Making sense of seasonal sea-ice forecasts

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ECMWF

SPICES

The ECMWF seasonal forecasting system SEAS5

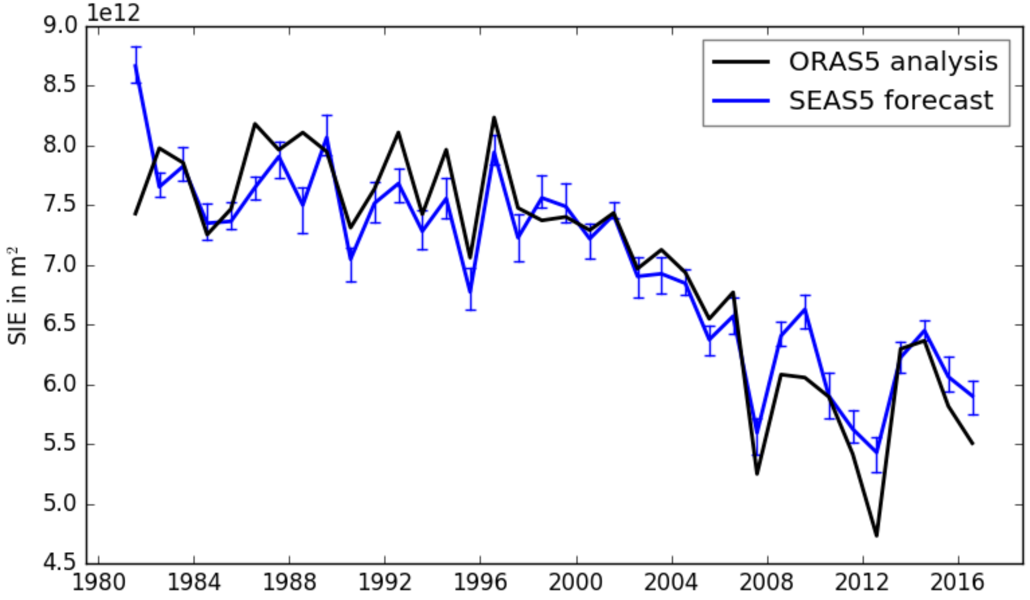
- Since November 2017, ECMWF seasonal forecasts include prognostics sea ice (LIM2)
- Seamless approach: SEAS5 uses the same forecast model (IFS Cycle 43R1) and initial conditions (ORAS5) as ECMWF medium- and extended range forecasts
- Sea ice initialized by 3DVAR assimilation of sea-ice concentration from PMR observations, no sea-ice thickness observations assimilated
- SEAS5 reforecasts are available with 25 ensemble members started 1st of each month from 1981 to 2016 → good sample to estimate forecast quality, but for Arctic sea ice this is complicated by
    - Nonstationary behaviour - large trends
    - Availability of satellite observations for sea-ice thickness

For details see

- ORAS5 description: Zuo et al., ECMWF Technical Memorandum 823 (2018)
- ORAS5 polar performance: Uotila et al., Clim. Dynam. (2018)
- SEAS5 description and evaluation: Johnson et al., GMD (submitted)

SEAS5 forecast of Arctic sea-ice extent: performance depends strongly on target month

