Sea-ice modelling and predictability in polar regions

Sarah Keeley

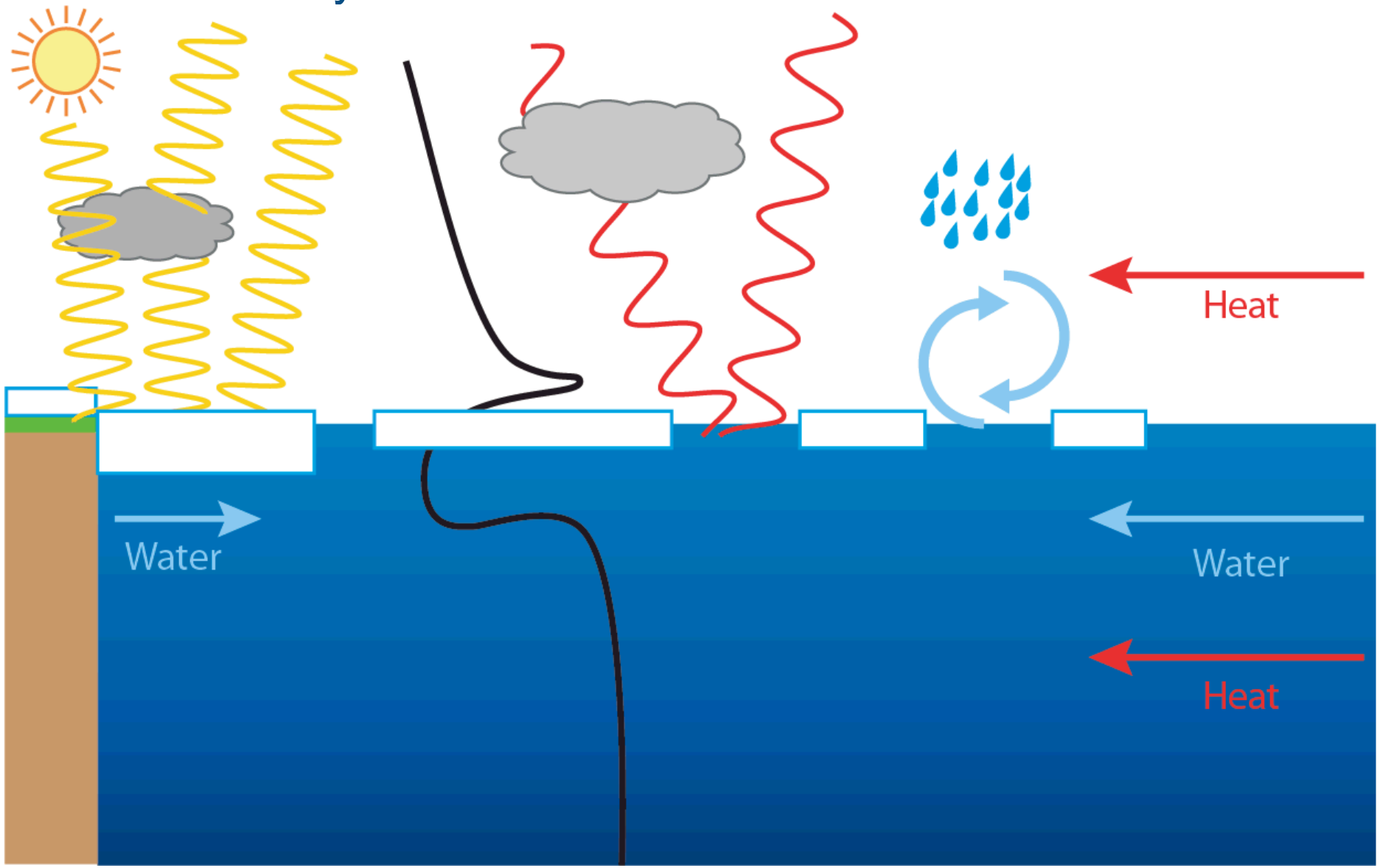
Marine Predictability Section

sarah.keeley@ecmwf.int

Why bother about sea ice?

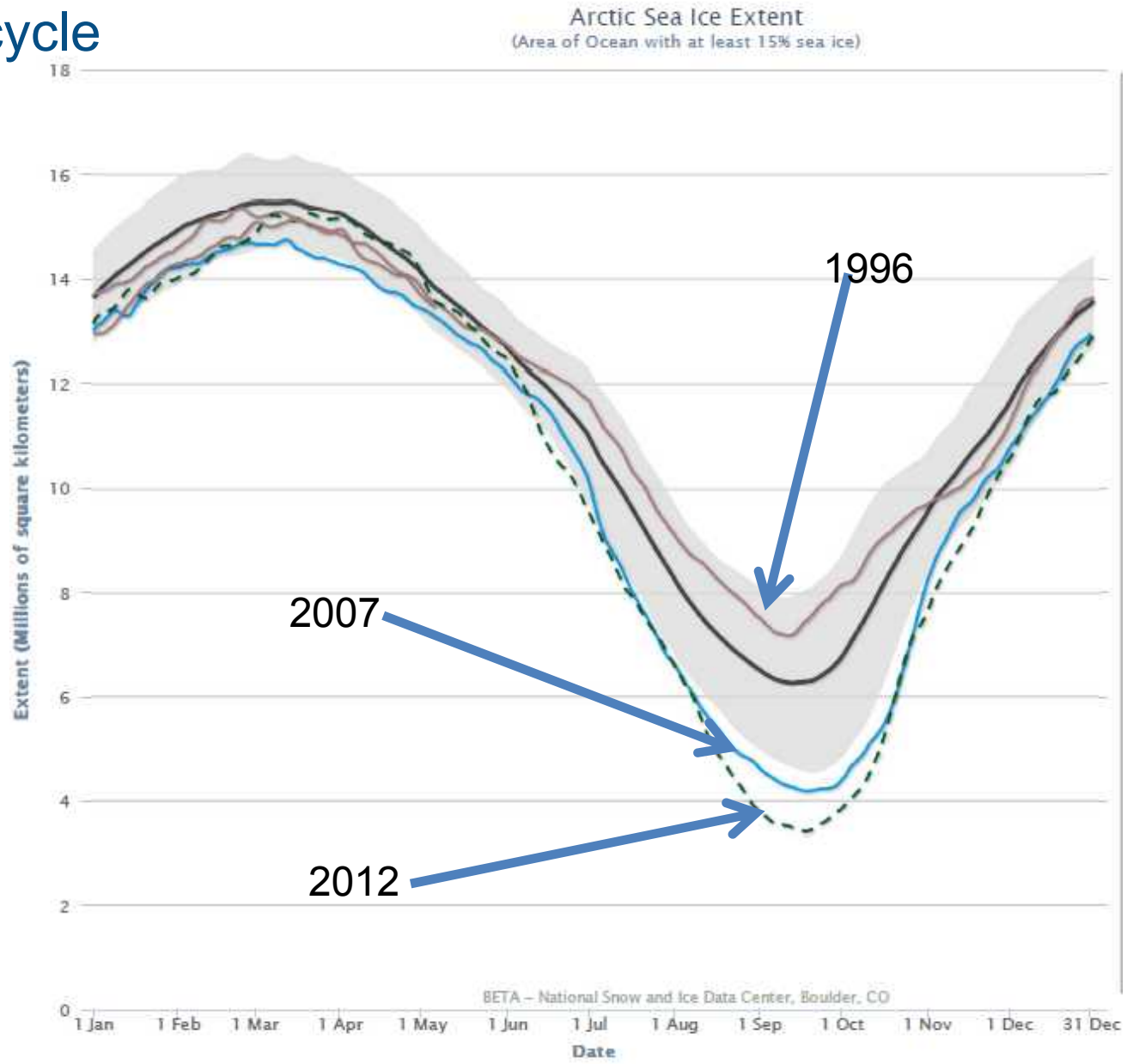
- Impact on energy balance
  - Albedo
  - Fluxes
- Density – brine (salt water) formation
- Importance for industry – shipping and energy
- Important for many communities and wildlife

The Polar System



ECMWF

Arctic Seasonal cycle



ECMWF

Ice Circulation

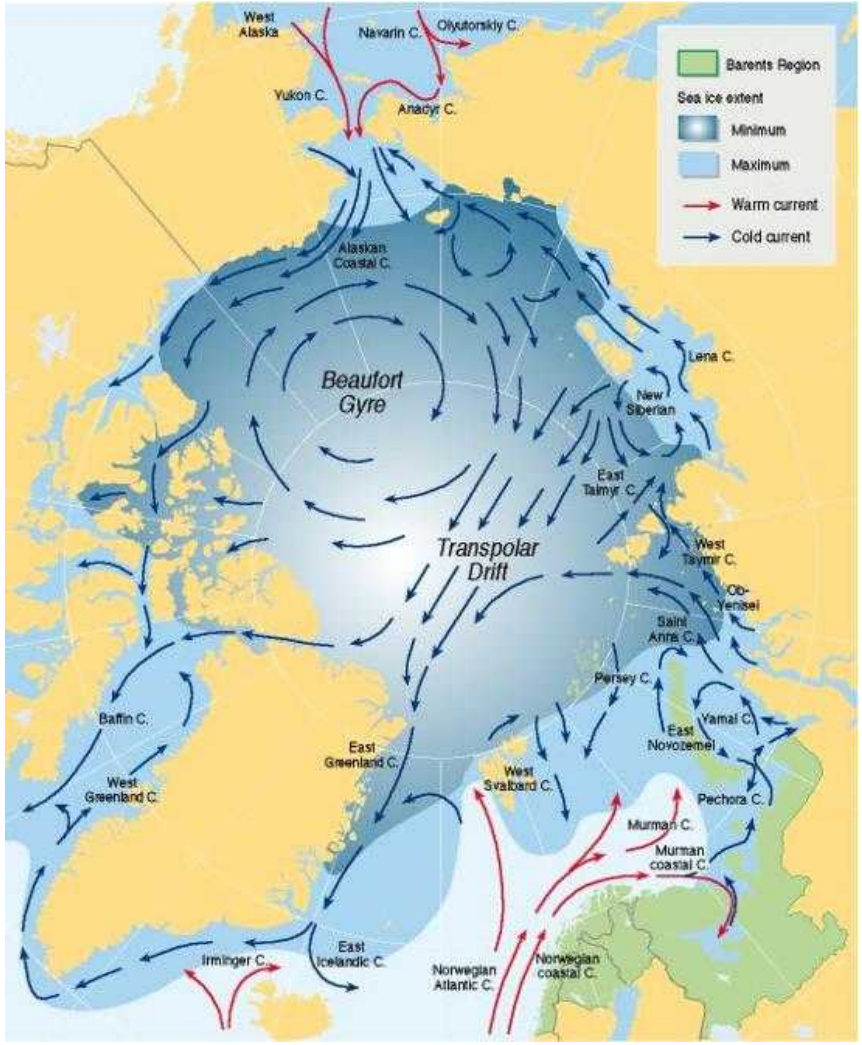
Intraseasonally:

Mainly wind driven, ocean has smaller role.

The ice drift relative to the wind changes through the year:

5° to wind in winter

18° to wind in summer



ECMWF

Albedo

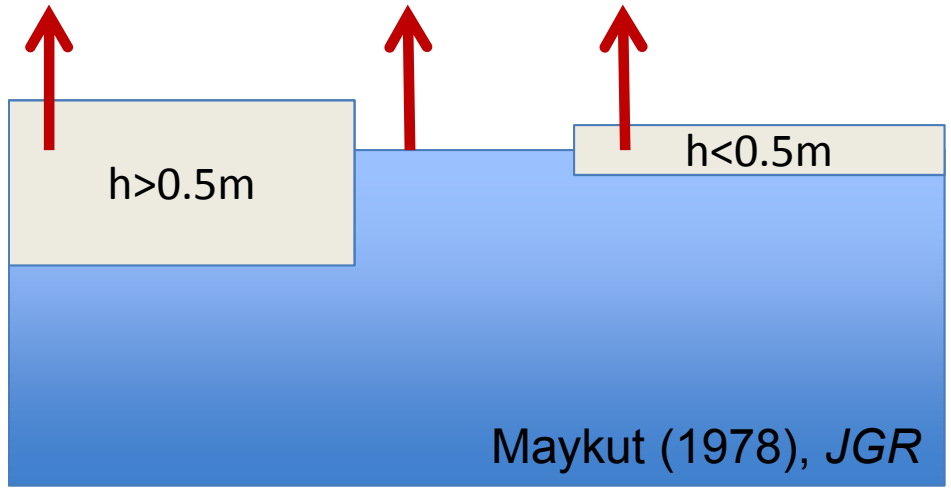
Depends on:

- Surface Characteristics:
  - Snow cover
  - Melt ponds
  - Thickness of ice
- Wavelength of incoming radiation
- Solar angle

Curry et al (2001), *JGR*
Shine (1984), *QJRMS*
Payne(1972), *JAS*

Impacts of Sea Ice

- Energy Fluxes:
  - Changes albedo of the region – solar heating of upper ocean
  - Thickness of the sea ice alters the surface heat fluxes
    - Winter; biggest effect – no sun and air colder than ocean
    - Leads in the ice are important (Badgerley, 1966)



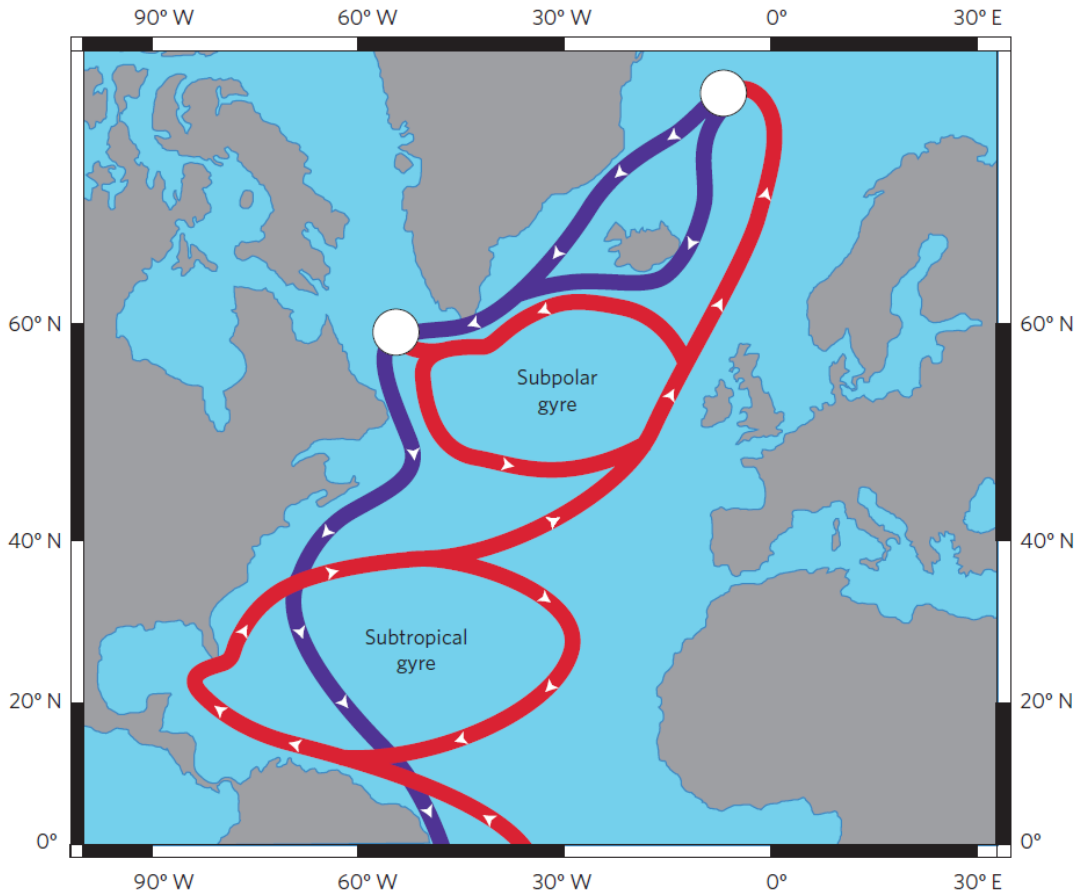
- Impact on waves
- Salinity fluxes:
  - Production of brine (freezing) and freshwater (melting)

Impacts on the ocean

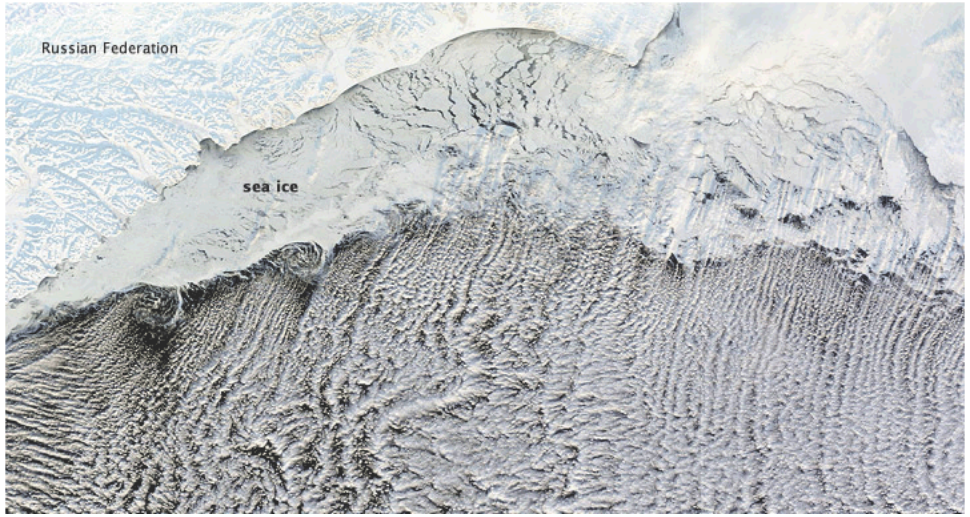
Deep convection:

- More important on longer time scales

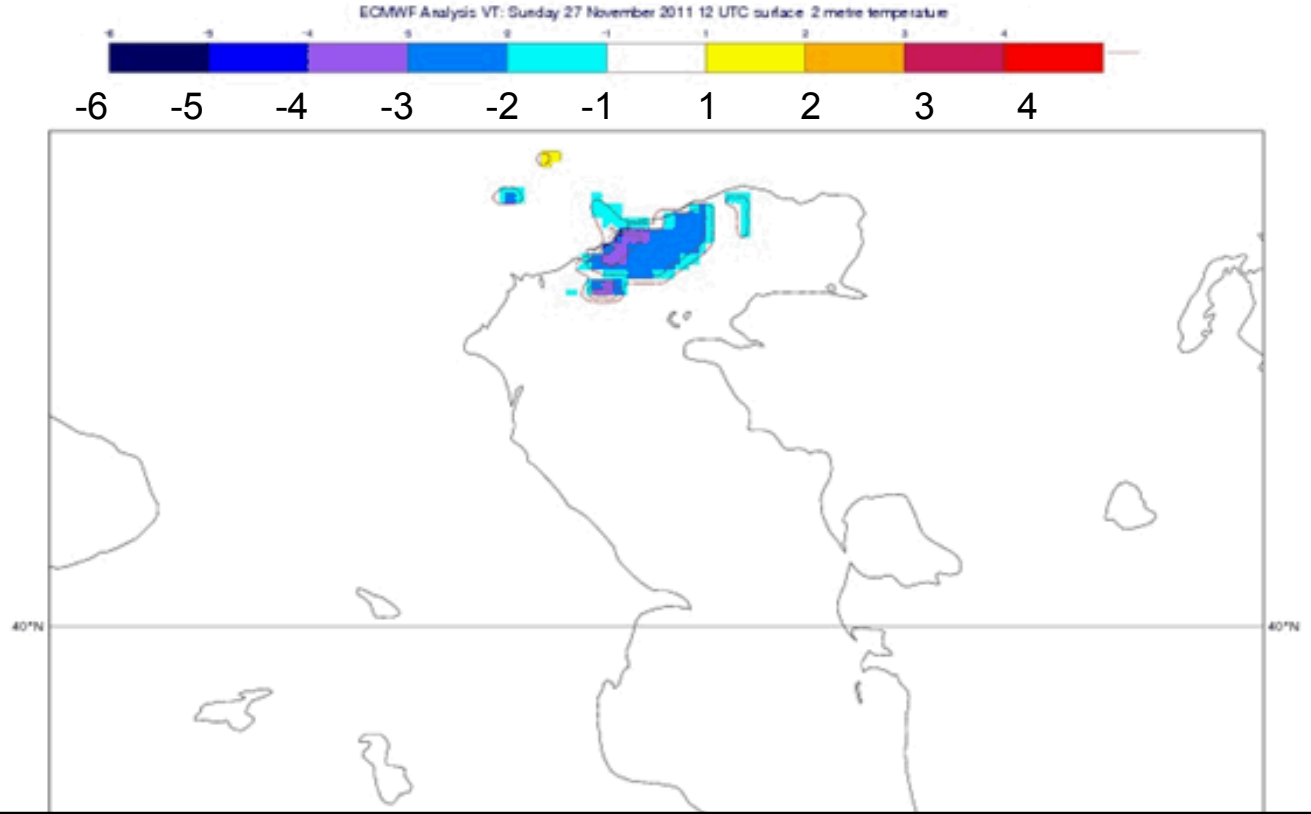
- Impact on the Gulf Stream and the Thermohaline circulation – part of the feedback on the Arctic system



Impacts on the atmosphere



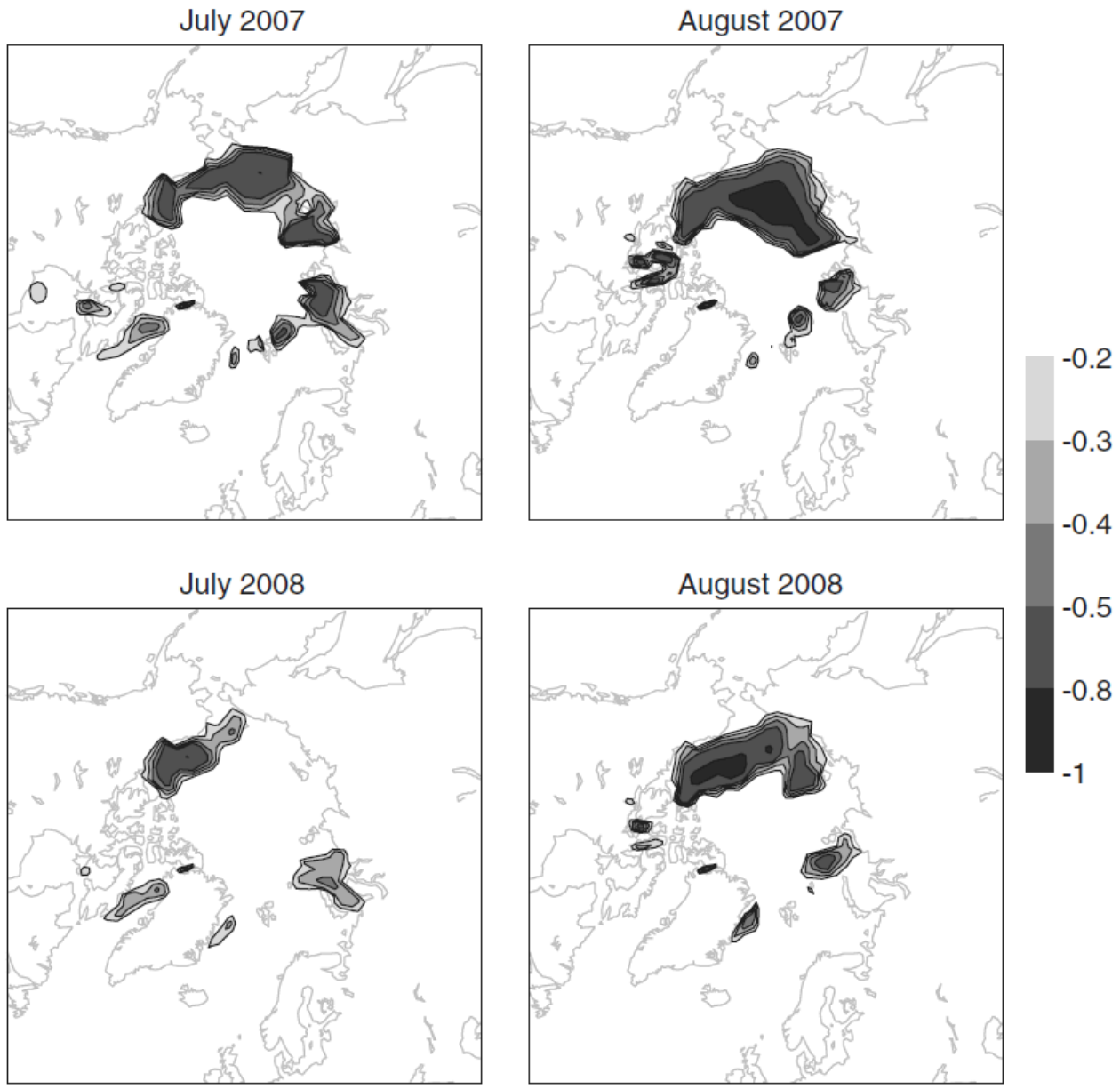
- Surface air temperatures
- Cloud
- Storm tracks
- Precipitation
- Large scale variability – NAO – seasonal timescale predictions



ECMWF

Impact on seasonal timescales

- Ice extent shown to be important in summer for monthly and seasonal timescales.



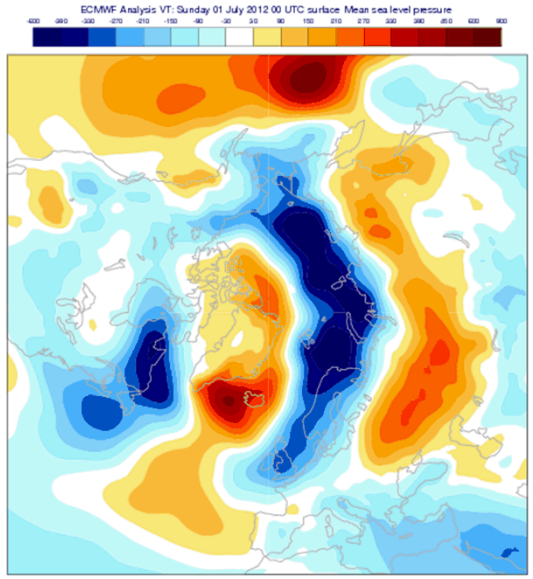
Balmaseda et al. (2010), Q*JRMS*

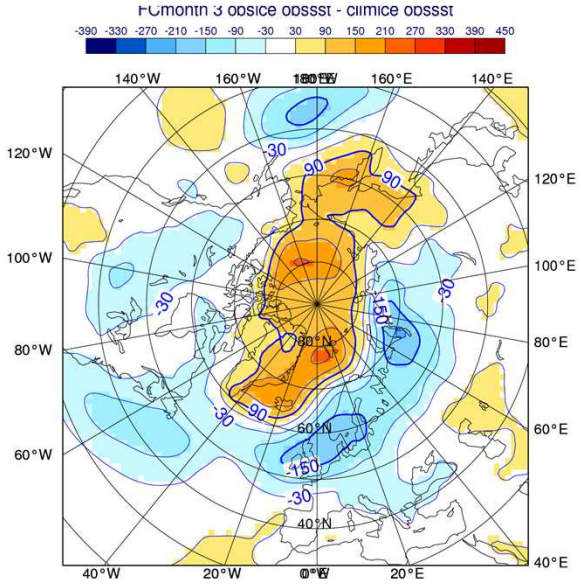
ECMWF

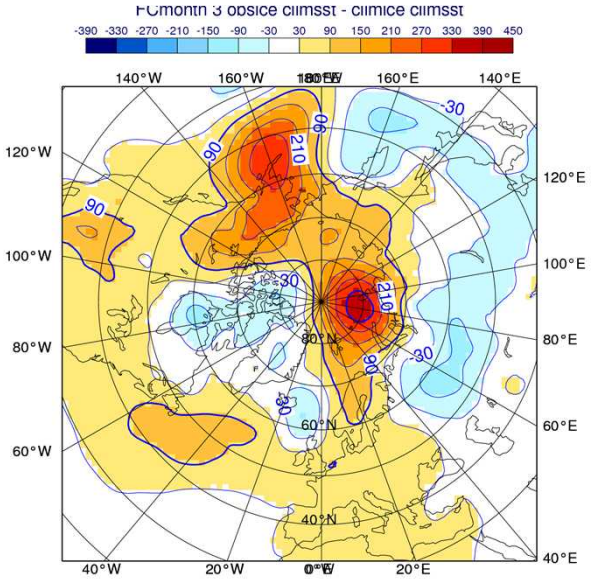
Summer sea ice impacts – Case study 2012

- Ensemble mean MSLP differences between experiments:

2012 sea ice - sea ice climatology







Reanalysis

SST 2012

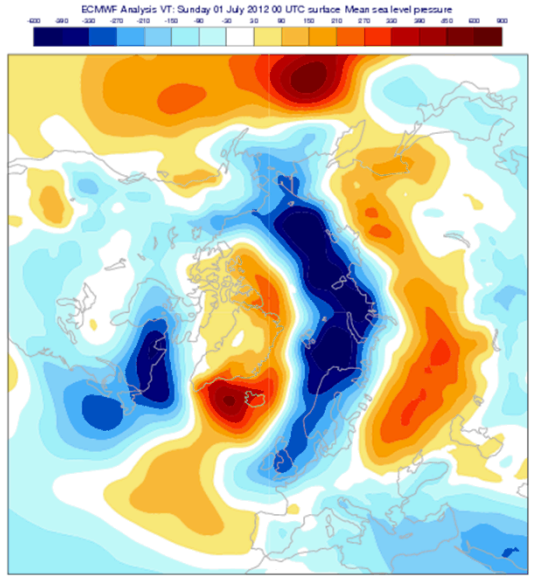
SST Clim

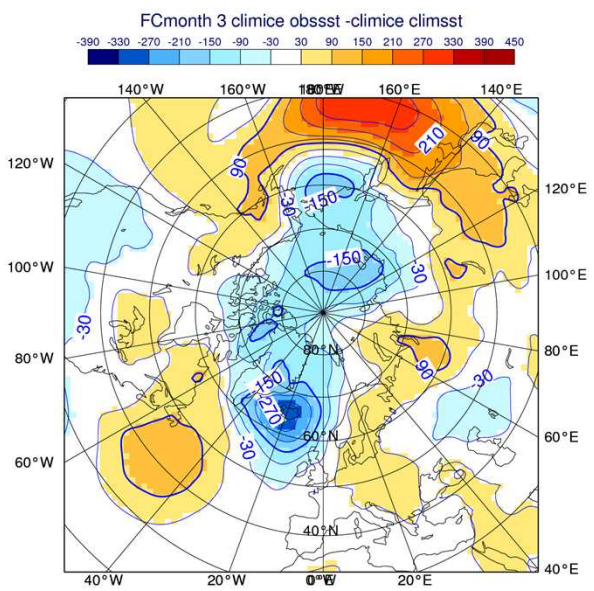
July MSLP anomaly
Era Interim 2012 - climatology

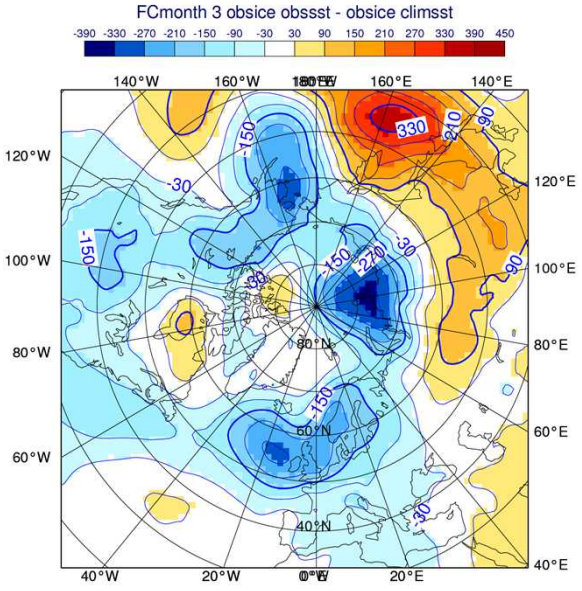
Summer SST impacts – Case study 2012

- Ensemble mean MSLP differences between experiments:

2012 SST - SST climatology







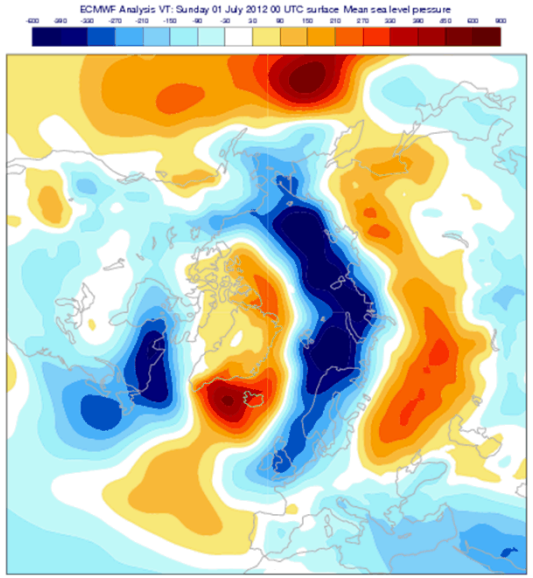
Reanalysis

Sea ice clim

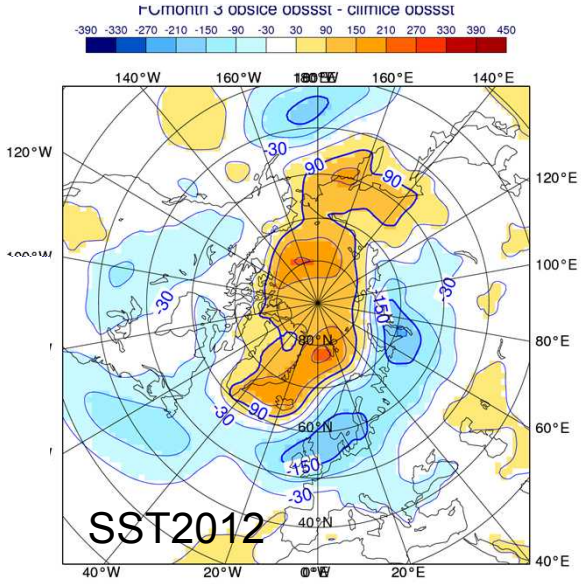
Sea ice 2012

July MSLP anomaly
Era Interim 2012 - climatology

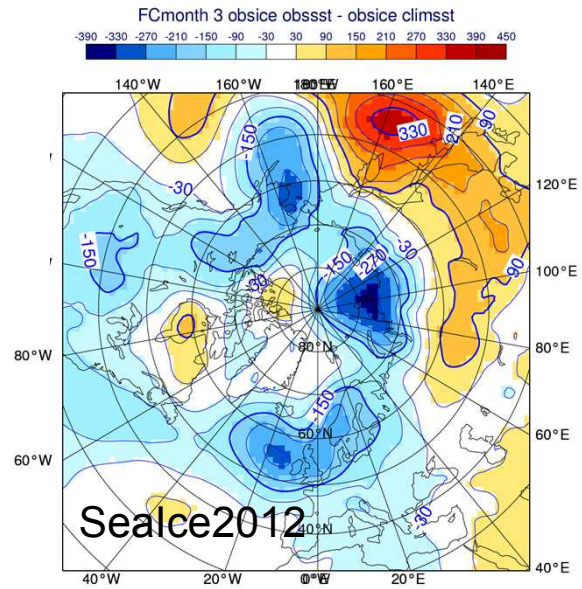
Results Sea Ice Predictability – July 2012



