton University, Ottawa, Canada. 30 pp. https://doi.org/10.22215/wirl/2016.1

Report prepared by: Ronald Saper, Adrienne Tivy, Derek Mueller, Greg Crocker, Mike Hicks, John McClintock, Hai Tran, Carrie Young and Melissa Nacke

15 February 2016

Acknowledgments

The following people were instrumental in the planning of the first meeting of the Glacial Ice Hazards Working Group:

Angela Cheng
Greg Crocker
Derek Mueller (Host)
Ron Saper (Chair)
Adrienne Tivy (Co-Chair)
Hai Tran

The following people took on the responsibility of chairing the breakout session groups and writing the detailed breakout summaries:

Greg Crocker
Mike Hicks
John McClintock
Derek Mueller
Ron Saper
Adrienne Tivy
Hai Tran
Carrie Young

The following people helped execute the meeting and prepare/edit this summary document

Derek Mueller
Melissa Nacke
Ron Saper
Adrienne Tivy

We gratefully acknowledge the following organizations for contributing to the costs of room rental, audio visual equipment rental, and catering:

Water and Ice Research Lab, Carleton University
1125@ Carleton Meeting Space
The Arctic Program of the National Research Council

Executive Summary

This report documents the first meeting of the Glacial Ice Hazards Working Group (GIHWG) on the 25th and 26th of June, 2015 at Carleton University in Ottawa, Canada. The vision of the group is to bring together the many diverse and widely distributed people concerned with floating hazards composed of freshwater ice (or substantially freshwater ice) every two years. Our purpose is to foster collaboration, data sharing and interdisciplinary work on icebergs and ice islands, and to begin framing and prioritizing research and development objectives where needs are greatest.

The origin of the group is based on one of the recommendations from a report entitled Preliminary Research Plan for Glacial Ice Hazards (Saper, 2011), which called for a biannual meeting convened by the Applied Science Group of the Canadian Ice Service (CIS). This report was a deliverable to the CIS under a contract managed by Tom Carrieres. Later, in 2014, Adrienne Tivy (CIS) and Ron Saper (Carleton University) decided to organize such a meeting, but rather than being sponsored by CIS, the meeting would be organized by a committee of individuals from various organizations. Derek Mueller of Carleton University agreed to host the initial meeting, and he joined the organizing committee along with Greg Crocker (Ballicater), Angela Cheng (CIS) and Hai Tran (CIS).

Forty-six people participated by attending at least part of the meeting in person, by telephone, by videoconference, or by providing slides in advance of the meeting. The participants included invited academics, government employees, and private sector people that were known to the organizing committee, or who were identified by other invitees. There was no publicity for this initial meeting, no fee for attendance, and no formal papers presented.

This report outlines the meeting format, and provides brief summaries of the discussions in a more or less uniform format for readability. For completeness, the detailed breakout summaries prepared by breakout session chairs are included (with some editing) as an Annex to this report.

Although there was no fee for participation, all participants were required to contribute, in advance, a seven slide presentation deck adhering to a common template with no distribution restrictions. Virtually all participants complied, and these presentations are a substantial output of the meeting in their own right because they reflect first-hand initial assessments of research priorities, report on many activities, and identify key resources. These presentations are available for download at the working group web page (http://wirl.carleton.ca/gihwg).

The meeting identified four broad needs: 1) the need for sharing and archiving of comprehensive data sets/observations; 2) the need for better schemes for model inter-comparison and evaluation; 3) the need to incorporate understanding of climate change and glaciology into activities; and 4) the need to prepare protocols for large scale field operations (response to calving of ice islands).

People interested in participating in or keeping current with the activities of the GIHWG should visit the website and follow instructions to subscribe to the email listserv, which is hosted free of charge by Carleton University.

TABLE OF CONTENTS

Introduction

The Glacial Ice Hazards Working Group (GIHWG) comprises researchers and practitioners concerned with icebergs and ice islands. The group aims to be geographically diverse, and includes participants from academia, government and industry primarily from Canada but also the U.S. and Norway (see Annex I). The objective of the group is to foster collaboration, data sharing and interdisciplinary work on icebergs and ice islands, and to begin framing and prioritizing research and development where needs are greatest. Participation is open to all interested parties. Forty-six people participated[1] in the two day inaugural meeting held at Carleton University on June 25th & 26th, 2015. Meetings every two years are envisaged, with the date for the next meeting proposed as mid-to-late 2017. To help maintain contact and facilitate discussion between meetings, the GIHWG has a webpage (http://wirl.carleton.ca/gihwg) and an email listserv.

This report describes the working group, outlines the format of the inaugural meeting, and provides brief summaries of the discussions in a more or less uniform format for readability. Annex I is the list of participants and their current affiliations and contact information. Annex II shows the template and instructions for the Structured Introductions. For completeness, the detailed breakout summaries prepared by breakout session chairs are included (with some editing) as Annex III of this report.

The Glacial Ice Hazards Working Group is managed informally by individuals and is not attached at any particular organization or group of organizations. The venue of meetings is expected to rotate to different cities. It is hoped that the meetings and activities will be run by interested individuals with the support of a variety of affiliated organizations.

[1] Participants either attended at least part of the meeting in person or via tele/videoconference, or they provided introductory slides in advance according to a template for the Structured Introduction session. Several more people expressed interest in being kept informed via email communications, but are not listed as participants in the meeting.

Structure of the Inaugural Meeting

The inaugural meeting kicked off with a round of Structured Introductions, followed by a series of break-out sessions (breakout chairs are indicated in square brackets), and closing with a brief plenary discussion. This structure (excluding the welcome and coffee/meal breaks) is mirrored by the remaining main body sections of this report:

Opening Remarks

Thursday AM: Structured Introductions – seven slides “homework”

Thursday AM: Breakout Session 1: Observations

Group A: Remote Sensing [Ron Saper]

Group B: *In situ* observations to support science and government [Derek Mueller]

Group C: Observations to support operations [Carrie Young]

Thursday PM: Breakout Session 2: Modeling

Group A: Icebergs and ice island drift modeling (hours to days) [Hai Tran]

Group B: Icebergs and ice island deterioration modeling [Greg Crocker]

Group C: Seasonal to inter-annual predictions and climatology [Adrienne Tivy]

Group dinner at Mill Street Brew Pub

Friday AM: Breakout Session 3: Research priorities, knowledge gaps/requirements

Group A: Immediate time horizon supporting operations (1-2 years) [John McClintock]

Group B: Medium & long-term horizon supporting operations (3-10 years) [Mike Hicks]

Friday PM: Plenary closing session

Meeting adjourned at 2pm Friday.

Each of the three breakout sessions had 2-3 parallel groups. Video- and tele-conferencing was available throughout the meeting to facilitate remote participation.

Structured Introduction Session

In order to provide maximum benefit with limited time and to ensure balance, the Structured Introductions allowed 5 minutes for each participant/research group/organization to present seven slides following a preset template (see Annex II). Each short presentation amounted to introductory presentation reviewing their work history, areas of interest, what they have to offer the GIHWG, pressing gaps in tools/data/knowledge and the challenges they currently face. In addition an image/picture of interest and short list of favourite references was requested.

Most of the morning was taken up with the Structured Introductions. The format was rapid fire, and allowed people to get a sense of who was doing what very quickly, and identify possible collaborators.

Breakout Session 1: Observations

The first Breakout Session divided the participants into three groups based on forms of observations relevant to icebergs and ice islands. These groups were: A) remote sensing; (B) *in situ* observations to support science and industry; and (C) observations to support operations. To guide the discussion each group was asked to take an inventory of current observations, an inventory of techniques for observations, current challenges of observing and priorities for the futre.

