Sea ice and polar predictions

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Reading, 5th December 2017

ECMWF

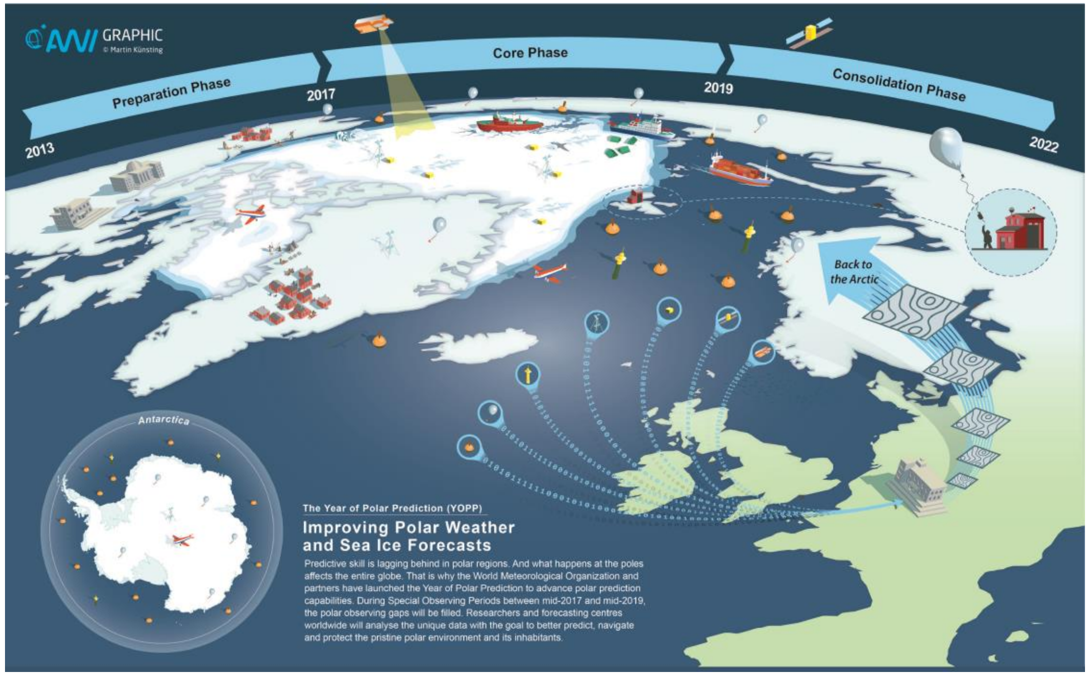
Talk outline

1. Introductory remarks on polar predictions and sea ice
2. Sea ice thickness from L-band observations and ocean analysis
3. Large-scale atmospheric impacts of sea ice
4. Sea-ice predictions

Common thread:
the challenge of observing and modelling
the thickness of thin sea ice (< 1m)

→ *L-band radiances provide a unique opportunity*

Year of Polar Prediction

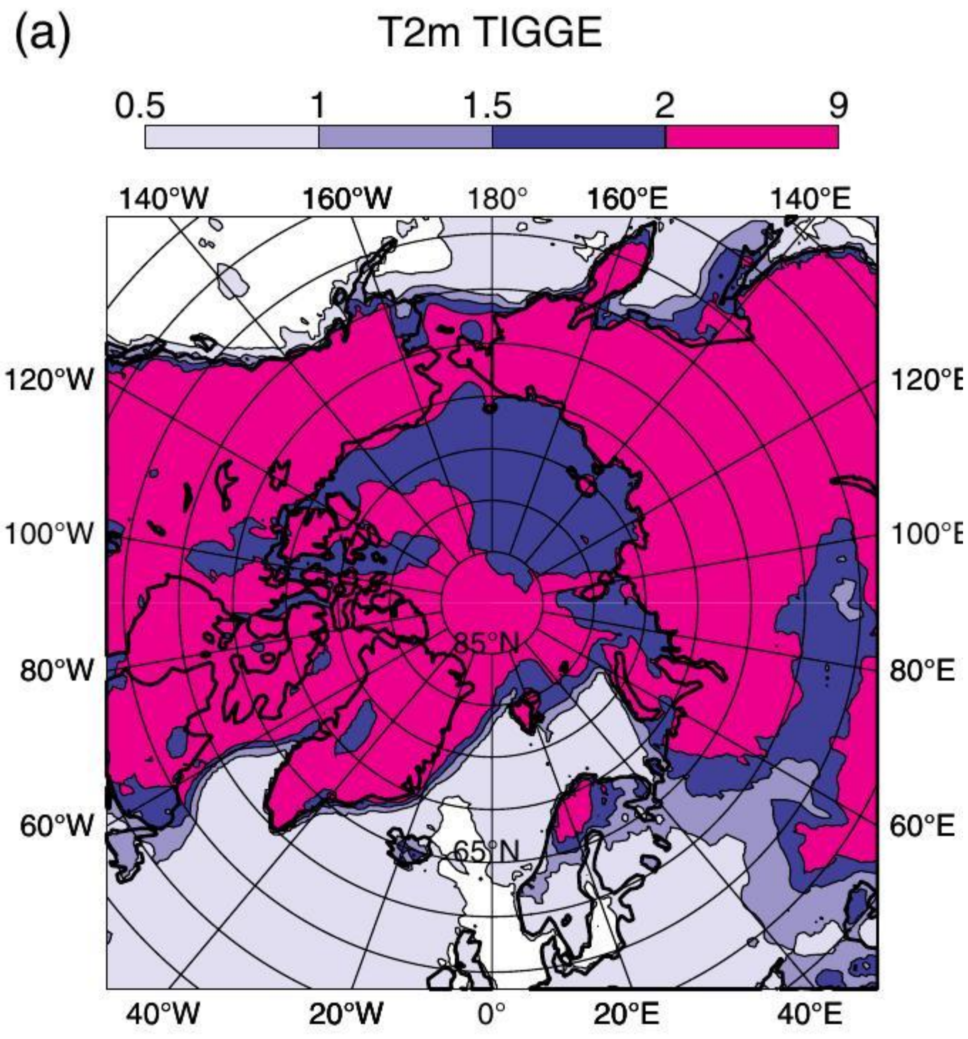


Coordinated by the
World Meteorological Organization (WMO)

Period:
mid 2017– mid 2019 (Launch: 15th May 2017)

- **Goal: Improving predictions of weather and environmental conditions in polar regions and beyond**
- International collaboration between academia, operational forecasting centres, and stakeholders
- Improving the polar observing system, as well as weather and climate prediction models in polar regions

Challenges for polar predictions



Bauer et al., QJRMS 2016

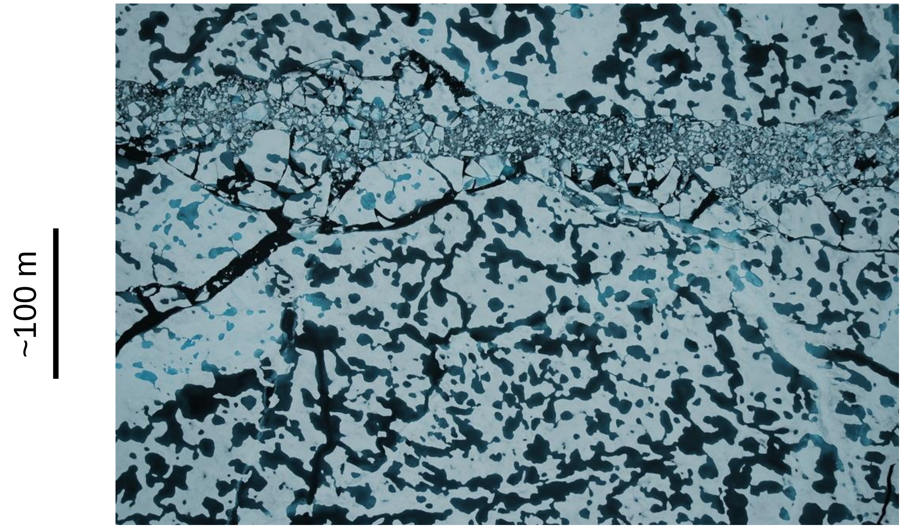
- spread of daily-mean analysis 2m temperature between major operational NWP centres for DJF 2014
- enhanced spread over snow- and sea-ice covered areas
  - high variability and strong dependence on model assumptions
  - sparse network of conventional observations
  - challenges for satellite retrievals