July MSLP anomaly
Era Interim 2012 - climatology



sea ice: 2012-climatology

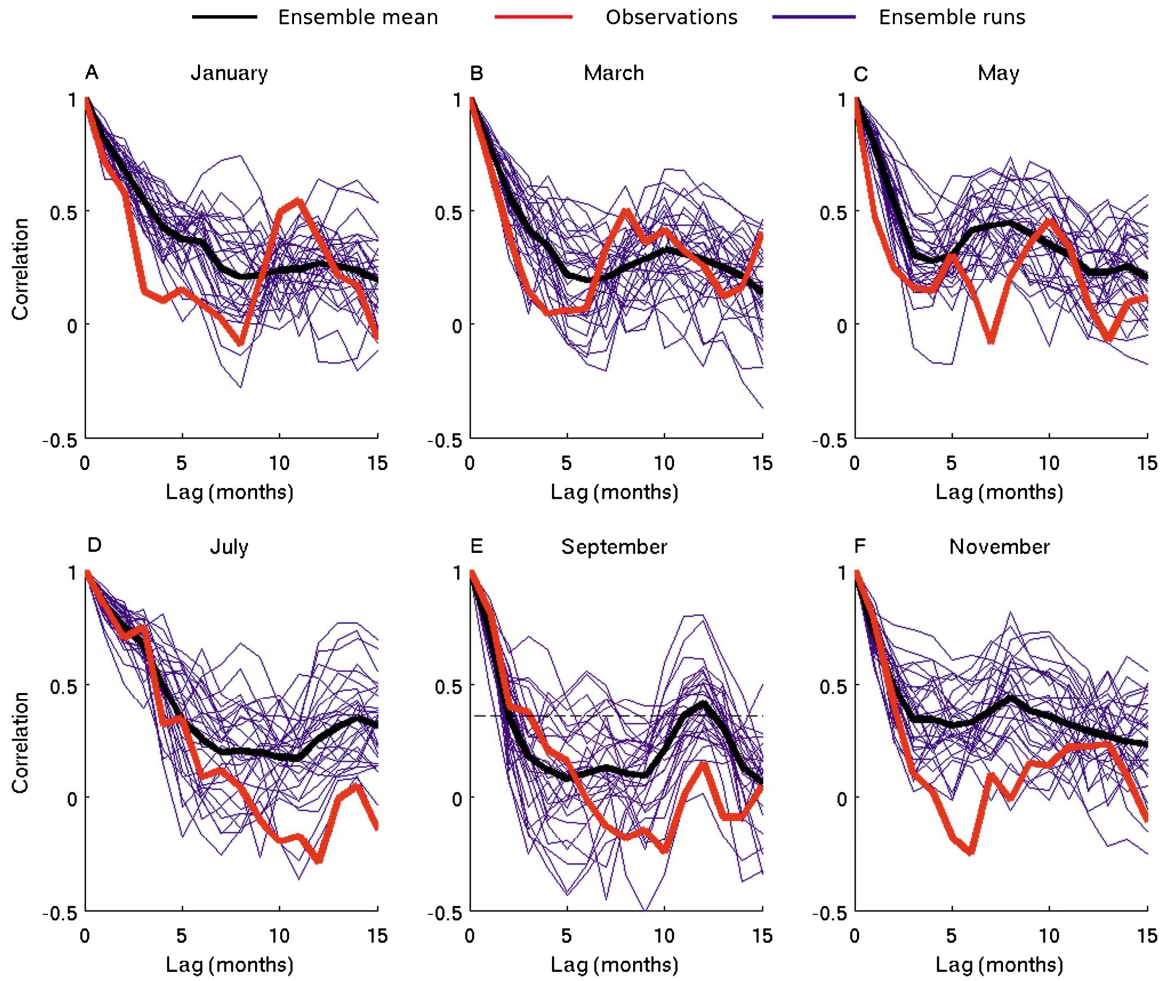


SST: 2012-climatology

ECMWF

Predictability of sea ice

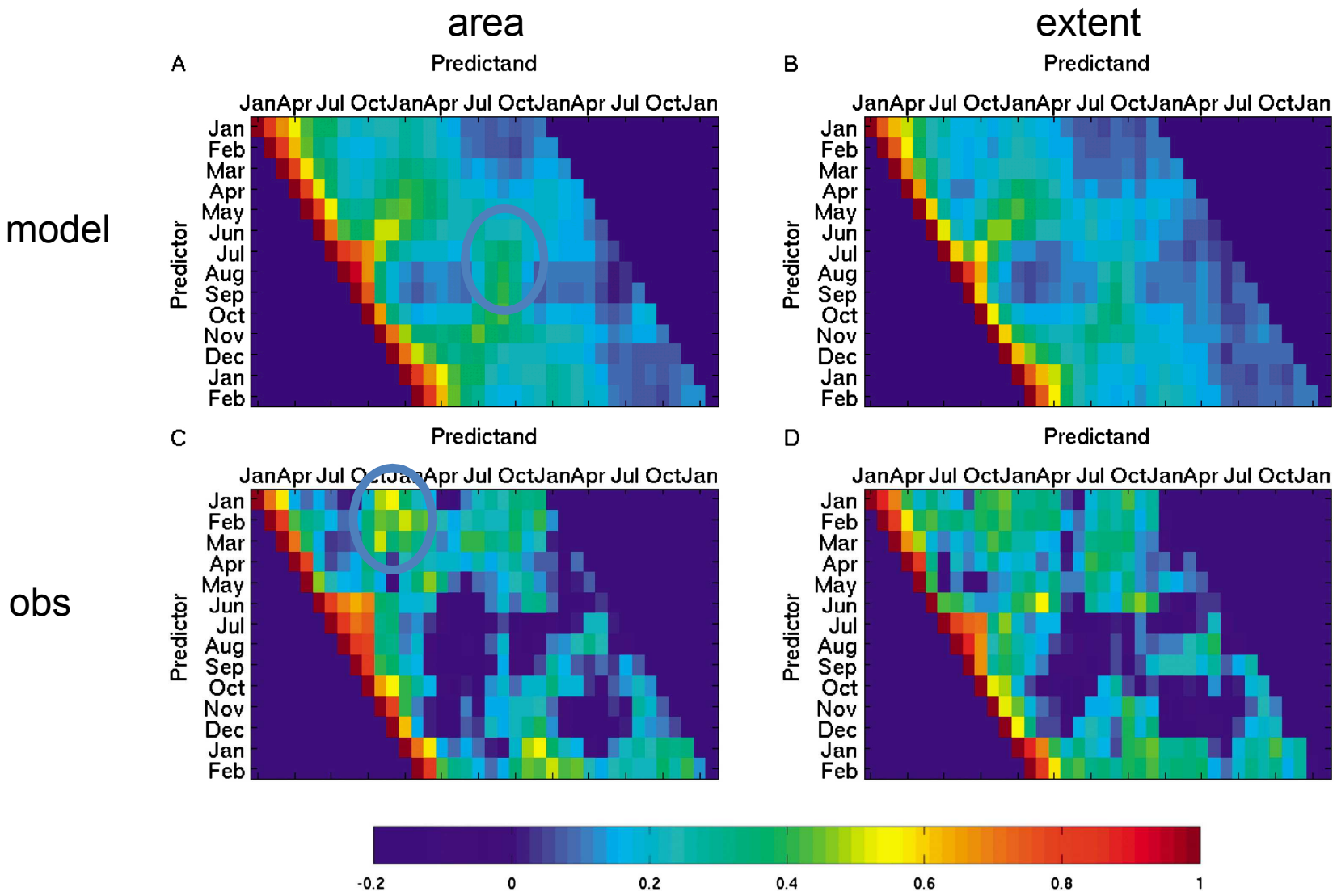
- Persistence of the system:
  - Sea ice area patterns have a decorrelation time of 2-5months (observed)
  - Sea ice volume decorrelation time of around 5 yrs (modelled)
  - Area better predictor than extent
- Re-emergence:
  - SST
  - Thickness anomalies



