Projections of 21st century Arctic sea ice loss

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Outline

- Sea ice projections/ensembles 101
- How is Arctic sea ice projected to change in the 21st century?

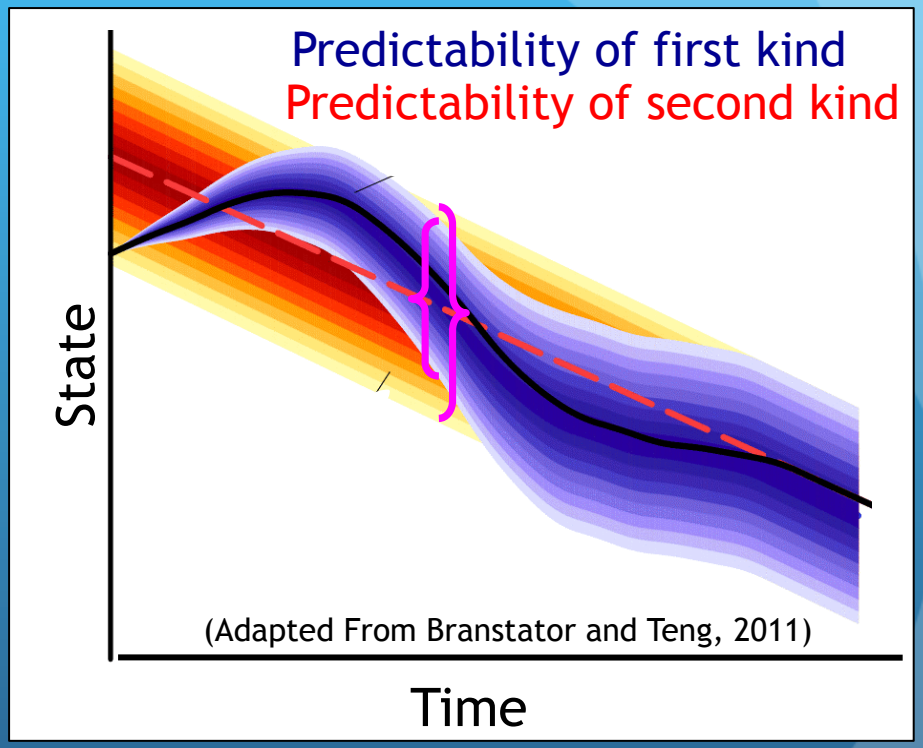
Kinds of Predictability

Of the First Kind:

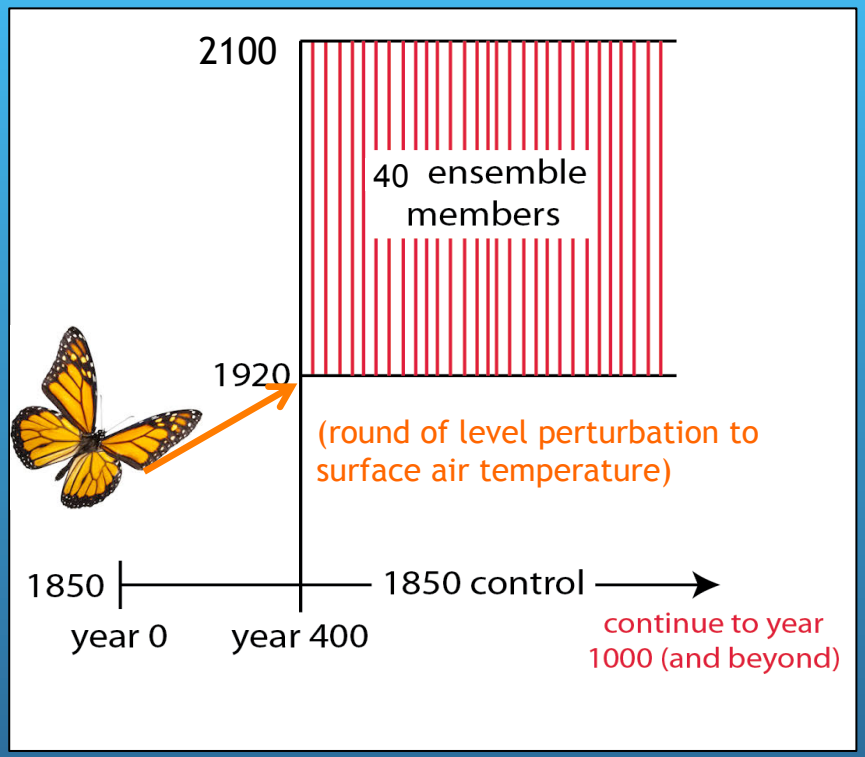
- Initial value problem (e.g., weather, seasonal to decadal predictions)
- Predictability is lost after a certain time due to chaotic system behavior

Of the Second Kind:

- Boundary value problem
- Prediction of statistical properties of the climate system subject to some external forcing (e.g., climate projections