Must make better use of existing and new satellite-based observations to progress

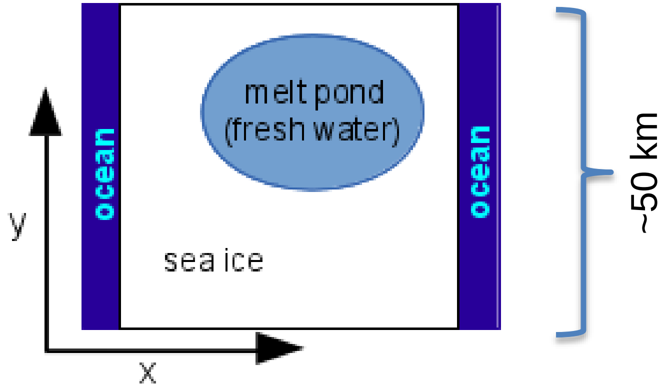
Reminder #1: simplification of sea-ice heterogeneity in models and observations

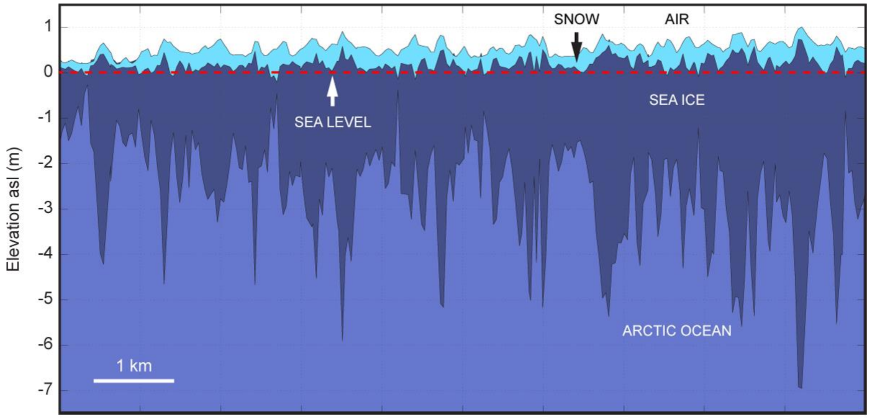
small-scale observations

large-scale models and observations

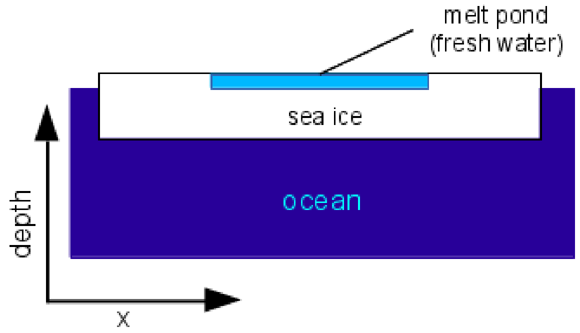


aerial photograph of broken sea ice with melt ponds

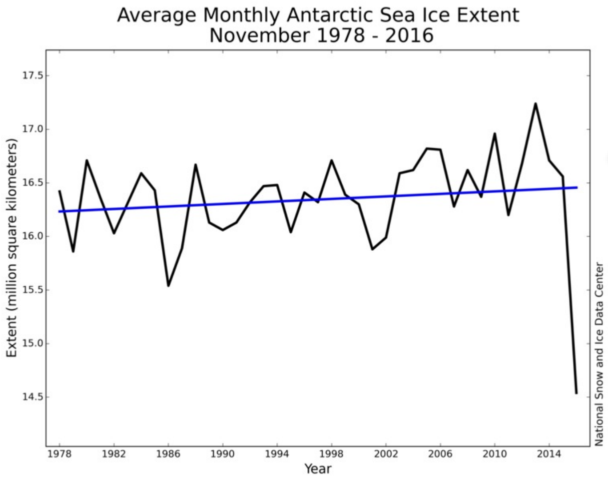




ice thickness transect from Operation IceBridge

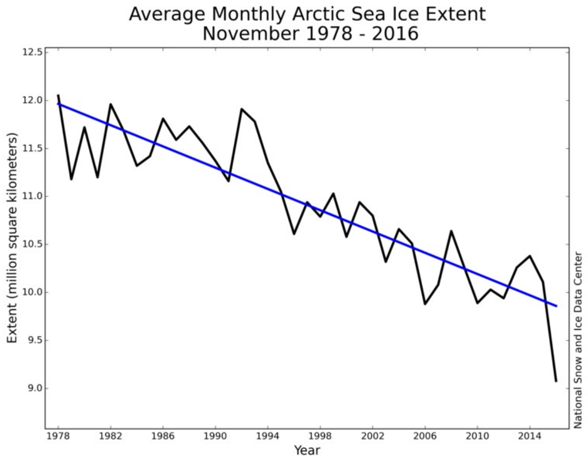


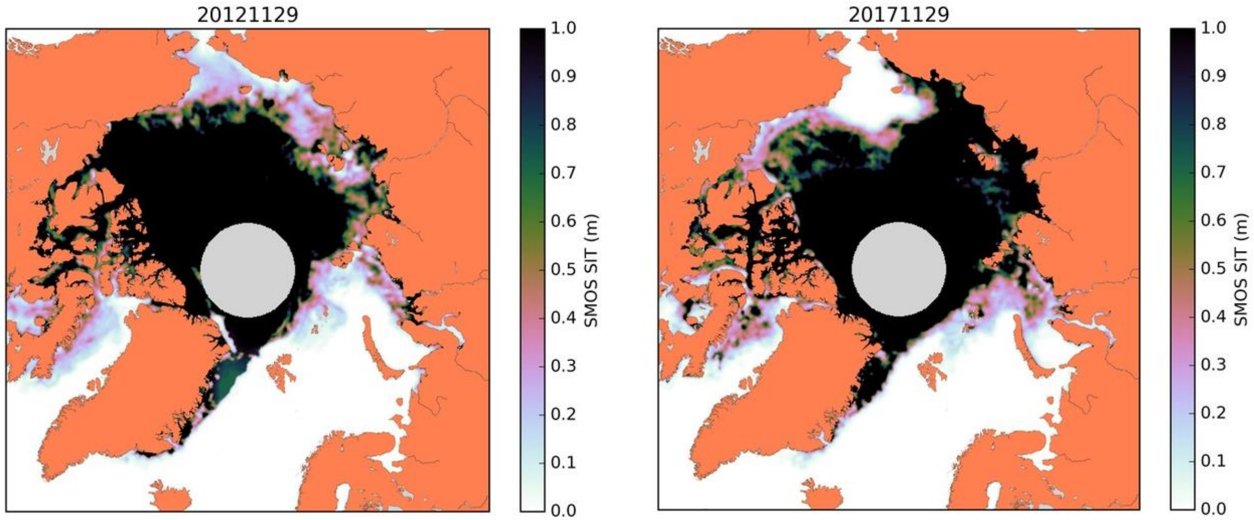
Reminder #2: sea-ice variability and trends are very strong



Antarctic: always good for surprises

Arctic: rapidly changing mean state = major challenge to modelling and forecasting