Blanchard-Wrigglesworth et al. (2011), *J. Clim*

ECMWF

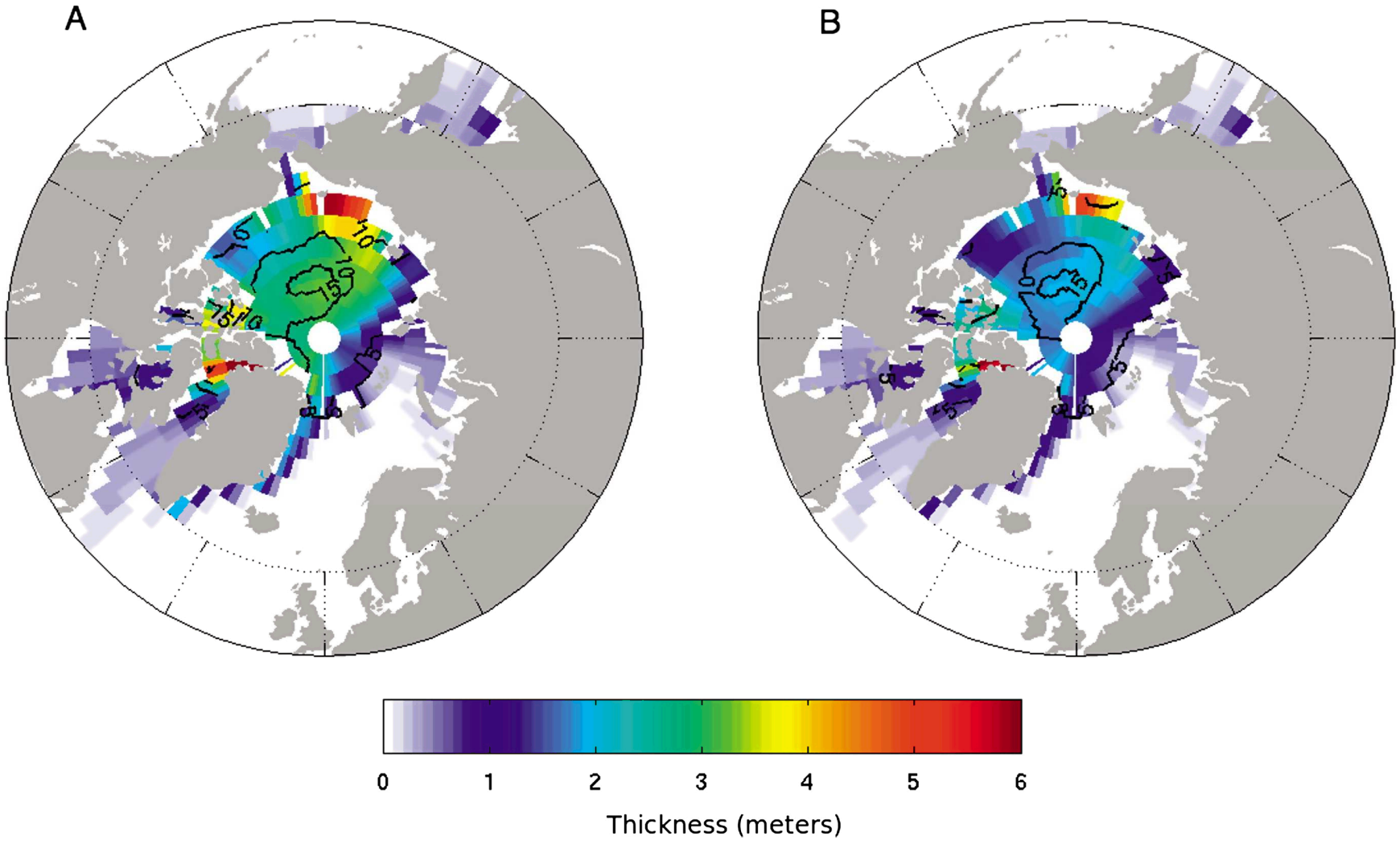
Predictability of sea ice



ECMWF

Blanchard-Wrigglesworth et al. (2011), *J. Clim*

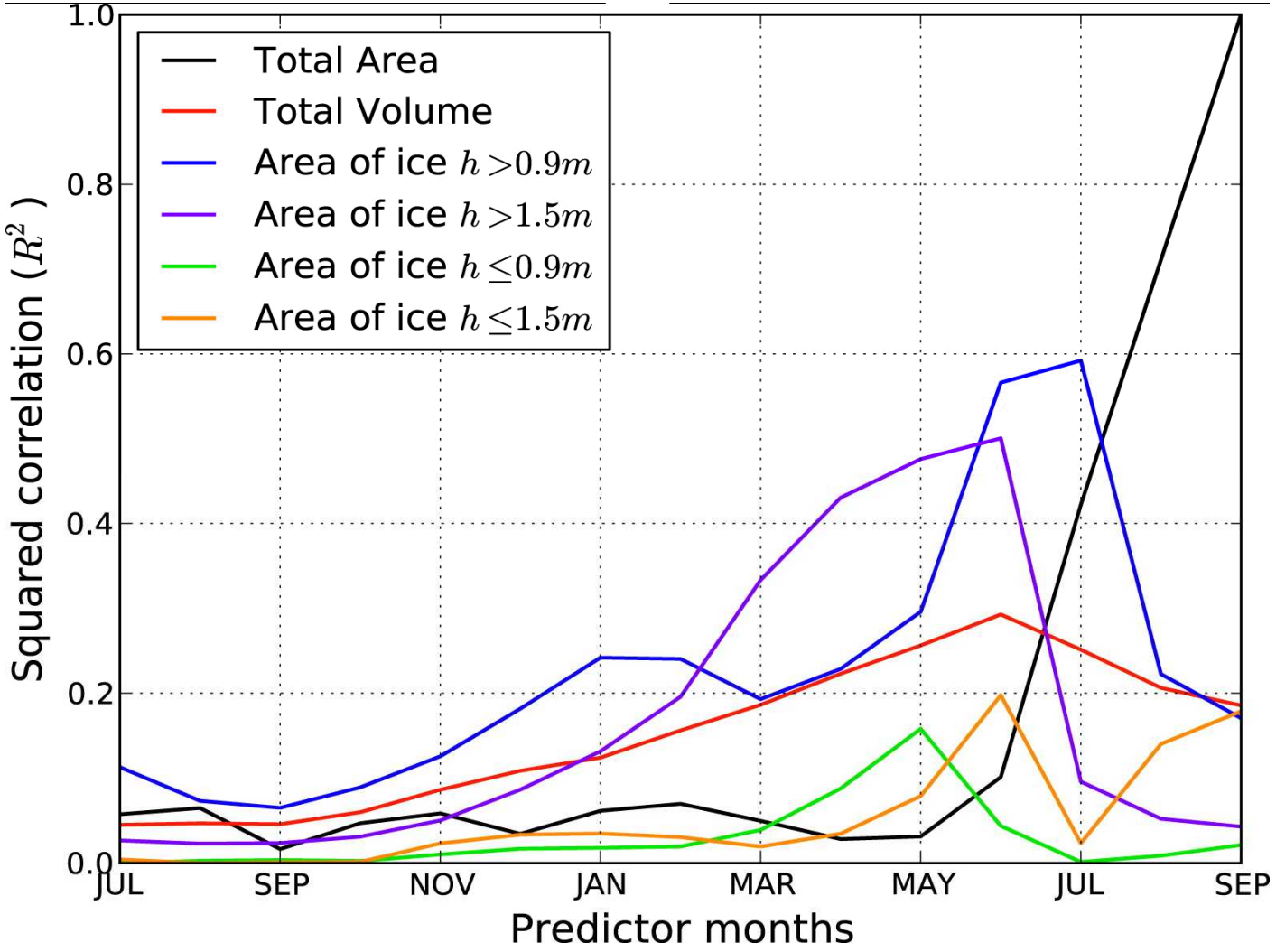
Persistence of thickness



ECMWF

Blanchard-Wrigglesworth et al. (2011), *J. Clim*

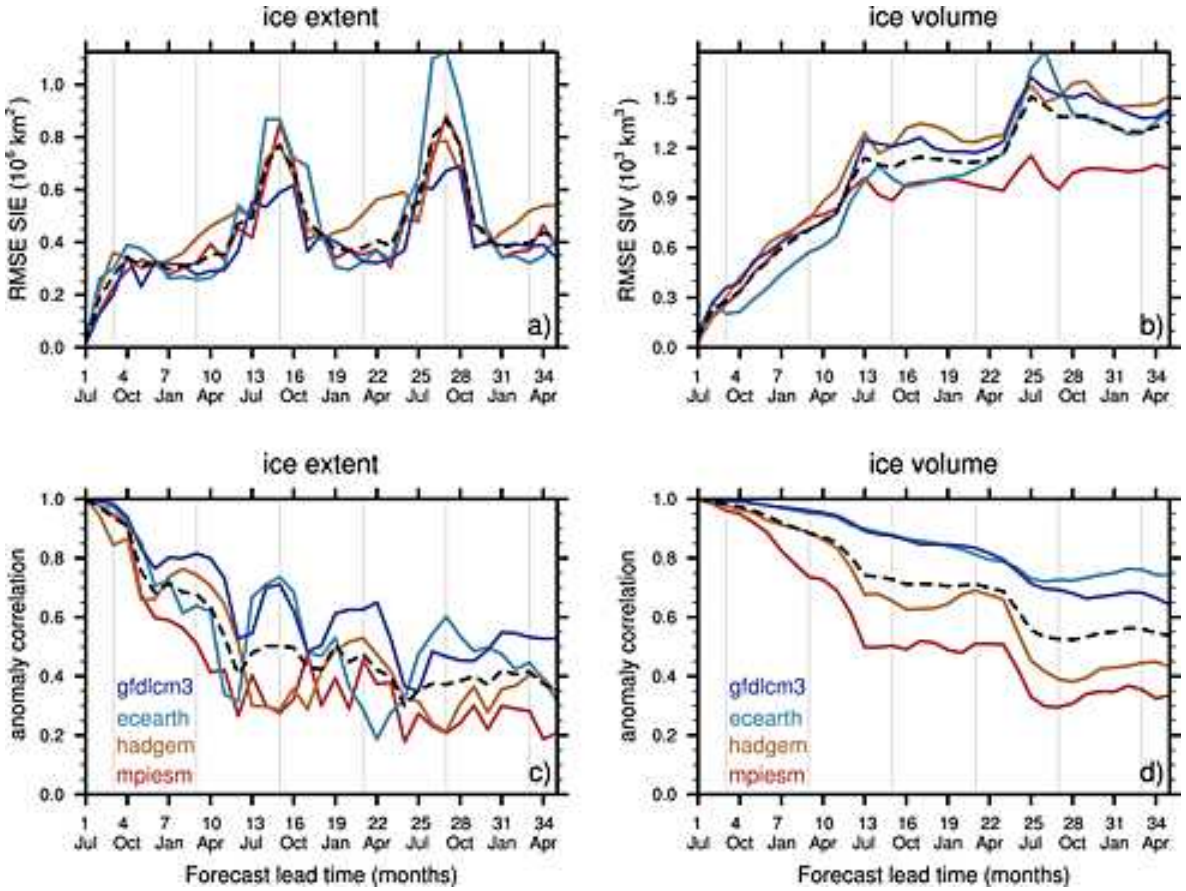
Thickness to predict September ice area

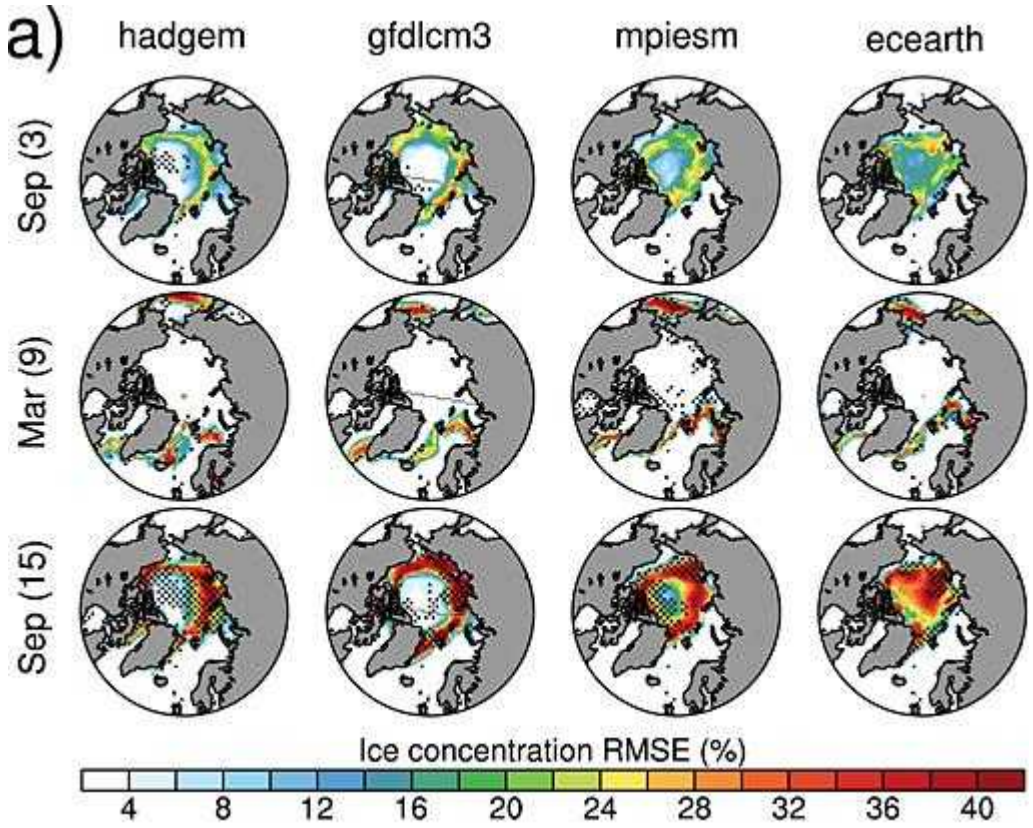


ECMWF

Chevallier & Salas y Mélia (2012), *J. Clim*

Assessment of Arctic predictability in models

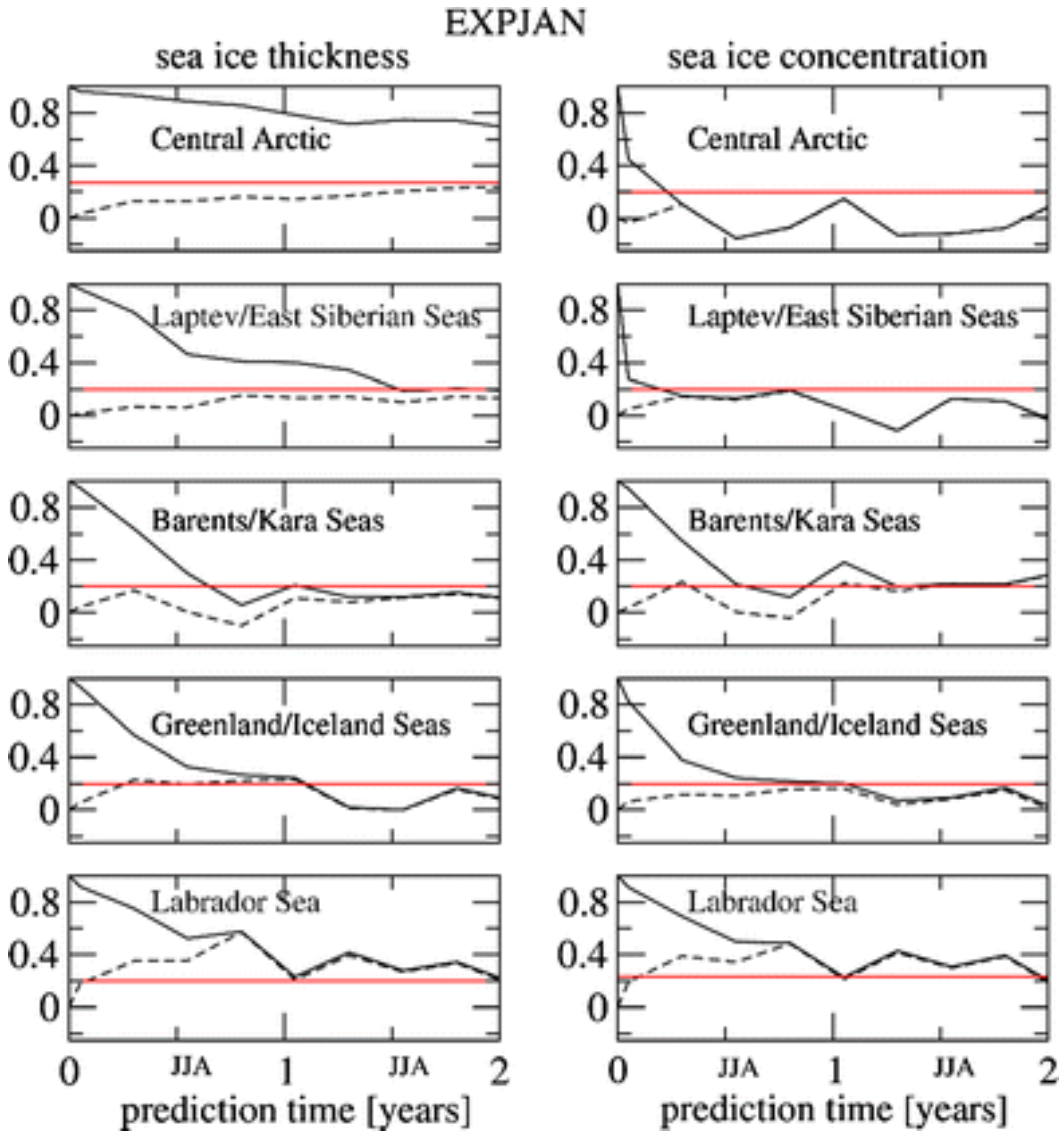




Tietsche et al (2014), *GRL*

Perfect Predictability study

- Predictability varies spatially
- In most areas persistence is the cause
- Labrador Sea –dynamics play a role



Koenigk & Mikolajewicz, 2008, *Clim Dyn.*

ECMWF

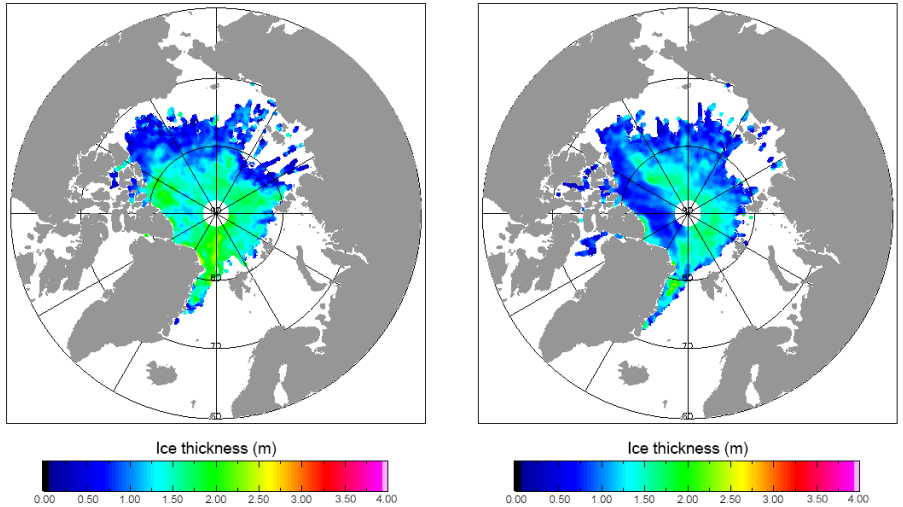
Not many surface observations...