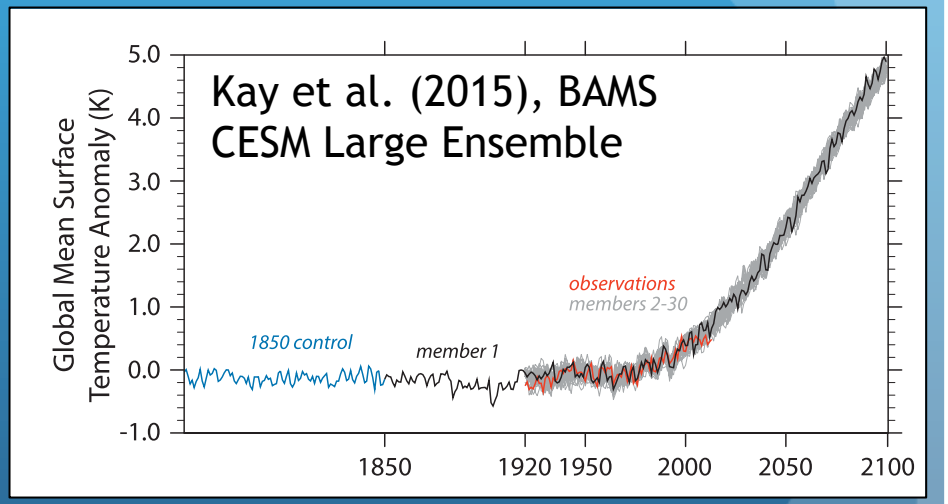


Ensembles 101



Different kinds of ensembles:

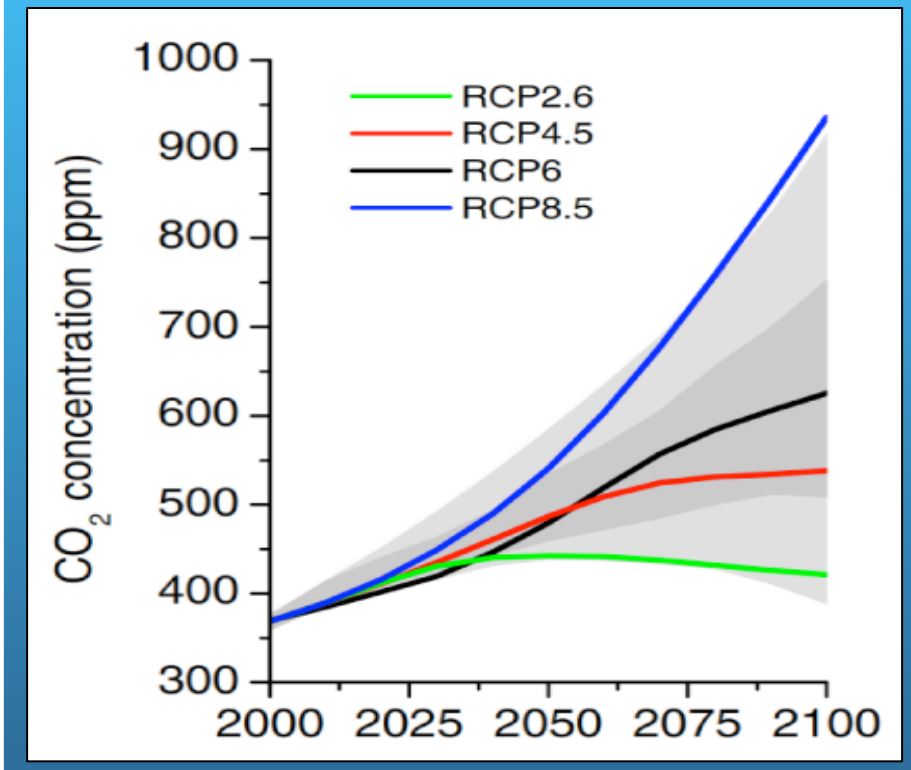
- Initial conditions ensembles
- Perturbed physics ensembles
- Multi-model ensembles

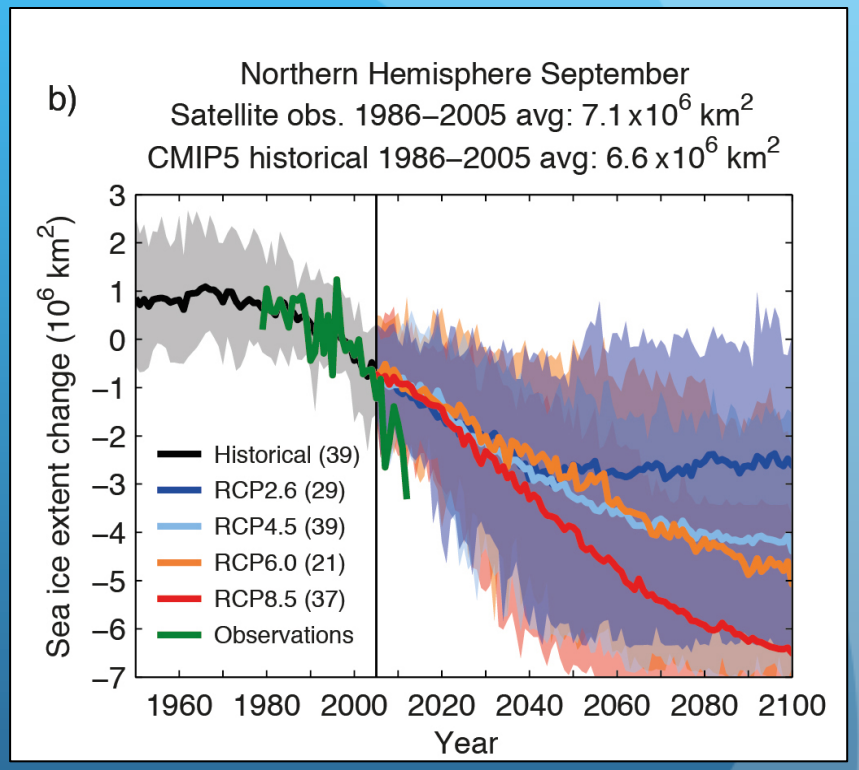


CESM Large ensembles (40): RCP8.5 (Kay et al., 2015, BAMS)
CESM Medium ensemble (15): RCP4.5 (, Sanderson et al. 2015, J. Clim.)
Other large ensembles exist (Canadian Model, GFDL, MPI, Hadley Center Model)

