Prediction of Arctic sea ice on subseasonal to seasonal time scales

Lorenzo Zampieri
lorenzo.zampieri@awi.de

Alfred Wegener Institute for Polar and Marine Research

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

Importance of Sea Ice Forecasts

Why do we need (Arctic) sea ice forecasts?

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

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

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

Formulation of seasonal sea ice forecasts is required

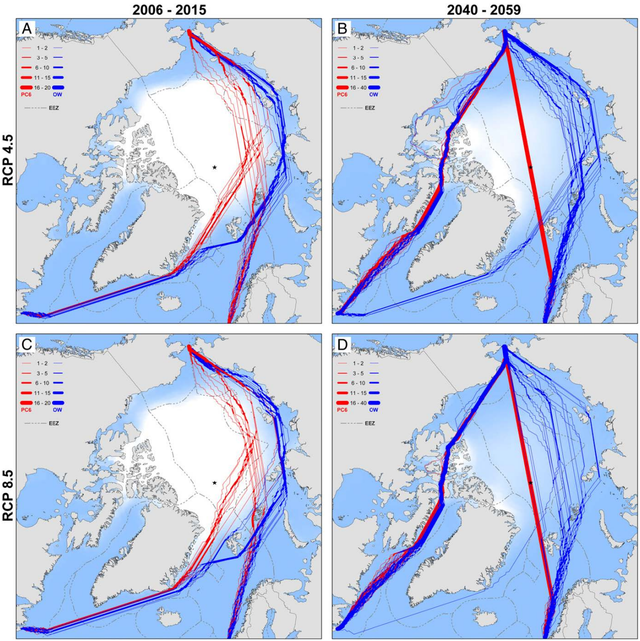


Figure: Hypothetical September navigation routes. Smith and Stephenson (2013)

Are we able to effectively verify a sea ice forecast?

The Forecasts Verification

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

Research Objectives

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 Forecasts - S2S Database

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

F. Vitart et al. (2017)

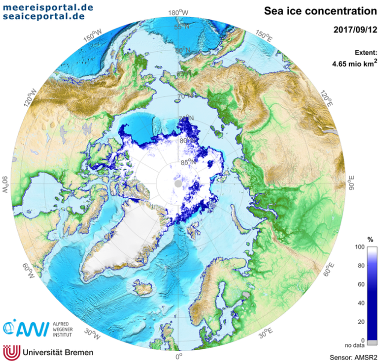
The Forecasts - S2S Database

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

Model Name	Ocean	Sea Ice	Frequency	Ens. Size	Length
BoM	✓		twice a week	33	62 days
ECCC			weekly	21	32 days
ECMWF 1			twice a week	51	46 days
HMCR			weekly	20	61 days
ISAC-CNR			weekly	41	31 days
JMA			twice a week	25	33 days
CMA	✓	✓	daily	4	60 days
ECMWF 2	✓	✓	twice a week	51	46 days
KMA	✓	✓	daily	4	60 days
Météo France	✓	✓	weekly	51	32-61 days
NCEP	✓	✓	daily	16	44 days
UKMO	✓	✓	daily	4	60 days

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

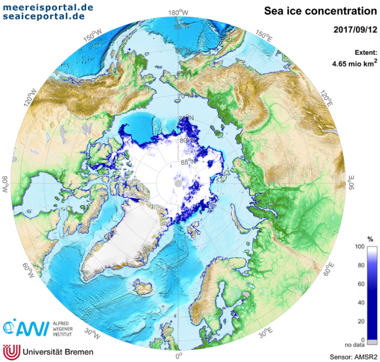
The resolution is $\sim$ 6 km.



G. Spreen et al. (2008)

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

The resolution is $\sim$ 6 km.



G. Spreen et al. (2008)

Models own analysis

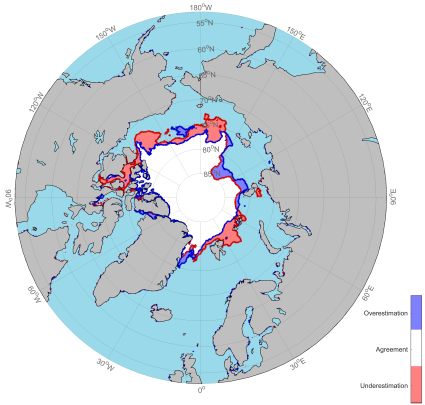
The idea behind the models own analysis is to define virtual observations based on the control forecasts evaluated at the initial time of each single forecast.