Summer/autumn (ASO) forecast from 1st July



- Almost unbiased, good skill

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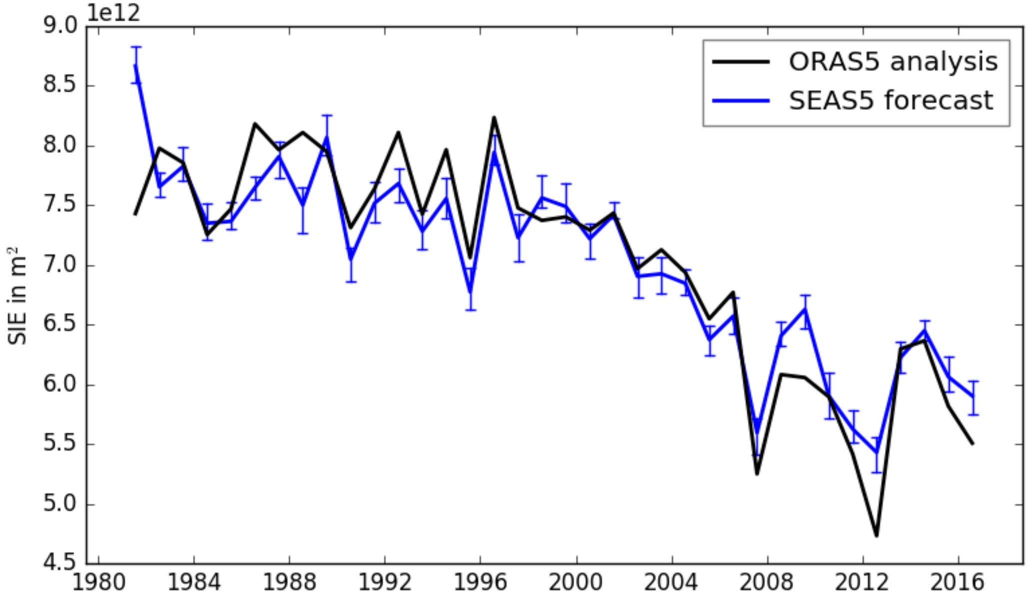
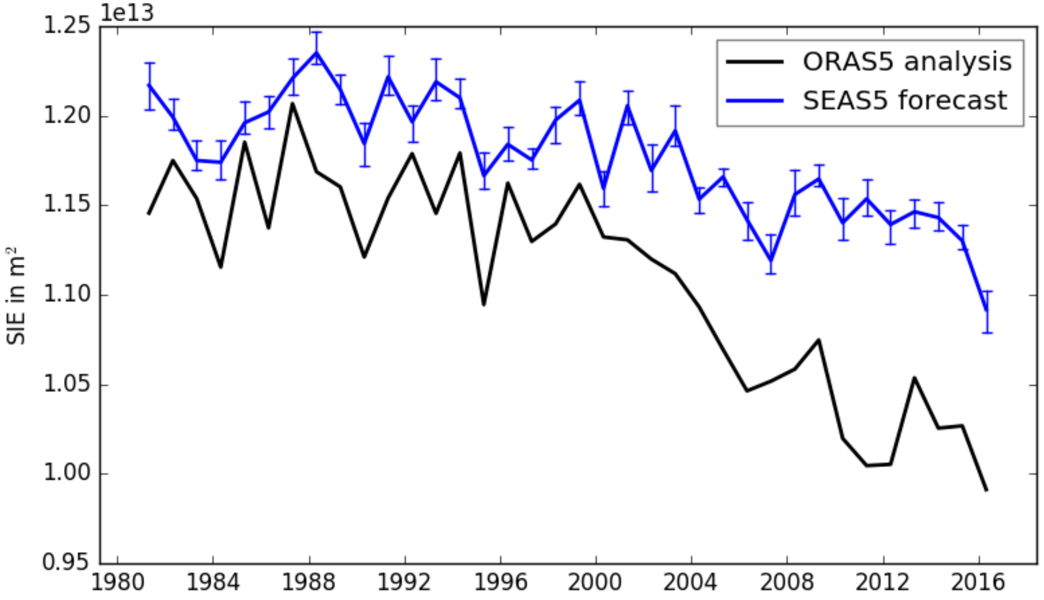


- Almost unbiased, good skill

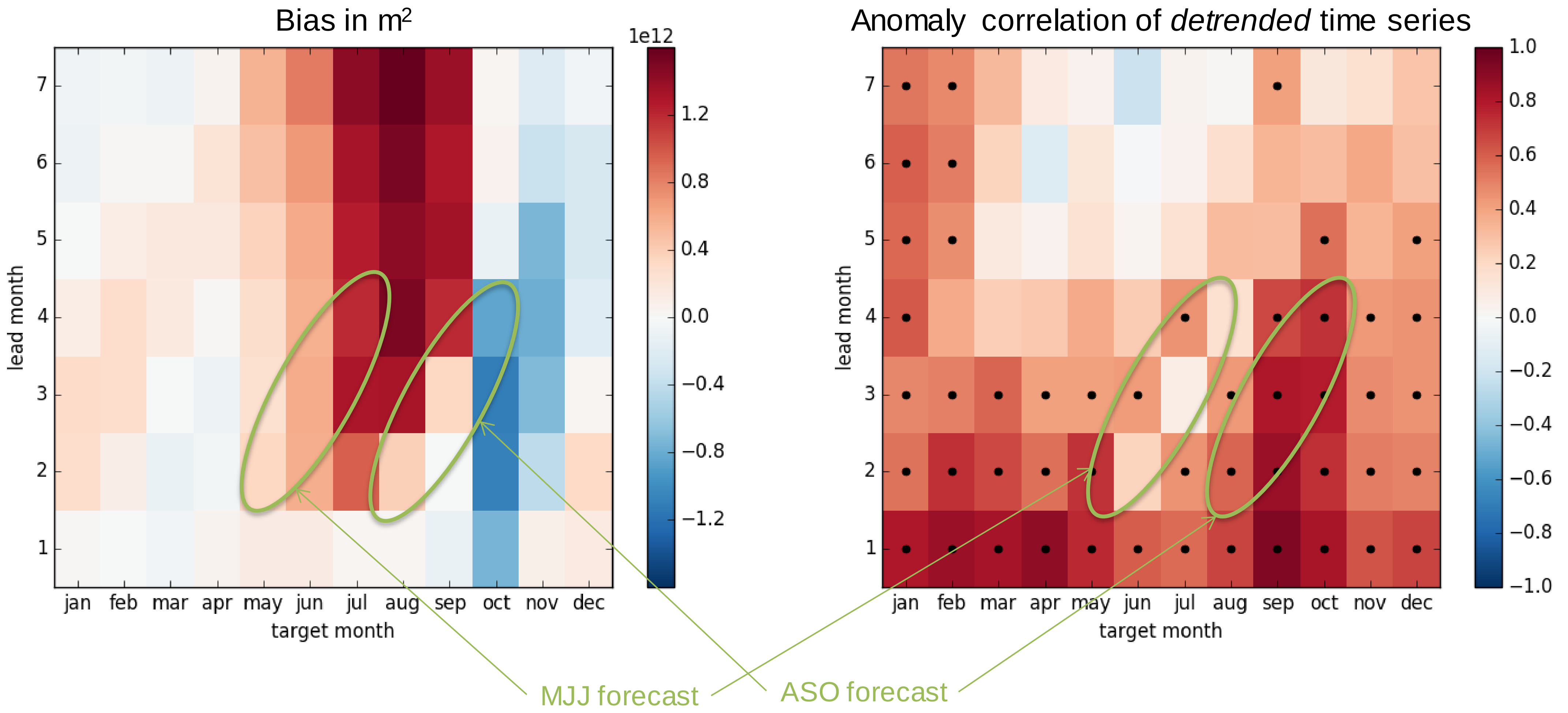
Spring/summer (MJJ) forecast from 1st April



