Arctic Sea-Ice Prediction: Challenges and Opportunities

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Sea Ice Prediction Network

Photo by Matt Kennedy, 2012
Extreme Ice Project
Our goals are to

- Improve sea ice forecasts
- Advance the Sea Ice Outlook
- Improve sea ice models
Network Leadership Team

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Jim Overland, NOAA/University of Washington
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Elizabeth Hunke, Los Alamos National Laboratory

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National Oceanic and Atmospheric Administration (NOAA)
National Aeronautics and Space Administration (NASA)
Department of Energy (DOE)
Sea Ice Outlook and the Prediction Network

June, July, August 2014 Sea Ice Outlook contributions by method (total n = 79)

+ Spread of quantitative methods is narrowing
+ Bias decreases over time
Sea Ice Outlook and the Prediction Network

June & July 2015 Sea Ice Outlook contributions by method (total n = 63)

September mean sea ice extent, million km²

- Heuristic: n = 8
- Statistical: n = 27
- Modeling: n = 22
- Mixed: n = 6

2014 observed

Figure by Larry Hamilton
Sea Ice Forecast Systems

Challenges:
- Initialize non-observable quantities (e.g., ice thickness)
- Need to know observation uncertainty for ensemble generation
- Sea ice ensemble methods and coupled data assimilation not well developed
- Model error
- Metrics for calibration not well developed
- Requires massive computing effort
Synthesis of Sea Ice Outlooks through 2014

Stroeve, Hamilton, Bitz, & Blanchard-Wrigglesworth (2014)

+ Evidence now that some forecasts systems are better
Forecast of September Sea Ice Extent at 4 Month Lead Time

+ Retrospective forecasts in these 5 models are skillful
+ Shows importance of retrospective forecast

Figure by E. Blanchard-Wrigglesworth
Forecast of September Sea Ice Extent at 4 Month Lead Time

Persistence (level to beat)

Forecasts

Bias in sea ice extent (RMSE in $10^6 \text{km}^2$)

Not known why some retrospective forecasts are more skillful than Outlooks

Figure by E. Blanchard-Wrigglesworth
Forecast of September Sea Ice Extent at 4 Month Lead Time

Skill of Atmospheric Circulation Forecasts from ECMWF

Fig by A Simmons

about as good as weather forecast at ~10 day lead time
Forecast of September Sea Ice Extent at 2 Month Lead Time

Bias in sea ice extent (RMSE in $10^6$ km$^2$)

Not known why less skillful at shorter lead time
Method for Estimating **Predictability**

Compare ensemble forecasts to another ensemble member

**Sea Ice Area in million km\(^2\)**

- **Parent Model Run**
- **Model Ensemble, perturbed from parent**

Spread is from chaos, it’s irreducible
Forecast of September Sea Ice Extent at 2 Month Lead Time

Persist (level to beat)

Predictability Estimates

Forecasts

Bias in sea ice extent (RMSE in $10^6$ km$^2$)

+ Predictability indicates room for improved forecasts
What Gives Us Sea Ice Predictability?

Initial state: concentration, thickness, SST, melt ponds, snow depths

Transport with currents and winds

Climate forcing: CO\textsubscript{2}, aerosols, etc

What inhibits Predictability?

Atmospheric weather/chaos is irreducible

Why don’t we achieve predictability?

Model errors, Initialization errors, climate forcing uncertainty
Stroeve et al., 2015; Fig by Ed Blanchard-Wrigglesworth

5 model mean captures reduced Laptev ice, but not as much as observed.
Sea Ice Outlook Spatial Distributions

Probability of Sea Ice Presence by Model

- Multi-model is best forecast
- Forecasts capture 2014 features in some areas
- Still working on evaluation methods

Figure by Ed Blanchard-Wrigglesworth
Sea Ice Outlook Spatial Distributions

First Ice-Free Day (IFD)

B-W / NCAR CESM1
Cullather / NASA GMAO

Observed
Wang / NOAA CFSv2

Initialized 7 Aug, so can’t predict prior to day 220

Figure by Ed Blanchard-Wrigglesworth

May 1=121
June 1=152
July 1=182
Aug 1=213
Sep 1=244

Julian Day

120 140 160 180 200 220 240 260
Sea Ice Outlook Spatial Distributions

Distribution of Ice Free Day (IFD) Observed and in 2 Contributions

Laptev Sea south of 86°N

- x Observed 2014
- Red square Observed 2000–2014 Climato
- Blue triangle NCAR CESM Forecast
- Green circle NASA GMAO Forecast

Forecast(s) captured 2014 anomaly & distinct from climatology

here too
High Resolution and Global Coverage

Refined mesh grids, here showing an unstructured Veronoi mesh
Best qualities of regional and global models

Figure by W. Skamarock
Predicting Arctic Sea Ice
+ Even now we could provide thickness, snow depths, ridged-ice fraction, ice age

Soon we could provide lead orientation, floe size
Summary

Sea ice forecasts are currently skillful at least 4 months in advance of September. Predictability is even longer.

Challenges:
- Initialize variables that aren’t well-observed
- Improve models
- Coupled, multivariate data assimilation for ensemble initialization
- Improve evaluation and calibration methods

Opportunities:
- Beyond September, Beyond extent, Beyond monthly
- Refined mesh grids, new rheologies and model physics
- Acquire observations that we know will help
We are collecting and tabulating details about forecast systems

<table>
<thead>
<tr>
<th>Model characteristics</th>
<th>Kauker et al.</th>
<th>NRL-ACNFS</th>
<th>Blanchard-W. et al.</th>
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<th>Zhang and Lindsay</th>
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Network Function, since September 2013

- Sea Ice Outlook Calls (3 times each summer)
  Each followed by Report

- Co-authored papers & CLIVAR newsletter

- Research highlights and informational webinars
- AGU meetings
- Annual workshop
- Periodic telecons with action teams

- Excellent website, updated nearly daily
- Email lists

- And more
Lessons learned from the 2014 SIO modeling contributions

- All groups run ensembles of simulations, most with more than 10 members
- Uncertainty associated with stochastic atmospheric forcing is well evaluated
- Some groups have started providing user-relevant diagnostics
- Uncertainty associated with initial conditions is not systematically evaluated
- Uncertainty associated with model parameters/physics is not evaluated
- Predictions become more confident (individually and as a group) over time

Slide from F Massonnet
Advanced Analysis of SIO Contributions

Example for the “Pan-Arctic September” contributions

June 2014 Sea Ice Outlook contributions by method (total $n = 28$)
Heuristic, statistical, all modeling, mixed, and assimilation+fully coupled modeling

Heuristic $n = 4$
Statistical $n = 11$
Modeling $n = 10$
Mixed $n = 3$

June 2015 Sea Ice Outlook contributions by method (total $n = 30$)

Heuristic $n = 4$
Statistical $n = 12$
Modeling $n = 11$
Mixed $n = 3$

This style of figure appears in the SIO report for June 2014