Verification Metrics

IIEE - Integrated Ice Edge Error

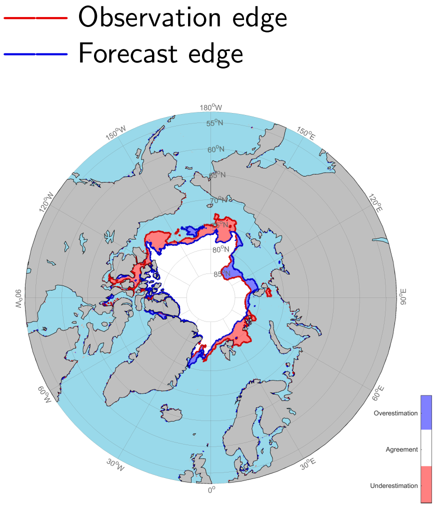
H.F. Goessling et al (2016)

—— Observation edge
—— Forecast edge



$$IIEE = O + U$$

IIEE - Integrated Ice Edge Error



$$IIEE = O + U$$

- Conceptually simple and easy to calculate from sea ice concentration
- IIEE is an area (m^2)
- Decomposition into

  Misplacement Error
  $ME = 2min(O, U)$

  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.

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

- 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)

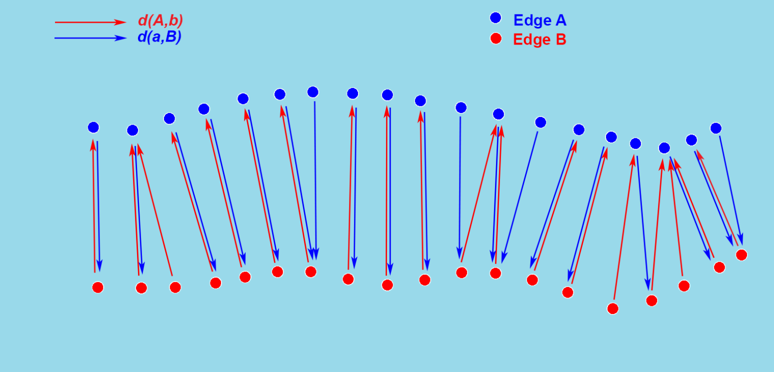
MHD - Modified Hausdorff Distance

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

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

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

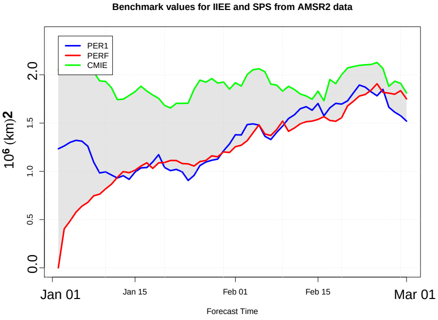
D.S. Dukhovskoy et al. (2015)

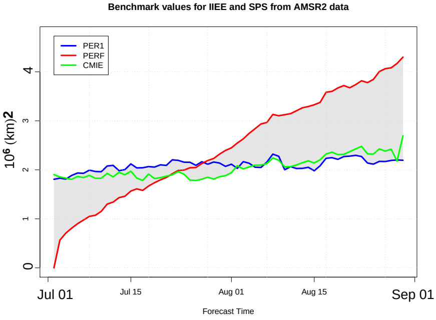


Benchmark values for IIEE and SPS

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)





