Predictability and probability of a summer ice-free Arctic

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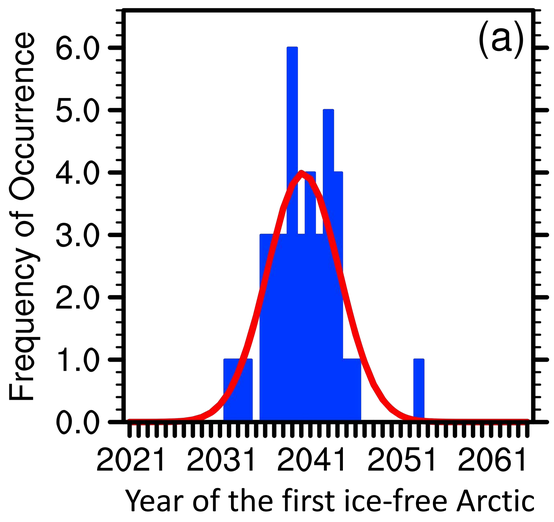
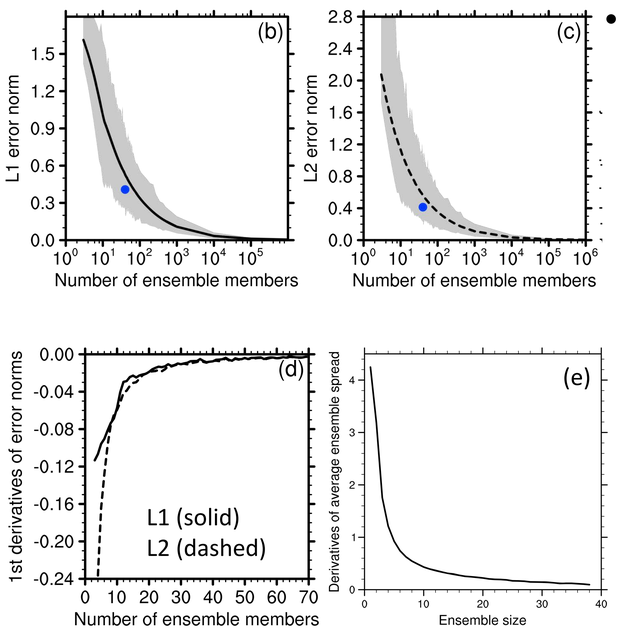
Motivation: How predictable is the first occurrence of sea ice free conditions in the Arctic Ocean? Using large ensemble simulations, this question can be answered and probabilistic projections of ice-free years can be provided for a range of future emission scenarios. "Ice-free" is here defined as an ice-extent of less than 1 million km^2, the commonly used threshold for an ice-free Arctic.

Method: A suite of Community Earth System model (CESM) ensembles, including the CESM LE (Kay et al. 2015, 40 members), the medium ensemble (Sanderson et al. 2015, 15 members) and the low warming scenario (Sanderson et al. 2017, 10 members) were analyzed. The CESM performs well for many metrics of Arctic summer sea ice, making it a suitable model for studying projections of an ice-free Arctic.

Predictability of the first ice-free Arctic



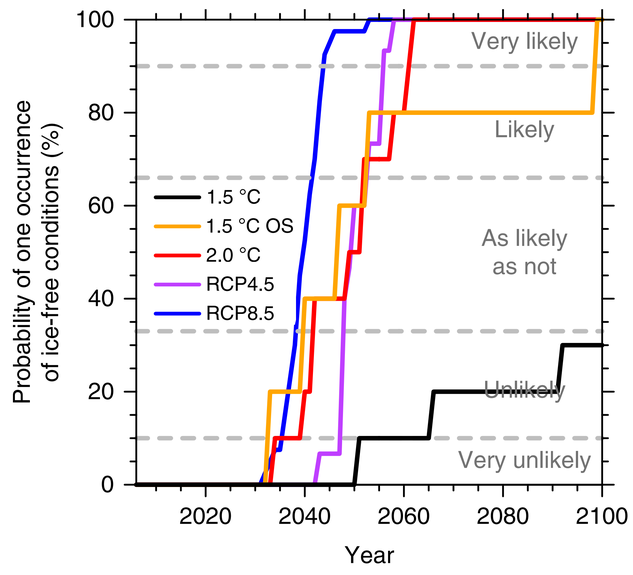
- The first occurrence of an ice-free Arctic carries a ~20 year predictability uncertainty from internal variability (based on the CESM LE, but consistent with other CMIP5 models, see Jahn et al. 2016)
- Model and scenario uncertainty add this this internal-variability uncertainty

