

Arctic sea ice remote sensing products, and initialisation of forecasts in the Arctic

Ed Blockley Polar Climate Group, Met Office Hadley Centre





Motivating questions

- Arctic sea ice satellite products:
 - What are the limitations of Arctic sea ice remote sensing products?
 - What work is underway to reduce these limitations/uncertainties?
- Arctic sea ice initialisation in forecast models:
 - How do people initialise sea ice in NWP (short-range to seasonal) forecasting systems?
 - What opportunities can Arctic sea ice remote sensing products provide for improving predictive skill of forecasts in the Arctic?



Contents

- Introduction: Arctic sea ice prediction
- Initialisation of Arctic sea ice in operational systems
- Arctic sea ice remote sensing products
 - Sea ice concentration (SIC)
 - Sea ice thickness (SIT)
- Potential for satellite sea ice thickness products to improve seasonal prediction
 - Motivation for SIT initialisation
 - Impact of SIT initialisation on Met Office GloSea sea ice forecasts
- Summary



Why forecast Arctic sea ice?

- Access to the Arctic Ocean
 - Commercial shipping, tourism, fishing, oil & mineral extraction
 - Community resupply, subsistence hunting & fishing

- Impact on ocean/atmosphere:
 - Summer. sea ice (& snow) reflects Sun's radiation
 - *Winter*. sea ice (& snow) insulates ocean from cold atmosphere







Sea ice initialisation in operational systems

- Sea ice concentration:
 - Most centres use passive microwave (SSMIS, AMSR-2)
 - E.g. OSTIA as lower boundary conditions for UM assimilation of OSI-SAF within FOAM
 - Some also use visible channels (AVHRR, VIIRS)
- Sea ice thickness:
 - Prescribed/constant thickness (e.g., UM atmosphere only)
 - Free-running model (ocean/coupled analysis with SSMIS)
 - Short-range ocean predictions now starting to include satellite thickness (SMOS, CS2)





Satellite measurements : sea ice

Sea ice is highly heterogeneous! UNFORTUNATELY.....

- No satellite instrument exists that can measure:
 - Sea ice concentration
 - Sea ice drift / velocity
 - Sea ice thickness
 - ...or anything useful really....
- All satellites measure:
 - Some kind of electromagnetic radiation
 - Or retrieval/lag time
- We have to infer useful information from this
- All products involve some level of assumption...





Satellite sea ice concentration

With thanks to the ESA CCI team:

Leif Toudal Pedersen, Technical University of Denmark Roberto Saldo, Technical University of Denmark Thomas Lavergne, MET Norway Matilde Brandt Kreiner, DMI Stefan Kern, ICDC Hamburg John Lavelle, DMI





Passive microwave SIC

- Passive microwave data has been used for SIC since 1979
- Cornerstone of climate monitoring for >30 years
- Sensing surface "brightness temperature"
 - Microwave radiation emitted by Earth's surface
- Algorithms used to distinguish between open water and ice
- Using "tie points" as reference for open water and 100% ice cover





Figure: example relationship of 19V vs. 37V brightness temperatures (K) used to infer SIC.



Passive microwave SIC



110

100

90

80

70

60

----- CalVal

NASA Team ······ Near90 ----- 6H

OSISAF/BR

ASI

Bootstrap

NASA Team2 Near90GHz

NORSEX85H

UMass-AES

NORSEX

TUD

mean

trend

Bristol

CalVal NASA Team



Algorithm comparison & validation

ESA CCI Sea Ice project

- Testing ~30 algorithms against trusted datasets:
 - Cases of sea ice concentration: 0; 15; 85; 100%
 - Thin ice dataset (5-50cm)
 - Melt ponds dataset

Met Office

Hadley Centre

- Right plot shows example of algorithm inter-comparison for SIC of 15 and 85%
 - Values shown are standard deviations of each algorithm
- Development of the new "SICCI" algorithm (similar to OSI-SAF, but with adjustments).