Group A – Remote sensing

Inventory of Observations

- RADARSAT-2 is currently the major source of remotely sensed data for glacial ice hazards
- RADARSAT-1 archive imagery is useful for long term studies and climatology
- ENVISAT ASAR archive imagery is also a significant source of historical data from the European Space Agency (ESA)
- Sentinel-1A has recently been launched by ESA and should be useful in future for iceberg detection
- TerraSAR-X from Germany has also been used in some studies but it covers very small areas
- LANDSAT is a useful optical sensor with a long archive
- In future, Sentinel-2 will offer resolution similar to LANDSAT but with a much wider swath
- In future, PlanetLabs will offer daily optical coverage from microsatellites
- In future, the RADARSAT Constellation Mission will offer daily radar coverage of all the North

Inventory of Techniques

- Wesley Van Wychen (Ottawa U) reported on quantitative ice flux output from all major glaciers in Canada derived from satellite data
- Derek Mueller (Carleton U) is working on the Canadian Ice Island Drift and Deterioration Database

(CI2D3) which will be useful for studying ice islands and focuses on the 2008, 2010, and 2012 Petermann Glacier calvings. The database will be a geodatabase created from analysis of RADARSAT-1/2, ENVISAT and other imagery. Anna Crawford (Ottawa U) will be studying ice island drift and deterioration using the CI2D3 data and *in situ* data.
- Ron Saper (Carleton/CIS) reported on an effective iceberg discrimination technique based on HH and HV backscatter from icebergs to separate icebergs from most ship targets, he also described planned work on ice island backscatter modeling based on ice crystal structure
- Angela Cheng (CIS) reported work at the Canadian Ice Service on iceberg detection from RADARSAT-2 data
- Des Power (C-CORE) noted that iceberg backscatter using a program called GRECOSAR will soon be underway led by C-CORE

Current Challenges
- Data management is a major challenge as data sources proliferate
- Detection of icebergs in strong ocean clutter and sea ice is difficult at present
- Resolution of spaceborne imaging radar is often marginal for detection of small icebergs
- There is a lack of validated data sets to support remote sensing studies

Priorities Moving Forward
- Improved detection/discrimination of icebergs and ice islands and improved integration into operational data flows
- Modeling of iceberg and ice island backscatter to support remote sensing
- Integration of remote sensing with drift and deterioration models
- Improved validation through more *in-situ* measurements and correlated ground truth

Group B – In situ observations to support science and government

Inventory of Observations
- The group was aware of iceberg messages (CIS and IIP) and a database of iceberg sightings at NRC that contains position, basic shape, and size information
- Published studies tend to be focused and yield small sets of data on a few variables at specific places and times including small numbers of above and below water profiles, environmental parameters, and a variety of specialized measurements such as local currents, albedo, temperatures, etc.
- The group arrived at a comprehensive list of variables that should be measured when studying the drift and/or deterioration of an individual ice hazard
- The group expressed the need for a comprehensive picture of what data is available and to identify data providers

Inventory of Techniques
- 3D shape modelling above and below the waterline is possible using combinations of photo/videogrammetry, multibeam sonar.
- Autonomous Underwater Vehicles (AUVs), Unmanned Aerial Vehicles (UAVs) and Unmanned Surface Craft (USCs) are becoming more mature and can measure environmental variables and/or map ice hazards safely
- Overflights (PAL, IIP, CIS) yield counts, size classes and positions of ice hazards
- Empirical relationships are often used within models to estimate required model parameters such as sail and keel dimensions from a simple observation such as waterline length or class of waterline length (e.g. bergy bit, small, medium, large, and very large icebergs)
- Beacons can be used to track iceberg and ice island drift, but are difficult to place and are frequently lost due to calving and rolling.
- Ice thickness measurements can be made on tabular bergs and ice islands over time using ice penetrating radar and ice surface position

- Acoustic Doppler Current Profilers (ADCPs) or other current meters for ambient ocean current measurements
- Conductivity-Temperature-Depth (CTD) profiles are used for salinity, temperature and pressure
- Photography and videography is important
- Thermistor or thermocouple chains could be employed to measure ice internal temperature, but there are substantial deployment challenges

Current Challenges

- There is a need for an easily accessible and comprehensive source of data to characterize icebergs
- There is a general shortage of most types of data other than regionally patchy iceberg location, size and shape
- Icebergs are hazardous to approach and frequently roll, shedding instrumentation packages
- It is difficult to rapidly and accurately measure ice hazard dimensions from aircraft and ships and to re-sight them reliably making it difficult to estimate drift and deterioration

Priorities Moving Forward

- Identification of a repository to centralize access and collection of *in situ* observations
- A database of drift tracks (from beacons or other means) is important
- Improved leverage to help motivate industry to collect more types of high quality data and to freely share observations or at least metadata in an open access repository
- Collaboration among groups to ensure that studies measure a comprehensive set of variables (see Annex III, Table III-1 for a full listing)
- Develop a science, logistics and funding plan for the next major ice island calving event so we can have a coordinated response

Group C - Observations to support operations

The majority of iceberg observations to support operations come from the oil and gas industry.

Inventory of Observations

- Detailed iceberg tracks near offshore installations
- Point observations from vessels and aircraft (latitude, longitude, size, shape, date/time)
- Atmospheric and oceanographic data are sparse, and include buoys off the East Coast and industry observations from offshore installation and supply vessels

Inventory of Techniques

- Many observations are estimated rather than measured (e.g. iceberg dimensions, drift)
- Iceberg draft is usually calculated from waterline length using a formula that is considered accurate to ± 25%
- Marine radars on the offshore facilities that can provide detailed tracks for approaching icebergs
- The majority of atmospheric and oceanographic data are collected automatically or modeled using limited data sources

Current Challenges

- Availability and access to near-real time data
- Data coverage is limited to regional data sets for both iceberg and atmospheric/oceanographic data
- Manually observed/estimated sizes can lack consistency; not all observers are trained to the same standard
- Atmospheric and oceanographic data measurements on platforms are logged automatically but are not monitored which can lead to quality problems
- Observed iceberg and concurrent atmospheric and oceanographic datasets are rare
- Iceberg profiles are in limited, are typically old, and usually cover above water only
- The quality of vessel based atmospheric and oceanographic measurements is questionable
- ADCP data collection is not standardized

Priorities Moving Forward

- Improved access to iceberg and atmospheric and oceanographic data on the Global Telecommunications System (GTS)
- Improved data collection onboard vessels (icebergs and atmospheric/oceanographic data)
- Better data coverage and availability further north for operations further afield
- Collection of atmospheric and oceanographic data outside of the historical operation areas (i.e., the Grand Banks)
- Upgrade empirical relationships for draft and mass calculations
- More above and below water iceberg shape profiles are required
- Standardize collection parameters and formats for ADCP profiling

Breakout Session 2: Modeling

The second breakout session focused on modeling and was composed of three groups: A) iceberg and ice island drift modeling (hours to days); B) iceberg and ice island deterioration modeling; and C) seasonal to inter-annual predictions and climatology. To guide the discussion each group was asked to take an inventory of current models, an inventory of modeling techniques,and summarize the current modeling challenges and priorities for the future.

Group A – Iceberg and ice island drift modeling (hours to days)

Inventory of Models

- Canadian Ice Service (CIS) maintains an iceberg drift model in both research and operational versions for estimation of iceberg tracks for berg sightings. This supports the estimation of the Limit of All Known Ice (LAKI), and this model is also used by the International Ice Patrol (IIP).
- The Canadian National Research Council (NRC) originally built the iceberg drift model under contract to the CIS, and now both organizations maintain slightly different versions.
- Provincial Airlines (PAL) of Newfoundland licence the NRC model for tactical use in ice management in support of offshore activities near Newfoundland.
- The Centre for Arctic Resource Development (CARD), an academic research institute within C-CORE, has a similar iceberg drift implementation based upon the published paper describing the model developed for CIS.

Inventory of Modeling Techniques

- All of the above models utilize a deterministic approach whereby the iceberg trajectory is predicted using external numerical models for ocean and atmospheric (weather) prediction.
- Statistical models were studied in the 1980s which use the observed iceberg trajectory and oceanographic principles to predict the likely path and the position uncertainty for short times into the future.
- There is a consensus that ocean currents are the major influence on iceberg and ice island drift

Current Challenges

- The short term forecasting of iceberg and ice island drift needs to be improved to make ice management more effective
- There is a shortage of accurate oceanographic and iceberg shape information to provide input to existing models
- Small scale turbulent ocean eddies which can cause iceberg/ice island looping motions cannot be predicted by large scale ocean models

- Currently-used drift models do not take advantage of and use detailed iceberg trajectory history information usually available as part of ice management operations
- Sea surface height information or other indirect means of estimating ocean slope is not typically used in contemporary models but is believed to be relevant to drift

Priorities Moving Forward

- The use of statistical techniques to improve short term accuracy of drift models should be re-examined
- More high-quality atmospheric and oceanographic observations are needed to validate drift models and improve drift model inputs
- Better information on iceberg shape above and below water is needed if deterministic models results are to be successful and to validate statistical models

Group B – Iceberg and ice island deterioration modeling

Inventory of Models

- The North American Ice Service (NAIS), comprising the Canadian Ice Service (CIS), the International Ice Patrol (IIP), and the U.S. National Ice Centre, maintain and operationally run an iceberg deterioration model in addition to iceberg drift models to support the estimation of the Limit of All Known Ice (LAKI)
- Academics also have some models of iceberg deterioration
- Tactical Modeling of deterioration is not seen as valuable since tactical timescales are quite short
- Deterioration models are believed to be important for population studies or long term planning

Inventory of Modeling Techniques

- The common deterioration models use a method developed by White *et al.* reported in 1980
- White's model account for melt by solar radiation, wave-induced melt, forced convection, buoyant convection and calving. Calving is based on Finite Element Model results.
- White's model and related models have some crude approximations and have not been validated in a meaningful way
- A model using dimensionless groups has been developed to predict the deterioration of bergy bits and growlers (Ballicater, 2012)
- Some work based on Antarctic icebergs attempts to quantify mass loss as a function of latitude, water temperature and drift speed (Budd et al, 1980)
- Carleton University has done some work on surface ablation of ice islands (e.g. Crawford et al, 2015).