- Substantial high bias
- moderate skill even after bias removal

Bias and skill overview for SEAS5 Arctic sea-ice extent forecasts

Verification for each pair of target and lead months (1981-2015)



Satellite observations of sea-ice cover and thickness

Sea-ice concentration (SIC)

= area fraction covered by sea ice

- routine daily global observations since 1979 by satellite passive microwave radiometry
- observation uncertainty from ~2% to ~30% depending on algorithm and ice conditions

Sea-ice thickness (SIT)

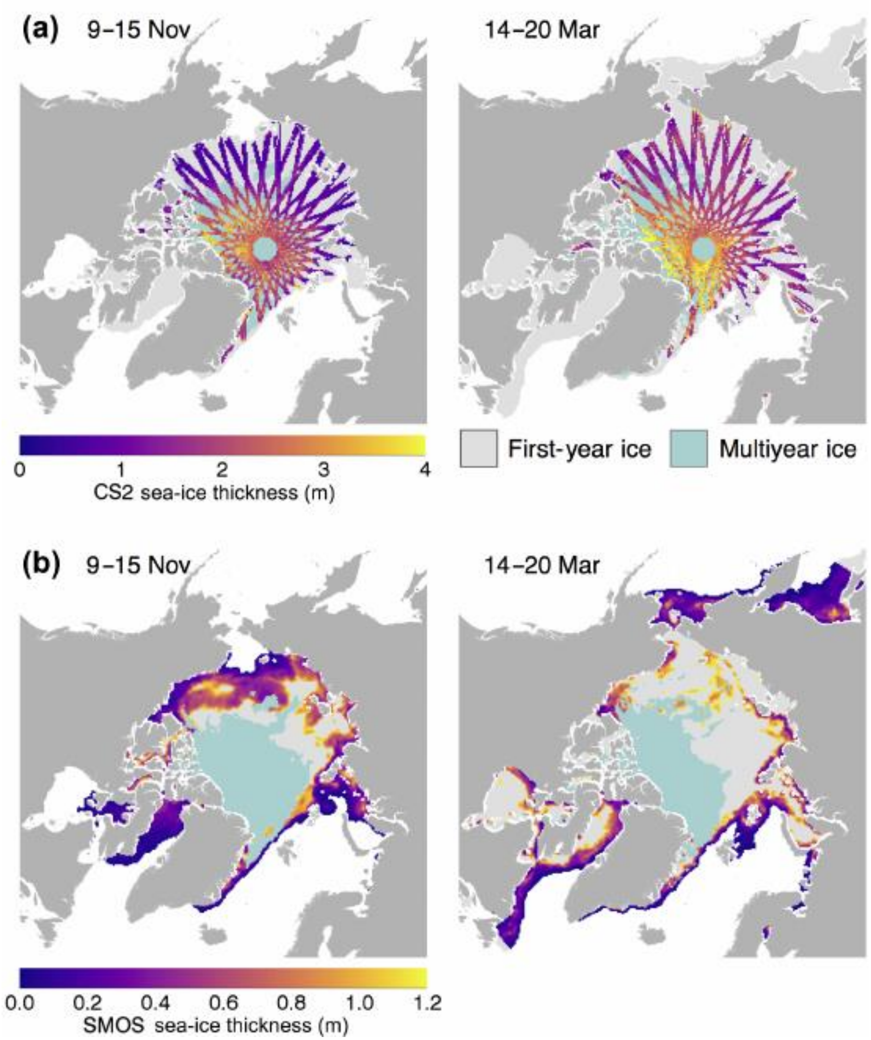
= vertical extent of sea ice

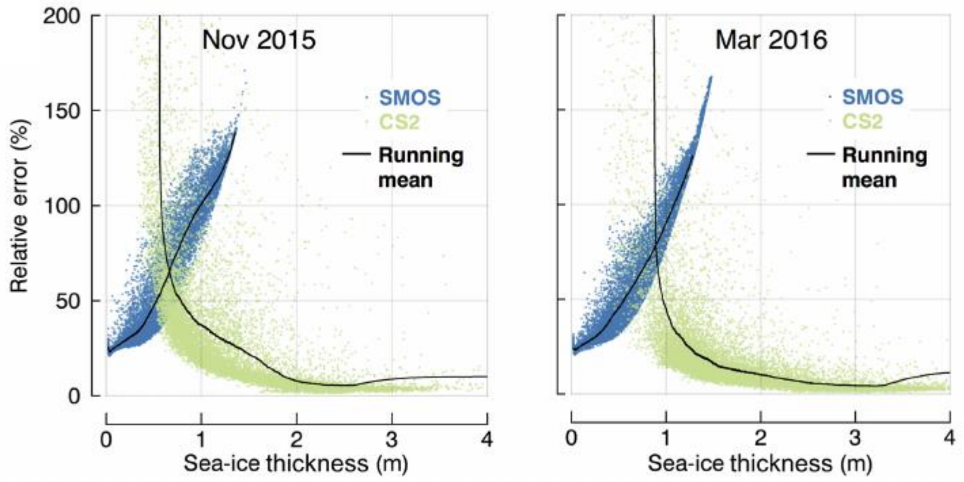
- satellite observations from laser/radar altimetry and L-Band/infrared radiometry
- relatively poor temporal and spatial coverage
- Complex retrieval models and high uncertainties

Sea-ice thickness holds more “predictive power” than sea-ice concentration, yet it is much more difficult to observe

→ Here, experiments use *thickness* observations for initialization, but *concentration* observations for verification

CS2SMOS: weekly-mean Arctic sea-ice thickness product from merged CryoSat-2 and SMOS satellite observations