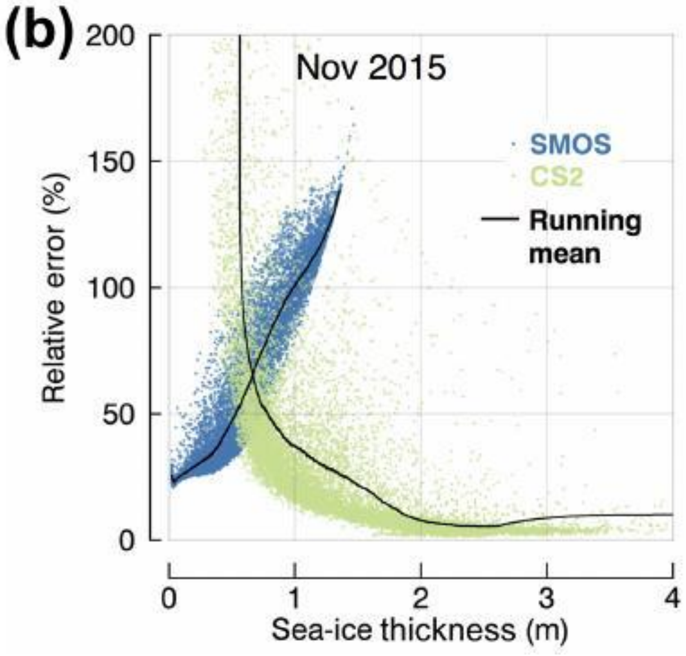




Sea-ice thickness (SMOS) in different years with same ice extent

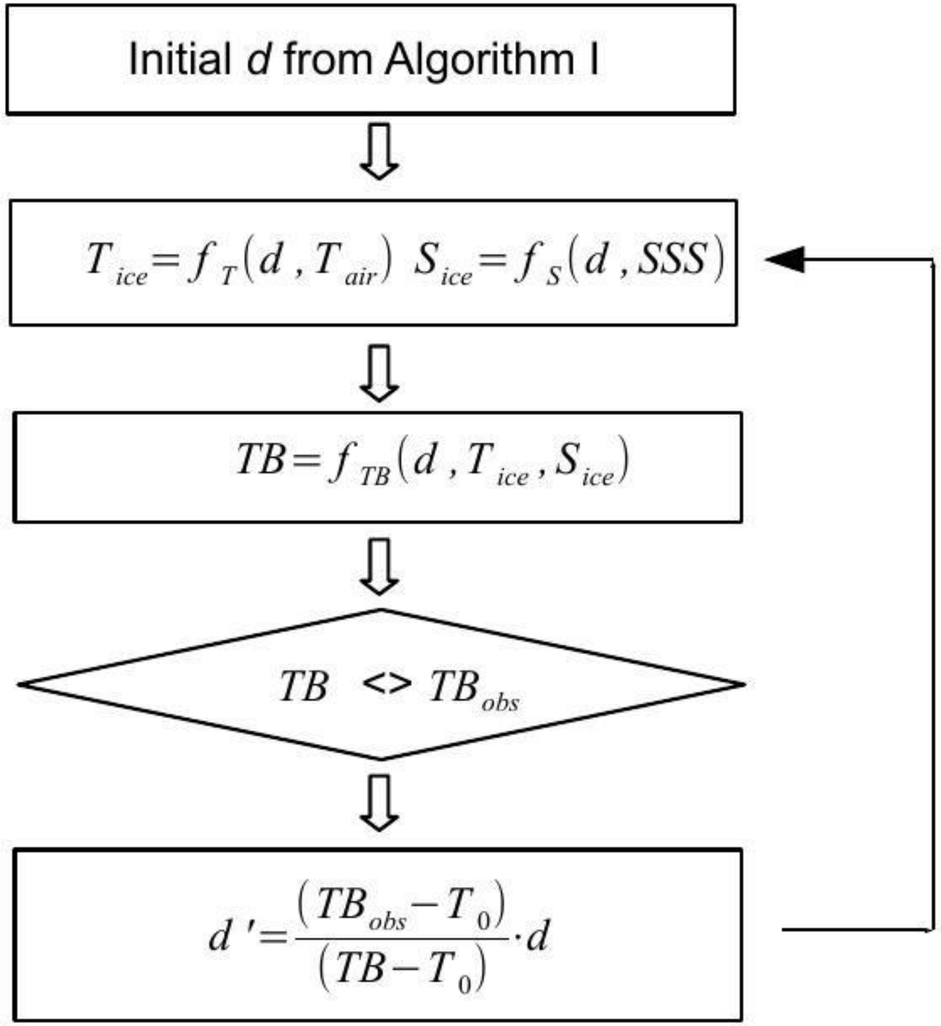
Overview of remote-sensing sea-ice observations

- Sea-ice concentration from higher-frequency passive microwave radiometry
  - mature observation type, since 1979
  - uncertainties mostly well characterized
- drift, deformation, stresses, leads, surface temp, snow, ...
- sea-ice thickness:
  - new types of satellite sensors since the 2000s, short records
  - several complementary methods:
    - thermal infrared (e.g. MODIS)
    - laser altimetry (ICESat and ICESat2)
    - radar altimetry (CryoSat2)
    - L-band radiometry (SMOS, SMAP, Aquarius)
  - uncertainties often large and poorly characterized
  - **indispensable for modern sea-ice modelling efforts**



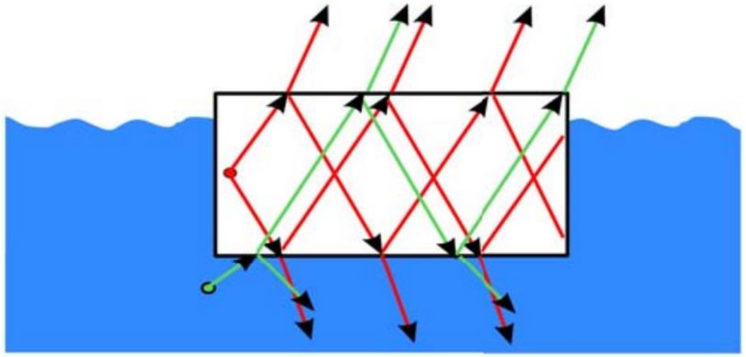
Ricker et al., TC 2017

L-band sea-ice thickness retrievals (University of Hamburg method)



- emissivity model for a dielectric slab of sea-ice
- *ice temperature* T_{ice} and *ice salinity* S_{ice} need to be estimated from independent data sources and thermodynamic modelling

→ L-band TB is a function of *ice thickness d*



Kaleschke et al., GRL 2012
Maass 2013, PhD thesis
Tian-Kunze et al, TC 2014

SMOS-SIT product and ORAS5 reanalysis

UHH SMOS sea-ice thickness product

- daily-mean Arctic maps on 12.5 km grid
- from SMOS TB intensity for 0-40° incidence
- available from October to April since 2010 with <24h latency