CESM ensembles available at: https://www.earthsystemgrid.org/home.html

Sea ice projections 101

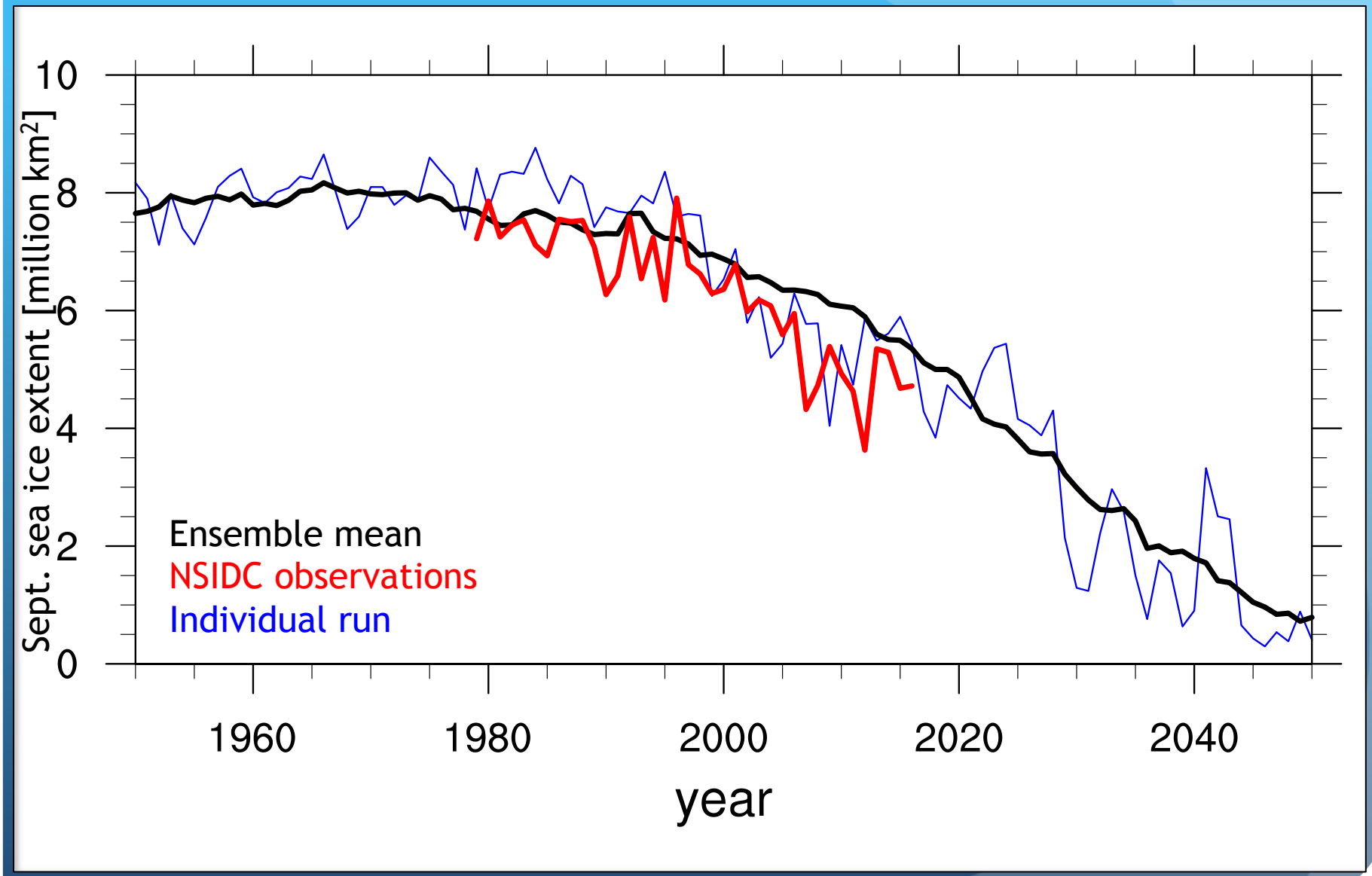




Ensemble mean: thick line, average of all models and many runs, reduces internal variability influence strongly