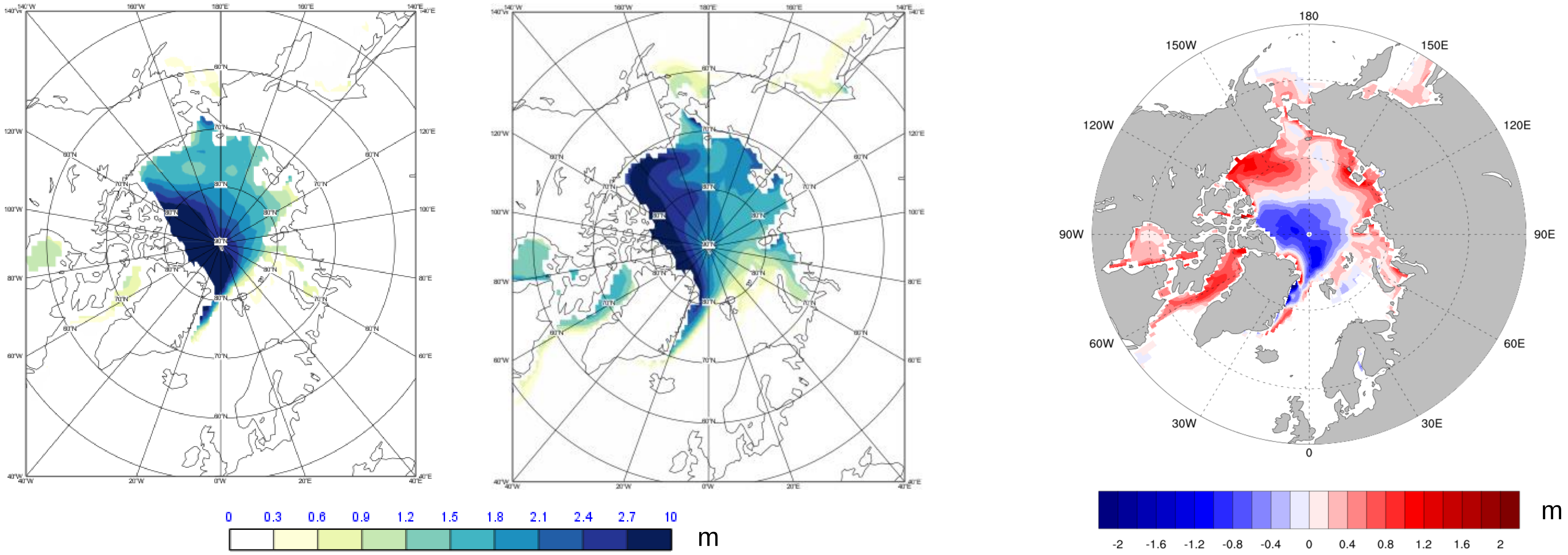
- Exploits complementarity between altimetry (CryoSat2) and L-band radiometry (SMOS): spatial coverage (left), and retrievable thickness (top)
- Weekly temporal resolution, because otherwise CS2 spatial coverage is insufficient
- Available during the cold season (November to March) from 2011 to near-realtime

Ricker et al., The Cryosphere 2017

Sea-ice thickness in CS2SMOS observations and the ECMWF reanalysis

Average sea-ice thickness in March 2011-2015

CS2SMOS observations | ORAS5 analysis | ORAS5 – CS2SMOS



ORAS5 has thinner multi-year ice north of Greenland and central Arctic, but thicker seasonal ice
→ *Ice thickness in regions with seasonal sea-ice cover more important for seasonal predictions*

Initializing seasonal forecasts with CS2SMOS observed sea-ice thickness

Step 1: *baseline initial conditions* 2011-2016 from multi-year baseline analysis experiment

- Low-resolution analogue of operational ocean analysis system (ORAS5-LR)

Step 2: *SPICES initial conditions* 2011-2016 from multi-year analysis experiment

- Additionally constraining SIT to CS2SMOS observations (nudging with 10-day time constant)