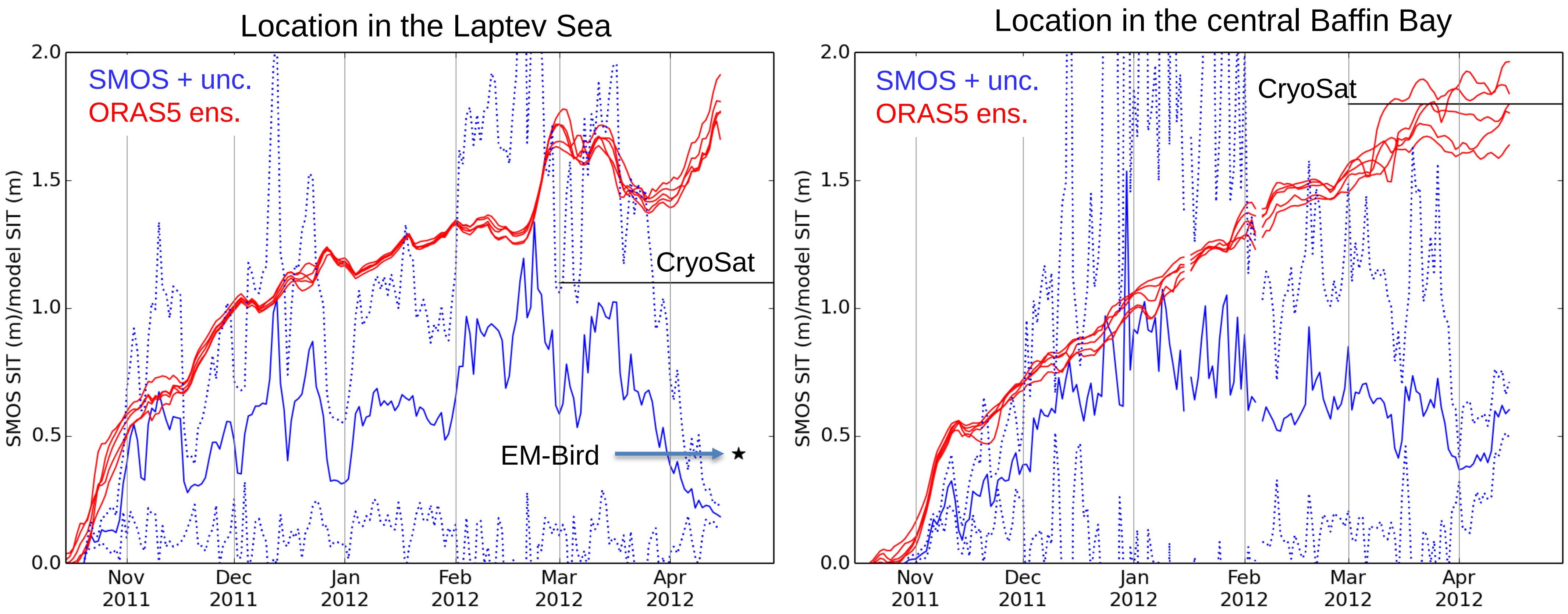
ECMWF ORAS5 reanalysis

- global ocean-sea ice reanalysis on ~ ¼ degree grid
- model: NEMO3.4 including LIM2 sea ice
- observations: in-situ T & S, altimeter sea surface height, sea-ice concentration, *no sea-ice thickness*
- assimilation: NEMOVAR using 3DVAR-FGAT

Provides ocean and sea-ice initial conditions for all ECMWF forecasts

→ *compare daily mean Arctic sea-ice thickness for the winters 2010/11 to 2016/17*

Comparison of ORAS5 and SMOS sea ice thickness (not assimilated)



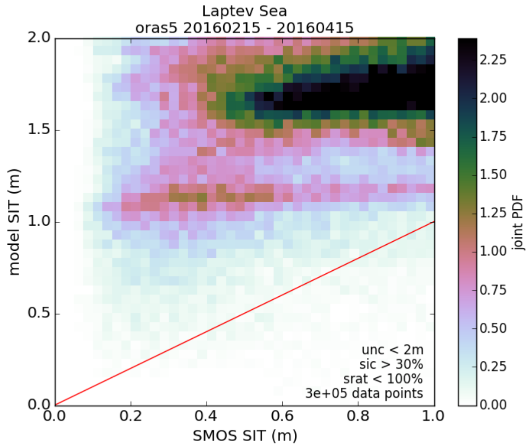
- *Early in the freezing period: good agreement*
- *Late in the cold season: model consistently thicker than observations*
  → caused by both model and observation errors depending on feature/region

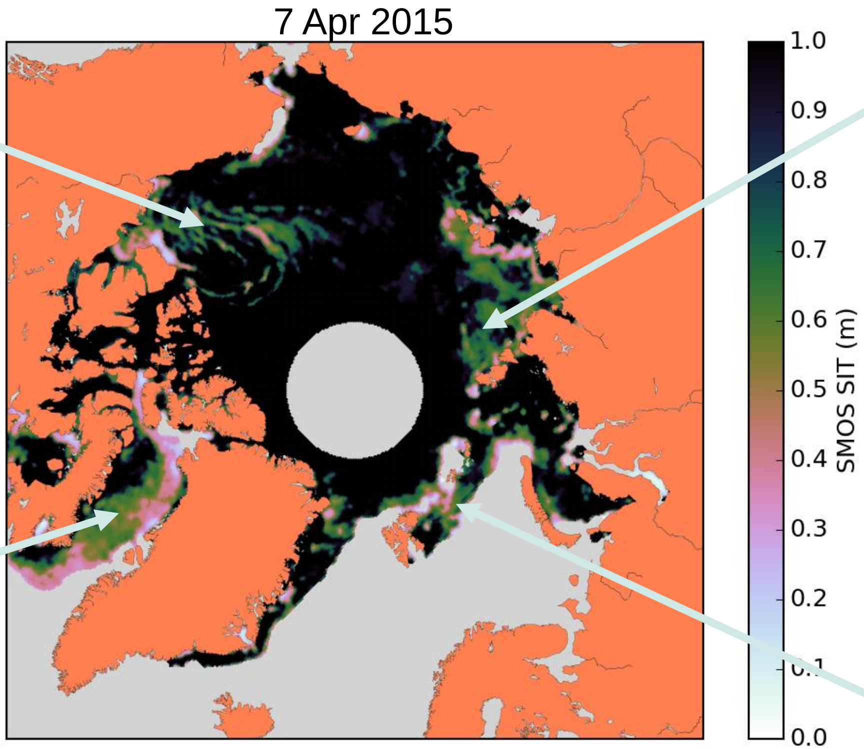
Tietsche et al. (2017), The Cryosphere Discussions

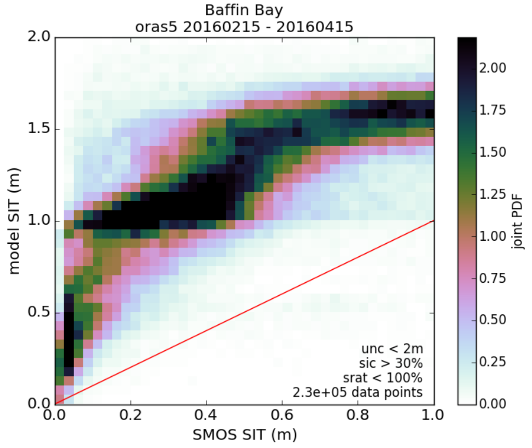
Ice thickness from ORAS5 and SMOS in late winter