Predictive Skills of S2S Forecast Systems

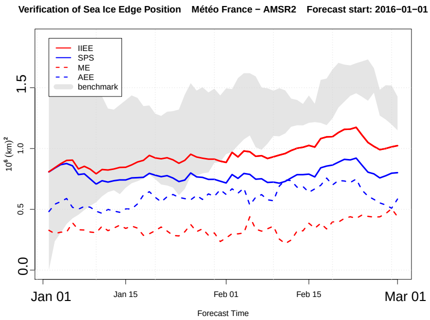
Single Forecast Verification

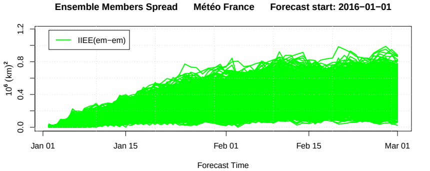
Ens. members: 50

Start: 01.01.2016

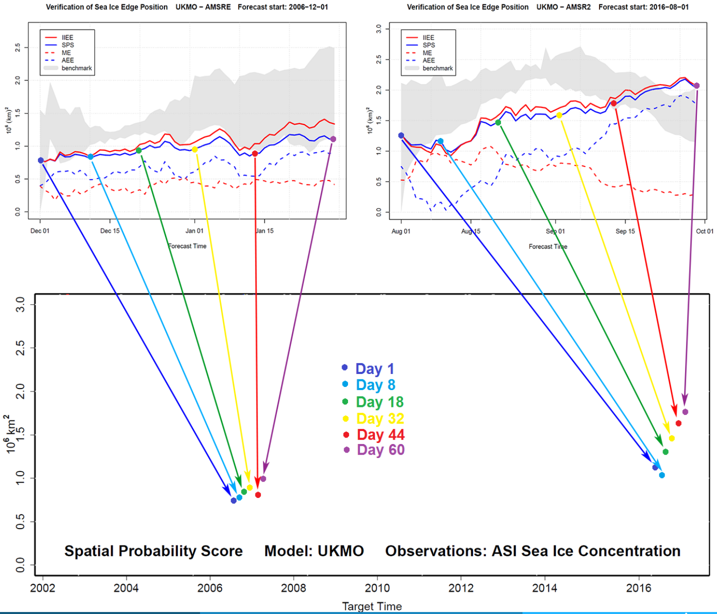
Météo France

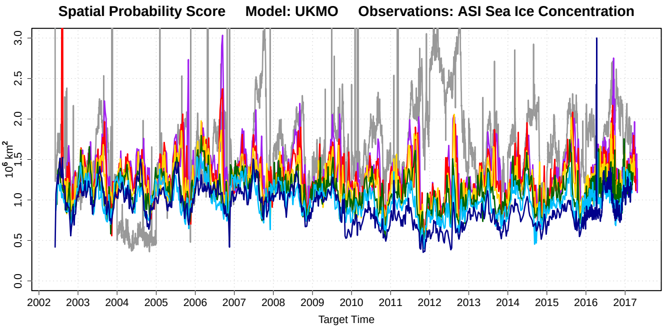
Forc. length: 60 days

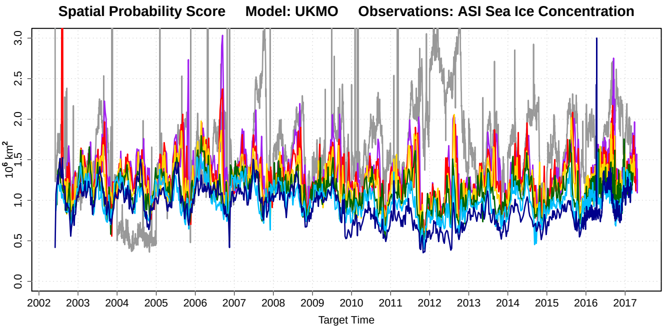


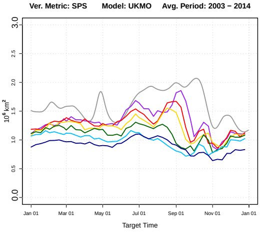


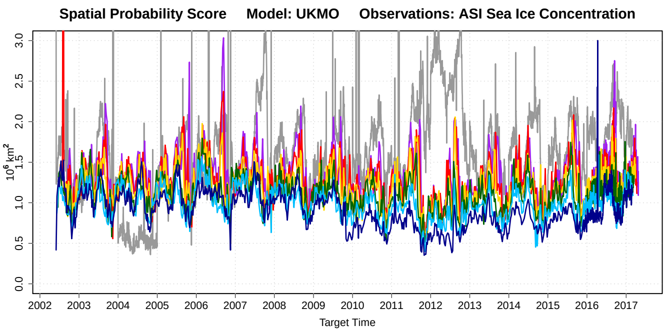
Extensive visualization of the results

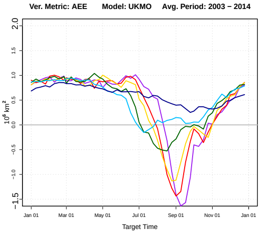


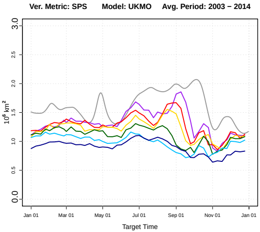

Spatial Probability Score Model: UKMO Observations: ASI Sea Ice Concentration
$10^6\,km^2$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Target Time