ECMWF

Observations

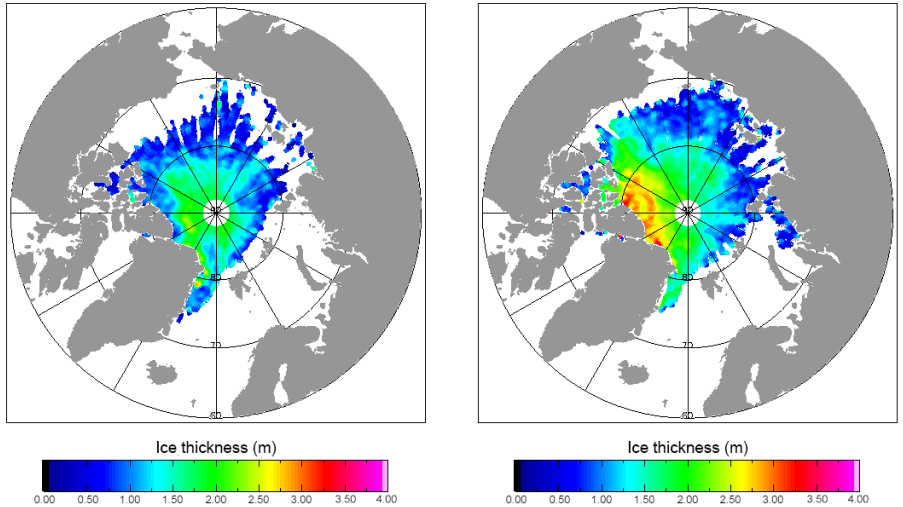
Ice Thickness

October 2010

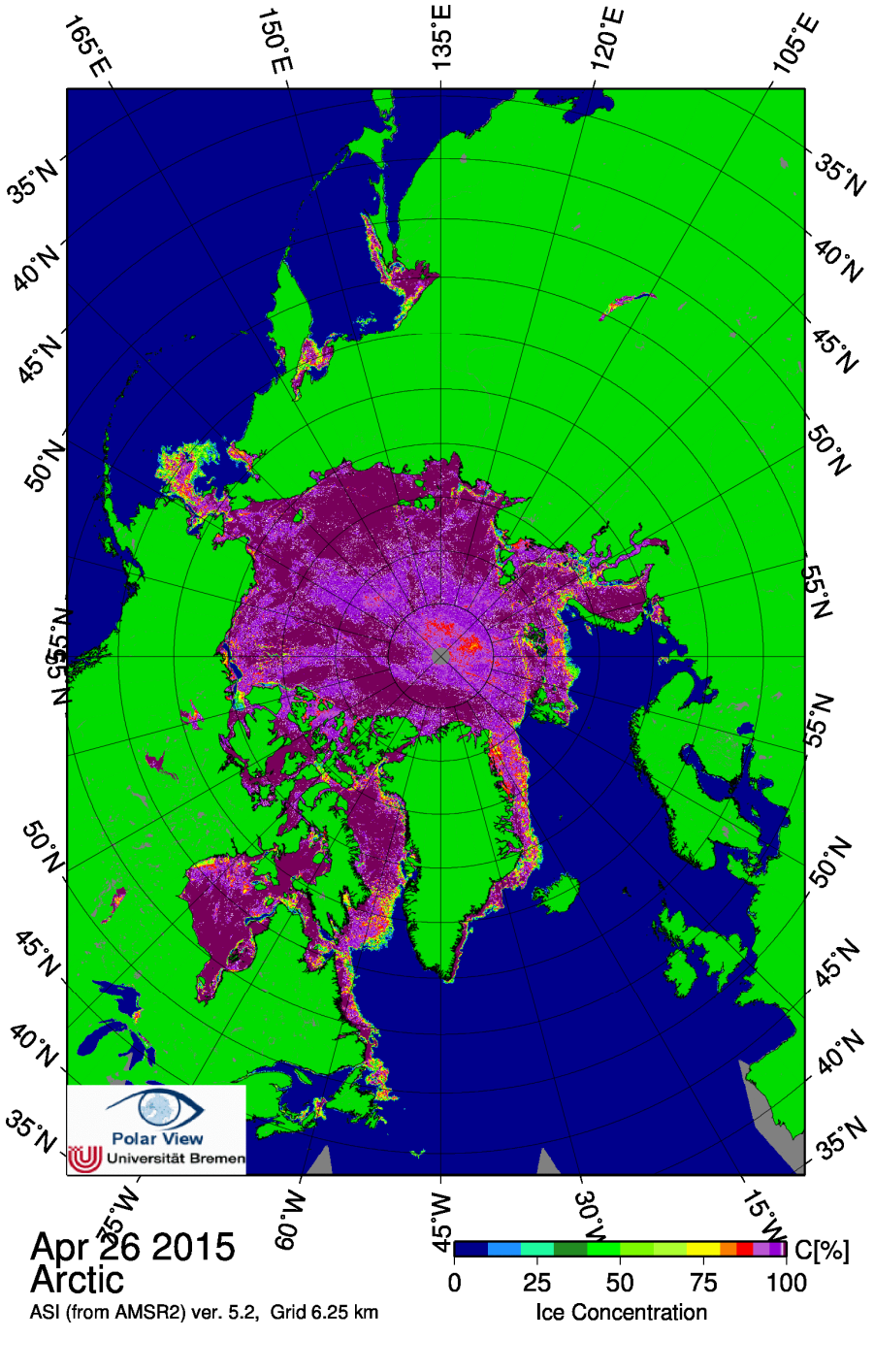


October 2011

October 2012



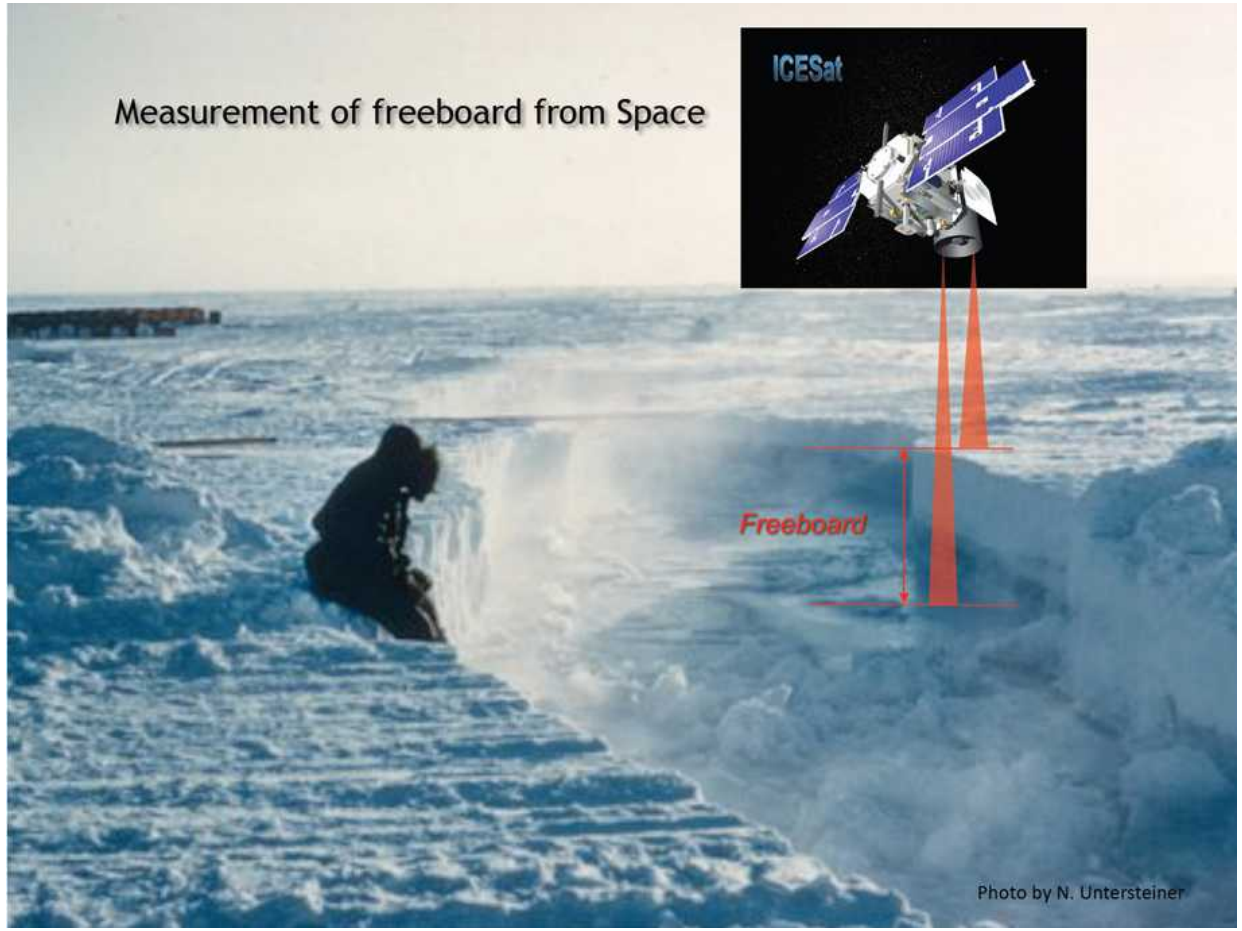
October 2013



CryoSat/Rachel Tilling, University College London

Observations - thickness

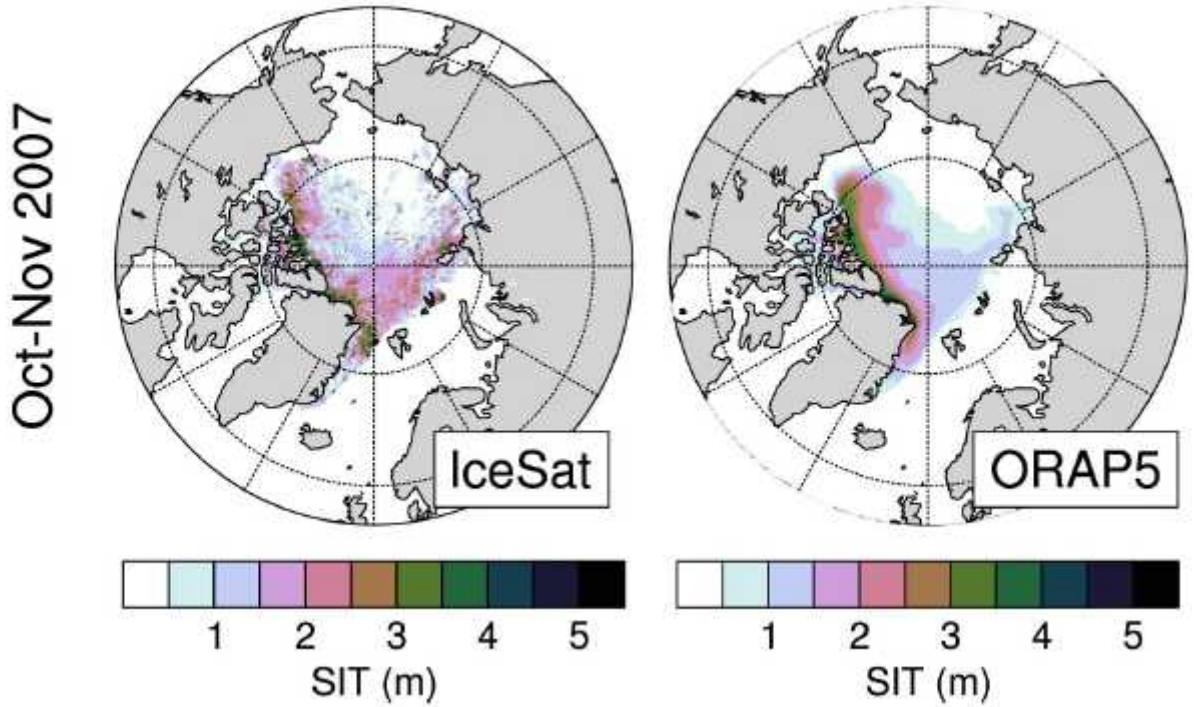
- IceSat (2003-2009)
  - IceSat2 (2017)
- CryoSat2
  - Thickness > 2m
- SMOS
  - Thickness up to 0.5m



Initialisation of ice model

Using ORAP5

3DVAR ocean reanlysis – uses sea ice concentration

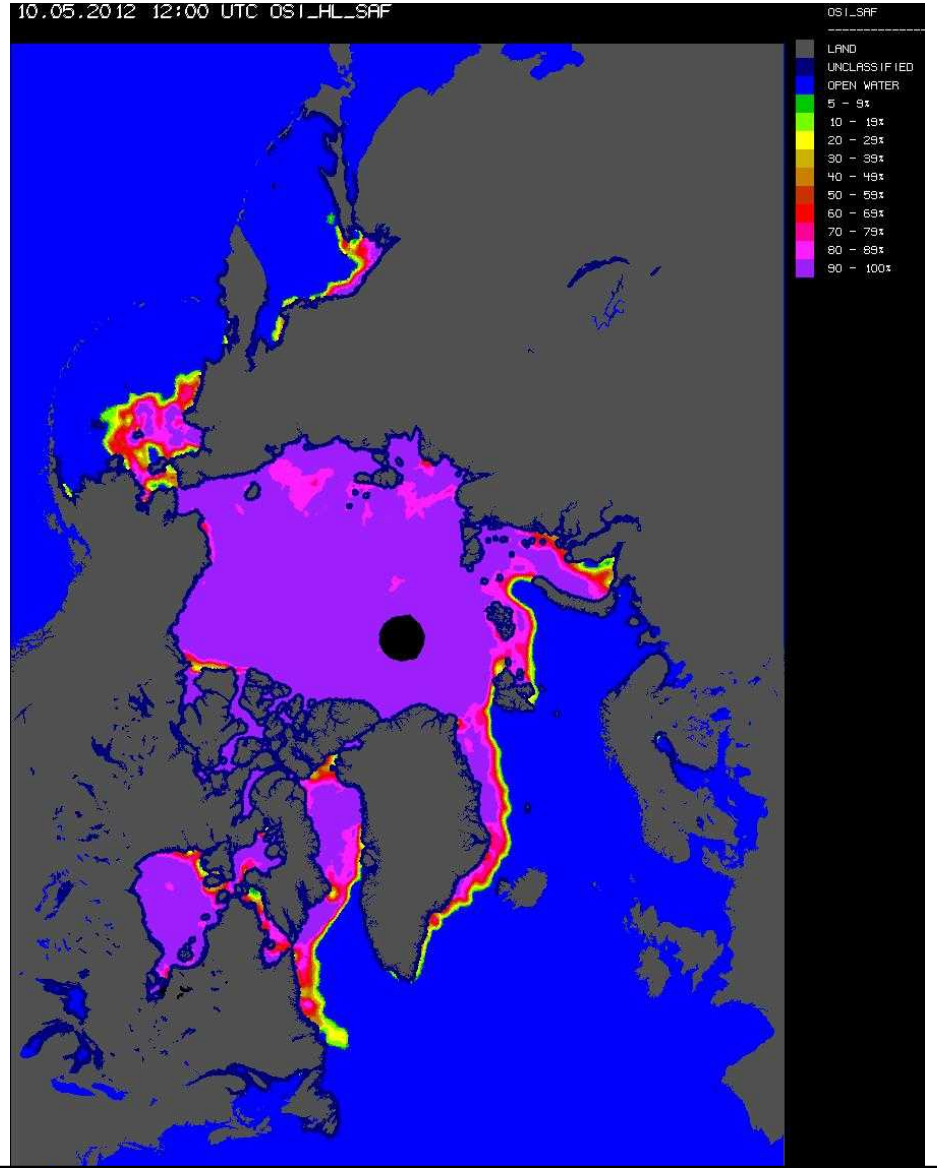


Tietsche et al 2014

ECMWF

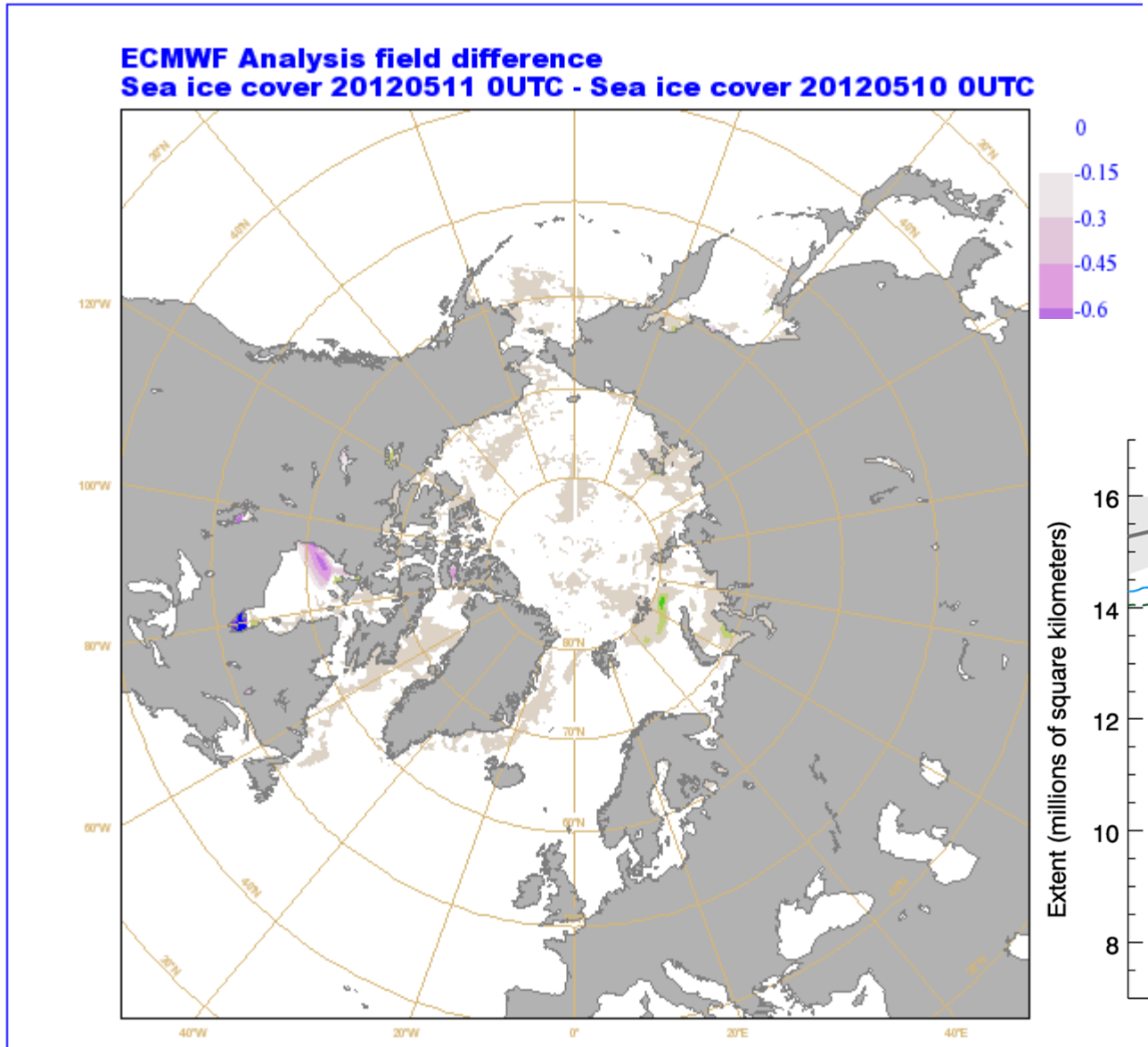
Sea Ice in our current forecasting system

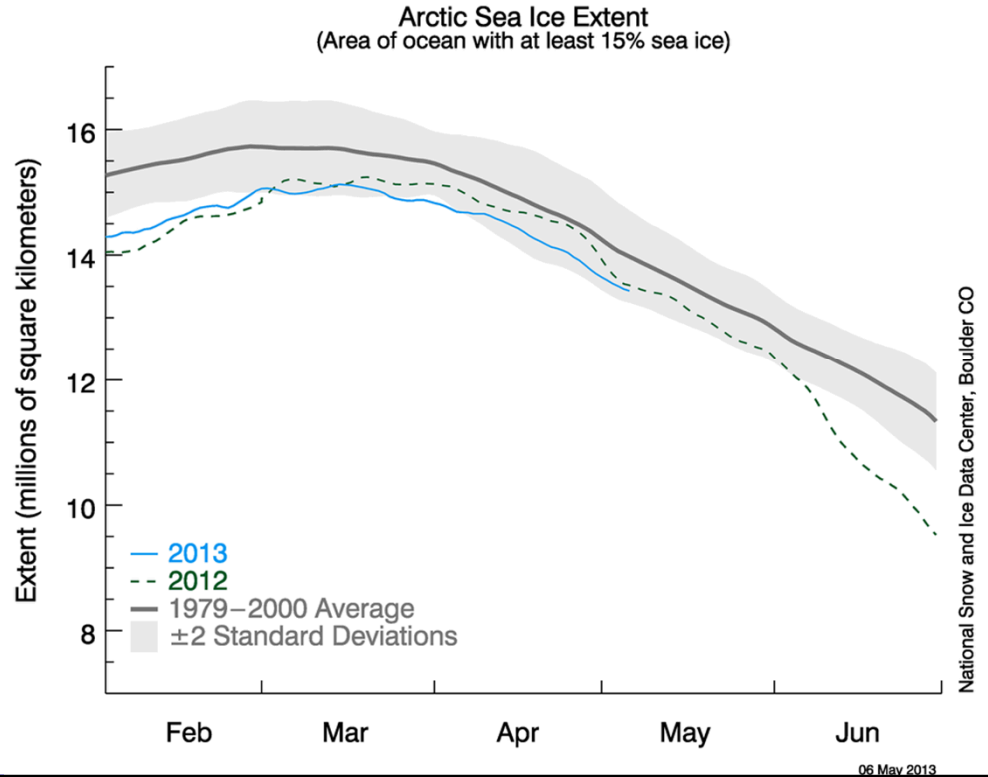
- High Resolution model (10 day forecast):
  - Initial conditions of sea ice – use OSTIA (OSISAF)
  - Persist ice for the forecast



ECMWF

Sea Ice in our current forecasting system





Sea Ice in our current forecasting system

- High Resolution model (10 day forecast):
  - Initial conditions of sea ice – use OSTIA (OSISAF)
  - Persist ice for the forecast

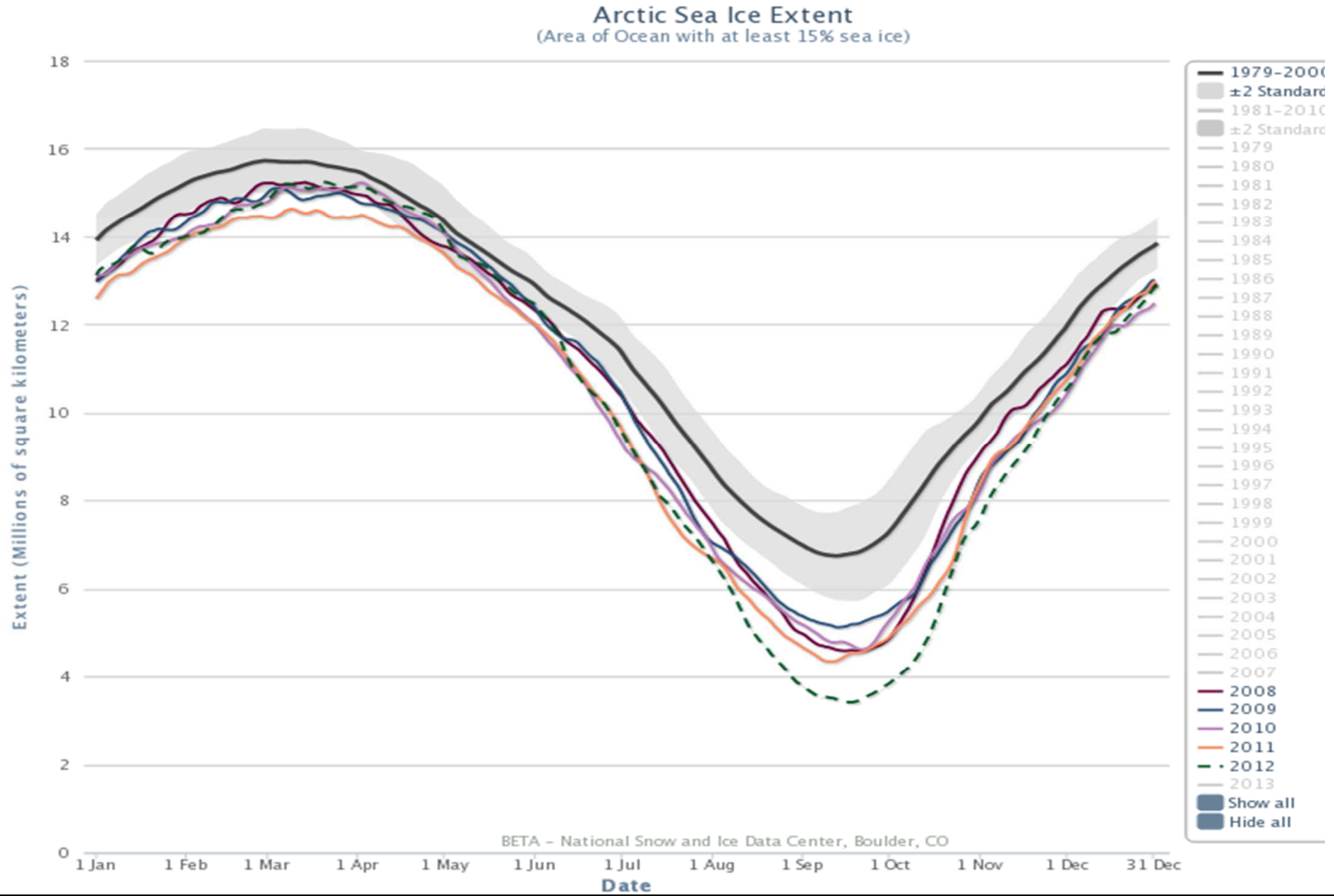
- EPS and Monthly Forecast (coupled ocean atmos model)
  - Persisted sea ice for first 10 days
  - Persisted sea ice anomaly – relaxing toward climatology (last 5years)

- Seasonal Forecast System 4:
  - Sea ice condition from previous 5 years
  - Sea-ice for the first 10 days of the forecast persists the initial sea-ice analysis; then over the next 20 days there is a transition towards the specified ice conditions from the previous 5 years.

