Toward user-relevant seasonal forecasts of Arctic sea ice: The FRAMS project

Bill Merryfield

Canadian Centre for Climate Modelling and Analysis (CCCma)
**Forecasting Regional Arctic Sea Ice from a Month to Seasons**

Funded by Canada’s Marine Environmental Prediction and Response network (MEOPAR) 
Endorsed by Year of Polar Prediction (YOPP)

- **Overall objective**: develop multi-model *user-relevant* forecasts of Arctic Sea ice on time scales from a month to seasons

- Seasonal sea ice forecasting capabilities for ECCC, including Canadian Ice Service

- Multi-model sea ice forecasting capabilities for the WMO ArcRCC, inputs for PARCOFs
Regional Climate Centres (RCCs)

WMO seasonal forecasting framework

Lead Centre

Regional Climate Outlook Forums (RCOFs)
Regional Climate Centres (RCCs)

WMO seasonal forecasting framework

Lead Centre

Regional Climate Outlook Forums (RCOFs)
Welcome to the Arctic RCC Network

RCCs are Centres of Excellence that assist WMO Members in a given region to deliver better climate services and products including regional long-range forecasts, and to strengthen their capacity to meet national climate information needs.

ArcRCC-Network is based on the WMO RCC concept with active contributions from all the Arctic Council member countries through a mutually agreed structure consisting of three sub-regional geographical nodes, namely, (i) North America Node, (ii) Northern Europe and Greenland Node and (iii) Eurasia Node.

**Climate monitoring**

Climate monitoring products to be shown here.

**Long-range forecasting**

Products like seasonal outlooks.

**Data access**

Search datasets for the Arctic.

**Northern Europe and Greenland Node**

Collaboration between Norway, Sweden, Denmark, Finland and Iceland.

**North American Node**

Collaboration between Canada and USA.

**Northern Eurasia Node**

Led by the Russian Federation.

Norway: data services  Canada: forecast production  Russia: climate monitoring
development and delivery of seamless, reliable and high-quality products and services for the pan-Arctic region including provision of LRF using an MME approach with products of relevance for the whole Arctic (e.g., sea ice)
FRAMS overview

• 485k Canadian $ over 3 years (~2018-2021)
• 1 Postdoc, 1 PhD, 2 MSc

Funded investigators

Bertrand Denis, ECCC-MSC/UQAM
Bruno Tremblay, McGill U.

Chris Bone, Geography, U. Victoria
Bill Merryfield, ECCC-CCCma/U. Vic.

Collaborators

Adrienne Tivy, ECCC-CIS
Greg Smith, ECCC-MRD
Jean-François Lemieux, ECCC-MRD
Steve Howell, ECCC-CRD

Michael Sigmond, ECCC-CCCma
Jackie Dawson, Geography, U. Ottawa
Ron Pelot, Engineering, Dalousie U.

End Users – Fednav, Canadian Coast Guard,…
FRAMS Components

- **Forecasting component**: acquire data from forecast models, develop multi-model forecast products

- **Analysis component**: understand processes associated with sea ice predictability, model errors

- **End user component**: meet with end users to mutually understand end user needs and forecast capabilities, co-design products
## Forecasting component

### Forecast models

<table>
<thead>
<tr>
<th>label</th>
<th>name</th>
<th>centre</th>
<th>sea ice component, rheology</th>
<th>max resolution/range</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>CanCM3/4</td>
<td>MSC</td>
<td>CanICE, cavitating fluid</td>
<td>≈200 km / 12mon</td>
</tr>
<tr>
<td>M2</td>
<td>GEM-NEMO</td>
<td>MSC</td>
<td>CICE, 5 ice categories, EVP</td>
<td>≈ 40 km / 12mon</td>
</tr>
<tr>
<td>M3</td>
<td>CFSv2</td>
<td>NOAA (US)</td>
<td>GFDL SIS, 5 ice categories, EVP</td>
<td>≈ 40 km / 9 mon</td>
</tr>
<tr>
<td>M4</td>
<td>System 5</td>
<td>Météo France</td>
<td>GELATO, 4 ice categories, EVP</td>
<td>≈ 40 km / 6 mon</td>
</tr>
<tr>
<td>M5</td>
<td>GloSea5</td>
<td>Met Office</td>
<td>CICE, 5 ice categories, EVP</td>
<td>≈ 10 km / 6 mon</td>
</tr>
<tr>
<td>M6</td>
<td>SEAS5</td>
<td>ECMWF</td>
<td>LIM2</td>
<td>≈ 10 km / 7 mon</td>
</tr>
<tr>
<td>M7</td>
<td>En-GIOPS</td>
<td>MSC</td>
<td>CICE, 10 ice categories, EVP</td>
<td>≈ 10 km / 1 mon</td>
</tr>
</tbody>
</table>