Extensive fracturing in the Beaufort Sea

extensive polynias in Laptev Sea

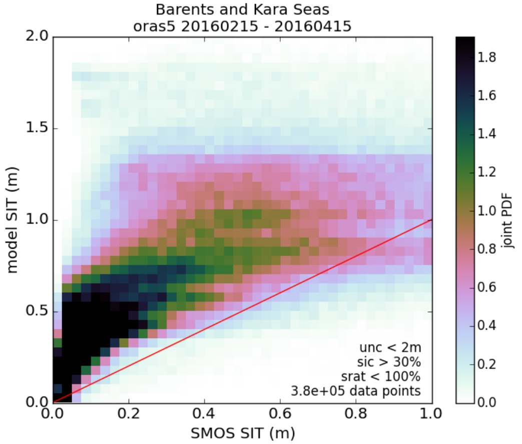






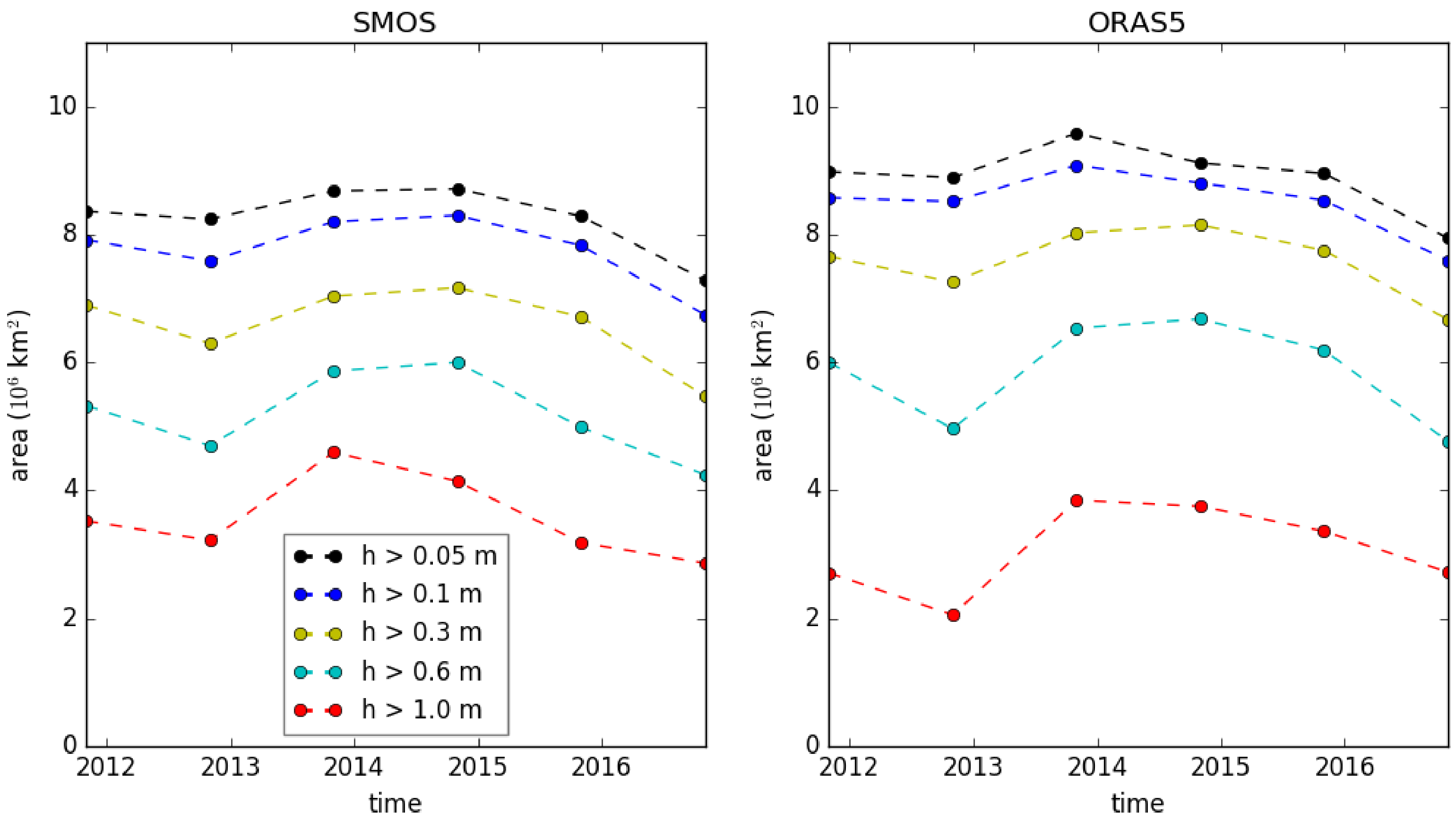
Thin ice in Baffin Bay?

reasonable agreement in Barents and Kara Seas



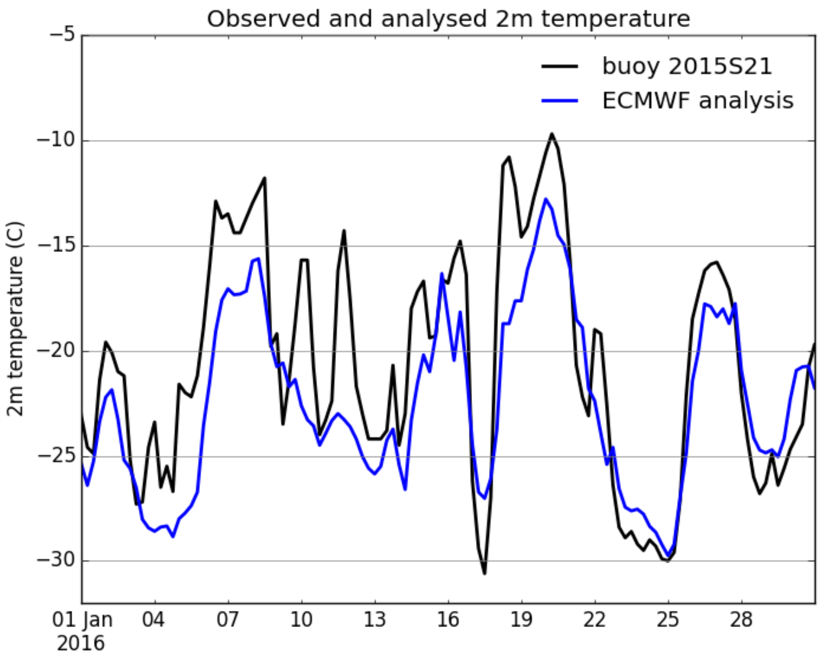
Year-to-year changes in large-scale ice thickness

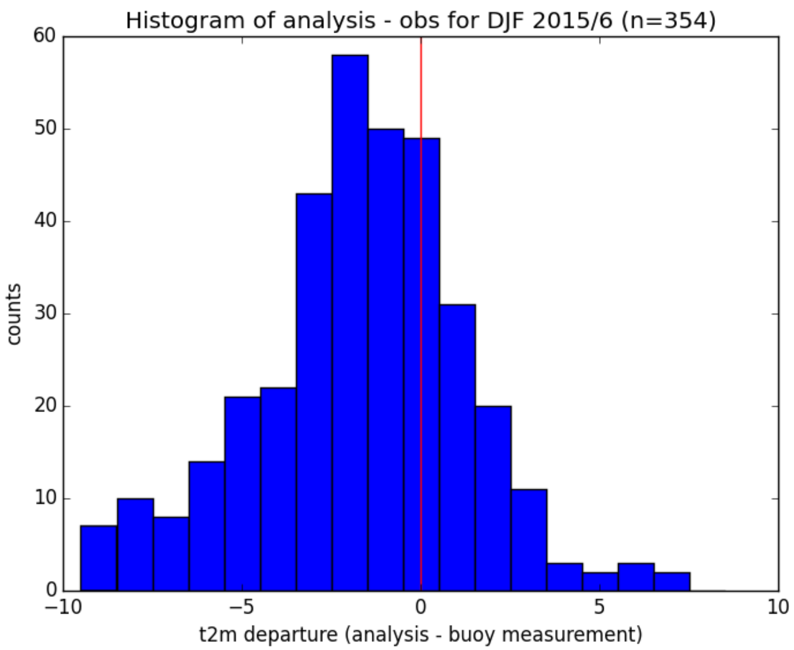
Area of Arctic covered by sea ice thicker than various thresholds in November