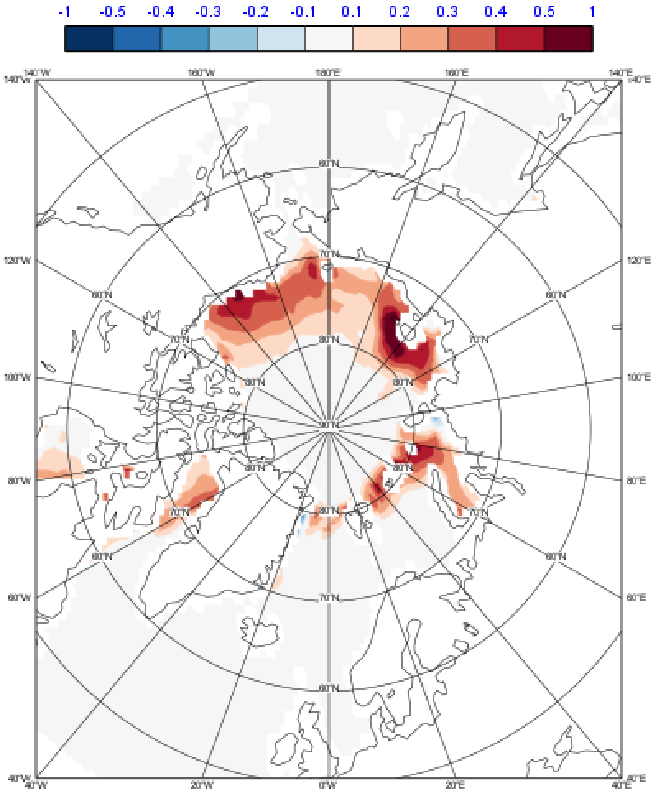
Step 3: *seasonal re-forecasts* 2011-2016 from baseline and SPICES initial conditions

- Forecast model SEAS5-LR: atmosphere cycle 43R3 @ TCo319 resolution, ocean @ 1° resolution
- 7 months lead time, 25 ensemble members, every month from Jan 2011 to Dec 2016

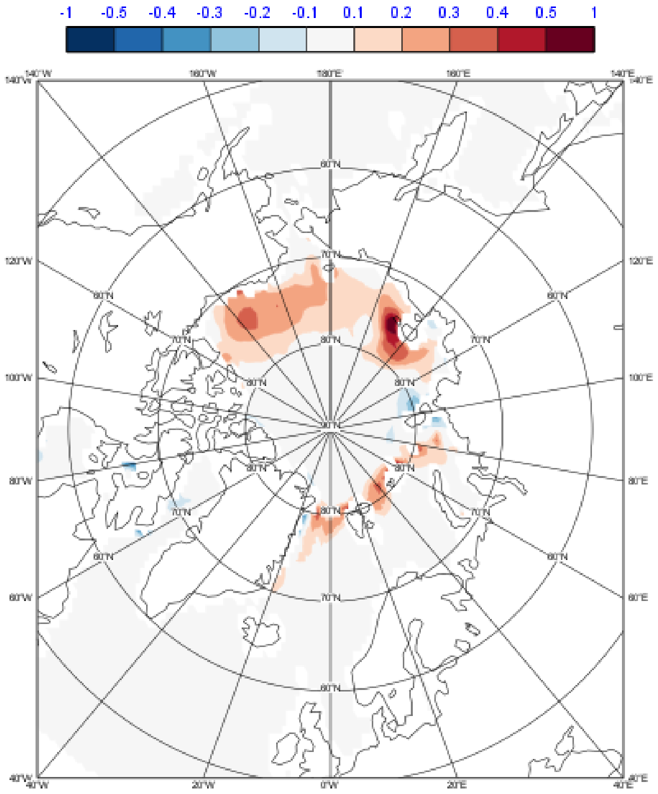
Impact of CS2SMOS SIT initialization on SIC forecast bias