Current Challenges

- Deterioration modeling is complicated by the irregular shapes of iceberg surfaces and their evolution over time
- Models are over-simplified in many cases.
- The insulating effect of snow cover in northern regions is not modeled
- Calving of icebergs/ice islands into smaller masses is hard to predict
- Almost no validation work has been done
- Separate validation of individual deterioration mechanisms may be difficult

Priorities Moving Forward

- Collection of data sets that can be used to validate deterioration models
- Daily mass and shape of several icebergs are needed over 3-4 weeks under different environmental conditions especially under a variety of water temperatures and sea states
- Ice temperature profiles may be useful
- The Canadian Ice Island Drift and Deterioration Database (CI2D3) data set being collected by Carleton University and the Canadian Ice Service (CIS) may be useful to determine ice island deterioration rates and study large-scale fracture using numerical methods

Group C – Seasonal to inter-annual predictions and climatology

Inventory of Models

- Seasonal forecasting: heuristic model based on winter sea ice and atmospheric patterns (PAL), statistical model based on winter ice extent (Peterson, DFO)
- No one was aware of any models to forecast inter-annual variation in iceberg frequency or size

Inventory of Modeling Techniques

- Seasonal: follow-up with CIS on how outlook is produced
- Inter-annual: group felt it would be possible to model life-cycle of an iceberg although it hasn't be done yet
- Iceberg datasets available for climatology: PERD iceberg sighting database, iceberg messages (sightings from aircraft and ships), observations around offshore platforms, potential to generate targets from SAR satellite imagery (Danish Meteorological Institute, C-CORE, and CIS have done this)

Current Challenges

- Improving seasonal forecasts requires: accurate sea ice forecasts, historical iceberg population data - for example creating a homogenized time-series from the IIP record of the number of icebergs south of 48^{o}N, climate records surrounding operational areas
- Improving inter-annual forecasts requires: understanding of processes controlling the rate of icebergs exiting fjords, monitoring iceberg transit from Greenland south to Grand Banks, ability to detect icebergs in pack ice, tracking iceberg drift over many years
- Developing an iceberg climatology requires: estimating iceberg populations from observations of opportunity; agreement on an approach to best address spatial and temporal gaps in observation or survey coverage; for a SAR-derived dataset challenges include disk space and computer power, validation and verification of targets against *in situ* observations.

Priorities Moving Forward

- Priority for industry is a seasonal 3-category forecast to predict light, moderate and heavy iceberg seasons

Breakout Session 3: Research Priorities, Knowledge Gaps/Requirements

The third breakout session focused on priorities and needs for the future in terms of both modeling and observations. Breakout session #3 was composed of two groups: A) the immediate future supporting Operations (1-2 years); and B) the medium and long-term future (3-10 years).

Group A: Immediate future - supporting operations (1-2 years)

Knowledge Gaps and Information Requirements

- Iceberg charts provide useful information, however more information on individual icebergs and ice islands and their history is needed for operational use, especially near the Grand Banks
- Regional sea ice charts for the Eastern and Western Arctic should be released more frequently than weekly, to inform operations
- Some advances in publishing atmospheric and oceanographic data (such as waves, winds, currents, sea surface temperature, fog) to the Global Telecommunications System (GTS) have been made, but more efforts are needed to ensure observations are shared so that data can be validated and used immediately
- There is a lack of adequate upstream iceberg sightings to seed the CIS drift model. Current satellite data observations are limited in terms of spatial and temporal coverage and there is a shortage of reconnaissance flights upstream
- There is an absence of relatively long term (several days or weeks) sets of observations of individual iceberg measurements and drift tracks, as well as coincident environmental measurements. These are needed to support iceberg detection, and drift and deterioration modeling efforts
- Iceberg draft measurements are in short supply and profiles to understand underwater shape, iceberg mass, and draft would be helpful to improve confidence in draft estimates and improve drift model accuracy.
- Verification of iceberg drift models and model skill evaluation is needed to improve confidence in results and facilitate cross comparison. Quantitative key performance indicators are needed which go beyond such qualitative metrics as “fairly good” that are based upon predicting the sector of drift to within 30 degrees
- Ocean models need verification through ocean current measurements, especially in the Orphan Basin and Flemish Pass

Research and Operational Priorities

- More information on individual iceberg tracks and history is needed
- More frequent information is needed for CIS regional chart areas
- Develop methods for exploitation of shared atmospheric and oceanographic information in real-time
- Propose and test additional data sources and techniques for upstream sighting of icebergs and ice islands
- More long-term *in situ* observations of icebergs and ice islands are needed including underwater shape (e.g. keel depth)
- Quantitative methods for evaluating drift model performance are needed to improve confidence in the results.
- Ocean models should be verified using *in situ* current measurements in Orphan Bay and the Flemish Pass.

Group B: Medium & long-term future (3-10 years)

Knowledge Gaps and Information Requirements

- Develop a protocol that documents best practices in response to significant ice island calving events
- Develop a schematic illustration that shows activities/experiments along the path of an ice hazard to help visualize knowledge gaps
- Processes that impact different stakeholders (academia, government, industry) occur at different temporal and spatial scales
- Has there been an increase in tabular ice island fragments?
- Verify/explain anecdotal observations that suggest that ice hazards near the Grand Banks/Labrador are smaller than in previous years
- Observations and *in situ* measurements are needed to answer science questions
- Remote sensing plays an essential role, particularly in remote areas
- *In situ* measurements need to be prioritized and coordinated among stakeholders

Research Priorities

- Improve our collective understanding on how climate change is impacting glacial ice hazards
- Include glacial calving and ice hazard deterioration in freshwater budgets
- Investigate the connection between observed changes in calving rates and the number of icebergs transiting south of 48^{o}N

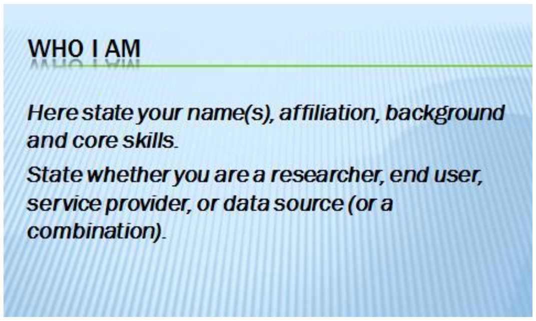
Plenary Closing Session

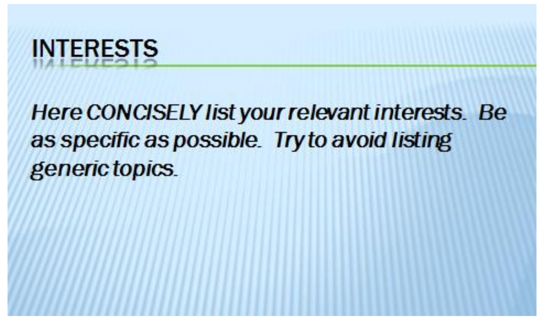
The plenary closing session focused on next steps for the GIHWG. There was a consensus that the group is needed and should be fostered. It was suggested that the next meeting should be held in St. John's in the second half of 2017. Communication and discussion in the meantime will be facilitated by a group website and email listserve. The organizers agreed to put together a draft summary of the meeting for circulation and review. A final version will be posted on the website. Participation in future meetings will be open to all and, once a website and list serve are in place, the group will be promoted. Following the closing session, a photo was taken outside the HCI building which appears on the cover of the report. Many participants had left by then so we have only a subset of attendees in the photo.