### Forecast products

<table>
<thead>
<tr>
<th>Forecast element</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice extent/area</td>
<td>benchmark for comparison with previous studies</td>
</tr>
<tr>
<td>Sea ice probability (SIP)</td>
<td>probability of local concentration exceeding user-defined thresholds</td>
</tr>
<tr>
<td>Ice-free/freeze-up dates</td>
<td>timing of local seasonal ice retreat and advance</td>
</tr>
<tr>
<td>Canadian Ice Service outlook</td>
<td>Model-based CIS Seasonal Outlook, updated based on user inputs</td>
</tr>
<tr>
<td>Shipping-relevant products</td>
<td>innovative tailored products incorporating feedback from end users</td>
</tr>
</tbody>
</table>
Calibrated Sea Ice Probability: $P(\text{SIC} > 15\%)$


May-init 2018 September SIP

Calibrated forecasts far more similar to each other than raw forecasts
Calibrated Sea Ice Probability: $P(SIC > 15\%)$


Calibrated forecasts far more similar to each other than are raw forecasts
Continuous Rank Probability Skill Score (CRPSS) vs climatology 1993-2010

**Reliability and Brier Score 1993-2010**

*developmental version

A. Dirkson plots

*September from May*
Available GPCs + GFDL-FLOR

Sep Multi-Model CRPSS vs initialization month

ECMWF     Met Office     MF     ECCC     (GFDL)
SEAS5 + GloSea5 + System 5 + CanSIPS + FLOR

2000-2015 Multi-Model September Hindcast Skill
CRPSS = 1 – CRPS_{fcst}/CRPS_{climo}

Dirkson et al. in preparation
Skillful seasonal forecasts of Arctic sea ice retreat and advance dates in a dynamical forecast system

M. Sigmond, M. C. Reader, G. M. Flato, W. J. Merryfield, and A. Tivy

Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, British Columbia, Canada, 2Canadian Ice Service, Environment and Climate Change Canada, Ottawa, Ontario, Canada

• Define
  - Ice-free date (IFD): SIC<50% for ≥10 days
  - Freeze-up date (FUD): SIC>50% for ≥10 days

• FUD more skillful than IFD

• Requires daily SIC
Forecast anomaly (base: 2009-17)

Observed anomaly (base: 2009-17)

Historical skill (detrended ACC for 1981-2010)

- Correctly predicted the **late** ice-free dates in Hudson Bay and Baffin Bay

- Also correctly predicted **late** ice-free date in Kara, E Siberian and Beaufort seas, and **early** ice-free date in Laptev and Chukchi Seas
FRAMS outputs are contributing to WMO PARCOFs

Second Session of the Pan-Arctic Regional Climate Outlook Forum (PARCOF-2), virtual forum, October 2018

Consensus Statement for the Arctic Winter 2018-2019 Season Outlook

Figure 10: Forecast for the 2018 Fall freeze-up (a) actual freeze-up date and (b) anomaly (difference from normal) based on the 2009-2017 period. The freeze-up date is first day when the ice concentration exceeds 50%.

Figure 11: March 2019 probability of sea ice at concentrations greater than 15% from CanSIPS (ECCC). Ensemble mean ice extent from CanSIPS (black) and observed mean ice extent 1998-2017 (green).
Next steps

- **Real time multi-model** SIP & IFD/FUD forecasts for ArcRCC/PARCOF

- **Probabilistic IFD/FUD forecasts**

- **Bias correction of Polar Pathfinder** ice motion vectors

- **Evaluate ice drift forecasts** using bias corrected Polar Pathfinder as truth

- **WMS-based visualization** of forecast & sea ice information

- **Upgrade Canadian Ice Service outlooks** using model-based predictors
Extra slides
Timeline for seasonal sea ice forecasting

*1st operational seasonal prediction system with interactive sea ice

**mirrors current Met Office system
Timeline for seasonal sea ice forecasting

Scientific literature

Forecasts of pan-Arctic sea ice extent/area
(deterministic forecasts of anomalies)

- Wang et al. (2013) CFSv2
- Sigmond et al. (2013) CanSIPS
- Merryfield et al. (2013) CanSIPS + CFSv2
- Chevallier et al. (2013) pre-MF System 5
- Peterson et al. (2014) GloSea4