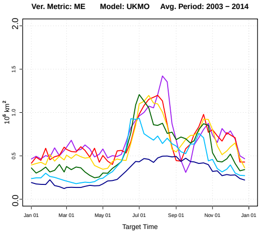

Spatial Probability Score Model: UKMO Observations: ASI Sea Ice Concentration
10^6 km^2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Target Time


Ver. Metric: SPS Model: UKMO Avg. Period: 2003 – 2014
10^6 km^2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Jan 01 Mar 01 May 01 Jul 01 Sep 01 Nov 01 Jan 01
Target Time


Spatial Probability Score Model: UKMO Observations: ASI Sea Ice Concentration
10^6 km^2
Target Time


Ver. Metric: AEE Model: UKMO Avg. Period: 2003 − 2014
10^6 km^2
Target Time

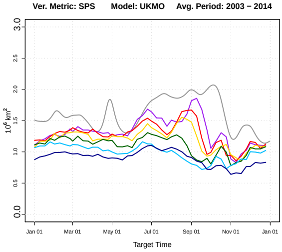

Ver. Metric: SPS Model: UKMO Avg. Period: 2003 − 2014
10^6 km^2
Target Time

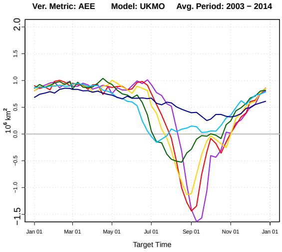

Ver. Metric: ME Model: UKMO Avg. Period: 2003 − 2014
10^6 km^2
Target Time

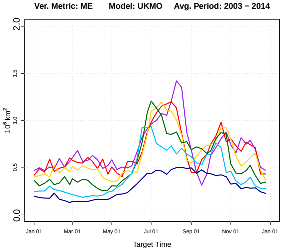
Predictive Skills Evaluation

SPS | AEE | ME

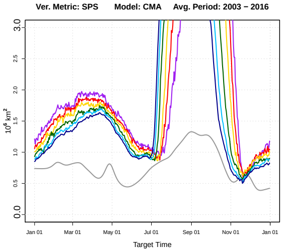
UKMO

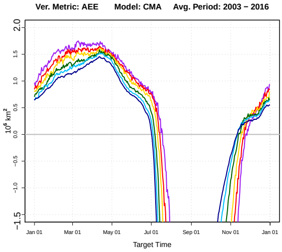


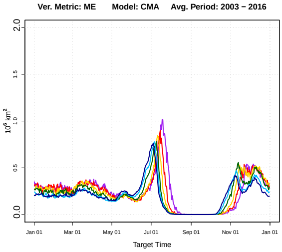




CMA







UKMO - CMA Comparison

Ens. members: 3
Start: 01.07.2016

UKMO

Ens. members: 3
Start: 01.07.2016

CMA

S2S Forecasts Systems Predictive Skills

Forecast System	Season		Issues		
	Winter	Summer	Assimil.	O-Mlt.	O-Frz.
CMA	🔴	🔴	✗	✗	✗
ECMWF 2	🟢				
KMA	🟢			✗	
Météo France	🟢	🟠	✗	✗	
NCEP	🟠	🟠	✗		✗
UKMO	🟢	🟢		✗	