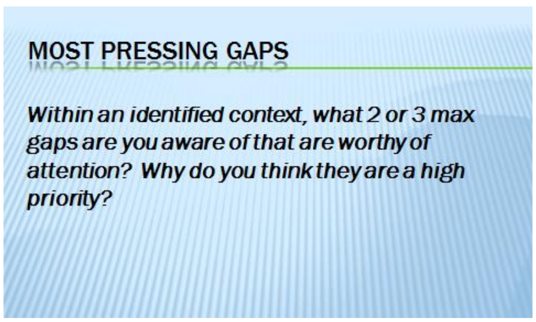
Annex I: List of Participants

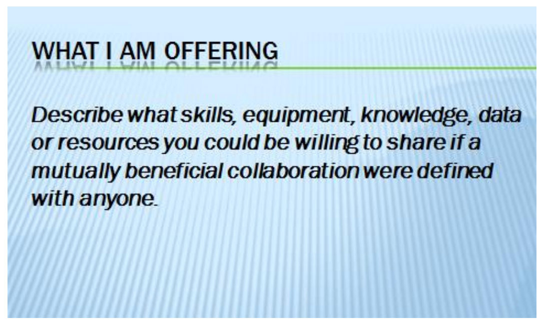
Surname	Firstname	Affiliation	Email	Venue
Andersson	Leif	NTNU	leif.e.andersson@itk.ntnu.no	Norway
Arkett	Matt	CIS Applied Science	Matt.Arkett@ec.gc.ca	Ottawa
Barron	Pat	Oceans Ltd	pbarron@oceansltd.com	Ottawa
Beaupertuis	Bernie	Suncor	bbeaupertuis@suncor.com	St John's
Bennett	John	C-CORE	john.bennett@c-core.ca	Ottawa
Bobbit	Judith	Oceans Ltd	jbobbitt@oceansltd.com	St John's
Bullock	Terry	Amec Foster Wheeler	terry.bullock@amecfw.com	St John's
Carrieres	Tom	CIS Modeling	Tom.Carrieres@ec.gc.ca	Ottawa
Chen	Jack	CIS Modeling	jack.chen@ec.gc.ca	Ottawa
Cheng	Angela	CIS Applied Science	Angela.Cheng@ec.gc.ca	Ottawa
Copland	Luke	Ottawa U	luke.copland@uottawa.ca	Ottawa
Crawford	Anna	Carleton U	anna.crawford@carleton.ca	Ottawa
Crocker	Greg	Ballicater	ballicater@sympatico.ca	Ottawa
Daley	Claude	MUN	cdaley@mun.ca	Ottawa
Dalton	Abby	U of Ottawa	abigail.dalton@ec.gc.ca	Ottawa
Desjardins	Luc	Carleton U	Desluc1@videotron.ca	Ottawa
deYoung	Brad	MUN	bdeyoung@mun.ca	St John's
Edel	Howard	ASL Environmental	howard.edel@rogers.com	Ottawa
Gagnon	Robert	NRC OCRE	Robert.Gagnon@nrc-cnrc.gc.ca	St John’s
Garbo	Adam	Carleton U	AdamGarbo@cmail.carleton.ca	Ottawa
Giguere	Marie-Andree	FEDNAV	MGiguere@fednav.com	Ottawa
Hicks	Michael	IIP	Michael.R.Hicks@uscg.mil	Ottawa
Hill	Chris	Canatec	chris_hill@canatec.ca	Calgary
Kubat	Ivana	NRC OCRE Ottawa	Ivana.Kubat@nrc-cnrc.gc.ca	Ottawa
Lamontagne	Philippe	NRC OCRE Ottawa	Philippe.Lamontagne@nrc-cnrc.gc.ca	Ottawa
Marko	John	ASL Environmental	markoj@shaw.ca	B.C.
McClintock	John	Amec Foster Wheeler	john.mcclintock@amecfw.com	Ottawa
McDermott	Sean	Horizon Ice	Sean@horizoncanada.com	Halifax
McKenna	Richard	R.F. McKenna	richard.mckenna@sympatico.ca	Ottawa
Melvin	Jason	Suncor	jmelvin@suncor.com	St John's
Mueller	Derek	Carleton U	derek.mueller@carleton.ca	Ottawa
Murphy	Noel	NRC OCRE St. Johns	Noel.Murphy@nrc-cnrc.gc.ca	St John's
Nacke	Melissa	Carleton U	MelissaNacke@cmail.carleton.ca	Ottawa
Pestieau	Paul	CIS Modeling	Paul.Pestieau@ec.gc.ca	Ottawa
Power	Des	C-CORE St John's	des.power@c-core.ca	Ottawa
Roberts	Jonas	Amec Foster Wheeler	jonas.roberts@amecfw.com	St John's
Saper	Ronald	Carleton U	RonaldSaper@cunet.carleton.ca	Ottawa
Stern	Alon	Princeton	sternalon@gmail.com	Princeton
Sudom	Denise	NRC OCRE Ottawa	denise.sudom@nrc-cnrc.gc.ca	Ottawa
Tiffin	Scott	Canatec	scott_tiffin@canatec.ca	Calgary
Tivy	Adrienne	CIS Modeling	Adrienne.Tivy@ec.gc.ca	Ottawa
Tran	Hai	CIS Modeling	Hai.Tran@ec.gc.ca	Ottawa
Turnbull	Ian	Card-Arctic	ian.turnbull@card-arctic.ca	St John's
Van Wychen	Wesley	U of Ottawa	wvanw046@uottawa.ca	Ottawa
Warbanski	Greg	Canatec	greg_warbanski@canatec.ca	Calgary
Young	Carrie	Provincial Airlines (PAL)	cyoung@provair.com	Ottawa

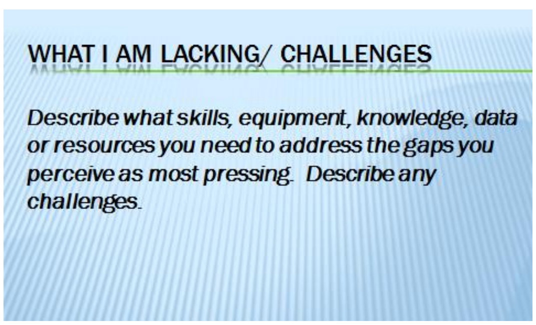
Annex II: Template for Structured Introductions

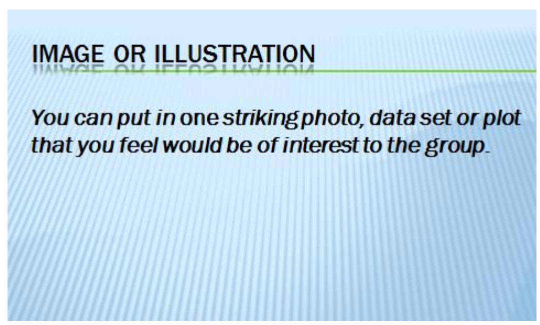


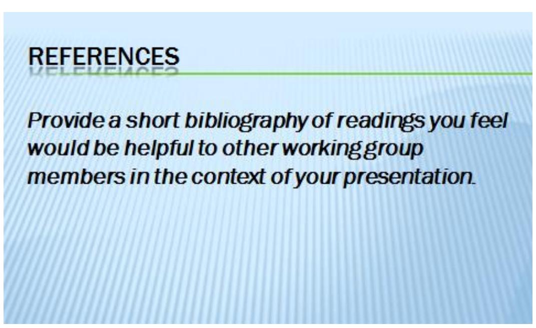












Annex III: Detailed Breakout Summaries

Breakout Session # 1:

Group A: Remote Sensing
Chair: Ron Saper
Participants: Matt Arkett, John Bennett, Angela Cheng, Abby Dalton, Luc Desjardins, Mike Hicks, Des Power, and Wesley van Wychen.

The International Ice Patrol (IIP) was created in response to the Titanic disaster over 100 years ago. Since then, the mandate of the IIP has remained advising those transiting the Atlantic Ocean on how to best avoid iceberg hazards. This is achieved by determining the Limit of All Known Ice (LAKI) using mainly Hercules C-130 aircraft that are specially equipped with radar and other sensors. Most flying is done close to the Grand Banks, with only occasional flights further north. The IIP is currently under pressure from the US Coast Guard to use fewer aircraft resources and transition to increased use of satellite remote sensing techniques. IIP is conducting trials and requires an increase in data for validation in order to compare with satellite imagery as they assess detection performance.