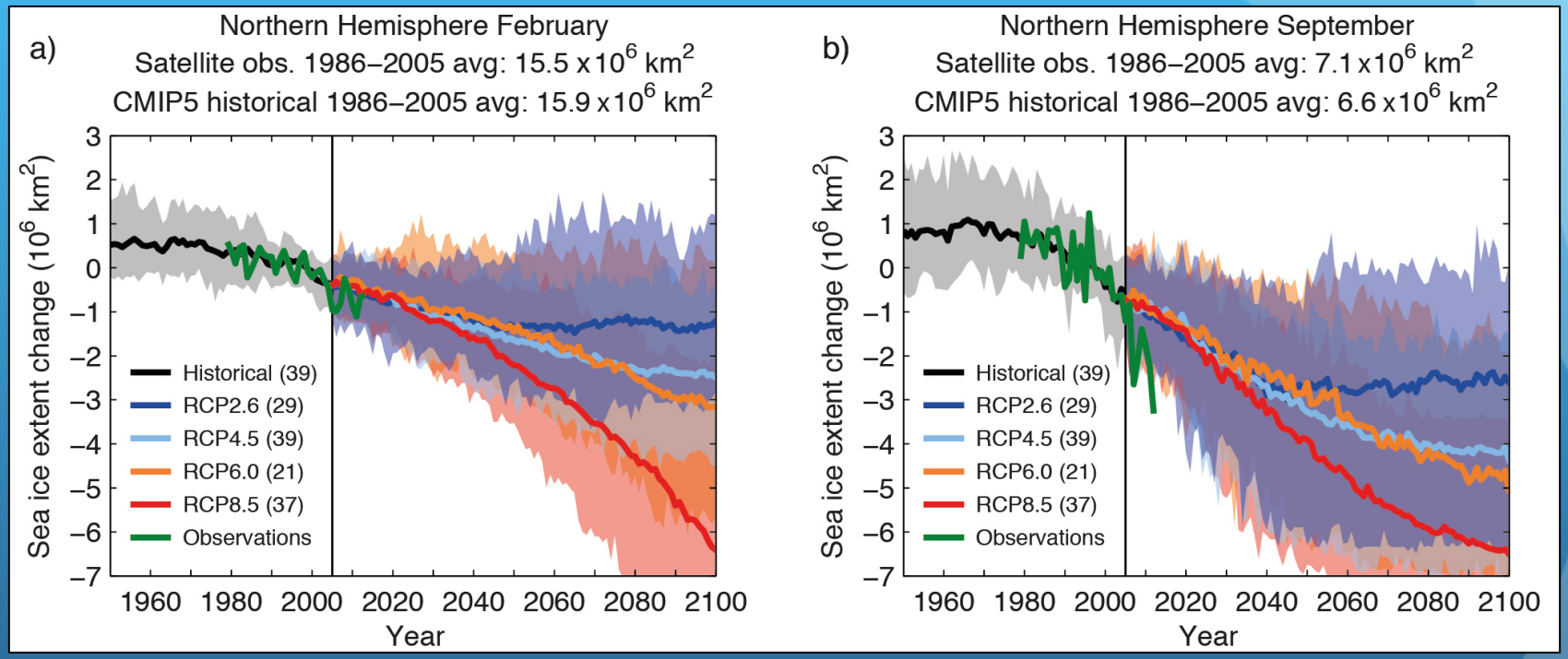
BUT: We don't live in an ensemble mean world, we live in one realization, no reason to expect we get the ensemble mean

Ensemble mean versus individual runs



How is Arctic sea ice projected to change?

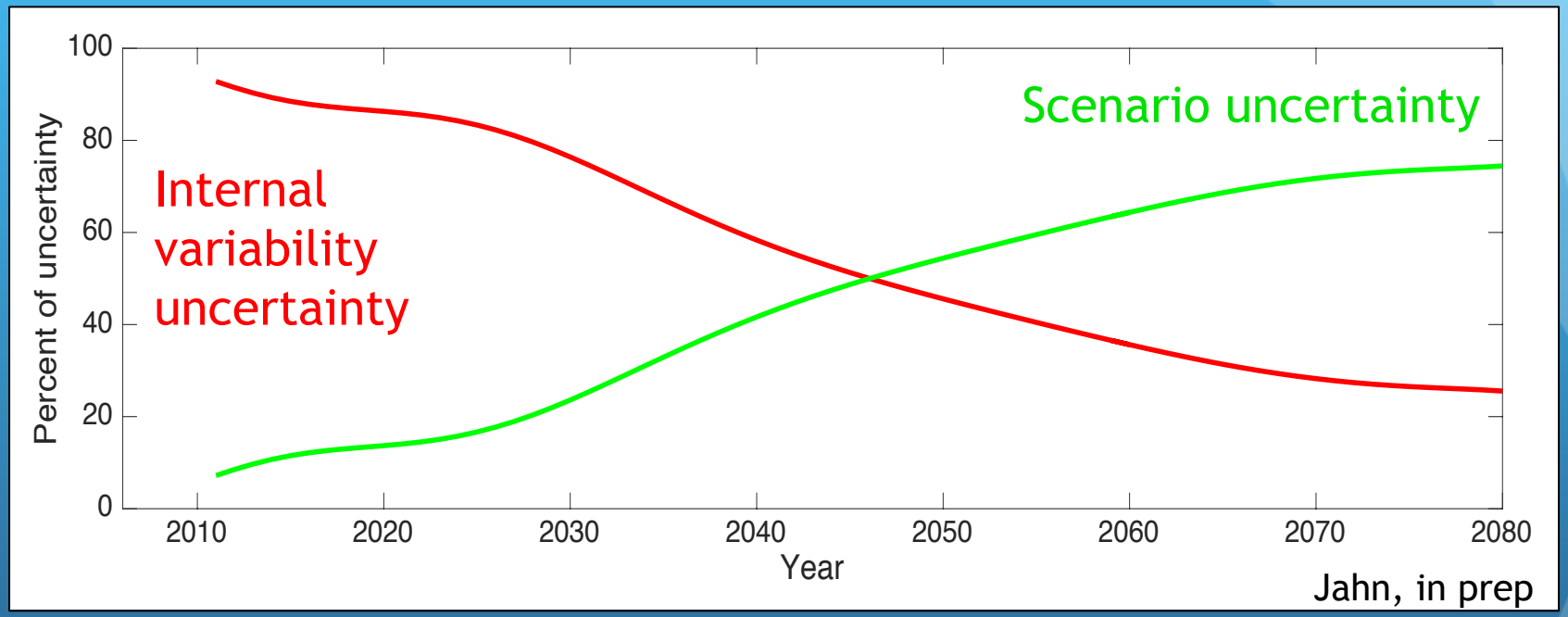
CMIP5 Arctic sea ice extent projections



Large model spread and after ~2040 large impact of emission scenario → but all going down