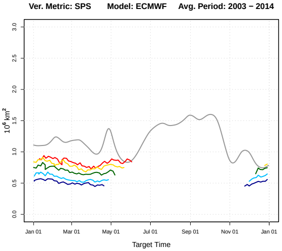
ECMWF - Predictive vs. Prescriptive

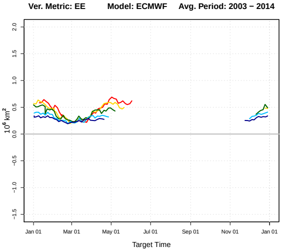
SPS

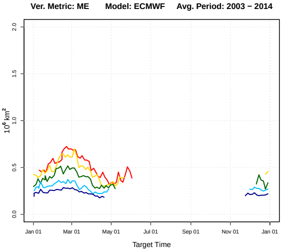
AEE

ME

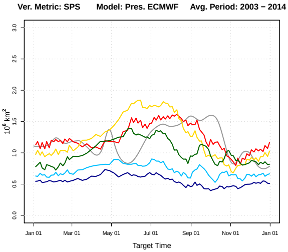
ECMWF 2

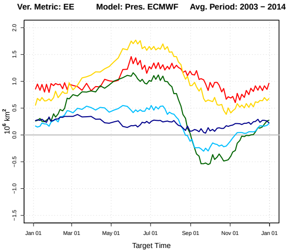


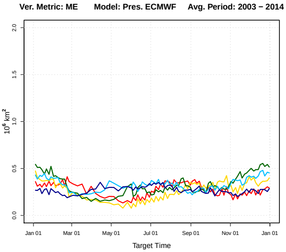




ECMWF 1







ECMWF - Predictive vs. Prescriptive

Predictive Version
Start: 01.08.2016

ECMWF 2

Prescriptive Version
Start: 31.07.2016

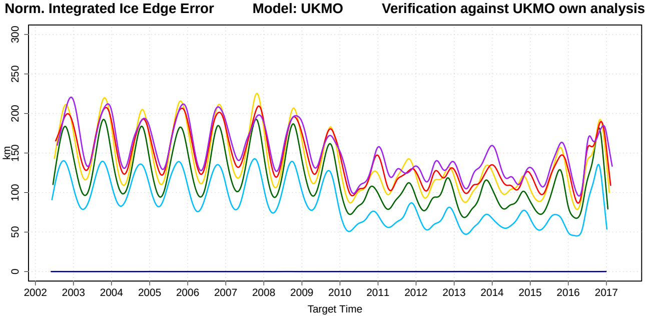
ECMWF 1

Verification Metrics Behavior

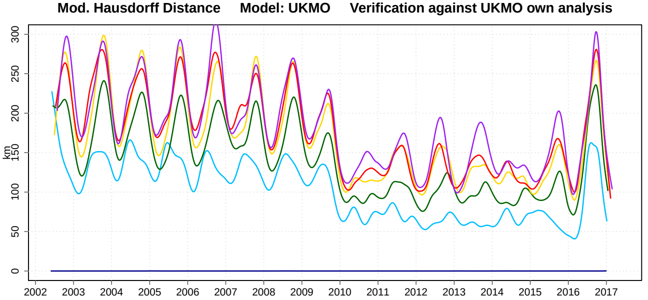
Comparison of MHD and NIIEE

Comparison of MHD and NIIEE

NIIEE



MHD



Comparison of MHD and NIIEE

Forecast Lead Time	Correlation Coeff.	Scaling Factor
Day 1	0.915	0.75
Day 8	0.813	1.18
Day 18	0.872	1.23
Day 32	0.860	1.24
Day 44	0.770	1.24
Day 60	0.672	1.23

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

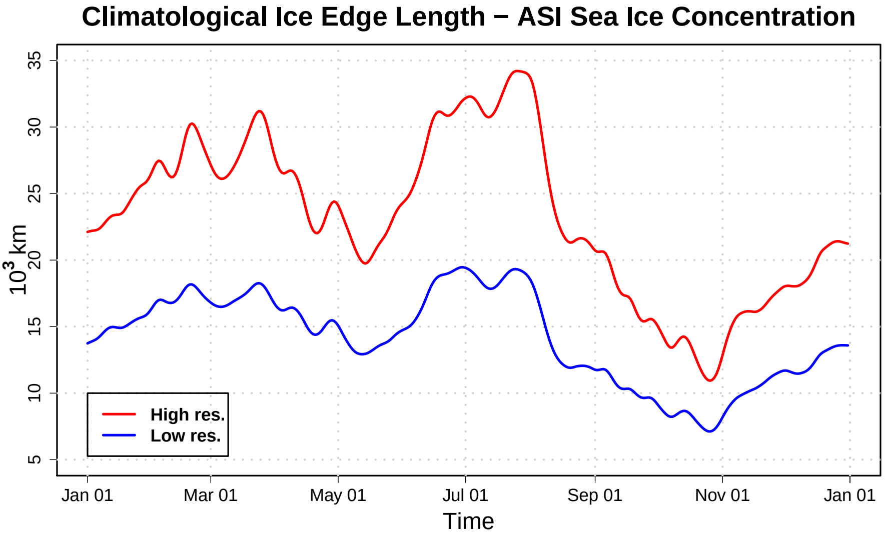
- Despite the early development stage of Arctic sea ice predictions on the seasonal time scale some of the S2S models are promising, exhibiting better predictive skills than the observation-based climatology and persistence.
- Critical aspects concerning the data assimilation procedure and the tuning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

