Predictability of extreme Arctic sea-ice anomalies

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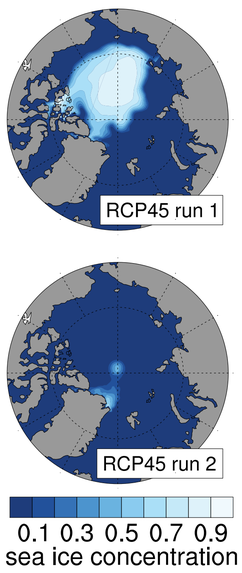
1. Motivation

Large Arctic sea-ice variability in MPI CMIP5 climate projections

In the CMIP5 RCP45 projections of 21st-century climate with the Max Planck Institute Earth System Model (MPI-ESM), Arctic sea ice declines and at the same time exhibits very strong interannual anomalies.

For instance, by 2053 the summer sea-ice extent of the Arctic can either be virtually zero or close to present-day conditions, depending on the realization (see Figure to the right).

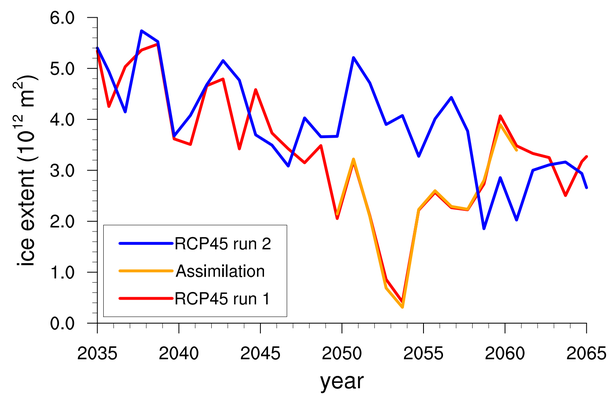
Here, we investigate the potential to predict these strong sea-ice anomalies under the perfect-model assumption.



2. Model and methods

A predictability case study under the perfect-model assumption

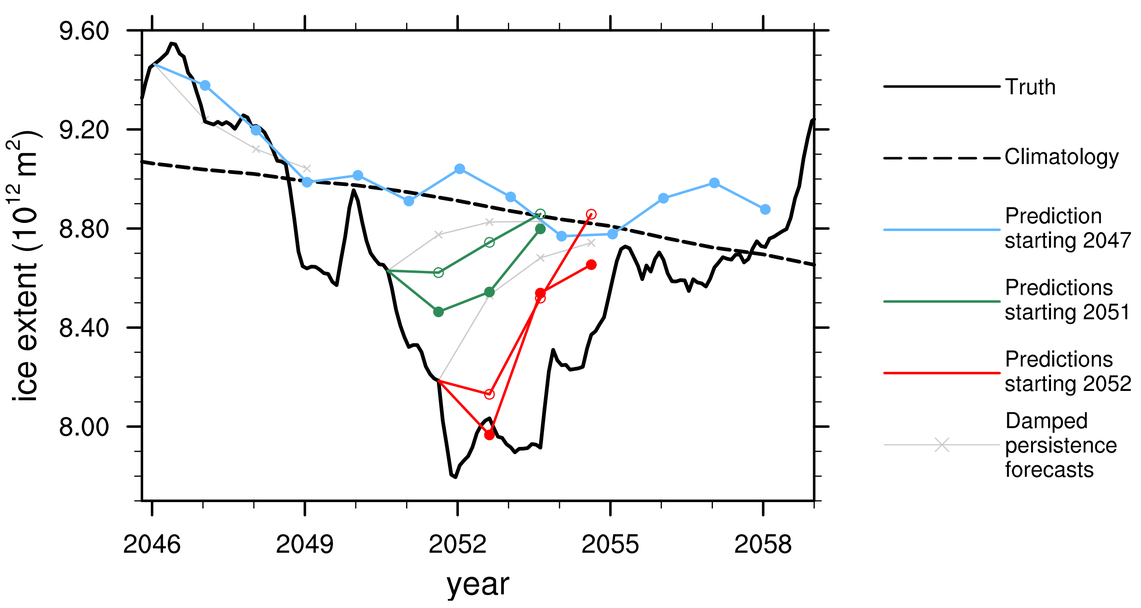
The Figure below shows time series of Arctic September sea-ice extent for two RCP45 runs together with the assimilation run that starts from run 2 and assimilates sea-ice concentration of run 1.