Sensors

RADARSAT-2 was identified as the major resource for spaceborne synthetic aperture radar (SAR) detection. Wesley van Wychen explained his use of RADARSAT-2 fine mode imagery and interferometric techniques to measure glacier flux rates thus monitoring iceberg production rates at all major Canadian glaciers for a significant number of years running.

The recent launch of the Sentinel-1A will likely prove beneficial for data collection. Sentinel-1 is currently providing a great deal of coverage of the East Coast of Canada. A second satellite, Sentinel-1B, is expected shortly. TerraSAR-X, from Germany, has also been used to research glacial ice hazards. RADARSAT-1 provides archive data and is of interest for historical iceberg population data over a large area.

The usefulness of optical sensors such as LANDSAT was discussed. The soon-to-be-launched Sentinel-2 optical satellite will offer resolution similar to LANDSAT but with a wider swath. Planetlabs is creating a dense constellation of high-resolution satellites, which aim to provide daily coverage of the entire planet. Des Power noted that the sheer volumes of remotely sensed data will be extensive and may require cloud-computing approaches.

Remote sensing for drift and deterioration models

Spaceborne sensors can be used to track large ice islands, which originate from ice shelves or floating glacial tongues. These same sources can also produce icebergs which are sometimes visible in spaceborne SAR. The Mitte Glacier can produce icebergs 300 m thick. The production rate of icebergs originating from the Trinity -Wyckham Glacier has dramatically increased, producing 60% of Canadian sourced icebergs in recent times. Ian Joughin from the University of Washington has determined that the Jakobshavn Glacier has dramatically increased its flow rate by a factor of 3 in recent years. Luc Desjardins, a former Canadian Ice Service (CIS) forecaster, is now working at Carleton University tracking the historical drift and breakup history of the Petermann ice islands. The specific drift and fracture patterns are under study and will be the subject of Anna Crawford's PhD thesis. Icebergs are often trapped for years in the source fjords, and then can be released suddenly by some mechanism in a very short period of time.

Angela Cheng stated that the CIS is studying iceberg detection and how to use satellite detections in drift and deterioration models.

Discriminating between ships and icebergs

Ron Saper has worked with the CIS on the discrimination of icebergs from ship targets. Automatic Identification System (AIS)[2] data can be used to help in discrimination.

Investigating radar backscatter from glacial ice hazards

Ron Saper expressed interest in modeling radar backscatter physics for glacial ice, as well as the potential for very deep penetration into glacial ice features. Des Power noted that C-CORE is currently involved in a backscatter modeling effort using an electromagnetics modeling framework called GRECOSAR.

[22] This automated system uses HF radio to exchange identification, position, course, and other information between vessels. It has also been used to collect vessel information using shore or space-based receivers.

Group B: Remote Sensing
Chair: Derek Mueller
Participants: Brad deYoung, Howard Edel, Mike Hicks and Derek Mueller

Introduction

The group spent much of their allotted time reviewing what iceberg data sets were available and what would be required for a comprehensive examination of processes related to drift and deterioration. What follows is not an exhaustive review (more needs to be done to inventory existing resources), but we brainstormed an idealized comprehensive set of variables that would reveal various relevant processes to ice hazard drift and deterioration. We also examined some challenges related to data collection, access and sharing of existing data, plus came up with a few recommendations for future initiatives.

Table III-1 lists the variables that should be measured for a comprehensive study on ice hazard drift and deterioration. Ideally, programs and projects would be designed to simultaneously measure as many of these variables as possible. Techniques discussed to accomplish these range from ship and aircraft based approaches to using autonomous/remote vehicles both on- and under-water and airborne. We discussed deploying beacons and mapping techniques to a limited extent.

Table III-1. Types of data that are important to elucidate key glacial ice hazard processes. Note that for many ocean variables (especially currents), measurements in both the near and far field are important. Hydrographic data needs to be at an appropriate scale.

Ice hazard	Ocean	Atmosphere
Size/Shape/Dimensions of sail and keel:	Currents at the surface	Wind speed and direction
Shape/type	Currents at depth (profiles)	Air temperature
Size class	Directional wave spectra	Relative humidity
Waterline length	Turbidity profiles	Downwelling shortwave radiation
Freeboard	Chlorophyll profiles	Albedo
Draft	Sea surface slope	Downwelling longwave radiation
Cross sectional area (windage)	Thermal infrared imagery	Upwelling longwave radiation
Mapping of sail and keel:	Hydrographic data	Atmospheric pressure
Rams		
Wave notches		
Complete 3D profiles (DEMs)		
Document/map:		
Failure planes/fractures		
Sediment distribution and/or albedo		
Colour		
Long-term logging:		
Drift track		
Orientation (in 3D)		
Surface ablation (sail and keel)		
Ice temperature (internal)		
Remote sensing:		
Imagery/Video (camera)		
Thermal infrared (camera)		
Satellite imagery (see group A)		

Opportunities and Challenges

There are several excellent databases that are publicly available such as the East Coast iceberg shape and sightings database at NRC, which contains observations on over 400 icebergs. This effort was funded by the Program of Energy Research and Development (PERD). The IIP and CIS also archive data on ice hazards from overflights and iceberg messages and other organizations likely have long-term records as well (including C-CORE, PAL and industry, etc.).

The group discussed several challenges that need to be addressed to improve data collection and availability. Industry tends to fund studies that are focused and this may lead to less comprehensive data sets. To overcome this limitation we need to strive to collect more variables whenever possible and collaborating with others to accomplish this is a reasonable approach. There are issues with getting beacons to stick on the ice. Some suggested spikes, drilling in the beacon and even using thermite. For growlers, tying a floating beacon to a net of chains has worked in the past. Some in the group were amazed that there is no rapid, inexpensive and reasonably accurate ways to measure the size of iceberg sails from the air or from a ship. This led to a discussion regarding the limitations of reconnaissance flight data that classify icebergs (small, medium, large and very large). These icebergs can't easily be re-identified and the measurements are so crude that deterioration cannot be determined (or even estimated). The group addressed the need for a comprehensive picture of what data is available and to define what is data is still required. Government, industry and universities could fill the data gaps given adequate funding.

Recommendations

The group expressed a need to create a database of *in situ* observations for individual icebergs. Ideally, this database would consist of as many variables as possible from Table X, which were deemed useful for government, industry and academics. There is a need for greater data sharing and open access data for ice hazard research. We should encourage industry (and other stakeholders) to share data or at least post their metadata so requests for access can be made. In particular, there are no repositories for ice hazard drift tracks, so this is an obvious starting point. Our discussion culminated with a recommendation to make a plan for the next major ice island calving event. We need to develop a protocol and get this endorsed by major organizations that might fund such an initiative, such as Petroleum Research Newfoundland and Labrador (PRNL) and CIS (who have large budgets for monitoring). A skeleton plan for logistics and science as well as a funding formula would greatly facilitate a rapid science/research response to an ice island calving.

Breakout Session #2: Modeling

Group A: Iceberg and ice island drift modeling (hours to days)

Chair: Hai Tran
Participants: Pat Barron Jr., John Bennett, Judith Bobbitt, Jack Chen, Luc Desjardins, Philippe Lamontagne, John McClintock, Des Power, Ron Saper, and Greg Warbanski.

The group recognized that there is an operational need for more accurate short-term forecasts of iceberg and ice island drift, and that these forecasts are needed to better assess risk and optimize ice management. Current tools often cannot correctly forecast short-term drift due to a shortage of accurate input data, notably ocean current data at appropriate scales, and iceberg shape information.

Typical operational models rely upon predicted wind and ocean current from external regional or global models, and then apply assumed drag coefficients and basic physical laws to accelerate the modelled ice masses. While the wind models are in relatively good shape and can be supplemented with measured surface winds, ocean current models will probably never be able to provide sufficient resolution of small scale eddies to derive accurate short term drift forecasts. Small eddies of this type are common on the Grand Banks and elsewhere. The small-scale eddies can be a few km across and vary both spatially and in temporally. Even very dense grid spacing for the model will not help since these must be supported with very dense observations that are impractical to implement.