NCEP
CFSv2

Met Office
GloSea4*

ECCC
CanSIPS

Météo-France
System 5

JMA-MRI
CPS-2

KMA
GloSea5GC2**

ECMWF
SEAS5
Seasonal forecasting challenges specific to sea ice

1) **Initialization**, especially of ice thickness
2) **Consistency** of initialization between hindcasts & real-time forecasts
3) **Bias correction** for concentration variable defined on $[0,1]$
4) **Fitting and calibration** of distribution defined on $[0,1]$
CanCM3/4 sea ice concentration biases

Freely running model 1981-2010 vs HadISST1.1

CanCM3

CanCM4

March

September

Merryfield et al. MWR (2013)
Standard procedures for seasonal forecasting

Ensemble of initialized forecast runs

Bias correction, calculation of anomalies

Fit raw anomalies to distribution

Calibrate fitted distribution
Sea ice probabilistic forecast method

Step 1: Fit “count” concentrations to **inflated beta distributions** on $[0,1]$

Step 2: Calibrate forecast distribution through *trend adjusted quantile mapping* derived from hindcasts:

---

**Observed**

**Trend-adjusted**

Dirkson et al. J. Clim. 2018
Sea ice probabilistic forecast method

**Step 1:** Fit “count” concentrations to **inflated beta distributions** on \([0,1]\)

- Beaufort
- Chukchi
- Laptev
- Kara
- Barents
- Central Arctic

**Step 2:** Calibrate forecast distribution through **trend adjusted quantile mapping** derived from hindcasts

**Hindcasts 1981-2011**

- Obs
- Hindcasts
- Calibrated

**Forecast 2012**

- Uncalibrated

*Dirkson et al. J. Clim. 2018*
Ice-Free Date skill

Based on anomaly correlation coefficient (ACC)

M. Sigmond plots

ACC May init.

Earliest

Max. lag

Current initialization

Improved initialization

M. Sigmond plots
Freeze-Up Date skill

Based on anomaly correlation coefficient (ACC)

ACC Nov init.  Earliest  Max. lag

Current initialization

ACC Nov init.  Earliest  Max. lag

Improved initialization

M. Sigmond plots
Freeze-up date, 30 Sep 2018 initialization

Forecast and current ice edge

Forecast anomaly
base period: 1981-2010

Median ice edge
1981-2010

Sea Ice Extent, 20 Nov 2018
Freeze-up date, 30 Sep 2018 initialization

*Forecast and skill*

**Forecast anomaly**  
base period: 1981-2010

**Historical skill**  
detrended ACC for 1981-201

→ Regions where *early* or *late* ice edge observed are relatively skillful
Second Session of the Pan-Arctic Regional Climate Outlook Forum (PARCOF-2), virtual forum, October 2018

Consensus Statement for the Arctic Winter 2018-2019 Season Outlook

**Fall Freeze-up**

Freeze-up Date and Concentration: 50%

- Mar 30
- Mar 1
- Feb 1
- Jan 1
- Dec 1
- Nov 1
- Oct 1

**Freeze-up Date Anomaly Climatology Period 2006-2017**

- later than normal
- near normal
- earlier than normal

**March 2019 Sea Ice Extent**

- near normal
- below normal

**Table 1:** Outlook for fall freeze-up by region

<table>
<thead>
<tr>
<th>Region</th>
<th>Fall freeze-up</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hudson Bay/Baffin Bay/Labrador Sea</td>
<td>earlier than normal</td>
<td>moderate to high confidence</td>
</tr>
<tr>
<td>Gulf of St. Lawrence</td>
<td>near normal</td>
<td>low confidence</td>
</tr>
<tr>
<td>Greenland Sea</td>
<td>later than normal</td>
<td>moderate confidence</td>
</tr>
<tr>
<td>Barents Sea</td>
<td>later than normal</td>
<td>high confidence</td>
</tr>
<tr>
<td>Kara/Laptev-East Siberian Seas</td>
<td>earlier than normal</td>
<td>high confidence</td>
</tr>
<tr>
<td>Chukchi Sea</td>
<td>near normal</td>
<td>low confidence</td>
</tr>
<tr>
<td>Beaufort Sea</td>
<td>later than normal</td>
<td>moderate confidence</td>
</tr>
<tr>
<td>Sea of Okhotsk</td>
<td>near normal</td>
<td>low confidence</td>
</tr>
<tr>
<td>Bering Sea</td>
<td>later than normal</td>
<td>moderate confidence</td>
</tr>
</tbody>
</table>

