Prediction of Arctic sea ice on subseasonal to seasonal time scales

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ECMWF Seminar

September 15th 2017
Overview

- Research Motivation and Objectives
- S2S Forecasts and Observations
- The Verification Metrics
- Predictive Skills of S2S Forecasts Systems
- Comparison of Predictive and Prescriptive Systems
- Considerations on Metrics Behavior
Research Motivations and Objectives
Why do we need (Arctic) sea ice forecasts?
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Climate change causes a decrease in summer sea ice *extent* and *thickness*

New scenarios for human activities in the Arctic region
Importance of Sea Ice Forecasts

Why do we need (Arctic) sea ice forecasts?

Climate change causes a decrease in summer sea ice extent and thickness

New scenarios for human activities in the Arctic region

- Marine transport
- Offshore fuel industry
- Mineral extraction
- Tourism
Importance of Sea Ice Forecasts

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New scenarios for human activities in the Arctic region

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- Offshore fuel industry
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Formulation of seasonal sea ice forecasts is required
Figure: Hypothetical September navigation routes. Smith and Stephenson (2013)
Are we able to effectively verify a sea ice forecast?
Are we able to effectively verify a sea ice forecast?

New dedicated verification metrics are needed to quantify the quality of the forecasted ice edge position.
This research consists in an extensive verification analysis of the S2S database with the following objectives:

- **Assessment of the predictive skills for S2S forecast systems**
- **Evaluation of the verification metrics behavior**
Forecasts and Observations
The S2S (subseasonal to seasonal) database collects mainly atmospheric forecasts (2003-2017). However, sea ice concentration is also provided.

F. Vitart et al. (2017)
The S2S (subseasonal to seasonal) database collects mainly **atmospheric forecasts** (2003-2017). However, sea ice concentration is also provided.

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Ocean</th>
<th>Sea Ice</th>
<th>Frequency</th>
<th>Ens. Size</th>
<th>Length</th>
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<td>61 days</td>
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<tr>
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<tr>
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<td>60 days</td>
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<td>51</td>
<td>46 days</td>
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<td>✓</td>
<td>daily</td>
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<td>60 days</td>
</tr>
<tr>
<td>Météo France</td>
<td>✓</td>
<td>✓</td>
<td>weekly</td>
<td>51</td>
<td>32-61 days</td>
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<tr>
<td>NCEP</td>
<td>✓</td>
<td>✓</td>
<td>daily</td>
<td>16</td>
<td>44 days</td>
</tr>
<tr>
<td>UKMO</td>
<td>✓</td>
<td>✓</td>
<td>daily</td>
<td>4</td>
<td>60 days</td>
</tr>
</tbody>
</table>
The "True State"

**ASI sea ice concentration data** produced by **University of Bremen**.

The resolution is $\sim 6$ km.

G. Spreen et al. (2008)
The "True State"

**ASI sea ice concentration data** produced by **University of Bremen**.

The resolution is $\sim 6$ km.

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**Models own analysis**

The idea behind the models own analysis is to define virtual observations based on the control forecasts evaluated at the initial time of each single forecast.

G. Spreen et al. (2008)
Verification Metrics
IIEE - Integrated Ice Edge Error

\[ IIEE = O + U \]

Observation edge
Forecast edge

Conceptually simple and easy to calculate from sea ice concentration

IIEE is an area ($m^2$)

Decomposition into

Misplacement Error

$$ME = 2\min(O, U)$$

and

(Absolute) Extent Error

$$AEE = |O - U|$$

$$EE = O - U$$

$$IIEE = AEE + ME$$
SPS - Spatial Probability Score

SPS is the evolution of IIEE in the probabilistic forecasts world. SPS is defined as the spatial integration of the local (Half) Brier Score.

\[
SPS = \int_S (p_o [sic \geq 15\%] (\vec{x}) - p_f [sic \geq 15\%] (\vec{x}))^2 dS
\]

- SPS can be applied to deterministic forecast, in this case \( SPS = IIEE \)
- It allows a probabilistic description of the observations
- SPS is an area \((m^2)\)
- Dividing the SPS (or the IIEE) by the climatological length of the edge we obtain an estimation of the mean distance between the edges

H.F. Goessling (submitted)
MHD - Modified Hausdorff Distance

\[ \text{MHD}(A, B) = \max \left\{ \frac{1}{|A|} \sum_{a \in A} d(a, B), \frac{1}{|B|} \sum_{b \in B} d(A, b) \right\} \]

\[ d(a, B) = \inf_{b \in B} [d(a, b)] \]

\[ d(A, b) = \inf_{a \in A} [d(a, b)] \]

D.S. Dukhovskoy et al. (2015)
Benchmark values for IIEE and SPS

IIEE and SPS are not straightforward to interpret without reference values. Those have been calculated using the observed sea ice concentration

- **Persistence from the previous year** (PER1)
- **Persistence from forecast beginning** (PERF)
- **Climatological median ice edge** (CMID)

![Benchmark values for IIEE and SPS from AMSR2 data](image1)