- Model: MPI-ESM with ECHAM6 (T63/L47) and MPIOM (GR15/L40)
- Perfect-model assumption: treat RCP45 run 1 as the truth and try to predict it
- Predictions with 9 ensemble members starting at various times during a large interannual sea-ice anomaly from 2047 to 2057
- Two kinds of initial conditions:
  1. Lagged-perfect initial conditions
  2. Assimilated-sea-ice initial conditions [1]

3. Predictions of annual mean ice extent

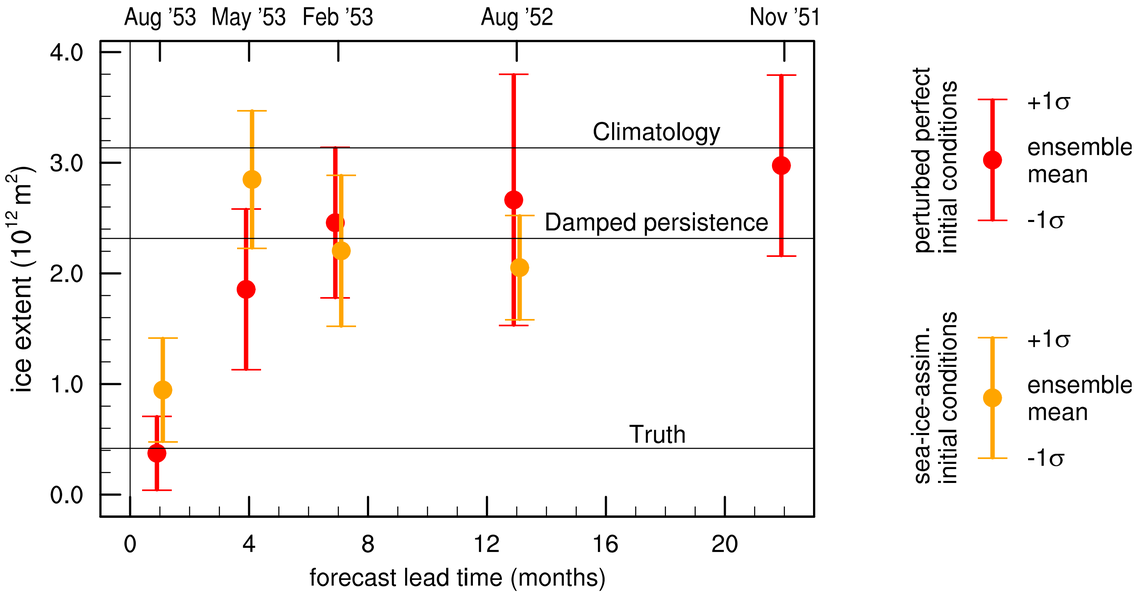
The Figure below shows ensemble mean predictions of annual-mean northern hemisphere sea-ice extent from lagged-perfect initial conditions (filled circles) and assimilated-sea-ice initial conditions (open circles). The RCP45 run 1 that is considered as the truth is shown in black; the solid line is its rolling annual mean, and the dashed line is its centered 30-year mean. Damped-persistence forecasts are given as a reference (gray crosses).



- The onset and amplitude of the large interannual anomaly are unpredictable
- The deepening of the anomaly can be predicted for the first lead year
- Predictions are better than a damped-persistence forecast for up to two lead years
- Predictions are better than a climatology forecast for up to three lead years
- Assimilated-sea-ice initial conditions provide predictive skill that is comparable to but less than that of lagged-perfect initial conditions

4. Predictions of summer ice extent

The Figure below shows Arctic sea-ice extent predicted for September 2053 for different lead times. The true extent of the RCP45 run 1, a damped-persistence forecast and a climatology forecast are given as horizontal reference lines.



- Predictions are better than a damped-persistence forecast for lead times of up to a few months
- Predictions are better than a climatology forecast for lead times of up to two years
- Assimilated sea-ice initial conditions seem competitive with lagged-perfect initial conditions for sub-annual lead times

5. Discussion & Outlook

Next step: find physical processes that determine predictability

- Fast atmospheric processes ↔ low predictability,
  e.g. Arctic surface wind stress in summer [2]
- Slow oceanic processes ↔ higher predictability,
  e.g. ocean heat transport into Arctic [3]

References
[1] S. Tietsche, D. Notz, J. H. Jungclaus and J. Marotzke, Sea-ice data assimilation in a global climate model – physical and statistical aspects, in preparation
[2] M. Ogi, I. G. Rigor, M. G. McPhee and J. M. Wallace (2008), Summer retreat of Arctic sea ice: Role of summer winds, *GRL, 35*, L08707
[3] Marika M. Holland, Cecilia M. Bitz and Bruno Tremblay (2006), Future abrupt reductions in the summer Arctic sea ice, *GRL, 33*, L23503

6. Conclusions

Ensemble predictions with MPI-ESM under the perfect-model assumption give upper bounds on predictability of large Arctic sea-ice anomalies in RCP45 runs:

1. It is easy to beat a climatology forecast
   → lead times less than two years (summer) to three years (annual mean)
2. It is hard to beat a damped persistence forecast
   → lead times less than a few months (summer) to two years (annual mean)
3. For sub-annual lead times, sea-ice-assimilated initial conditions are competitive with lagged-perfect initial conditions

Although sea-ice anomalies will be large in the future, there is only moderate prospect of predicting them in advance.

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IMPRS-ESM International Max Planck Research School on Earth System Modelling