Since currents can vary significantly in direction and strength over the range of depths at the scale of common icebergs, the underwater keel draft or shape of the ice mass can affect drift trajectory drastically. It is likely that more keel measurements will be needed for model verification and perhaps drift Modeling operations.

Some emphasized the need to measure the current directly below the iceberg or ice island at the start of a model run. This would be useful, but does not address the fact that, if small scale eddies are present, the current will be very different 2 km away or a few hours later. To be useful, the currents would have to be profiled from surface to the maximum draft of the iceberg, especially when wind driven currents can be expected to exhibit an Ekman spiral.

Sea surface height variations caused by weather systems are believed to contribute to surface currents as the water runs downhill after the low-pressure systems dissipate. While some report proprietary skill in predicting these kinds of surface currents and attest to their importance in predicting iceberg drift, most operational ocean and drift models are not able to exploit sea surface height measurements or pressure contours. More work could be done in this area.

While it is common to blame the model inputs for inaccurate drift forecasts, the certainty that ocean models will never be able to deliver the desired resolution suggests that fresh approaches are needed. It was noted that some work from the 1980's used so-called statistical approaches, and showed promise. In general the idea is to use to observed motion of the ice mass over time to estimate different ocean current components acting on a specific individual ice mass and then apply these to the forecast problem. Simply stated, the idea is to use information in the observed trajectories of icebergs to predict future motion. Current operational models do not use available trajectory tracks other than as a starting position and time for the model start. This is surprising because an iceberg (for example) behaves like a drift buoy with ideal characteristics for predicting currents acting on it.

It is generally believed that ocean models give good estimates of overall long term drift, and that physically-based drift models are still valuable, but that these should be somehow supplemented by the information in the observed drift of icebergs and ice islands, by improved knowledge of the underwater shape of the ice mass, and by examination of how ocean height data can be applied to estimation of barostrophic surface currents.

This lively discussion led to the conclusions that more *in-situ* measurements, fresh modeling approaches, and inclusion of barostrophic currents would help improve the accuracy of short-term drift models.

Group B: Iceberg and ice island deterioration modeling
Chair: Greg Crocker
Participants: Brad deYoung, Howard Edel, Mike Hicks and Derek Mueller

It was determined that the main users of iceberg deterioration models were academics, the North American Ice Service (NAIS) and the International Ice Patrol (IIP). Deterioration models are used by the aforementioned groups to fill in data gaps between reconnaissance flights and/or satellite imagery. It is of particular importance to the IIP who use deterioration models to help define their Limit of All Known Ice (LAKI). It was generally believed that they are of limited or no use for tactical operations as mass changes over the time scale of iceberg management operations are likely inconsequential. There may be some interest in deterioration models for longer term strategic planning, and iceberg population studies used in design engineering.

Known/current approaches to iceberg deterioration modeling

Deterioration is most commonly modeled using a method originally developed by White et al. in 1980. In this model, several contributing processes are assessed separately and then summed to give total deterioration. The processes include melt by solar radiation, wave induced melt, forced convection, buoyant convection, and calving. Iceberg drift and deterioration models in use today utilize this approach with very little modification since the original work 35 years ago. The individual processes are largely semi-empirical, with some based on engineering heat transfer equations for idealized shapes (e.g., forced convection), and some based on Finite Element Model (FEM) results (e.g., calving). In some cases the approximations are very crude. There has been very little evaluation of overall model performance due to a lack of useful field observations, and there has been almost no evaluation of the accuracy of the individual model components. In most cases the melt at all depths in water column are based on water temperatures observed or predicted at the sea surface only.

The deterioration of small ice masses (bergy bits and growlers) has been modeled at CIS using an empirical approach based on dimensionless groups. This was based on laboratory experiments and field observations (Ballicater Consulting Ltd., 2012). This approach is completely different from the component processes model used for parent icebergs and there is a discontinuity in modeling methods as iceberg sizes pass from >20 m in length to <20 m in length.

There have also been attempts to quantify iceberg deterioration rates using the changes in total ice mass or iceberg flux as a function of latitude. We are aware of at least one study of his type in the Antarctic (Budd *et al*, 1980)[3]. Also, there have been several studies of the overall deterioration of Antarctic icebergs in which single empirical models have been developed. These are based primarily on water temperature and ice drift speed. Some models of the melt of large Antarctic tabular icebergs and ice islands based on separate formulations for surface and basal ablation have also been developed. Some recent work at Carleton University has focussed on the surface ablation of ice islands (Crawford et al., 2015).

The challenges in iceberg deterioration modeling

The surface area of icebergs could vary significantly because of the irregular shapes. This is true not only from iceberg to iceberg, but also for individual icebergs over time. It is important because melting occurs at all exposed surfaces. Since detailed shape information is unlikely to be available in any operational context, this will contribute to the inherent uncertainty in any deterioration model.

[3] Budd, W., Jacka, T, and Morgan, V., 1980. Antarctic iceberg melt rates derived from size distributions and movement rates, Annals of Glac., 1:103-122.

The melt parameterizations were in some cases based on over-simplified models that do not accurately reflect the geometry or flow field. No easy solution was identified, and it was noted that it is a complex problem involving turbulent boundary layer dynamics, so simple solutions may not be achievable. In more northern regions the snow cover likely has an important effect on surface ablation of ice islands.

Lastly, the intermittent nature of iceberg calving (calving from icebergs, not calving of icebergs from glaciers) makes it difficult to predict/model except on average over long time periods. For ice islands major fracturing events play a key role in overall deterioration and are particularly difficult to model.

Priorities moving forward

The absence of an accurate and complete data set with which to calibrate and/or verify any new or improved iceberg deterioration models is a critical stumbling block to progress in this field. The data set must include observations of the mass of several different icebergs over long time periods (at least 3-4 weeks) in differing environmental conditions, particularly water temperatures and sea states. The errors in the mass or volume measurements at each time step must be small in relation to the change in mass over those time steps. Complete sets of environmental data should include wave period and height (ideally directional wave spectra), water temperature profiles, iceberg drift velocity, and ocean current velocity profiles. Detailed measurements of above water and below water shapes are also important. We did not discuss the ideal observation frequency for all environmental observations, but it is likely to be about every 3-6 hours. The frequency of iceberg size/shape data should be about daily and the frequency of the iceberg drift velocity should be half-hourly.

It was thought that quantifying the magnitude of individual melt processes would be difficult, although some information could be obtained from detailed observations of the change in shape over time. For ice islands the basal and surface melt could be separated out as could wave undercutting. Separate (perhaps laboratory) studies might be the best approach to identifying the importance of individual processes. High-resolution surface characterization including measurements of ice temperature profiles might also be useful for estimating near-surface stresses and estimating linear, site specific heat flux estimates.

For ice island deterioration, the data set being collected by CIS/Carleton University from RADARSAT-2 and other imagery could be used to determine average deterioration rates, and possibly the nature and significance of large scale fracture. Otherwise, the best approach to modeling large-scale fracture and calving of very large icebergs from ice islands is most likely to be achieved using numerical methods such as FEM.

Group C: Seasonal to inter-annual predictions and climatology
Chair: Adrienne Tivy
Participants: Angela Cheng, Abby Dalton, Marie-Andrée Giguère, Denise Sudom, and Carrie Young

Seasonal predictions

Two available techniques for short range forecasting were discussed: Provincial Aerospace Limited (PAL), a heuristic model based on early season survey, and North Atlantic Oscillation (NAO), which surveys sea ice extent and analog years, with guidance from the CIS and climatology.

A statistical forecast published by Ingrid Peterson on the BIO website is based mainly on sea ice extent. A follow up with Canadian Ice Service (CIS) operations on the construction of their outlook is needed.

A need for a three-category forecast was expressed to predict light, moderate and heavy iceberg years.

The following are required for improved seasonal forecasting:

- Accurate sea ice forecasts
- Historical iceberg population data, for example creating a homogenized time series from the IIP record of the number of icebergs south of 48°N
- Climate records covering surrounding operational areas

Interannual predictions

It is unknown whether any individuals/groups are providing interannual forecasts. It was thought that interannual forecasting would prove to be useful in planning for exploration activity. It was agree that interannual forcasting could be accomplished should a client require this.

Challenges to interannual predictions include:

- The gap between the glaciology community studying iceberg production and industry/PAL/IIP who monitors icebergs in the Grand Banks
- The processes controlling the exit of icebergs from fjords remains unknown
- Monitoring iceberg transit from Greenland to East Coast
- Difficulties associated with the detection of icebergs in pack ice
- Difficulties associated with tracking icebergs over many years

Iceberg climatology

Areal frequency is important to industry for the planning of future operations and exploration as well as to monitor and understand long-term change. Many groups are tackling this problem. The key challenge is estimating a population from observations of opportunity. Some useful techniques in wildlife biology might prove helpful.