IPCC 2013

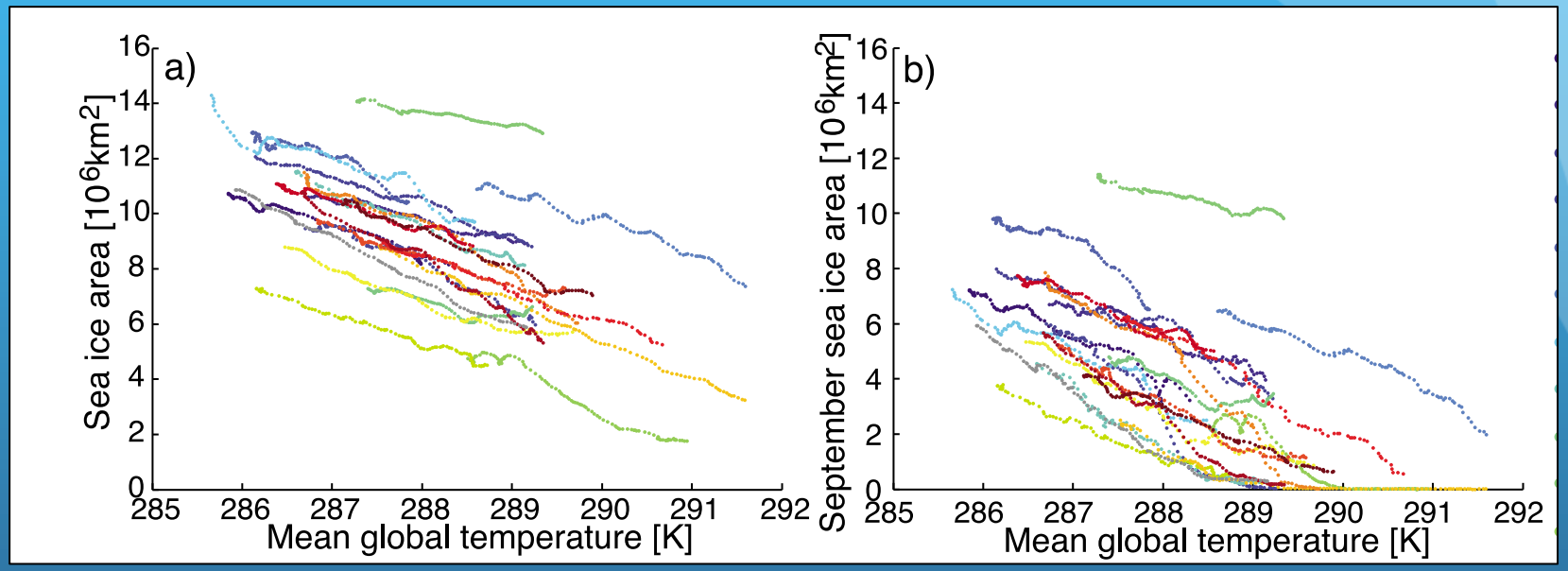
Projection uncertainty from different scenarios and internal variability: September sea ice extent



Calculated following Hawkins and Sutton's (2009) uncertainty decomposition method, using CESM1.1.1 ensembles

Until ~2045, internal variability uncertainty dominates the prediction uncertainty, after 2045 scenario uncertainty takes over → for the next decade, internal variability will make up >80% of projection uncertainty