SIC forecast bias for July when forecast from April 1st

SEAS5-LR

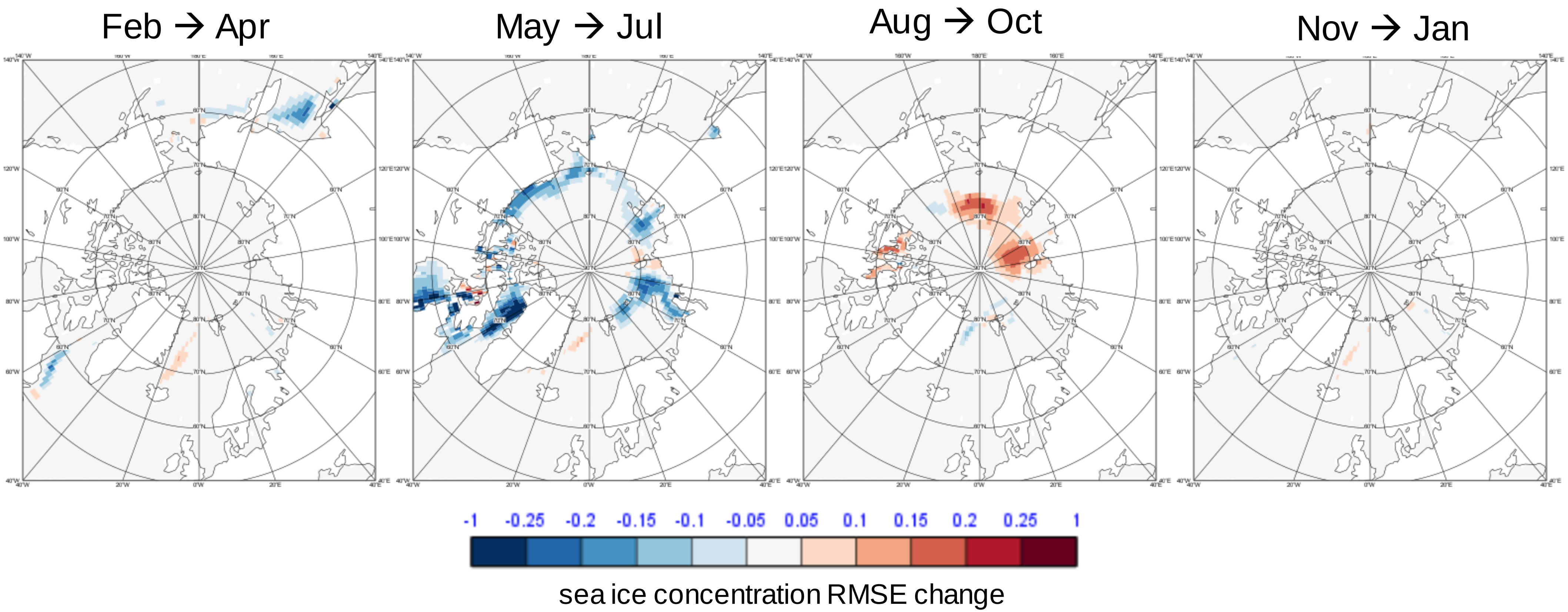


SEAS5-LR with CS2SMOS initialization



SEAS5 forecasts for summer have excessive sea-ice cover, which is much improved when using CS2SMOS sea-ice thickness for initialization

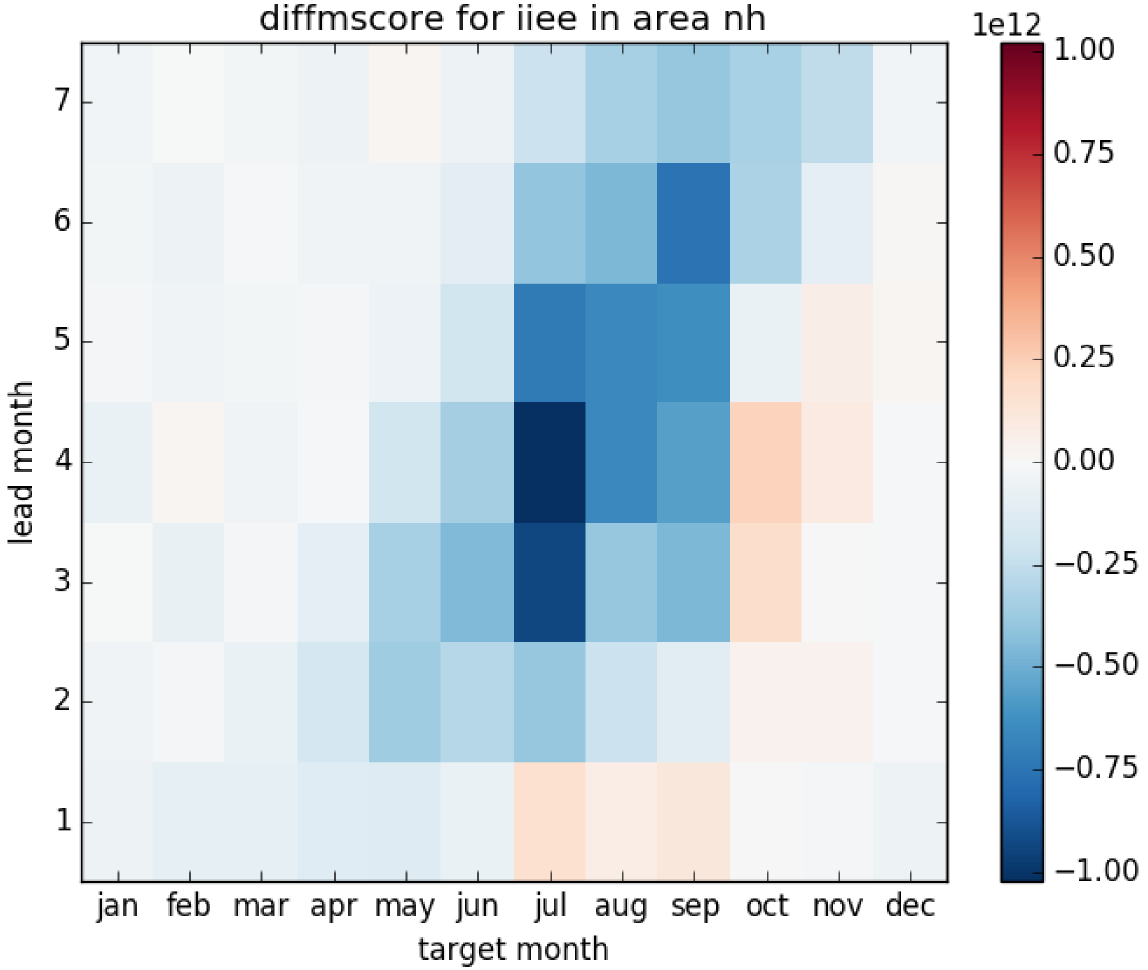
Impact of CS2SMOS initialization on SIC forecast RMSE