Available datasets for iceberg climatology include: PERD iceberg sighting database, iceberg messages (iceberg observations from aircraft and ships), and detailed observations around offshore platforms. The National Research Council (NRC) is continuing to populate the iceberg sightings database. The CIS is currently importing all flight data into ArcGIS and mapping visibility boundaries and sightings. The CIS is also collaborating with the Danish Meteorological Institute (DMI) on a joint climatology based project on RADARSAT archives. C-CORE is developing a product for the Labrador Coast.

Issues concerning the development of an iceberg climatology from satellite imagery include:

- The disc space and computer power
- Validation and verification of detection techniques
- The selection of a detection algorithm to reliably detect icebergs of suitable size under specified conditions

Breakout Session #3: Research Priorities, Knowledge Gaps/Requirements
Group A: Immediate future supporting operations (1-2 years)
Chair: John McClintock
Participants: John Bennett, Judith Bobbitt, Greg Crocker, Luc Desjardins, Marie-Andrée Giguère, Philippe Lamontagne, Melissa Nacke, Paul Pestieau, Jonas Roberts, and Hai Tran

In Canada, (oil & gas) operations are mainly on the Grand Banks off the coast of Newfoundland. There remains continued interest in ice hazards study/application for the Grand Banks. This includes supporting oil production at:

- Hibernia – including Hibernia Southern Extension
- Terra Nova
- White Rose – including White Rose Extension Project
- Hebron – with first oil targeted before the end of 2017

There is additional interest now in the Sackville Spur, Flemish Pass areas, e.g., for Statoil's Bay du Nord discovery.

Ice chart data products

The NAIS (North American Ice Service) iceberg charts are essential for many users, particularly for oil & gas operators and service providers. Given their relevance here and to perhaps spark some potential new content or application interest a generic chart with description is available at (http://www.ec.gc.ca/glaces-ice/?lang=En&n=2E32310A-1).[1]

Considering the charts, there was group interest in what other information layers or elements 'behind' the charts might be made available to interested users. For example:

- Knowing details of the individual icebergs behind the degree square counts (including: size, shape, any measurements, location, and date-time iceberg histories back to the original siting)
- Drift model details on re-sightings and tracking of multiple icebergs
- A MANICE-type or other formatted export of the individual iceberg observations/history and/or drift tracks might be of interest

The regional eastern and western Arctic ice charts are issued weekly. The frequency of observations, and perhaps resources to produce the charts, are limitations to them being prepared on a daily basis (as the iceberg charts are in season) at least during parts of the year. Some research thought might go into ways to increase the frequency of these charts. It was acknowledged that some of the ice chart information, if provided, should only be used by 'qualified' personnel that are aware of the limitations and assumptions. The same sort of ideas, i.e., added info layers or content for end users, might be worth exploring for other data product sources beyond NAIS. The idea of course being simply to improve the information content, visualization or utility.

Improved data sharing

Sharing or 'publishing' data is conducive to its validation and potential use. Real-time observations for example are critical for weather, sea state, and ocean forecasting. ExxonMobil (Hibernia Management and Development Company, or HMDC) and Statoil operations in the Flemish Pass are being increasingly open with their data for real-time access by the world (and local) modeling and forecasting community. Atmospheric and oceanographic service provider Amec Foster Wheeler described the value to operational forecasting to these operators and they agreed to share the data. Other operators should be convinced to follow suit. Waves, sea surface temperature and surface currents from Hibernia are being provided every half hour to Environment Canada (EC) who in turn put standard WMO-formatted data onto the Global Telecommunications System (GTS). At Statoil's Flemish Pass location, waves and sea surface temperature are posted every half hour to the GTS. Over the next three winters Amec Foster

Wheeler will be deploying a 3-meter atmospheric/oceanographic buoy on the transit corridor between St. John's and Hibernia. This is a research and development project being performed for HMDC. Atmospherics, sea surface temperature and waves are measured by the buoy. No current measurements are planned for this winter but maybe next winter if the power budget allows. This buoy will be at Hibernia during the summer months to measure fog conditions (i.e. will have a visibility sensor and other sensors in the summer). Data will go to the GTS every half hour. The buoy belongs to the Marine Institute of Memorial University (MI) who are partners with Amec Foster Wheeler in the HMDC Metocean R&D project. These monitoring and data reporting activities are particularly valuable since Environment Canada is presently limited in supporting the maintenance and operation of their offshore buoy network.

Iceberg observations are similarly essential to communicate and share for NAIS iceberg chart and bulletin production, and for any ice management service providers for the offshore. In addition to these operational practicalities, open and transparent sharing of these data is essential for marine safety and should be made mandatory. On a less frequent basis, say at the end of the ice season, observations should be quality controlled and go into the appropriate databases such as the NRC PERD iceberg-sighting database.

Populating CIS iceberg drift models

Iceberg sightings are required to seed the CIS iceberg drift models. Ideally these observations are far enough upstream (off Labrador or farther north) so that results are as complete, as informative and as timely as possible. Unless there are dedicated or opportune fixed-wing flights or reconnaissance planned, efforts upstream are generally limited to analysis of remote sensing data (where spatial and temporal coverage may be less than ideal).

No simple solutions were suggested; however, review of what additional data sources, including additional satellite imagery, or other opportunistic data sources, modeling or approximation techniques could be employed.

Long iceberg track histories and measurement records

Measurements over long periods of time, e.g., many days or longer, would improve understanding of iceberg deterioration particularly for ice islands with their long histories and significant risk they occasionally pose to offshore drilling and shipping. Deterioration is also of interest for iceberg drift estimation. At the other end of the size spectrum, bergy bit melt rates are usually based on lab studies, so some smaller time scale focus of several days might also be appropriate.

Any detailed observation record of iceberg date-time, location, and at least some iceberg size estimates or measurements, are quite valuable for iceberg drift modeling studies. If possible, coincident *in situ* or regional measurements of wind, current profile, and possibly ocean surface temperature and sea state should be measured or estimated as well. As with all data collection programs, good, complete metadata documentation should be assembled as well. Various forecast and reanalysis products might be employed to fill some of these gaps.

Iceberg profiles

Iceberg draft can be a key parameter for iceberg trajectory drift modeling, iceberg mass estimation, ice management, ice engineering design, and hydrocarbon production planning requirements. A number of iceberg profiling technologies exist for measurement of iceberg draft. These are largely ship-based though some research with gliders has been carried out. Several empirical relationships for estimating iceberg draft based on iceberg length are in use. While limited historical draft data exist for the Grand Banks, bigger iceberg draft information gaps exist for Bay du Nord or other interests for the Flemish Pass and areas farther north. The offshore supply vessels that generally deploy the equipment are frequently busy with other activities supplying and serving personnel and materials for the platforms. Ways to promote operational use of the various profiling systems and collect additional data are needed. This would result in:

- Additional data sets - to support the requirement areas noted above
- Improved confidence in the measurements
- Opportunities for continuous improvement in how the systems are used
- Iceberg drift models

Verification of modeled iceberg tracks

Verification of iceberg drift model results is essential to demonstrate confidence in the results, and to identify possible ways to improve inputs and the drift algorithms. While terms such as fairly good – where the metric was predicted trajectory within 30° of actual track – or bad, having well-defined measures of model accuracy or 'key performance indicators' might could be a beneficial component of quantifying model accuracy. Particular areas to verify are the Grand Banks for ongoing operations, and also Flemish Pass where future development activities are planned.

Verification of modeled ocean currents

A practical component needed is validation or verification of the various models. This is a major gap. An increase in real-time current observations is one way to address this and improved data sharing as noted above would facilitate this. The observations can be used for data assimilation, when models can do that, and for general model tuning. Other means to address verification of modeled currents are needed. Establishing data sets for model testing for new domains such as Orphan Basin, Flemish Pass would support this task. Some government and industry data exist in these regions, though some may be propriety or other limitations for their use exist. For new data collection programs, "Iceberg-like" drifter drogues centered to mimic iceberg drafts were one suggestion. Conventional current meter strings are another obvious means. The general requirements include determining and designing which areas to monitor and securing capital and operating cost funding support. While one or two people mentioned a need for a new current model, the consensus appeared to be that there were already enough current models, and that instead more observations were needed.