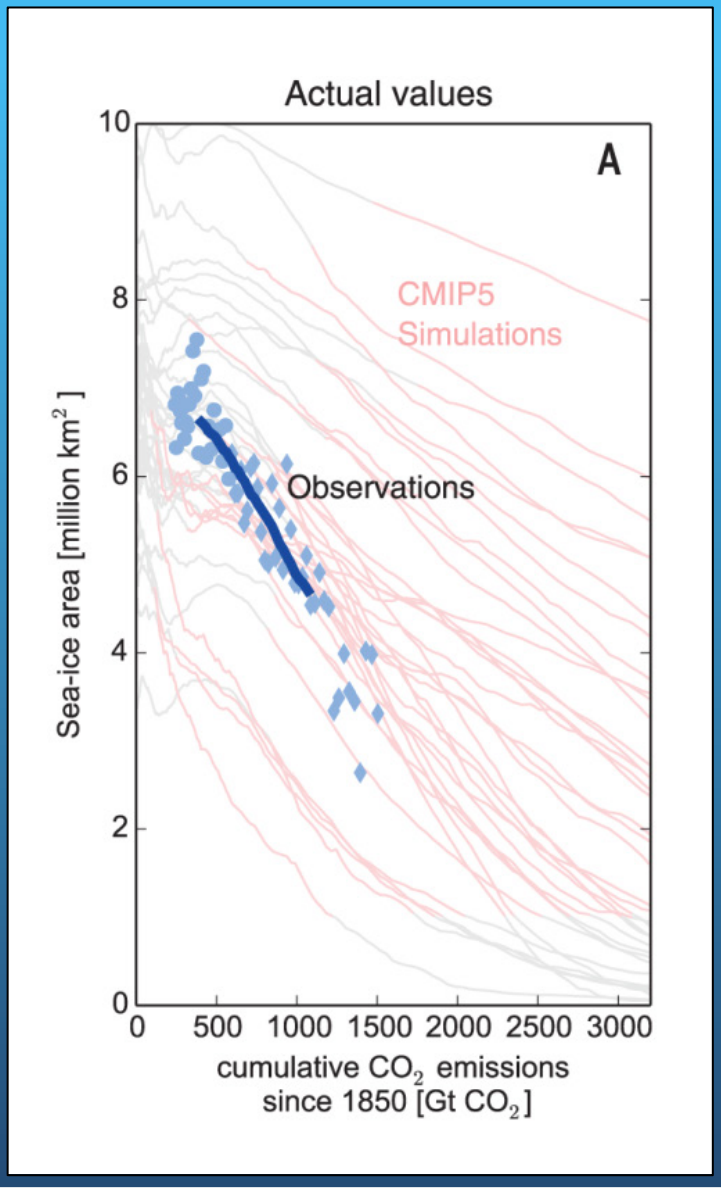
September sea ice and global temperature (CMIP3)



2°C change in annual mean global surface temperature above present is the most likely global temperature threshold for September sea ice to disappear (in 30-yr mean)

Mahlstein et al., 2012

September sea ice and CO_2 (CMIP5)



3 m² of sea ice area loss per 1 metric ton of CO_2

For the 30yr average sea ice, ice-free conditions are reached at additional 1000 Gt of CO_2

For current emissions of 35 Gt CO_2 per year, the limit of 1000 Gt will be reached before mid century.

Notz and Stroeve 2016, Science

Annual mean Arctic sea ice loss per person by country

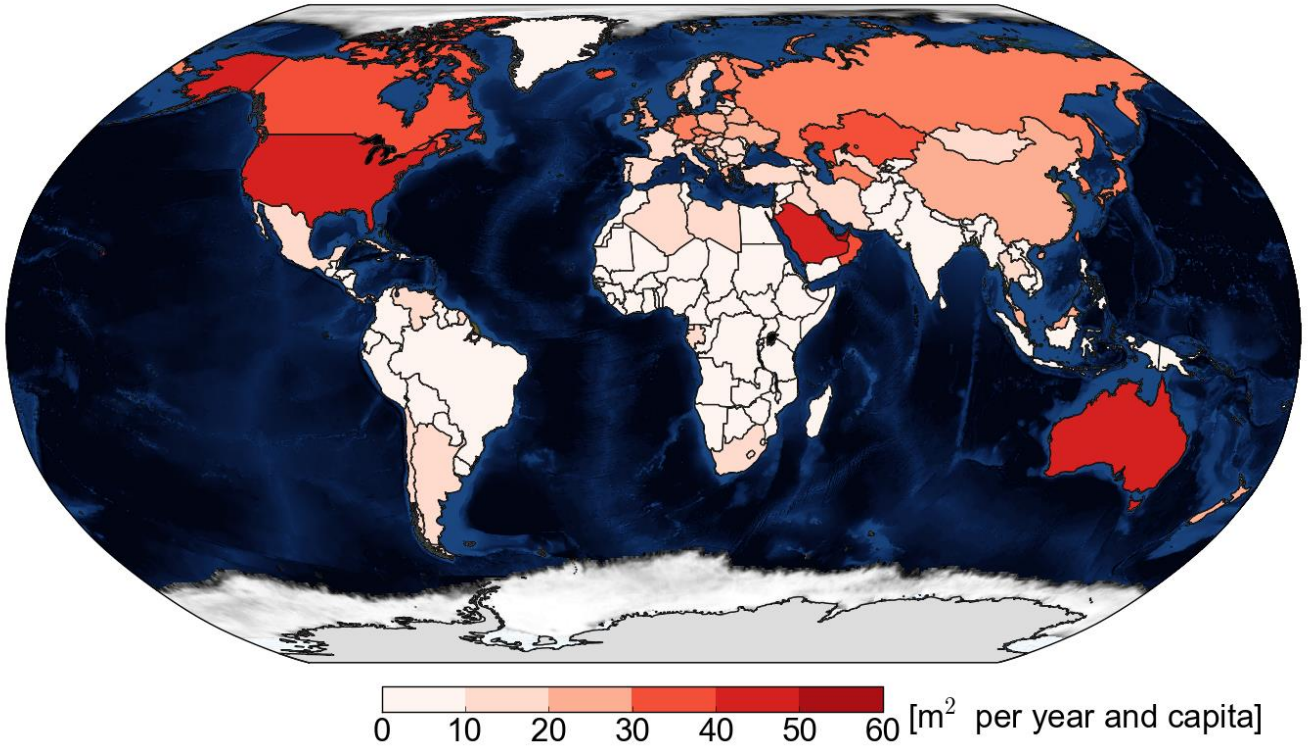


Fig. S1: Annual mean loss of Arctic September sea-ice area caused by average emissions of each citizen. Emission data are for the year 2013 [37]. These data are converted to Arctic sea-ice loss based on the observed sensitivity of 3 m^2 Arctic September sea ice loss per ton of anthropogenic CO_2 emission.