Metrics Behavior

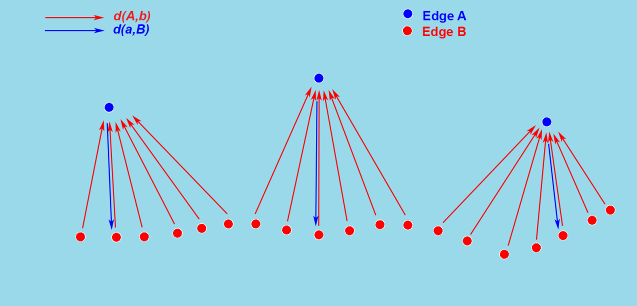
- IIEE and SPS are effective verification metrics to describe the quality of the sea ice edge position.
  Simplicity - Comprehensibility - Stability
- MHD is also able to evaluate the quality of the forecasted ice edge position. However it is less flexible than the two previous ones and affected by biases.
- 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.

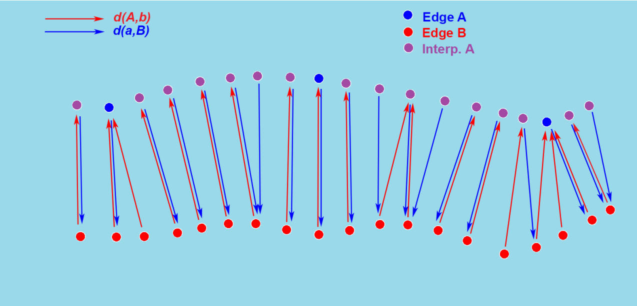
Thank you for your attention

Climatological Ice Edge Length

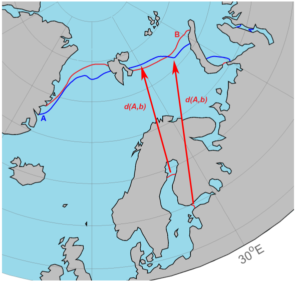


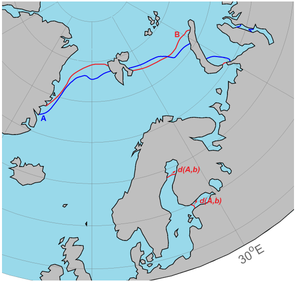
MHD Problems - 1

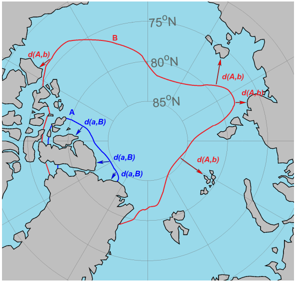


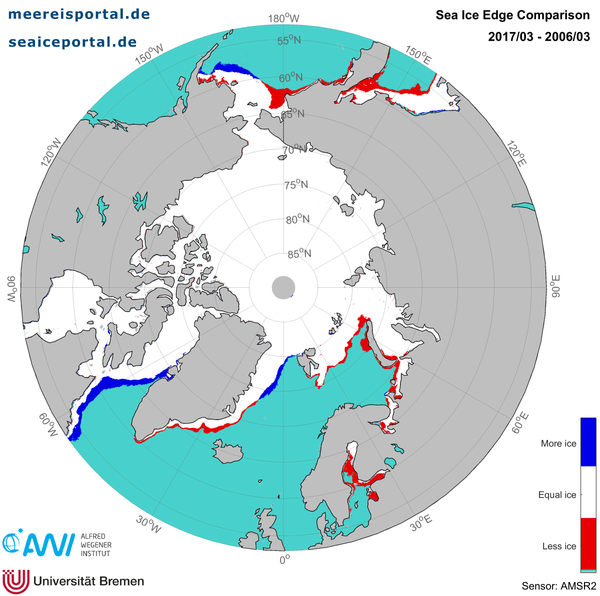


MHD Problems - 2









meereisportal.de
seaiceportal.de
Sea Ice Edge Comparison
2017/03 - 2006/03
180°W
150°E
120°E
90°E
60°E
30°E
0°
30°W
60°W
90°W
120°W
150°W
55°N
60°N
65°N
70°N
75°N
80°N
85°N
More ice
Equal ice
Less ice
Sensor: AMSR2
ALFRED WEGENER INSTITUT
Universität Bremen