A step back is a move forward

Thomas Lavergne, MET, Norway

Institute

 \sim



Satellite sea ice thickness

With thanks to the Centre for Polar Observation and Modelling (CPOM) :

Rachel Tilling, University of Leeds Andrew Shepherd, University of Leeds











Sea ice thickness measurements

- Satellite measurements available from:
 - Radar altimetry : (CryoSat-2, AltiKa, Envisat, ERS)
 "ice freeboard"
 - Laser altimetry : (ICESat, ICESat2)
 "snow freeboard"
 - Microwave brightness temperatures (SMOS)
 "total thickness" (ice+snow)





Sea ice thickness measurements

- Radar altimetry (CryoSat)
 - Wintertime only (melting problematic)
 - Direct overhead measurements only
 - · Poor accuracy for thin ice
- Laser altimetry (ICESat)
 - Cloud interference (not good in Arctic summer!)
 - · Direct overhead measurements only
- Brightness temperatures (SMOS)
 - Whole thickness snow+ice
 - · Poor accuracy for medium to thick ice
 - Good swath coverage

Snow loading/thickness problematic for all!



CryoSat-2 for thick ice	[> 1.0 m]
SMOS for thin ice	[< 0.5 m]



Improving snow loading

- CPOM Lagrangian snow on sea ice model
- Initialised on September 15th each year from Warren climatology
- Snow accumulated using ERA-Interim precipitation
- Grid cells moved according to daily ice motion vectors (Polar Pathfinder)
- Extent mask, motion, and accumulation repeated daily



Tilling et al. (2016)



Snow on sea ice model





Application to sea ice thickness



February 2017







Sea ice thickness initialisation

Improving seasonal sea ice forecasts made with GloSea seasonal ensemble prediction system

EU-APPLICATE project

[Blockley, E. W. and Peterson, K. A.: Improving Met Office seasonal predictions of Arctic sea ice using assimilation of CryoSat-2 thickness, The Cryosphere, 12, 3419-3438, 2018. https://doi.org/10.5194/tc-12-3419-2018]







Met Office Global Seasonal Forecast System (GloSea)



- Ensemble prediction system
- Monthly (60 days) & seasonal (210 days) forecasts
- NEMO ocean model; CICE sea ice model
- Experimental Arctic sea ice forecasts

- Initialised from FOAM operational ocean/sea ice analysis assimilating:
 - SIC + SLA, SST, T & S profiles
 - No Sea ice thickness (yet)





Motivation for sea ice thickness initialisation

- Blanchard-Wrigglesworth and Bitz (2014):
 - Sea ice thickness anomalies in GCMs have timescale of between 6 and 20 months
- Holland et al. (2011); Kauker et al. (2009):
 - Knowledge of winter ice thickness can provide predictive capability for summer ice extent
- Perfect model studies (e.g. Day et al., 2014):
 - Correct initialisation of thickness can lead to improved seasonal forecasts
- Collow et al. (2015); Blanchard-Wrigglesworth et al. (2017):
 - Sea ice seasonal forecasts are sensitive to changes in thickness initial conditions.





Sea ice thickness assimilation: proof of concept



- Including CryoSat-2 sea ice thickness within FOAM reanalysis (GloSea hindcast IC's):
 - 2010-2015
 - Using full thickness estimates from CPOM@UCL
 - QC of data
- Nudging SIT in sea ice model (CICE):
 - Using monthly thickness data
 - Similar to climatological relaxation
 - Difference with grid-cell mean thickness
 - Increments applied using a 5-day relaxation timescale





Sea ice thickness assimilation: proof of concept



- <- Modified winter thickness distribution:
 - Overall increase in thickness (& hence volume)
 - Particularly in the Atlantic sector

• End winter IC changes:

- Thickening: Atlantic sector & marginal seas
- Thinning: Beaufort, Chukchi, East Siberian Seas







What is the impact on GloSea seasonal forecasts?

- GloSea re-forecasts: May -> September
 - 3 start dates: 25-04, 01-05, 09-05
 - 8 ensemble members each
 - => lagged ensemble with **24 forecasts per year** of September-mean from spring
 - 5 years: 2011 2015
 - => total 120 seasonal forecasts

[Using prototype GC3 GloSea version]





Arctic extent comparison

- · General increase in extent
 - => reduction in low bias
- Ensemble distribution each year significantly different at 1% level (except 2013)





Integrated Ice Edge Error (IIEE)

- Using IIEE of Goessling et al. (2016)
 - Integral of all areas where model and observations disagree (sum of red and blue areas)
- · General reduction in ice edge error
 - 37% lower IIEE for 5-year total
- Each year ensemble distribution significantly different at 1% level (except 2013)







[[]Blockley and Peterson (2018)]

Local Atmospheric Impact : T2m





Met Office

Hadley Centre

2m Temperature -2 -3

- Reduced nearsurface temperature over Arctic Ocean
- Reduced temperature errors over Arctic Ocean
- Increased error south of Fram Strait
 - too much sea ice export?