Notz and Stroeve 2016, Science

So, when could the Arctic first be ice-free (not the 30-yr mean)?

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Arctic could become ice-free for first time in more than 100,000 years, claims leading scientist

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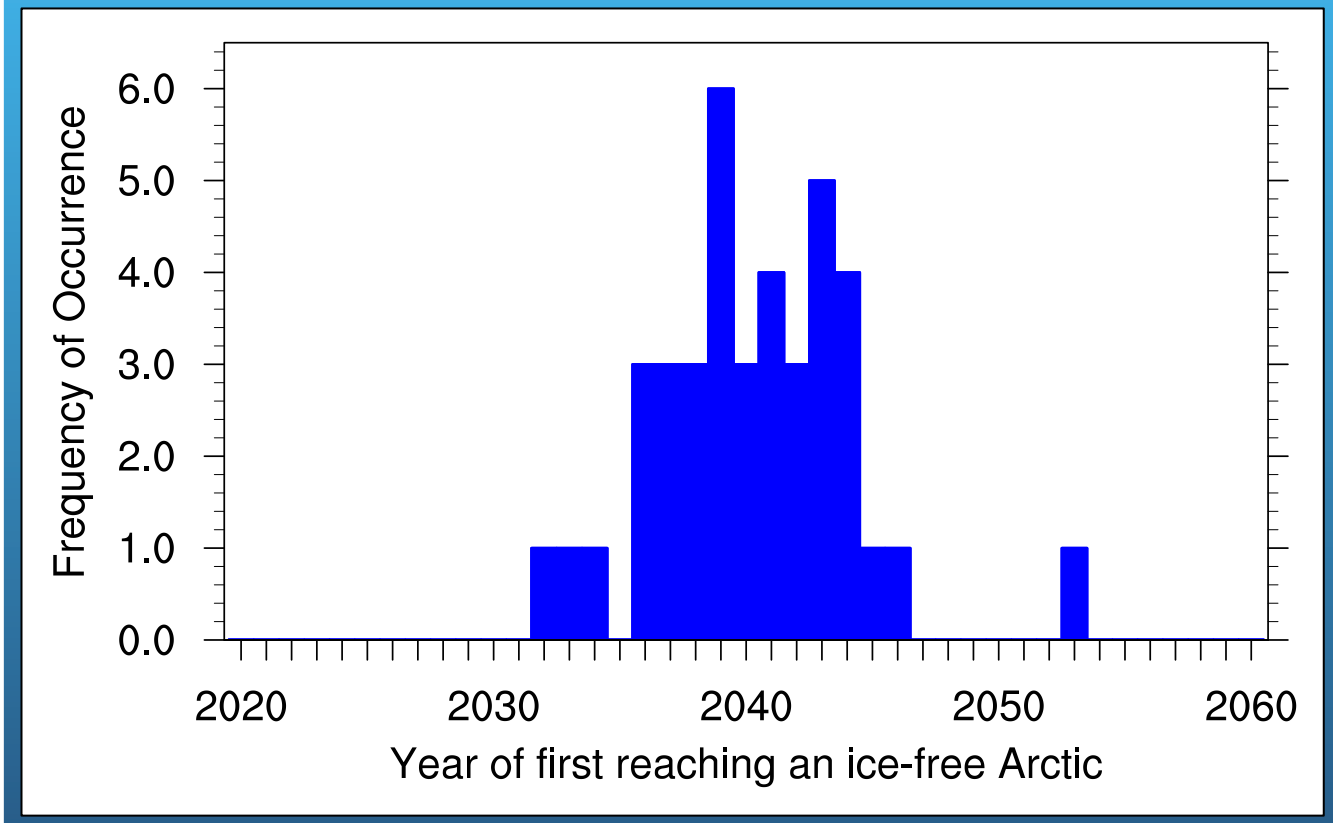
US Navy predicts summer ice free Arctic by 2016

When could the Arctic first be ice-free?

Influence of chaotic system on sea ice projections of the first occurrence of an ice-free Arctic in Sept in CESM LE