**Table 2:** Outlook for winter 2018-2019 sea ice extent by region

<table>
<thead>
<tr>
<th>Region</th>
<th>Sea-ice extent</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenland Sea</td>
<td>near normal</td>
<td>[low confidence]</td>
</tr>
<tr>
<td>Gulf of St. Lawrence</td>
<td>below normal</td>
<td>[moderate confidence]</td>
</tr>
<tr>
<td>Bering Sea</td>
<td>below near normal</td>
<td>low confidence</td>
</tr>
<tr>
<td>Barents Sea</td>
<td>below to near normal</td>
<td>[moderate confidence]</td>
</tr>
<tr>
<td>Sea of Okhotsk</td>
<td>below to near normal</td>
<td>low confidence</td>
</tr>
<tr>
<td>Labrador Sea</td>
<td>below to near normal</td>
<td>[low confidence]</td>
</tr>
</tbody>
</table>

**Figure 10:** Forecast for the 2018 Fall freeze-up (a) actual freeze-up date and (b) anomaly (difference from normal) based on the 2006-2017 period. The freeze-up date is the first day when the ice concentration exceeds 50%.

**Figure 11:** March 2019 probability of sea ice at concentrations greater than 15% from CanSIPS (ECOS). Ensemble mean ice extent from CanSIPS (black) and observed mean ice extent 1988-2017 (grey).
Planned upgrade to CIS seasonal outlook

Existing Seasonal Outlook
North American Arctic Waters
Summer 2014

Table 2: Eastern Arctic - Outlook Dates

<table>
<thead>
<tr>
<th>Arctic Events</th>
<th>Earliest Date (1968-2013)</th>
<th>Latest Date (1968-2013)</th>
<th>Median (1981-2010)</th>
<th>Outlook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baffin Bay Northern Route</td>
<td>10 Jun</td>
<td>18 Aug</td>
<td>13 Jul</td>
<td>5-7 Jul</td>
</tr>
<tr>
<td>- Open drift or less</td>
<td>13 Jun</td>
<td>15 Sep</td>
<td>27 Jul</td>
<td>19-21 Jul</td>
</tr>
<tr>
<td>- Bergy water</td>
<td>10 Aug</td>
<td>7 Oct</td>
<td>6 Sep</td>
<td>22-24 Aug</td>
</tr>
<tr>
<td>Baffin Bay Area</td>
<td>10 Aug</td>
<td>7 Oct</td>
<td>6 Sep</td>
<td>22-24 Aug</td>
</tr>
<tr>
<td>- Bergy water</td>
<td>10 Aug</td>
<td>7 Oct</td>
<td>6 Sep</td>
<td>22-24 Aug</td>
</tr>
<tr>
<td>Frobisher Bay to Home Bay Route</td>
<td>22 Jul</td>
<td>19 Sep</td>
<td>5 Aug</td>
<td>30 Jul-1 Aug</td>
</tr>
<tr>
<td>- Open drift or less</td>
<td>24 Jun</td>
<td>15 Sep</td>
<td>25 Jul</td>
<td>21-23 Jul</td>
</tr>
<tr>
<td>Frobisher Bay to Cape Dyer Route</td>
<td>24 Jun</td>
<td>15 Sep</td>
<td>25 Jul</td>
<td>21-23 Jul</td>
</tr>
<tr>
<td>- Open drift or less</td>
<td>24 Jun</td>
<td>15 Sep</td>
<td>25 Jul</td>
<td>21-23 Jul</td>
</tr>
</tbody>
</table>

- Envisaged advance is for these forecasts to become
  - model-based (direct or downscaled)
  - probabilistic
  - accompanied by skill measure

- Content may change based on end user needs
POLARIS/AIRRS indicators

- Navigation safety indicator based on ice conditions & ship class:

\[ RIO = C_1RV_1 + C_2RV_2 + \ldots + C_nRV_n \]

Risk Index Outcome

Concentration of ice type \( i \)

Risk Value \( n \)

Based on data from digitized CIS charts →

Stoddard et al. (2016)
POLARIS/AIRRS indicators

- ECMWF and FMI have been experimenting with POLARIS/RIO forecasting
- Ice types from regression on model variables

Extended-range sea ice forecasts for ship routing (ship class PC5)

1 July 2017 (30 days ahead)

15 July 2017 (45 days ahead)

Figure by J. Haapala, A. Gierisch, P. Uotila

Go
Go slowly
No go

Green: RIO \geq 0, \text{ permitted}
Yellow: -10 \leq RIO < 0, \text{ reduced speed}
Red: RIO < -10, \text{ not permitted}

Colour saturation: uncertainty of forecast
POLARIS/AIRRS navigability indicators

- Jackie Dawson will be sharing ship track database, initially for Hudson Bay