Average difference for all ensemble members 2011-15

Average difference in RMSE over all ensemble members 2011-15 (vs ERA-Interim)





Summary: sea ice thickness initialisation

- Sea ice thickness initialisation in GloSea shows promise:
 - Potentially large impact on sea ice forecast evolution & predictability
 - Particularly the ice edge in the Atlantic sector
 - Improvements beyond the sea ice [T2m]







SIT assimilation: next steps

- Development of SIT assimilation within FOAM ocean-sea ice analysis
- Development of SIT assimilation in NEMOVAR 3D-Var (alongside SIC)
- EU-SEDNA project: "Safe maritime operations under extreme conditions: the Arctic case"
 - Prescription of observational errors (instrument, algorithm, & representativeness errors)
 - Methods to represent appropriate model background errors
 - Using raw (L2) satellite tracks, from as many observational platforms as possible (including CS2 and SMOS)
 - Information being spread through the model using spatial and inter-variable error correlations



Summary





Summary - Arctic sea ice remote sensing

- Satellite sea ice concentration and thickness are not the truth
- However they can be useful tools if used appropriately
- Important to understand what is measured and what assumptions have been made
- Remote sensing products are important for prediction of Arctic sea ice
- Sea ice thickness is important on seasonal timescales
- Inclusion of SIT within initialisation can improve seasonal forecasts



The end

Thank you for your attention





Sea ice concentration improvements

- Improvements in ice edge location from Posey et al. (2015)
- Assimilating higher resolution AMSR2 passive microwave SIC
- Plus MASIE multi-sensor blended product
- Comparisons with NIC ice-edge product ->



Posey et al. (2015)



Relationship between thickness and extent errors

• Example : 2012

- Clear alignment between:
 - May ice thickness changes (shading)
 - September ice edge location errors (lines)
 - Black = Obs
 - Grey = GloSea Control
 - Pink = Thickness Initialised



Met Office Wider impact : Z500 & MSLP Difference



 Recall we have increased SIC

1.2

0.8

0.4

-0.4

-0.8

-1.2

- Mostly north of Svalbard
- Reduction over Arctic Ocean
- Increase over Siberia

Average difference for all ensemble members 2011-15 Black contours/hatching where differences significant at 95% level

Met Office Wider impact : Z500 & MSLP Error



- Improved over Arctic Ocean and within Canadian Archipelago
- Degraded over mid-latitudes
- Mostly not significant

Average difference in RMSE over all ensemble members 2011-15 (truth is ERAi)

Black contours/hatching where differences significant at 95% level

Met Office Hadley Centre Potential importance of ice thickness

- Perfect model study:
 - Day et al. (2014) using HadGEM1 perturbed ensemble
 - Initialisation of sea ice thickness important for monthly-seasonal forecast skill

- Normal model initialisation
- SIT initialised with model climatology
- Dots show significant diffs





GloSea initialisation: Uncoupled data assimilation (DA)





CPOM thickness QC

- Require the following:
 - thickness above 1m
 - thickness below 7.0m (to avoid outliers)
 - at least 10 altimeter points contributing towards the data point
 - maximum standard deviation of 2m amongst contributing data points
 - maximum COG distance 15km
 - as per CPOM suggestion (Andy Ridout)
 - to avoid smearing at ice edge

Sea ice thickness validation



Tilling et al. (2018)

IceBridge
CryoVExAirborne (seasonal)Buoy dataFixed (year-round)

- Validation of CryoSat-2 sea ice thickness from 2010-2017
- Average difference between CryoSat-2 and *in situ* thickness is 2mm (no significant bias overall)
- Standard deviations of the differences are comparable to accuracy of each instrument (13cm for CryoSat-2)