Assuming that peristence is good predictor for medium range and last 5 years good estimate for current year

ECMWF

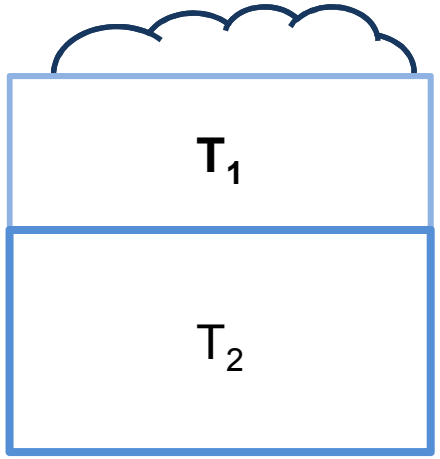
Sea Ice in our current forecasting system



Sea ice model

Model

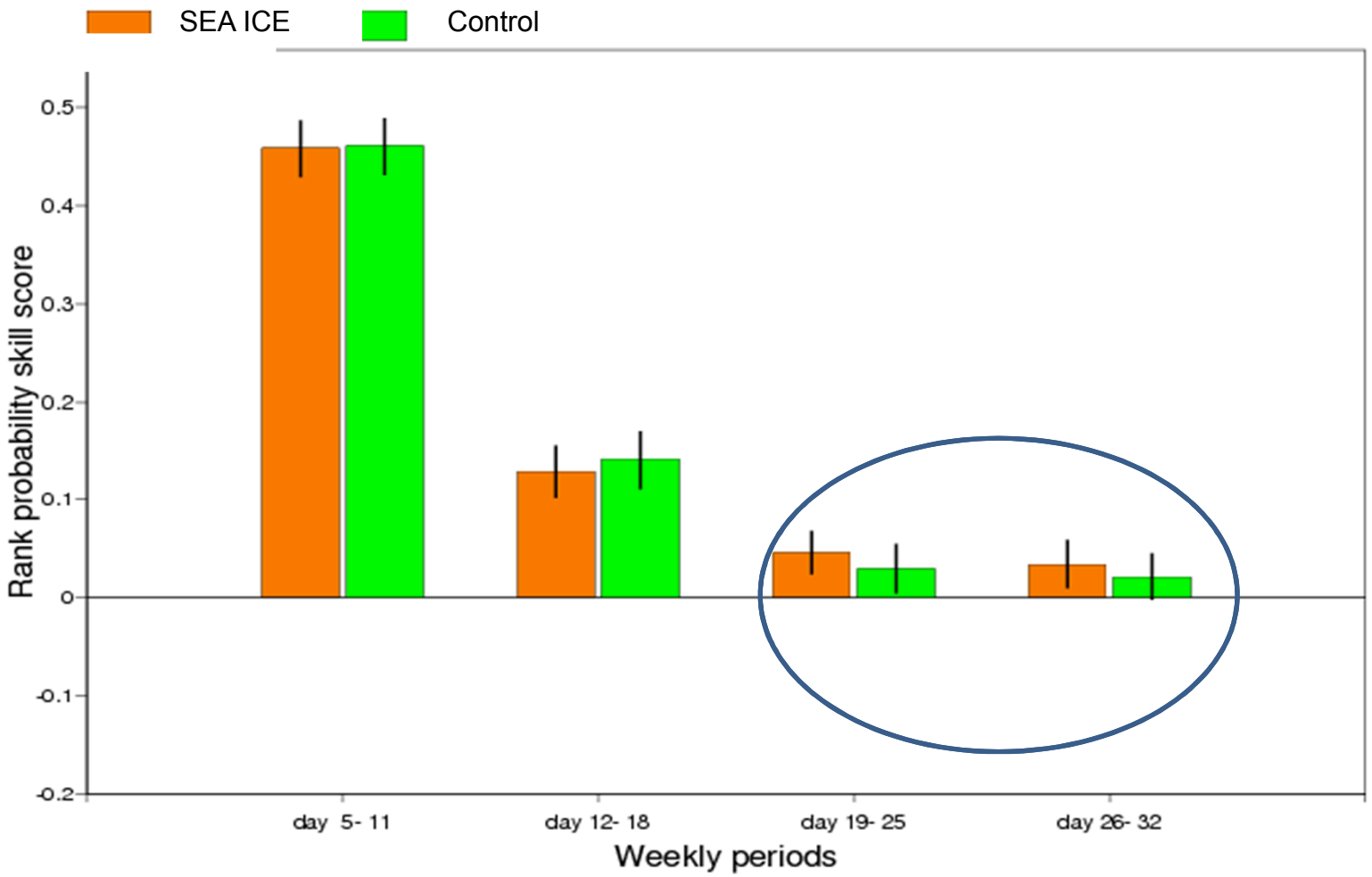
- Louvain-la-Neuve Ice Model (LIM 2)
- 3 thermodynamic layers (two ice layers and snow layer)
- Parameterised ice thickness distribution
- Transform of snow to ice
- Salt release (brine rejection)
- Uses viscous-plastic dynamics



Coupling to the atmosphere (IFS)

- Ice fraction, surface temperature of ice (or snow if present) and albedo returned to atmospheric and surface model
- Ocean ice model receives radiative fluxes and wind stress

Active sea ice model: Z500 Forecast Skill (weeks 1-4)



80 cases – The vertical bars represent the 95% level of confidence

ECMWF

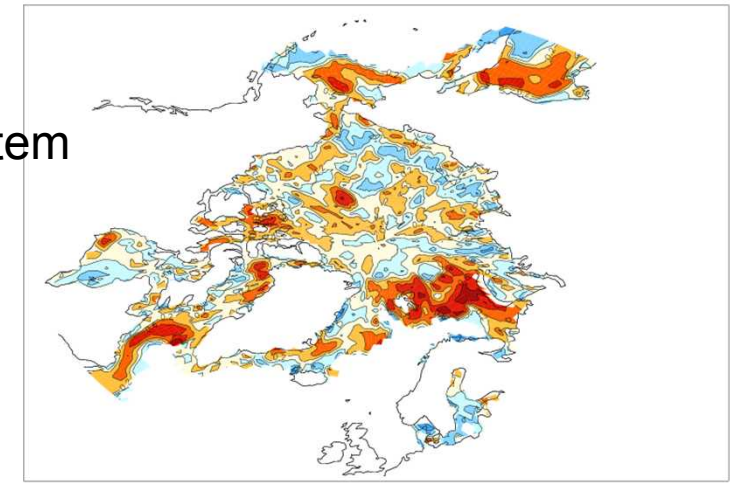
Correlations for week 4 Northern Hemisphere

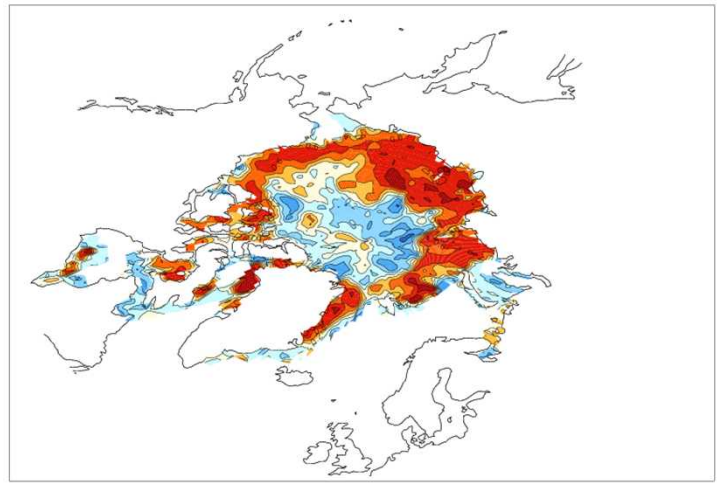
Winter cases

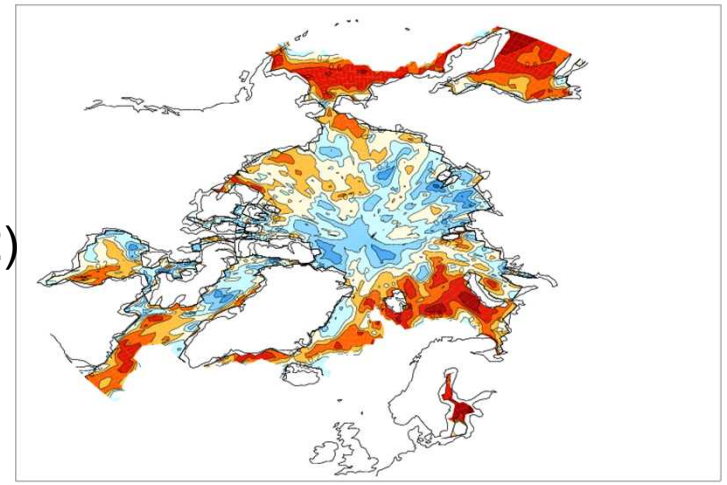
Summer cases

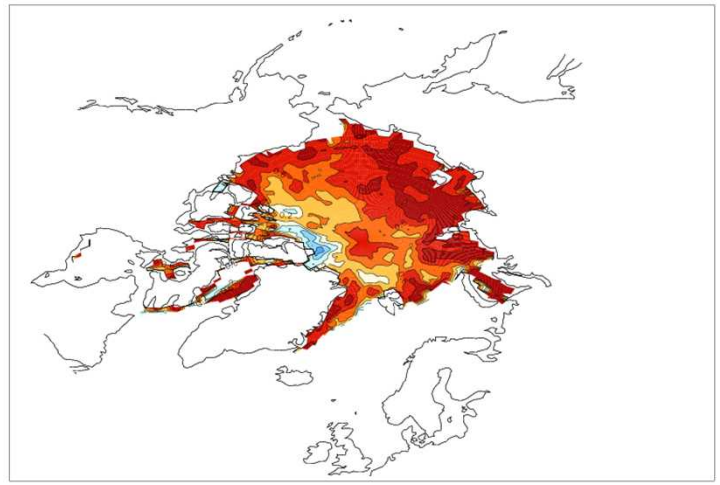
Current system (Pers+Clim)

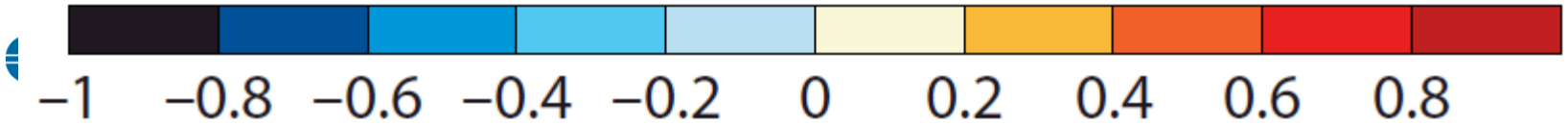
With sea-ice model (LIM2)











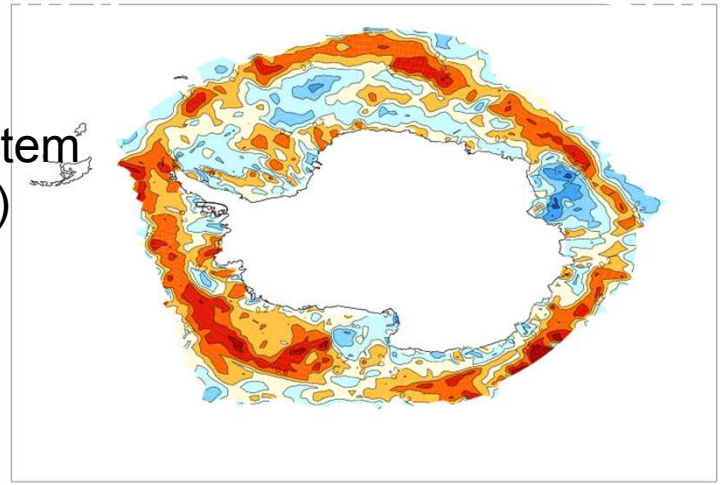
Correlations for week 4 Southern Hemisphere

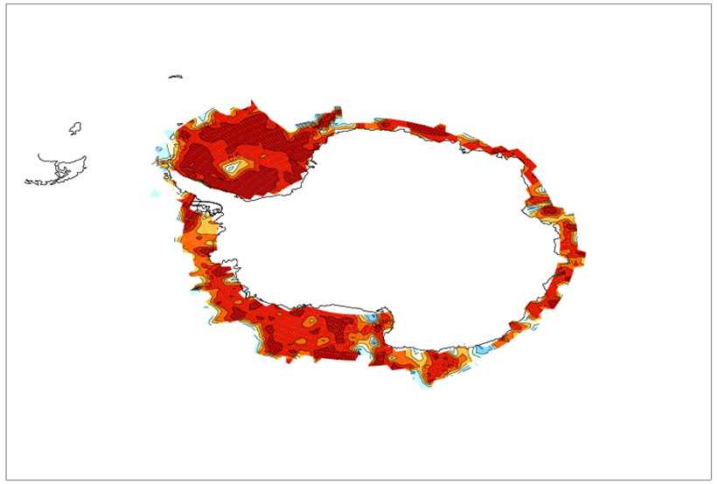
Winter cases

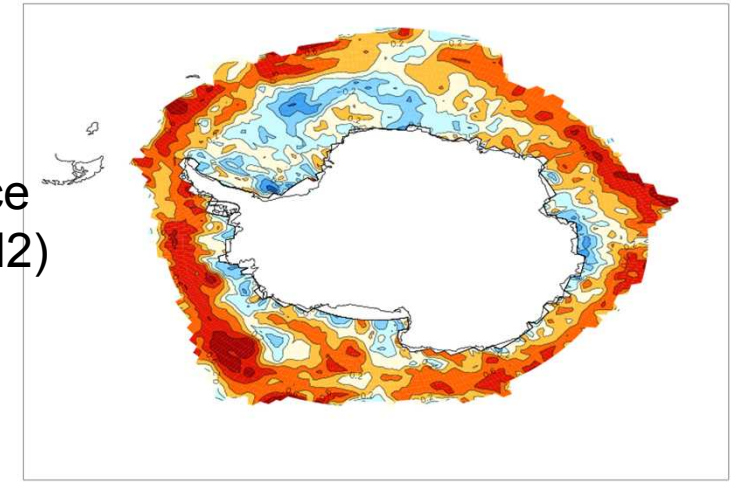
Summer cases

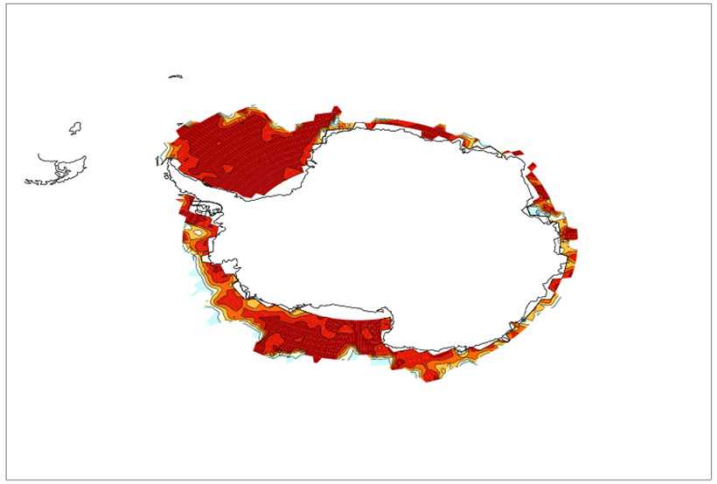
Current system (Pers+Clim)

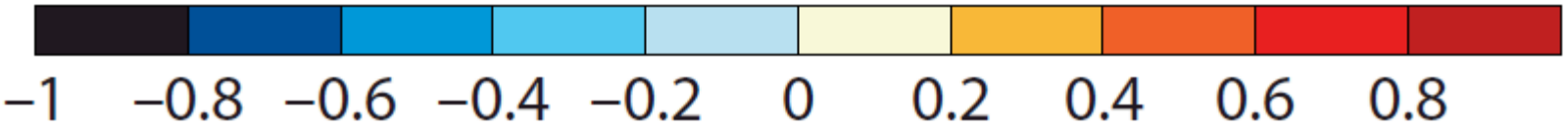
With sea-ice model (LIM2)