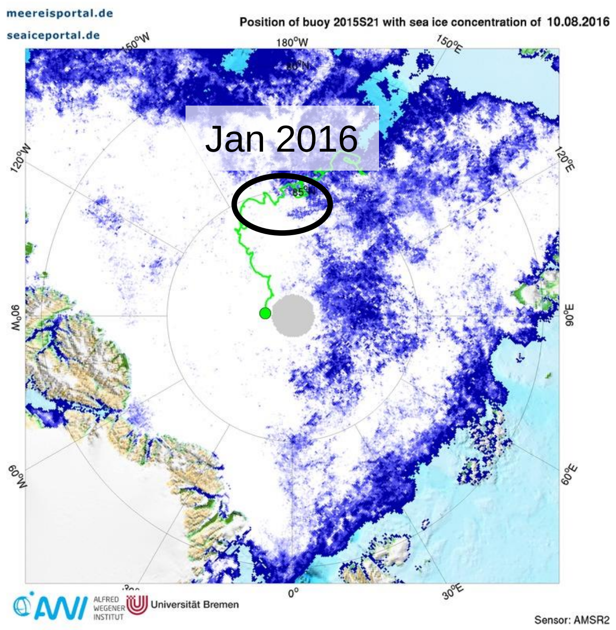


Near-surface temperature over sea ice

Validation of ECMWF t2m analysis against in-situ observations from drifting buoy



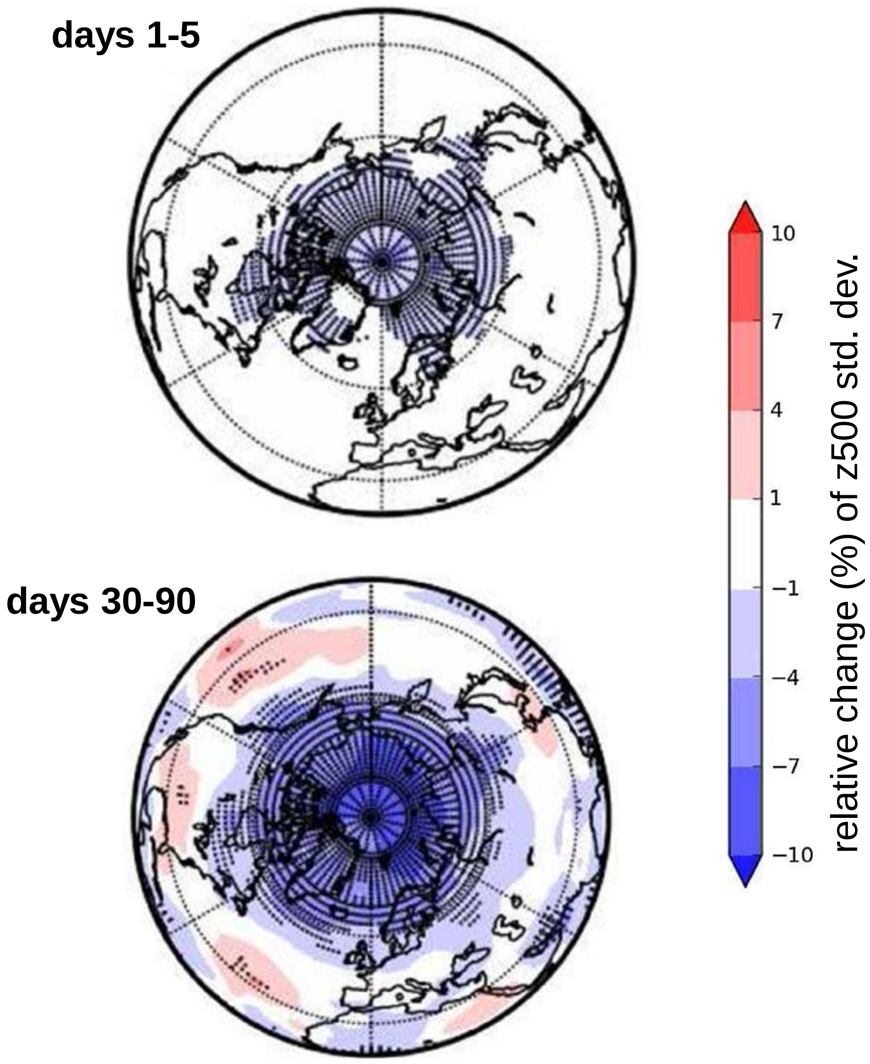




- NWP analysis error of t2m over remote sea ice can be large
- sea-ice thickness can modify surface heat balance considerably

→ scope for analysis improvement through better representation of sea-ice properties?

Large-scale atmospheric response to sea-ice surface warming

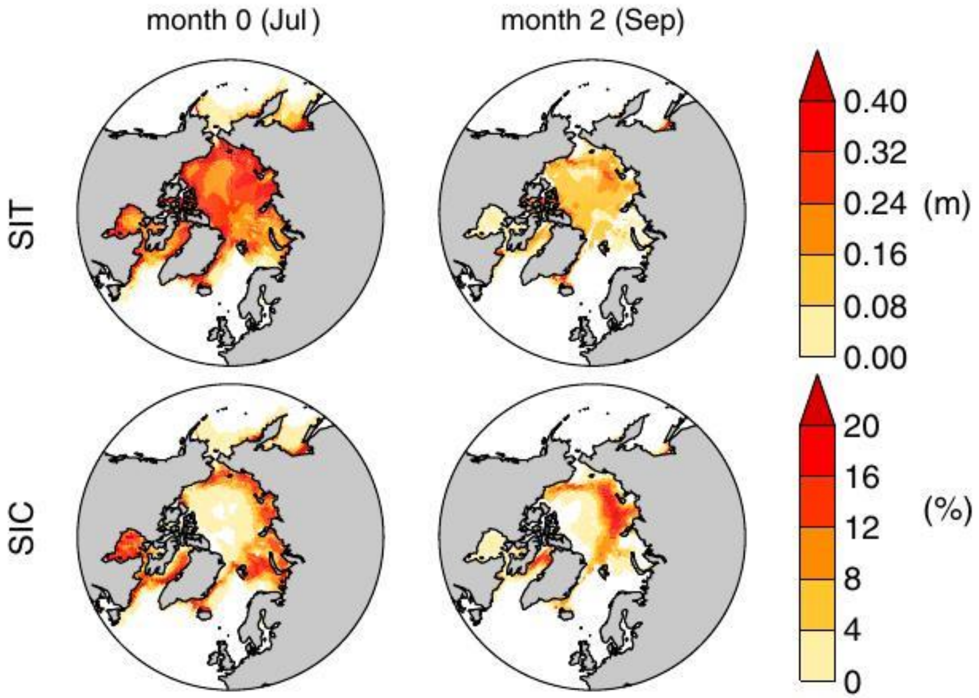


Semmler et al., Clim Dyn 2016

Idealized forecast experiments (408 pairs of forecasts for DJF 1979-2012) with ECMWF atmospheric forecast model (cycle 37r3):

Significant reduction of synoptic activity (std. dev. of high-pass filtered z500) with increased sea-ice surface temperature

Uncertainty in sea-ice thickness means uncertainty in sea-ice concentration later in the forecast