- reforecasts from 2011 to 2016, 25 ensemble members
- impact of CS2SMOS initialization varies a lot seasonally, but predominantly positive

Impact of CS2SMOS initialization: change in ice edge error

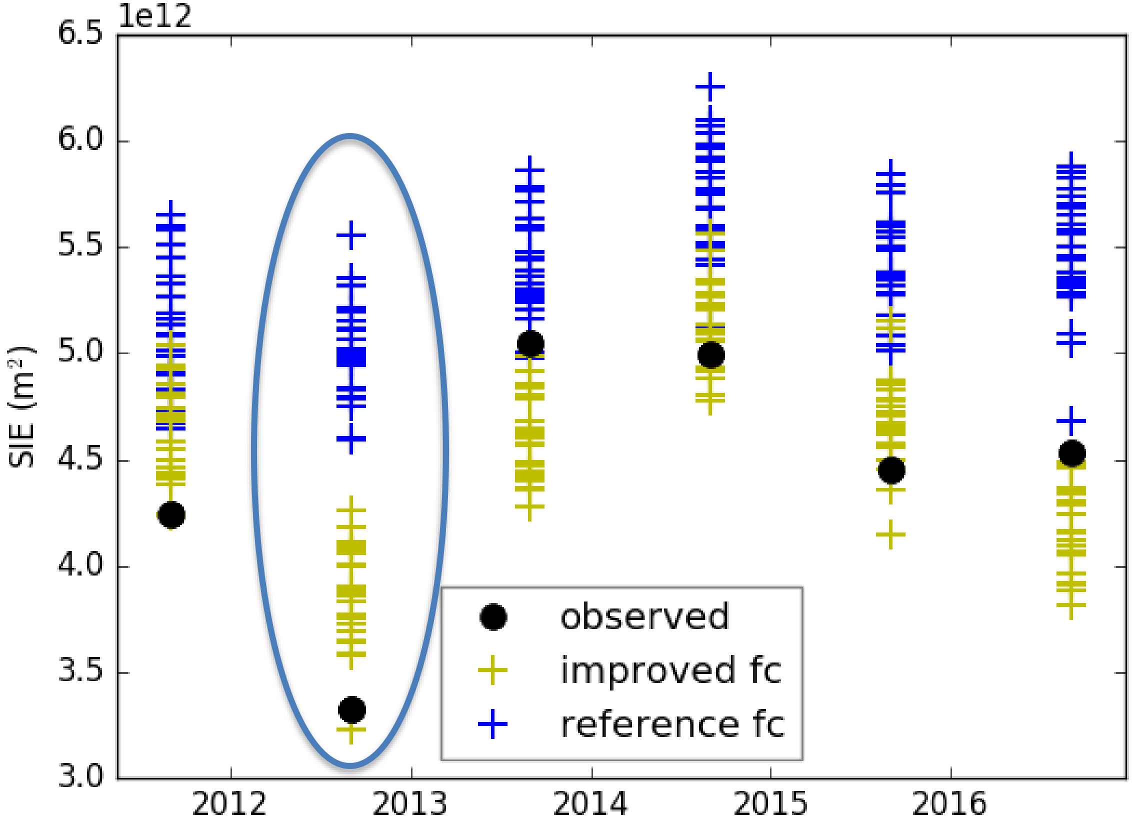
Verification 2011-2016 w.r.t. OSI-401b SIC

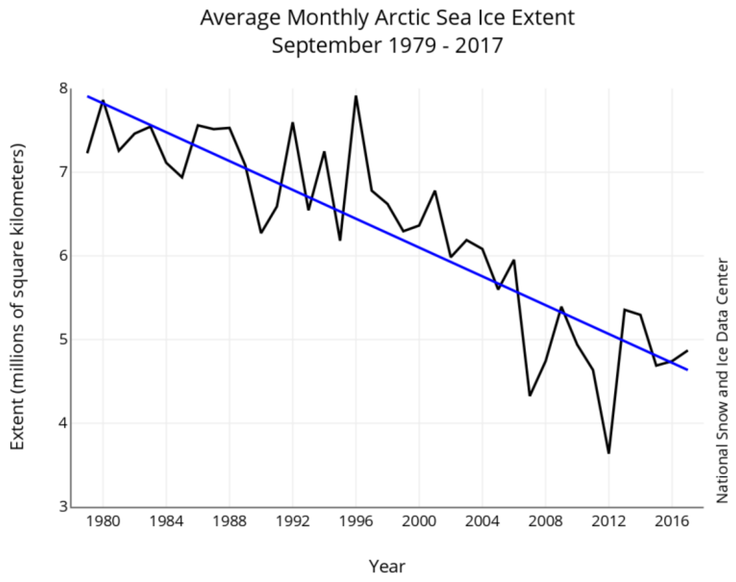


- Assess forecast impact using *integrated ice edge error* IIEE (Goessling et al., GRL 2016)
- blue = improvement; red = deterioration (unit of IIEE is m^2)
- Large improvement for summer forecasts
- Slight deterioration in autumn, and for first forecast month during summer