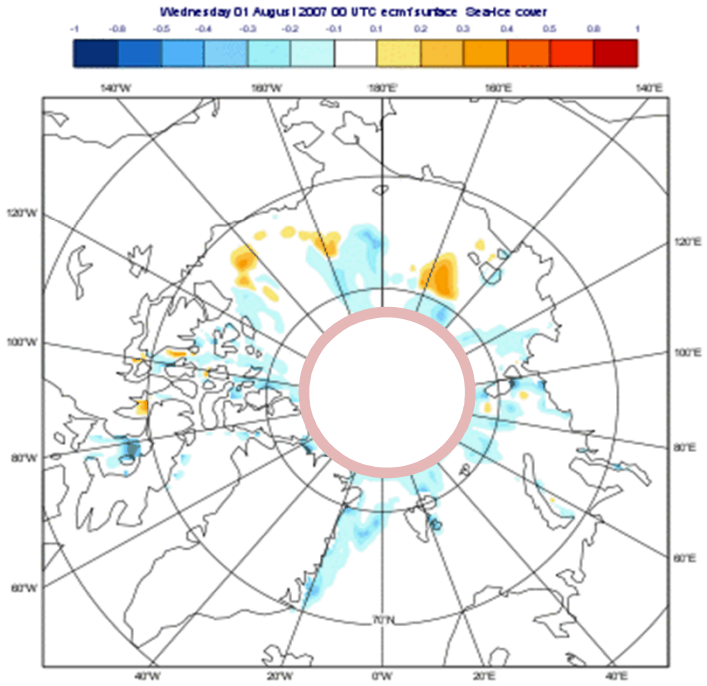


Extreme Events – case study 2007

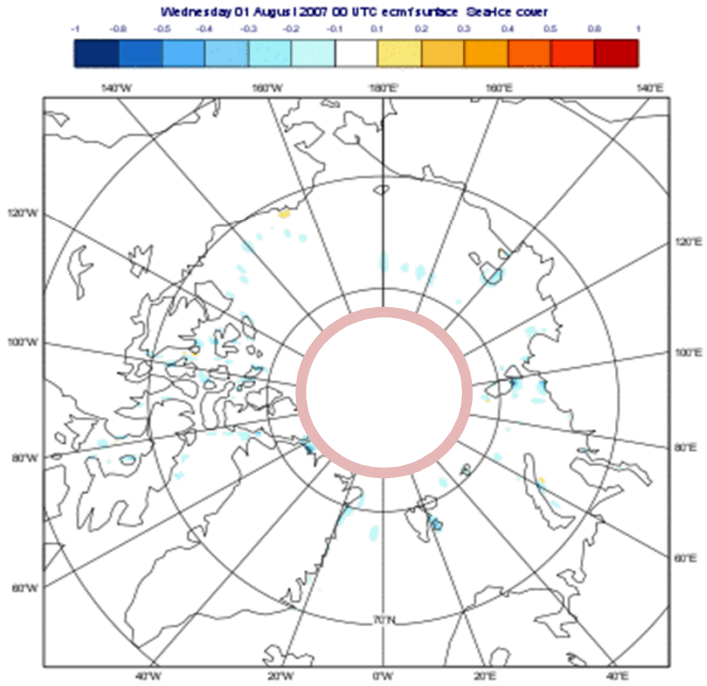
SEA ICE COVER: FORECAST – ERA-I

Note that area inside pink ring is fixed at constant 100% cover in ERA-I

With LIM2



Current System

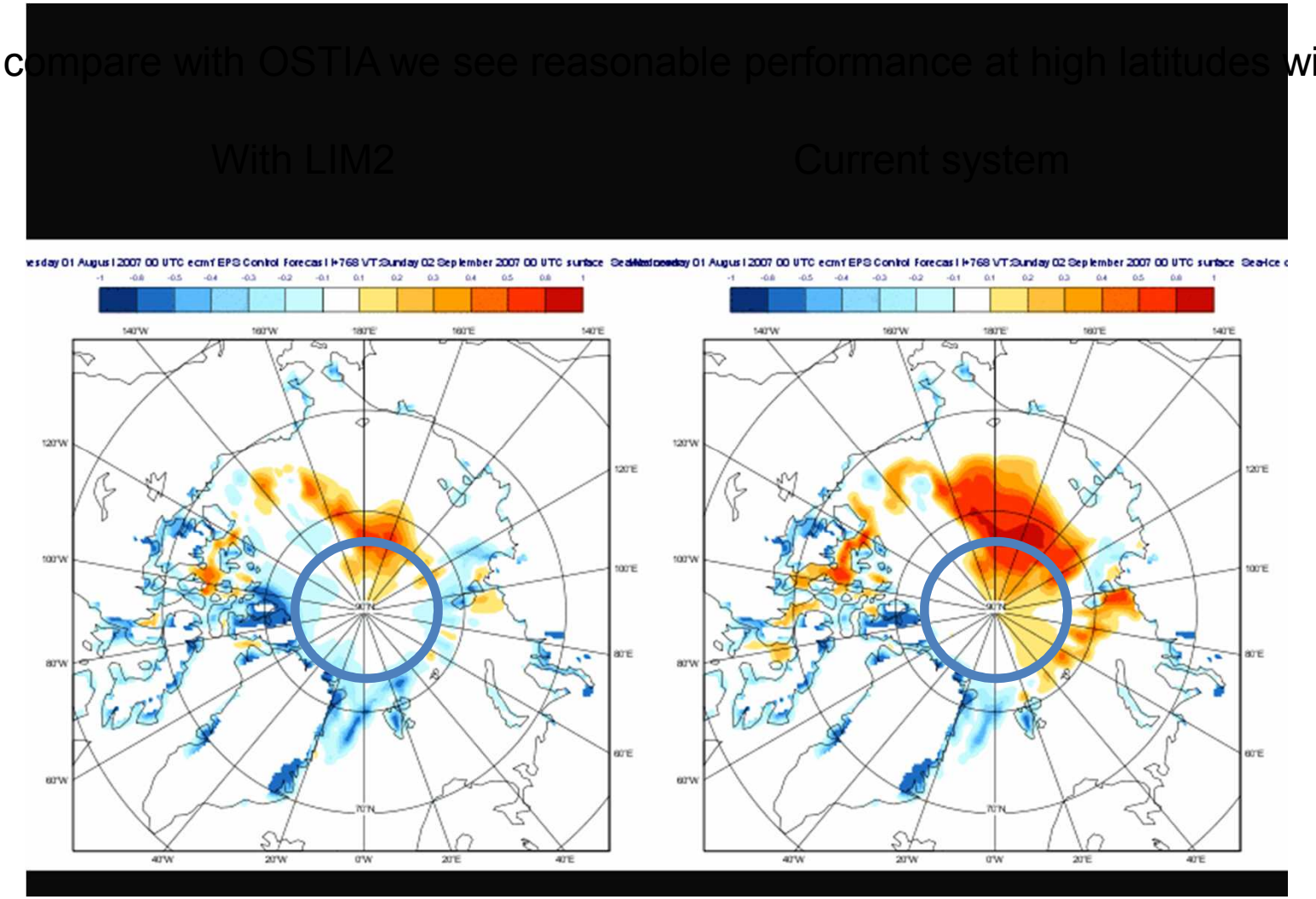


ECMWF

Extreme Events – case study 2007

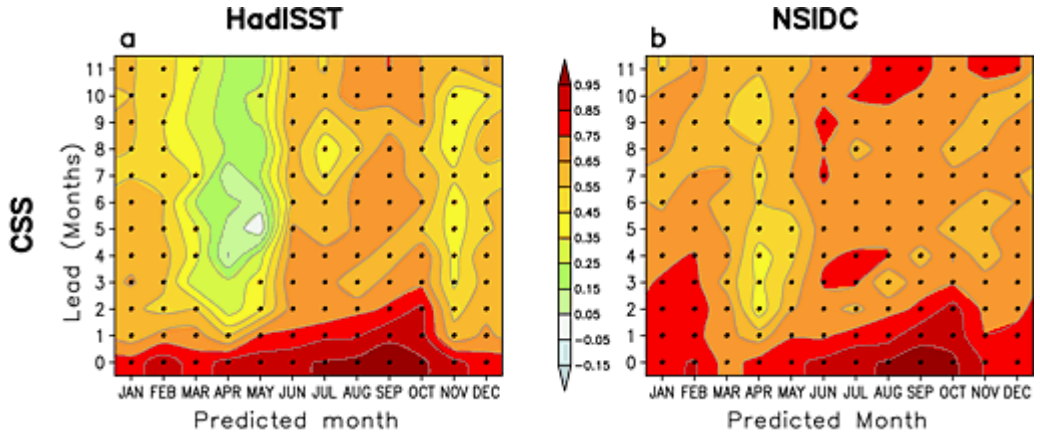
Note that area inside blue ring is fixed at constant 100% cover in ERA-I

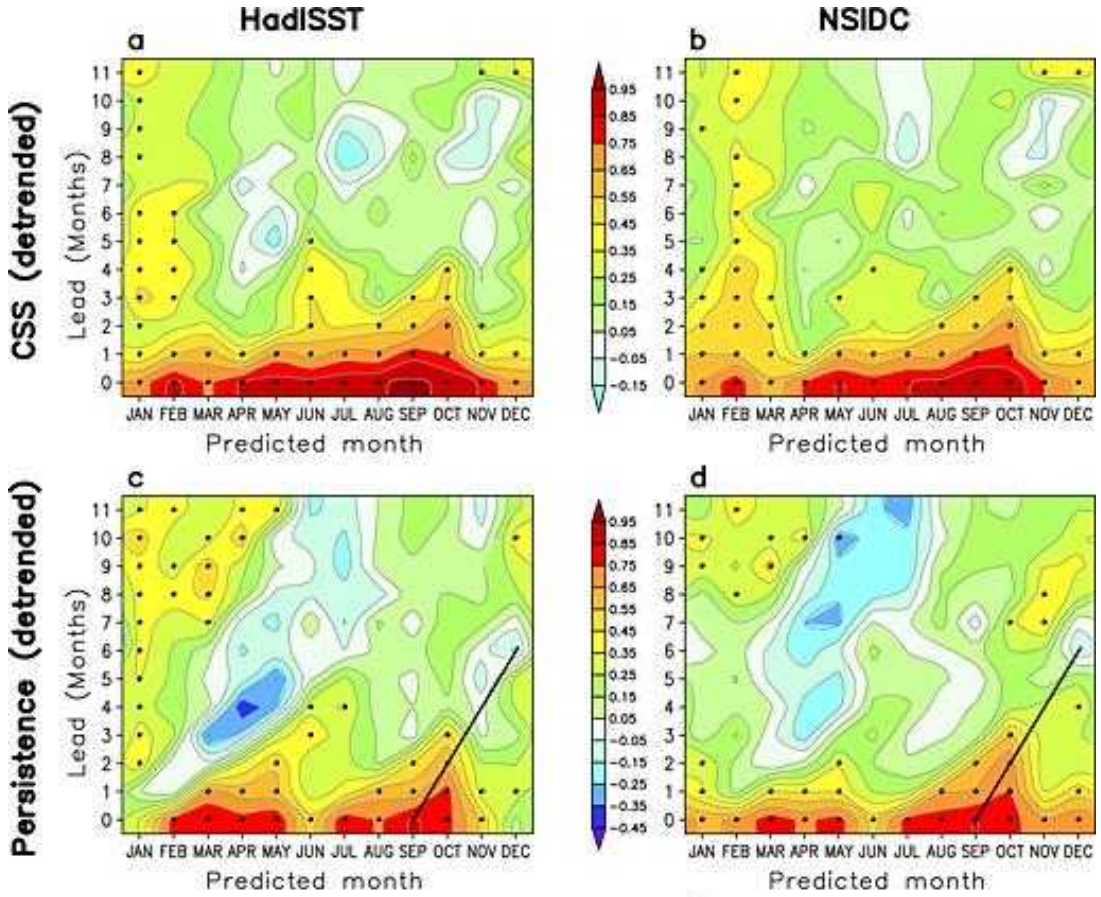
If we compare with OSTIA we see reasonable performance at high latitudes with LIM2



ECMWF

Seasonal forecast skill – Canadian Model



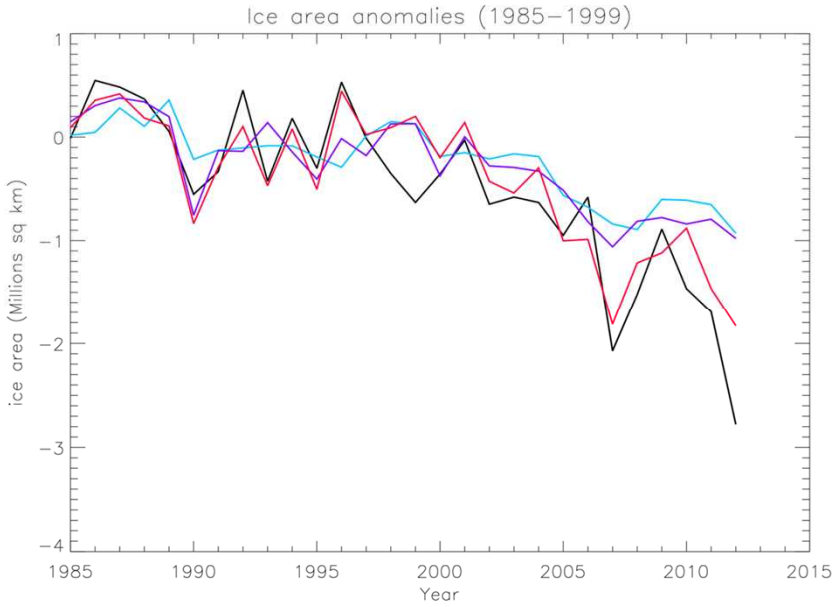


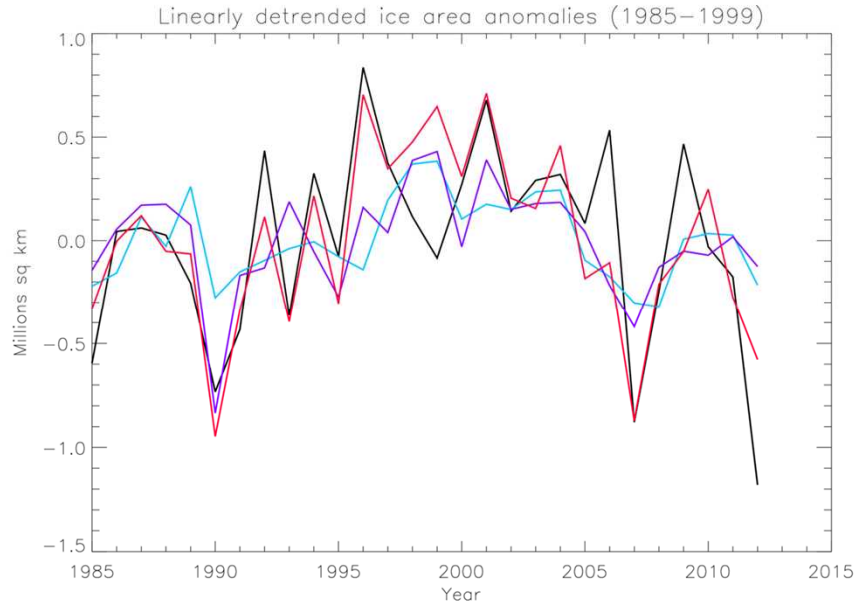
Large proportion of the skill comes from predicting the trend

Persistence of ice anomaly also important

Sigmond et al (2013), *GRL*

Seasonal prediction

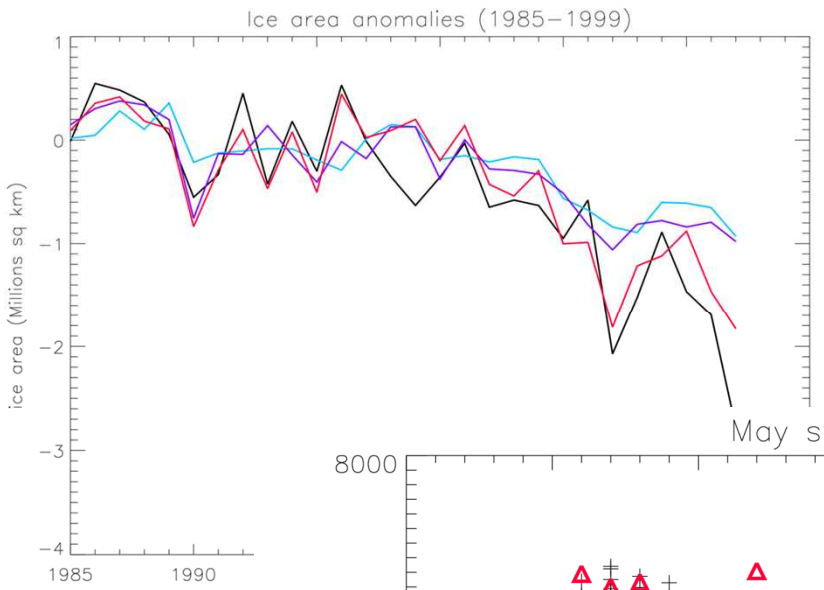


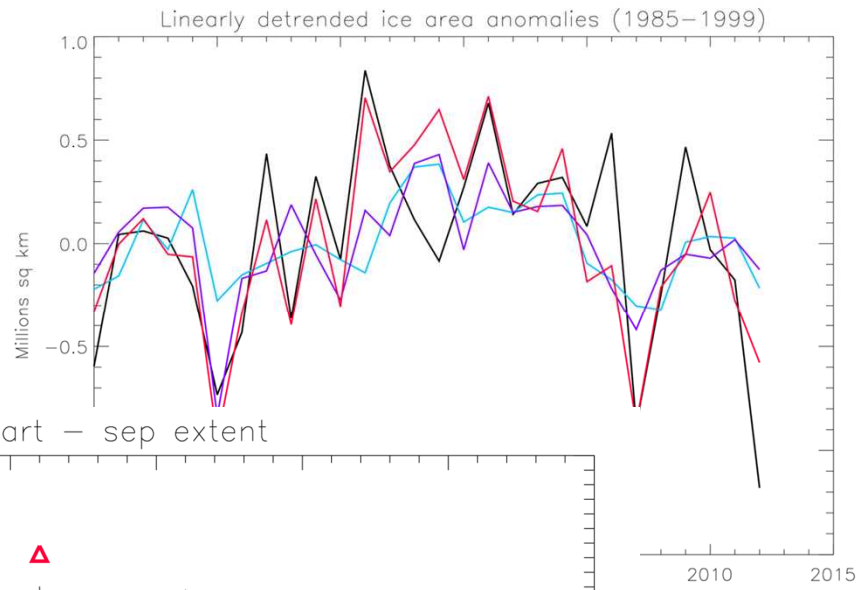


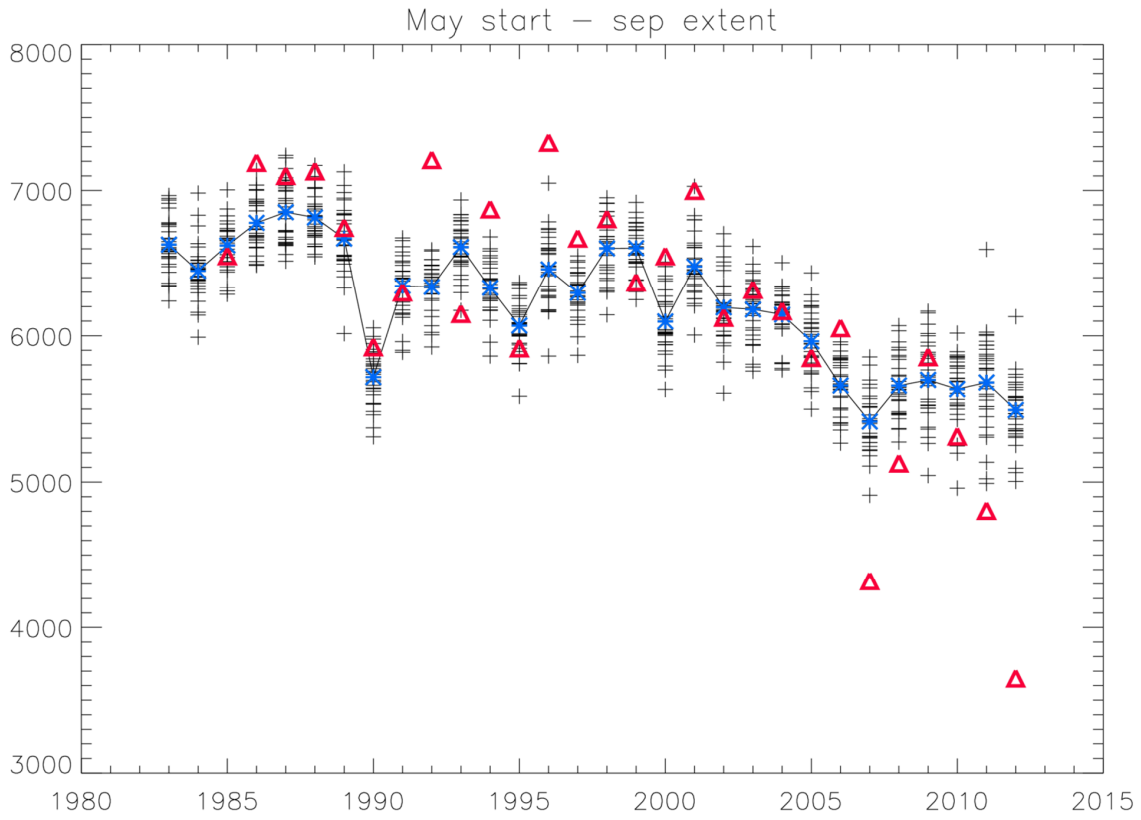
Hindcast start month	Anomaly correlation	Anomaly correlation (detrended)
February	0.81	0.42
May	0.82	0.49
August	0.92	0.80