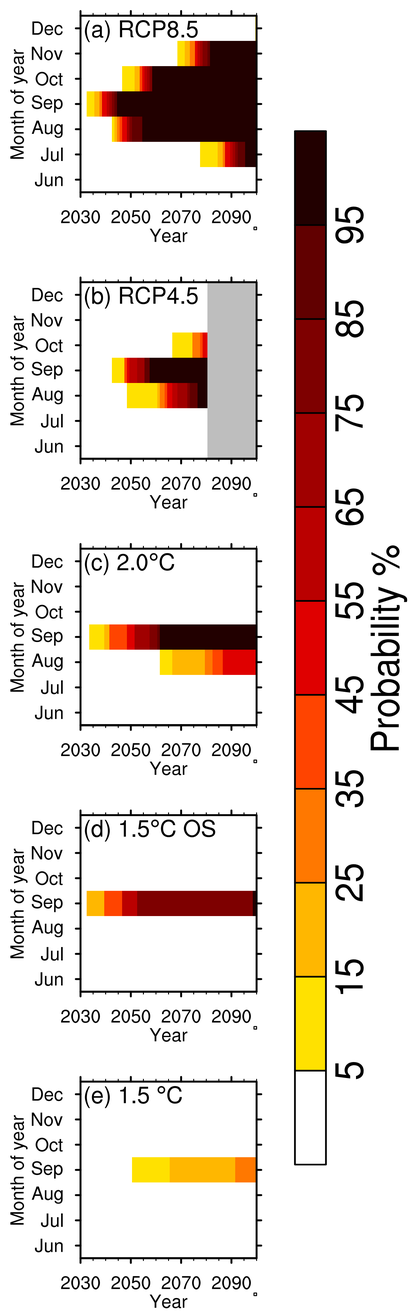


- L1 and L2 error norm analysis (b-d) and bootstrapping of the 40-member CESM LE (e) show that the benefit per additional ensemble member of capturing the full range of internal variability decreases most strongly for the first 10 ensemble members → ensembles of size 10 are a good cost-benefit compromise for this predictability question

From: Jahn, A., Kay, J. E., Holland, M. M., and Hall, D. M. (2016), How predictable is the timing of a summer ice-free Arctic?, *Geophys. Res. Lett.*, 43, 9113– 9120.

Probability of a first ice-free Arctic





- Limiting global warming to 1.5°C rather than 2.0°C reduces the probability of any ice-free conditions in September before 2100 from 100% to 30% and the probability of ice-free conditions in August from 50% to 0%.
- Under the business-as-usual scenario (RCP8.5), which leads to over 4°C warming by 2100, ice free conditions have a 100% probability of occurring at least once during 5 month of the year (July to November).

From: Jahn, A. (2018), Reduced probability of ice-free summers for 1.5° C compared to 2.0° C warming, *Nature Climate Change*, 8, 409-413.

Conclusions: Predictions of the first occurrence of an ice-free Arctic have an uncertainty of ~20 years due to internal variability. Only by limiting global warming to 1.5°C can ice-free conditions before 2100 potentially be avoided. Further warming guarantees at least one instance of an ice-free Arctic and increases the number of months that ice-free conditions may be present (up to 5 months under RCP8.5, with >4°C warming by 2100).

References and Funding: Kay et al. (2015), Community Earth System Model (CESM) Large Ensemble Project: a community resource for studying climate change in the presence of internal climate variability. *Bull. Am. Meteorol. Soc.* 96, 1333–1349; **Sanderson et al. (2017),** Community climate simulations to assess avoided impacts in 1.5 °C and 2 °C futures. *Earth Syst. Dynam.* 8, 827–847; **Sanderson et al. (2015).** A new ensemble of GCM simulations to assess avoided impacts in a climate mitigation scenario. *Climatic Change* 146, 303–318. Funding for this study was provided by NSF-1504348 and CU Boulder. Background picture by A. Jahn.