![Benchmark values for IIEE and SPS from AMSR2 data](image2)
Predictive Skills of S2S Forecast Systems
Ensemble members: 50
Start: 01.01.2016

Forc. length: 60 days

Verification of Sea Ice Edge Position
\[ \text{IIEE, SPS, ME, AEE benchmark} \]

Ensemble Members Spread
\[ \text{IIEE(em-em)} \]
Extensive visualization of the results

Verification of Sea Ice Edge Position  UKMO – AMSRE  Forecast start: 2006-12-01

Verification of Sea Ice Edge Position  UKMO – AMSR2  Forecast start: 2016-08-01

Spatial Probability Score  Model: UKMO  Observations: ASI Sea Ice Concentration

Day 1  Day 8  Day 18  Day 32  Day 44  Day 60
Spatial Probability Score  Model: UKMO  Observations: ASI Sea Ice Concentration


Prediction of Arctic sea ice

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Spatial Probability Score  Model: UKMO  Observations: ASI Sea Ice Concentration
Predictive Skills Evaluation

**SPS**

**AEE**

**ME**

**SPS**

**AEE**

**ME**

Lorenzo Zampieri (AWI - Uni HB)  Prediction of Arctic sea ice  September 15th 2017
Ens. members: 3
Start: 01.07.2016

UKMO

Ens. members: 3
Start: 01.07.2016

CMA
### S2S Forecasts Systems Predictive Skills

<table>
<thead>
<tr>
<th>Forecast System</th>
<th>Season</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMA</td>
<td>🟥</td>
<td>🟥</td>
</tr>
<tr>
<td>ECMWF 2</td>
<td>🟢</td>
<td></td>
</tr>
<tr>
<td>KMA</td>
<td>🟢</td>
<td></td>
</tr>
<tr>
<td>Météo France</td>
<td>🟢</td>
<td>🟠</td>
</tr>
<tr>
<td>NCEP</td>
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</tr>
<tr>
<td>UKMO</td>
<td>🟢</td>
<td>🟢</td>
</tr>
<tr>
<td>Predictive Version</td>
<td>Prescriptive Version</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>Start: 01.08.2016</td>
<td>Start: 31.07.2016</td>
<td></td>
</tr>
</tbody>
</table>

**ECMWF 2**

**ECMWF 1**
Verification Metrics
Behavior
Comparison of MHD and NIIEE

- Norm. Integrated Ice Edge Error
  - Model: UKMO
  - Verification against UKMO own analysis

- Mod. Hausdorff Distance
  - Model: UKMO
  - Verification against UKMO own analysis

NIIEE

MHD

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## Comparison of MHD and NIIEE

<table>
<thead>
<tr>
<th>Forecast Lead Time</th>
<th>Correlation Coeff.</th>
<th>Scaling Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>0.915</td>
<td>0.75</td>
</tr>
<tr>
<td>Day 8</td>
<td>0.813</td>
<td>1.18</td>
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<tr>
<td>Day 18</td>
<td>0.872</td>
<td>1.23</td>
</tr>
<tr>
<td>Day 32</td>
<td>0.860</td>
<td>1.24</td>
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<tr>
<td>Day 44</td>
<td>0.770</td>
<td>1.24</td>
</tr>
<tr>
<td>Day 60</td>
<td>0.672</td>
<td>1.23</td>
</tr>
</tbody>
</table>

The NIIEE and the MHD estimations of the mean distance between the edges are comparable! However...

- NIIEE is sensitive to the normalization procedure
- MHD is subject to noise likely caused by outliers
- MHD computation is much more demanding
Conclusions
Features of S2S Forecasts Systems

- Despite the early development stage of Arctic sea ice predictions on the seasonal time scale some of the S2S models are promising, exhibiting better predictive skills than the observation-based climatology and persistence.

- Critical aspects concerning the data assimilation procedure and the tuning of the models, which can strongly affect the forecasts quality.

- Expected benefits from an increased ensemble size could not be detected.

- The comparison of different versions of the ECMWF forecast system shows the benefits brought by a coupled dynamical description of the sea ice instead of its prescription based on persistence and climatological records.
IIEE and SPS are effective verification metrics to describe the quality of the sea ice edge position.

**Simplicity - Comprehensibility - Stability**

MHD is also able to evaluate the quality of the forecasted ice edge position. However it is less flexible than the two previous ones and affected by biases.

- Verification against satellite observation useful to monitor models skills.
- Verification against models own analysis useful to study the model response to modification in data assimilation.
Thank you for your attention
Climatological Ice Edge Length

Climatological Ice Edge Length – ASI Sea Ice Concentration

Time
Jan 01 Mar 01 May 01 Jul 01 Sep 01 Nov 01 Jan 01

$10^3$ km

High res.

Low res.

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MHD Problems - 2

Prediction of Arctic sea ice

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Alternative applications

Sea Ice Edge Comparison
2017/03 - 2006/03

meereisportal.de
seaiceportal.de

Sensor: AMSR2