ECMWF

Seasonal prediction

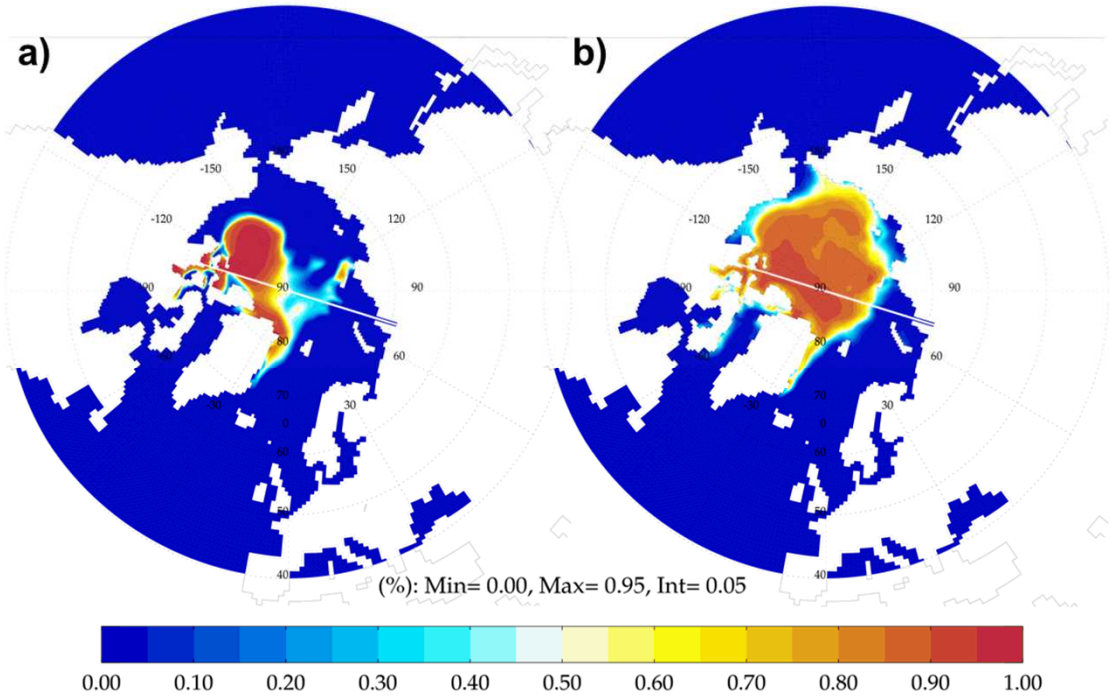






Seasonal prediction

- Not able to reduce ice cover
  - Albedo
  - Circulation errors



ECMWF

Albedo parameterisation

- Function of day of the year (in IFS surface scheme)
- Function of ice thickness, snow thickness and surface temperature (in LIM)
- Implementing LIM reduces the temperature over ice (5K in May)

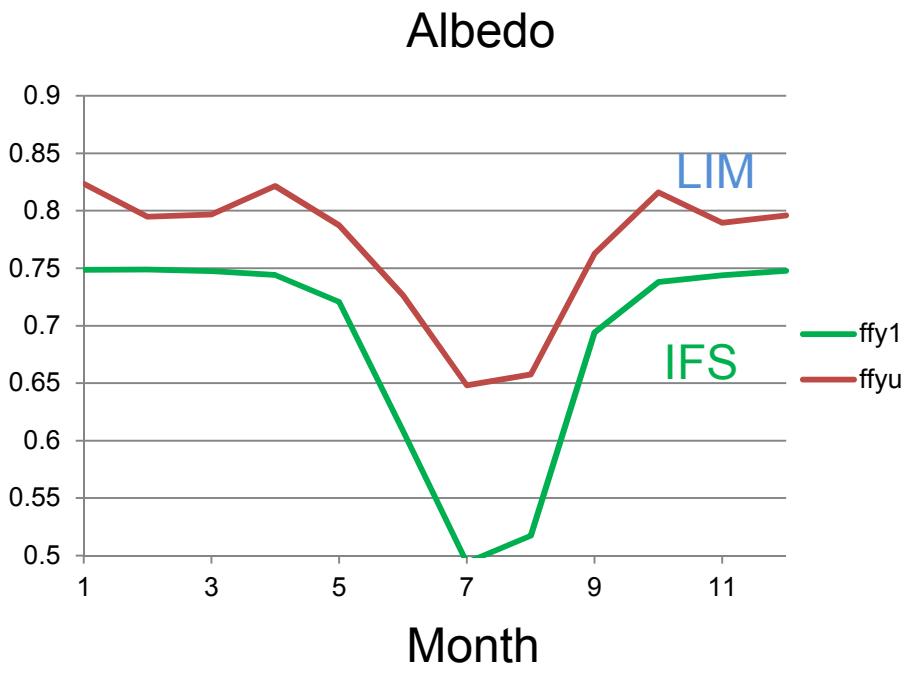


Figure courtesy of Linus Magnusson

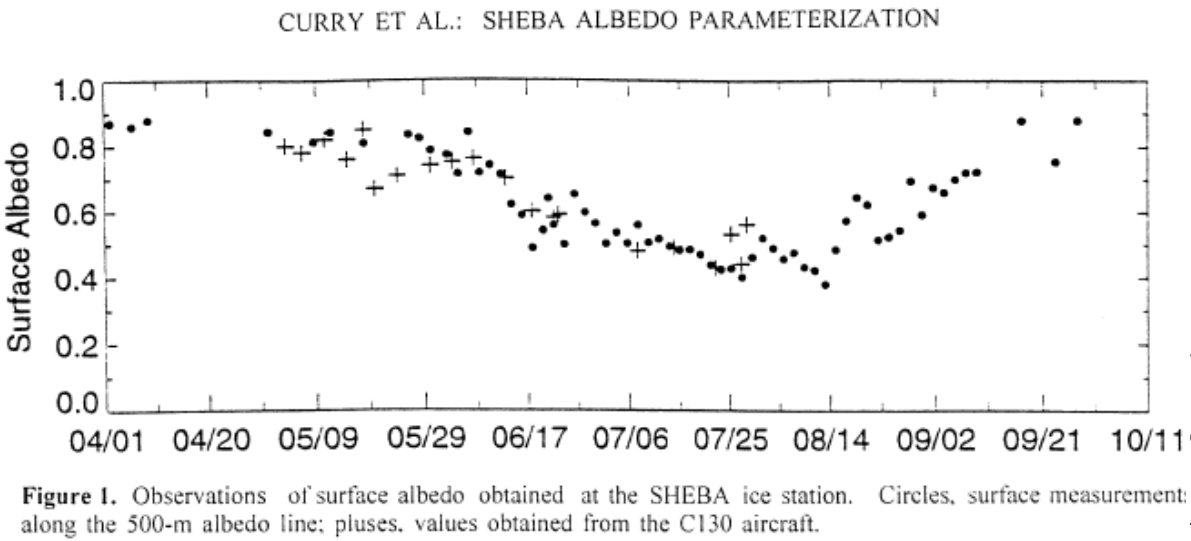
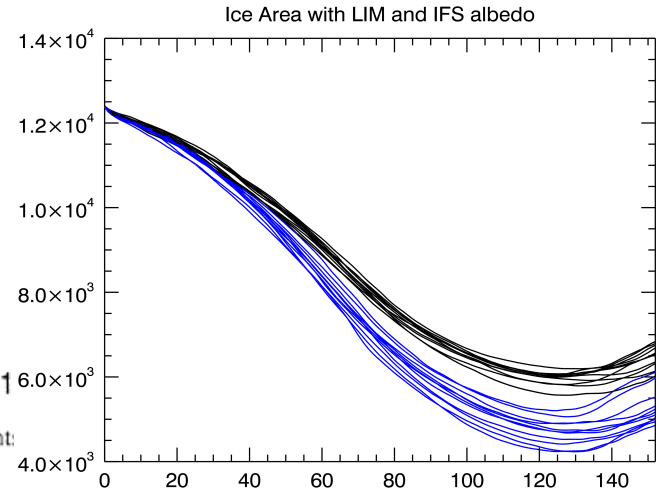
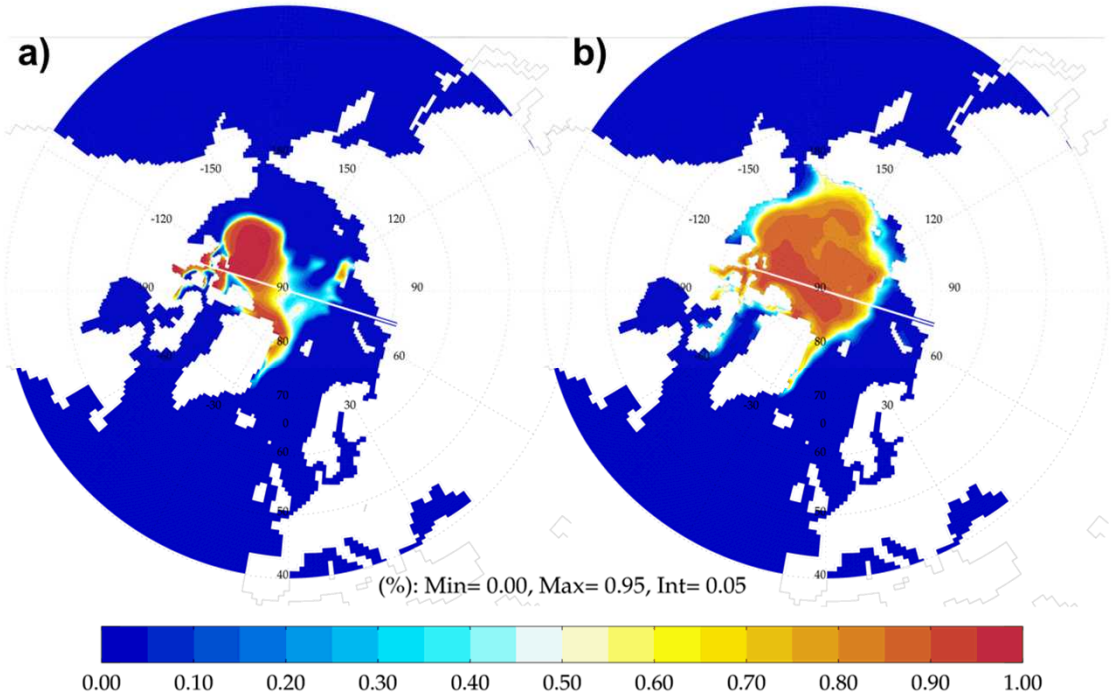


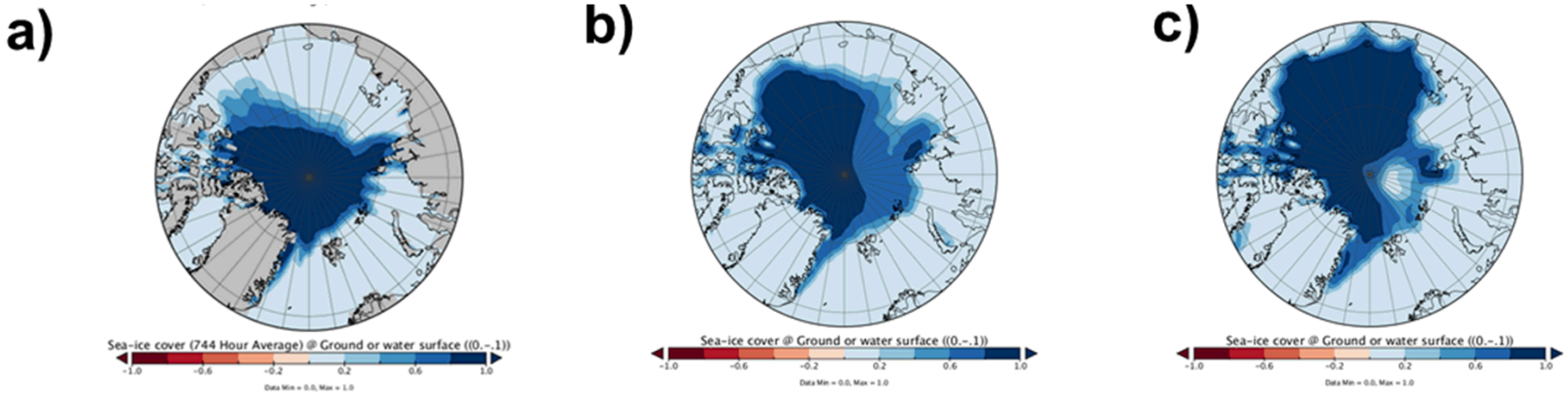
Figure 1. Observations of surface albedo obtained at the SHEBA ice station. Circles, surface measurement along the 500-m albedo line; pluses, values obtained from the C130 aircraft.



Seasonal prediction

- Not able to reduce ice cover
  - Albedo
  - Circulation errors

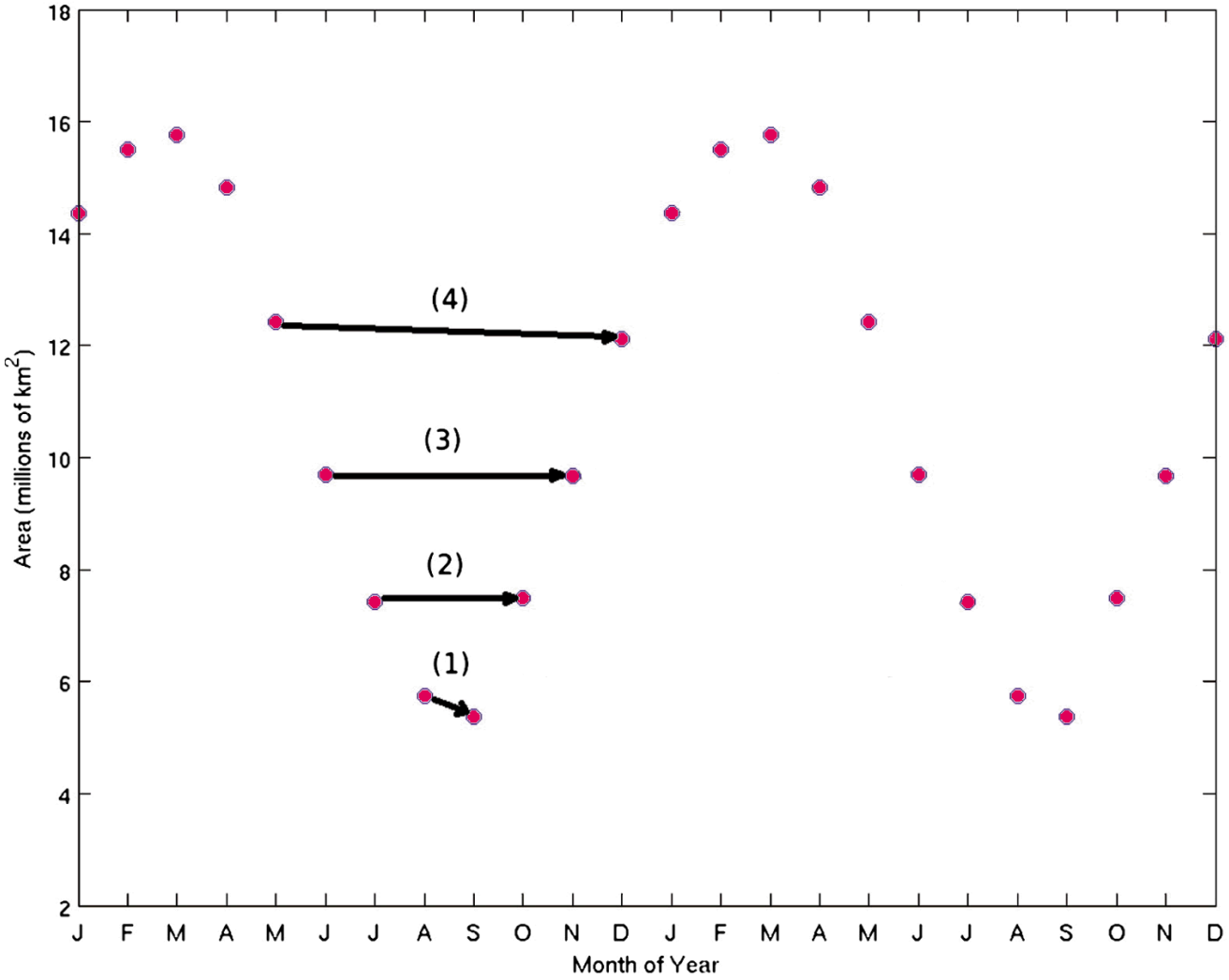




Conclusions

- Sea ice data are quite limited
- Important for determining the fluxes between the ocean and atmosphere – especially in winter
- Area has persistence for 2-5 months
- SST “reemergence” and ice thickness aid in predictability of area
- Rely on model studies for thickness:
  - persistence for about 1 year and main factor for predictability of thickness
- Operational systems show ability to predict sea ice extent for a lead time ~3 months.

ECMWF


Area (millions of km^2)
Month of Year
(4)
(3)
(2)
(1)
18
16
14
12
10
8
6
4
2
J F M A M J J A S O N D J F M A M J J A S O N D

ECMWF