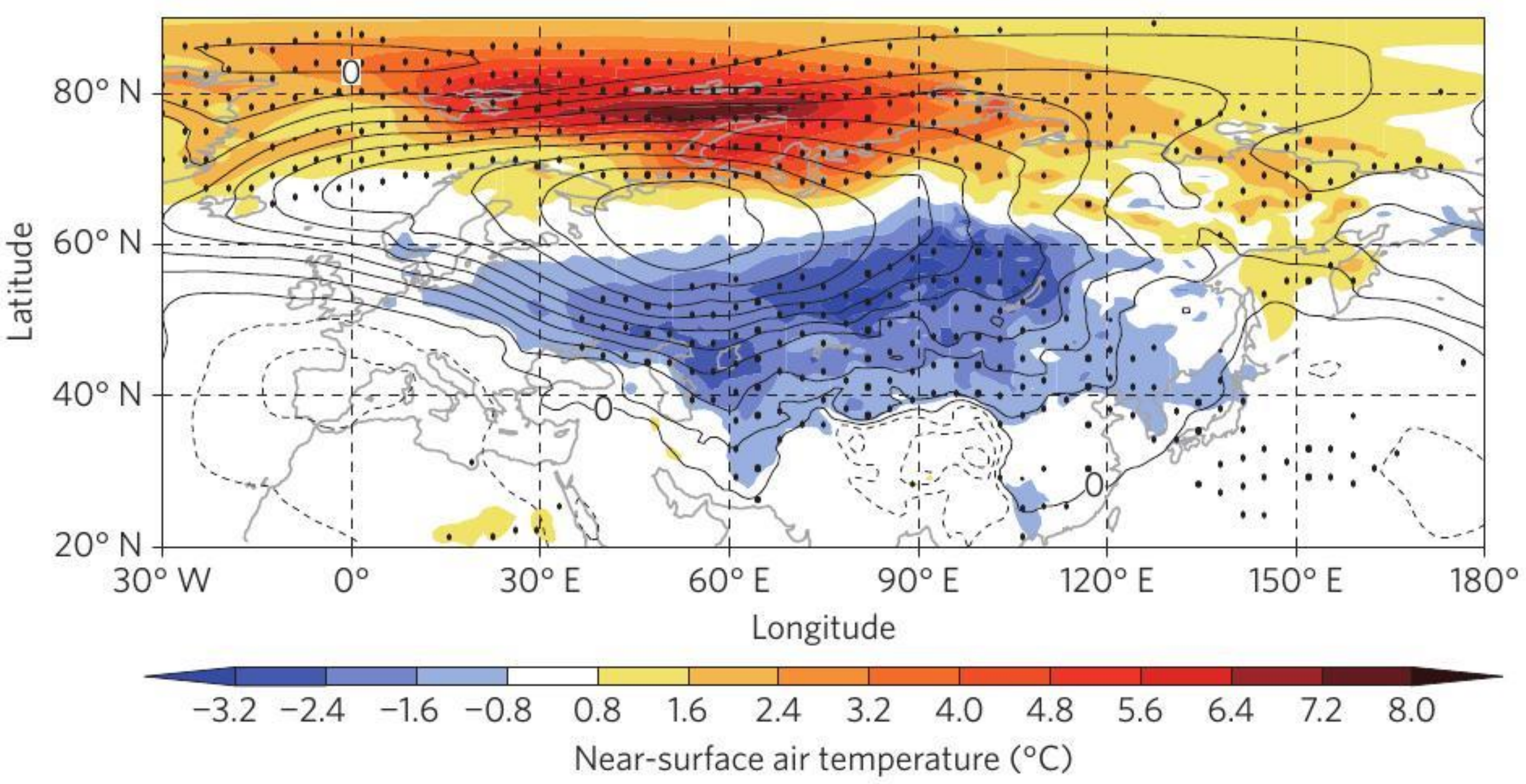


Day et al., GRL 2014

Idealized seasonal forecast experiments for summer in HadGEM climate model:

Increase in forecast RMSE when replacing perfect sea-ice thickness with climatology in identical-twin forecast experiments

Remote near-surface impact of sea-ice anomalies



Composite of DJF 2m temperature difference between years with low and high sea-ice cover in the Barents and Kara Seas (ERA-Interim 1979-2013)

Reduced sea ice leads to cold Eurasian winters

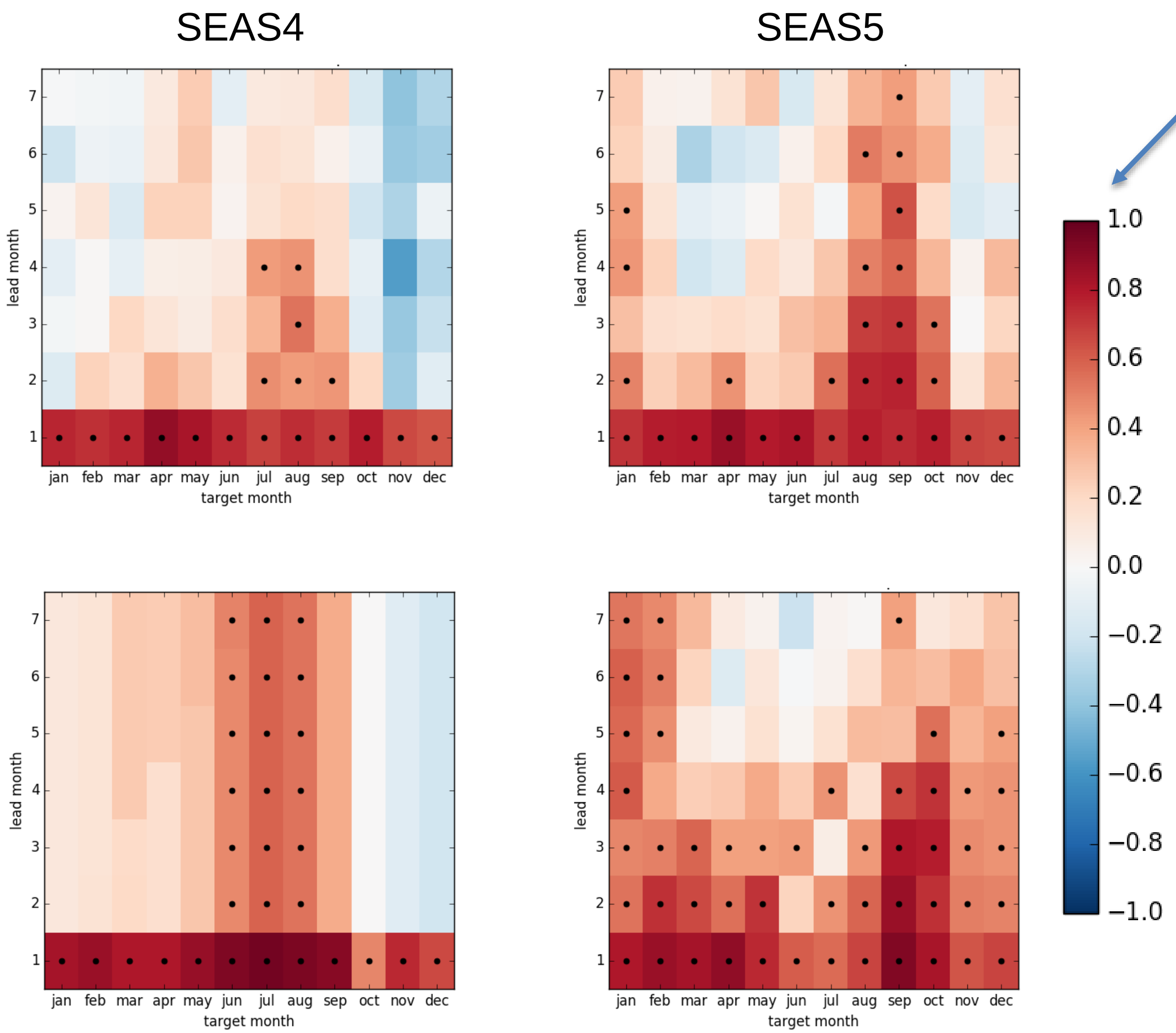
Mori et al., Nature Geoscience 2014

Improvements in sea ice and high-latitude skill in ECMWF seasonal forecasts

ACC of *detrended* time series 1981-2015 (>0.6 stippled)