→ Very promising, shows strong impact on new sea-ice thickness observations on forecasts

Impact of CS2SMOS initialization on September sea-ice extent forecasts

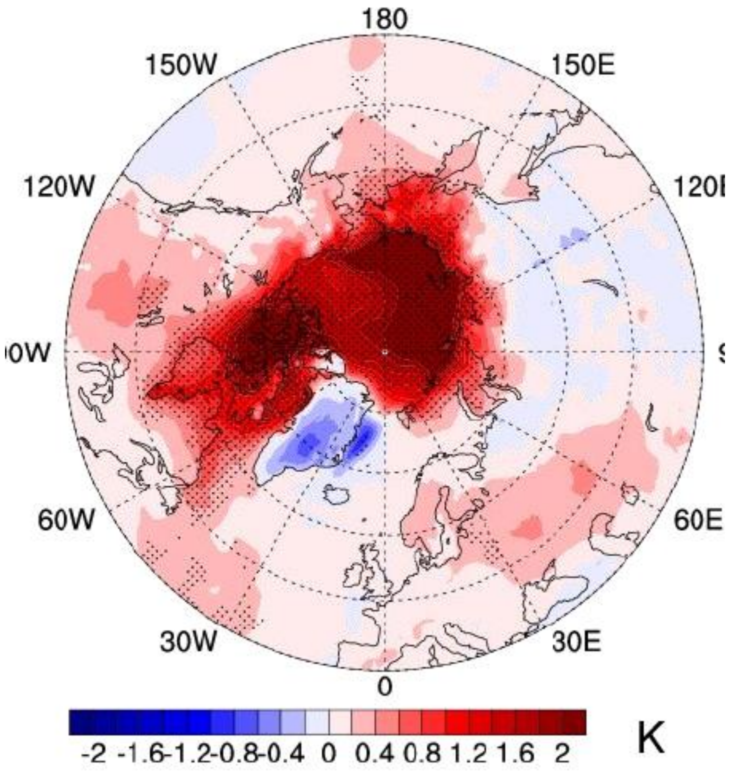




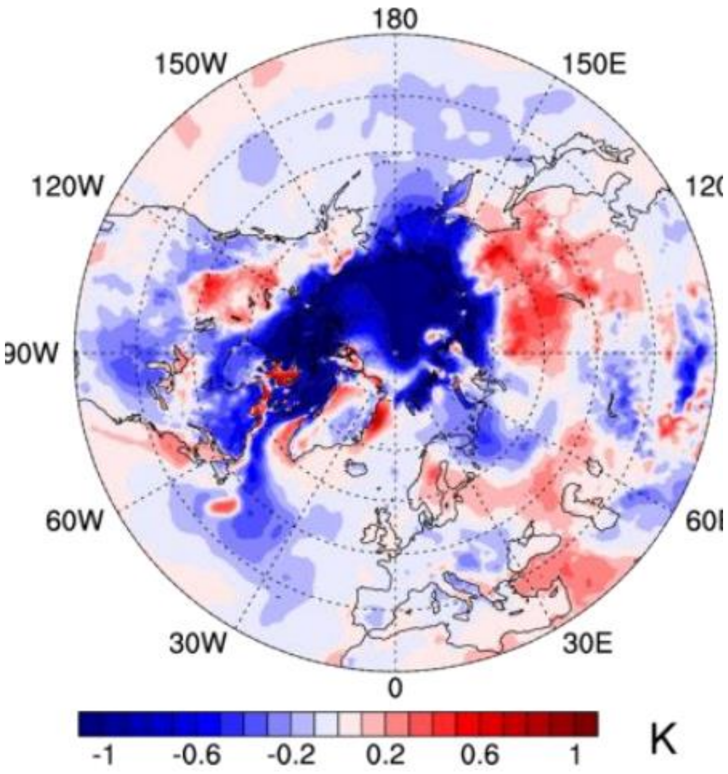
- Shown are ensemble members of forecasts of September sea-ice extent from July 1st
- Noteworthy strong improvement to 2012 forecast

Atmospheric impact of changed sea-ice forecasts

Change in forecast mean of October 2m temperature (from May)



Change in forecast RMSE of October 2m temperature (from May)



Changes in sea-ice cover forecasts impact near-surface atmosphere forecasts: strong locally, and detectable far away from sea ice

Summary

- Sea-ice thickness is essential for developing, initializing and verifying sea-ice forecasts
  → relying purely on sea-ice concentration can be misleading
- Performance of sea-ice forecasts varies strongly with lead and start month
  → deriving overall conclusions based on only one season can be misleading
- ECMWF SEAS5 sea-ice forecasts overall skilful, but have large high bias in summer that is hard to correct a-posteriori
- CS2SMOS observations to initialize sea-ice thickness in winter: forecast improvement for sea-ice concentration in summer
- Demonstrated impact of sea-ice initialization on atmospheric forecasts