Link Research and Observational Priorities to Activities

As one means to identify where or how Research and Observational Priorities (ROPs) might fit in practice, the table below presents a preliminary mapping of ROPS to activities that might be encountered or planned, or to selected stakeholders. The table cell entries indicate the author's initial assessment only of the likely significance or interest for each ROP-stakeholder pair. Clearly, follow-up dialogue with each group of stakeholders would be required to confirm the level of significance indicated. For example not all researchers or operators might share the same interest in a particular topic.

Having some specification or objectives for what information is required or ideally to be collected for each would help ensure any such exercises yield the most useful results. This is also helpful in working with stakeholders to demonstrate the need and resultant value to be achieved in promoting or selling the requirement for projects and vessels of opportunity. On consideration with these topics and ROP efforts should be kept in mind. That is, which of these items, in fact, a) truly need, or might lend themselves well to, a dedicated research program and course of critical investigation, and which b) may be addressed in other ways, e.g., through changes in operating practice, such as implementation of real time observations. With that consideration aside, that is, how these ROPs might be tackled, they are all items that would benefit from attention in the immediate time horizon of one to two years.

Table 1: Immediate future ROP and activities with estimated stakeholder interest (DRAFT)

	Offshore Oil & Gas Exploration	Offshore Oil & Gas Production	Shipping, Marine Transportation, Fishing	Environmental Monitoring (incl. service providers)	Government of Canada (e.g., DFO, EC) Operations or Research	Provincial or Territorial Governments (e.g., NL, NS, NU)	Academia (e.g., Carleton, MUN, U Ottawa, Dal)
Ice chart data products	High	High	Moderate	High	High	Moderate	Moderate
Improved data sharing	Moderate	Moderate	Low	High	High	Moderate	Moderate
More remote sensing	Low	Low	Moderate	High	High	Low	High
Populating CIS iceberg drift models	Low	Low	Low	Moderate	High	Low	Moderate
Long iceberg track histories and measurement records	Low	Low	Low	Moderate	Moderate	Low	High
Iceberg profiles	Moderate	Moderate	Low	Moderate	Moderate	Low	Moderate
Verification of modeled iceberg tracks	High	High	Low	High	High	Low	Moderate
Verification of modeled ocean currents	Moderate	Moderate	Low	High	High	Low	Moderate

Group B: Medium & long-term future (3-10 years)
Chair: Mike Hicks
Participants: Pat Barron Jr., Abby Dalton, Brad deYoung, Howard Edel, Derek Mueller, Ron Saper, Adrienne Tivy, Wesley van Wychen, and Carrie Young

The focus of the group was on understanding questions of glacial ice hazard climatology. All agreed to de-emphasize time frame in favour of focusing on taking advantage of existing opportunities to advance key work areas.

Generally speaking, the group agreed that there is a need to improve our collective understanding on how climate change is impacting the cryosphere (e.g. ice hazards associated with melting glaciers with respect to water resources and/or outburst flooding). The group agreed that the terrestrial cryospheric change is an important topic but not the highest priority for this working group.

During the discussion a series of questions about the impact of climate change on glacial ice hazards emerged. These included:

- Is there a connection between the number of icebergs transiting south of 48^{o}N latitude (and into the transatlantic shipping lanes) and observed changes in glacial calving rates?
- What is the relationship between ice hazard shape and observed changes in calving rates? i.e., is there a larger quantity of tabular ice island fragments being observed than in previous years? If so, what is causing this change?
- Recent observations from Canadian Coast Guard vessel captains suggest that ice hazards adrift near the Grand Banks and Labrador coast operating areas appear to be smaller than in previous years. Can we explain this observation?

Answers to these questions are key to those who are involved in planning long term activities in the vicinity of ice hazards, e.g., CIS, IIP, oil/gas industries, and academia

The group acknowledged the importance of understanding the time scales at which various processes occur. For example, icebergs that drift south of 48^{o}N during any given ice season depend on the sea-ice extent off the Newfoundland and Labrador coasts which, in turn, is governed by the predominant atmospheric and oceanographic conditions during the months preceding the height of the ice season (Dec-Feb). Whereas variations in calving rates at a particular glacier occur due to fjord topography/oceanography and interactions between the glacier and sea ice. Calving rates may change on the order of several years while changes in the primary glacial source of ice hazards may change on the order of decades.

Observations and measurements drive the science of these processes. All agreed that remote sensing plays an essential role in gaining insight, particularly in the remote areas of the high Arctic. The European Space Agency (ESA) Polar Thematic Exploitation Platform (Polar TEP) was identified as a means to "*provide polar researchers with access to computing resources, earth observation and other data, and software tools in the cloud. This will be deployed and integrated to allow users to investigate linkages between iceberg populations, observed and modeled changes in ice sheet movement and calving rates…*". The group agreed that there should be representation with ESA and CSA for capturing ice hazard monitoring requirements. Which is feasible as the CIS has a good connection with CSA, and ESA is a frequent participant in the International Ice Charting Working Group (IICWG).

In situ measurements at the glacier and on drifting ice hazards are also vital to validate satellite observations and to attain ice characteristics that are inaccessible from space. Due to time and cost, *in situ* observations must be prioritized. A suggested approach might be to identify three high priority glaciers for study from the Canadian Arctic Archipelago, as well as from west and east Greenland. Trinity and Wykeham glaciers on Ellesmere Island were identified as particularly high priority study areas.

The group discussed the idea of using a regional numerical model to explore the question of the role of glacial calving rate in determining the iceberg flux at 48^{o}N. There has been a large increase in glacial outflow from Greenland. Has this change influenced the number of icebergs seen on the Grand Banks? The suggestion was to use a regional numerical model, one that properly includes sea ice and has a well-resolved shelf-circulation, to explore the iceberg dynamics under differing conditions of iceberg source numbers. One approach would be to combine different source numbers – low, medium and high – with differing environmental conditions – negative, neutral, positive North Atlantic Oscillation (NAO) phase – to see how such variables influence the number, and perhaps volume, of icebergs passing 48 ^{o}N. It was recognized that this would be a challenge both for the ocean modeling and for the iceberg modeling, in particular representing the breakup and deterioration of the icebergs.

Discussion continued on the need for developing a protocol for responding to episodic ice island calving events long before this occurs. This would document important factors to consider after such an occurrence. Key elements of such a protocol would be to identify candidate sources for funding any research with an explanation of why this research is important, particularly to these potential funding sources.

The group also suggested the need to design an experiment that uses a map (or schematic) illustration that shows a series of research activities that would occur on different time scales: seasonal, decadal or climatological. The map would provide geospatial context to this experiment. Further details could be provided in a table for each time scale. For example:

Process	**Observations**	**Output**
Icebergs drifting south of 48^{o}N	Ice hazard sightings reported to IIP by aircraft and ships.	Time series of annual variability for ice hazards affecting transatlantic shipping.

Discussion Highlights

The following bulleted list summarizes highlights for this discussion:

- Understanding the impact of climate change on the cryosphere is an overarching theme to the group's discussion. Terrestrial glacial change is a part of the problem though the group focused discussion on marine glacial hazards.
- Both remote sensing and *in situ* observations are key to gaining an understanding of the processes affecting glacial ice hazards – from 'cradle to grave' so to speak. Staying attuned to changes in remote sensing is key; *in situ* measurement activities must be prioritized.
- Developing a protocol that documents best practices in response to significant calving events would be valuable. These should include potential research funding sources and justification to those sources for conducting research.
- Processes that influence interested parties (research, government and industry) occur at different time/spatial scales. A schematic illustration that shows activities/experiments along the path of an ice hazards would help visualize the problem.
- Glacial calving and iceberg deterioration should be considered in freshwater budget assessments.

The key elements of support include improved knowledge of iceberg (and presumably sea ice, though most of the discussions focused just on icebergs) climatology, drift modeling and risk assessment. For drift modeling, validated current models continue to be of interest. These in turn require near real-time current observations. Additional iceberg measurements are also needed to develop physical environment databases for planning and design activities for hydrocarbon production.

People want to be aware of activities such as oil & gas exploration, marine transportation for off Labrador and north to Baffin Bay or beyond; however, there weren't many specifics brought forward by the group. Nevertheless, these were felt to be areas of opportunity to be aware of so that new needs and challenges could be identified and addressed with further research such as measurement or modeling activities.