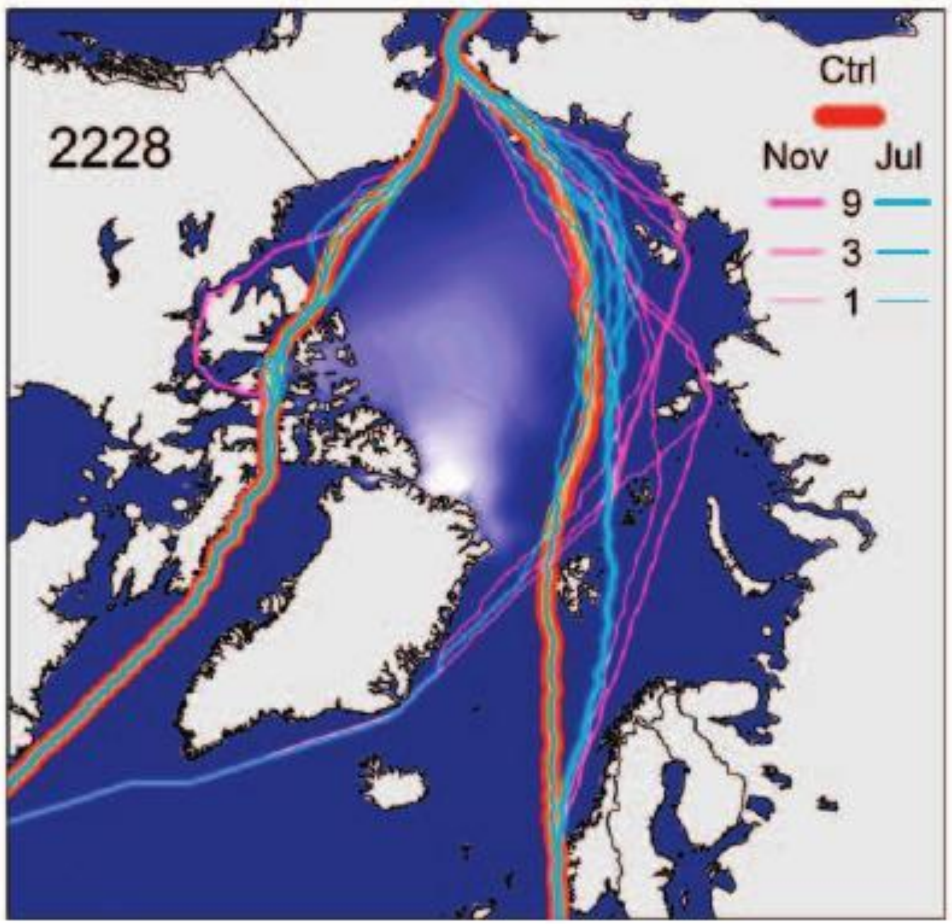
2m air temp (area mean 70N)

sea ice extent



- SEAS5 became operational 8 November 2017; it includes a sea-ice model, among many other improvements
- SEAS5 outperforms SEAS4 for most target months and lead times
- Characteristic seasonal and lead-time variations in skill → sea ice impact on surface temperature predictions

Seasonal predictions for navigating ice-infested waters



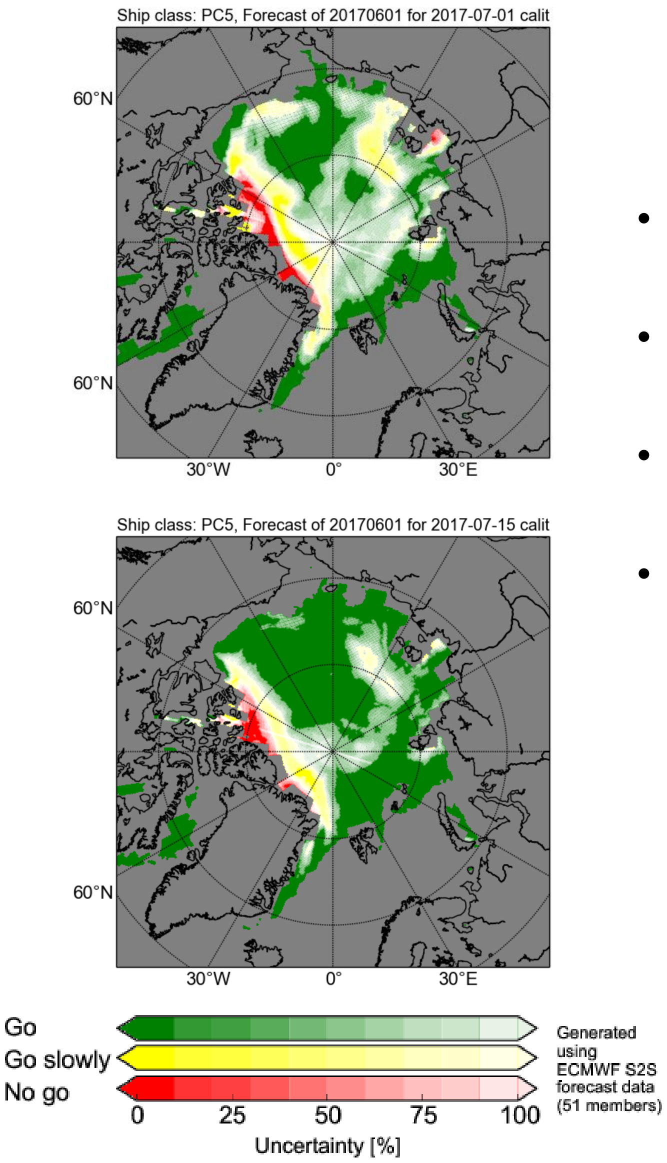
- Optimal shipping routes through the Arctic for mid-September (New York / Rotterdam → Yokohama)
- Routes calculated from sea-ice conditions in idealized seasonal forecasts started in preceding November and July
- Each line corresponds to solution from one ensemble member, thick lines where several ensemble members agree

Melia et al., ERL 2017

Extended-range sea ice forecasts for ship routing

1 July 2017
(30 days ahead)

15 July 2017
(45 day ahead)



- FMI produced a product demonstrator to help plan an ice breaker transit from Korea to Finland in July 2017
- Based on sea-ice concentration and thickness from ECMWF extended-range forecast from 1 June 2017, together with hindcasts for calibration
- Calculate Risk Index Outcome (RIO) from the International Code for Ships Operating in Polar Waters (adopted by IMO, in force since 2017)
- Ice breaker transit was through the Northwest Passage on 5 – 29 July (record for earliest passage in the season)

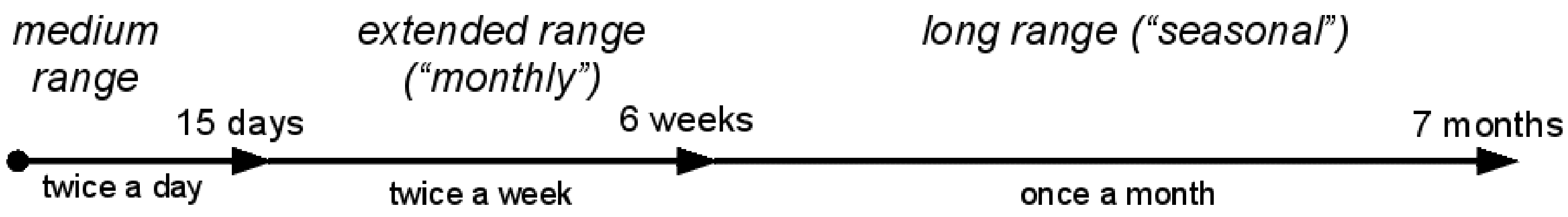
Green: RIO ≥ 0, permitted
Yellow: -10 ≤ RIO < 0, reduced speed
Red: RIO < -10, not permitted
Colour saturation: uncertainty of forecast

Figure courtesy of A. Gierisch and P. Uotila

Summary

- Sea ice is a key player for improving polar predictions
- Observing, modelling and predicting the presence of *thin sea ice* (<1m): challenging, but of paramount importance for progress
- Growing body of evidence for impact of sea ice presence and thickness on large-scale atmospheric circulation and forecasts from days to seasons
- For the marine sector (e.g. shipping), importance of sea-ice thickness increasingly acknowledged
- *low-frequency microwave radiances are currently the only way to observe the thickness of thin sea ice with sufficient spatial and temporal coverage*

Seamless earth system ensemble predictions at ECMWF



- forecasts with 50 ensemble members, global domain with 18/36km resolution
- ocean model NEMO 3.4, atmosphere model IFS
- "seamless": very similar model with the same initial conditions across all time ranges
- includes dynamical sea ice model LIM2
  - for medium/extended range operational since November 2016 (Cycle 43R1)
  - for seasonal range operational from November 2017 (SEAS5)