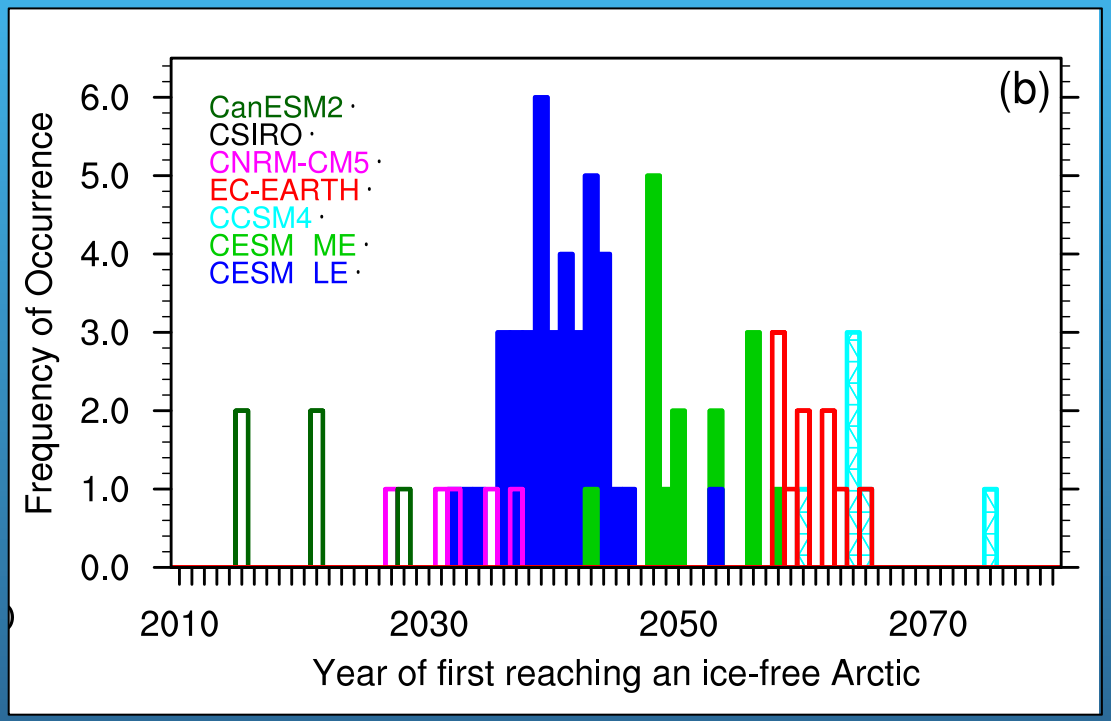


Within one model and one scenario (RCP8.5), large (20+ year) projection uncertainty for first ice-free year due to internal variability

Jahn et al., 2016, GRL

When could the Arctic first be ice-free?

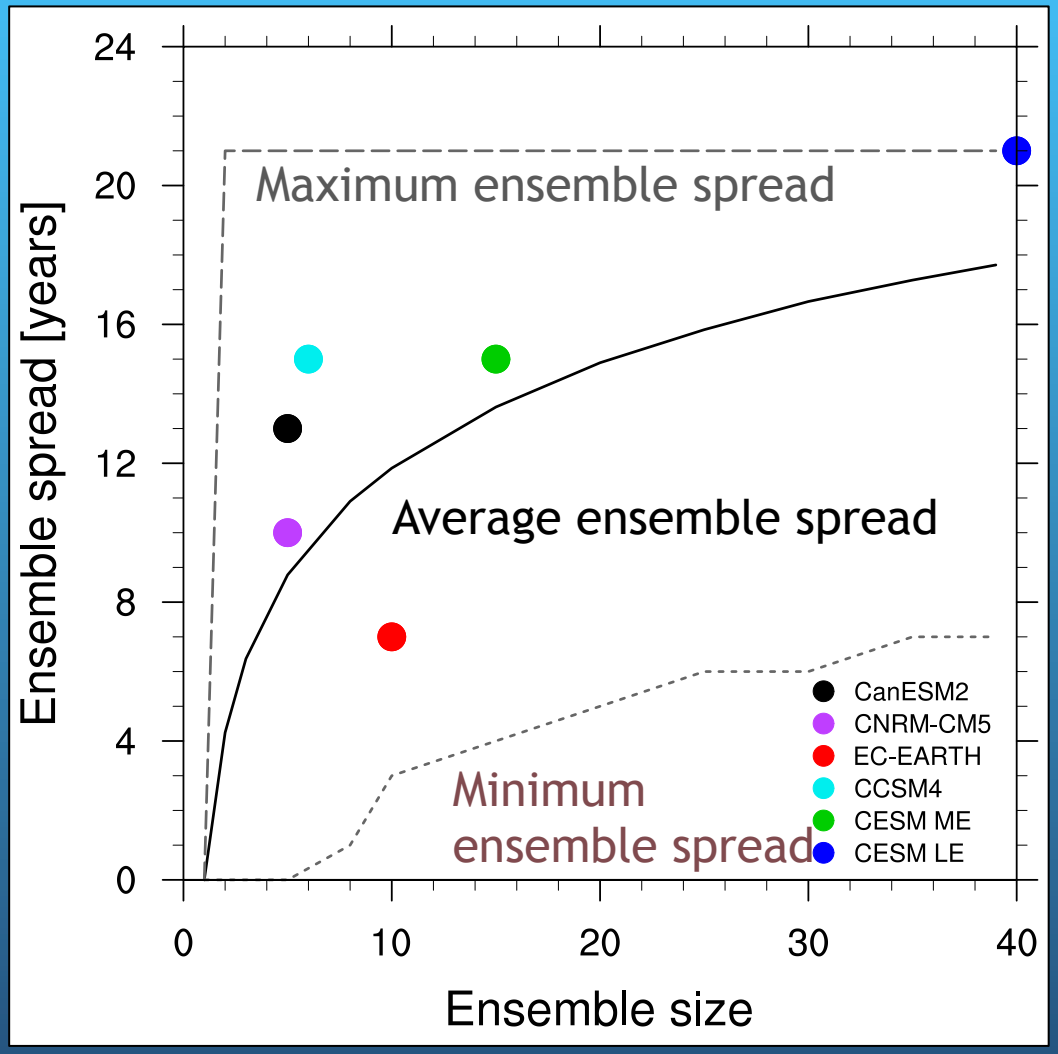
5 models contributed ensembles of size 5 or larger to CMIP5 archive



CMIP5 ensemble spreads for first reaching an ice-free Arctic range between 7-15 years, for ensembles of size 5-10

Jahn et al., 2016, GRL

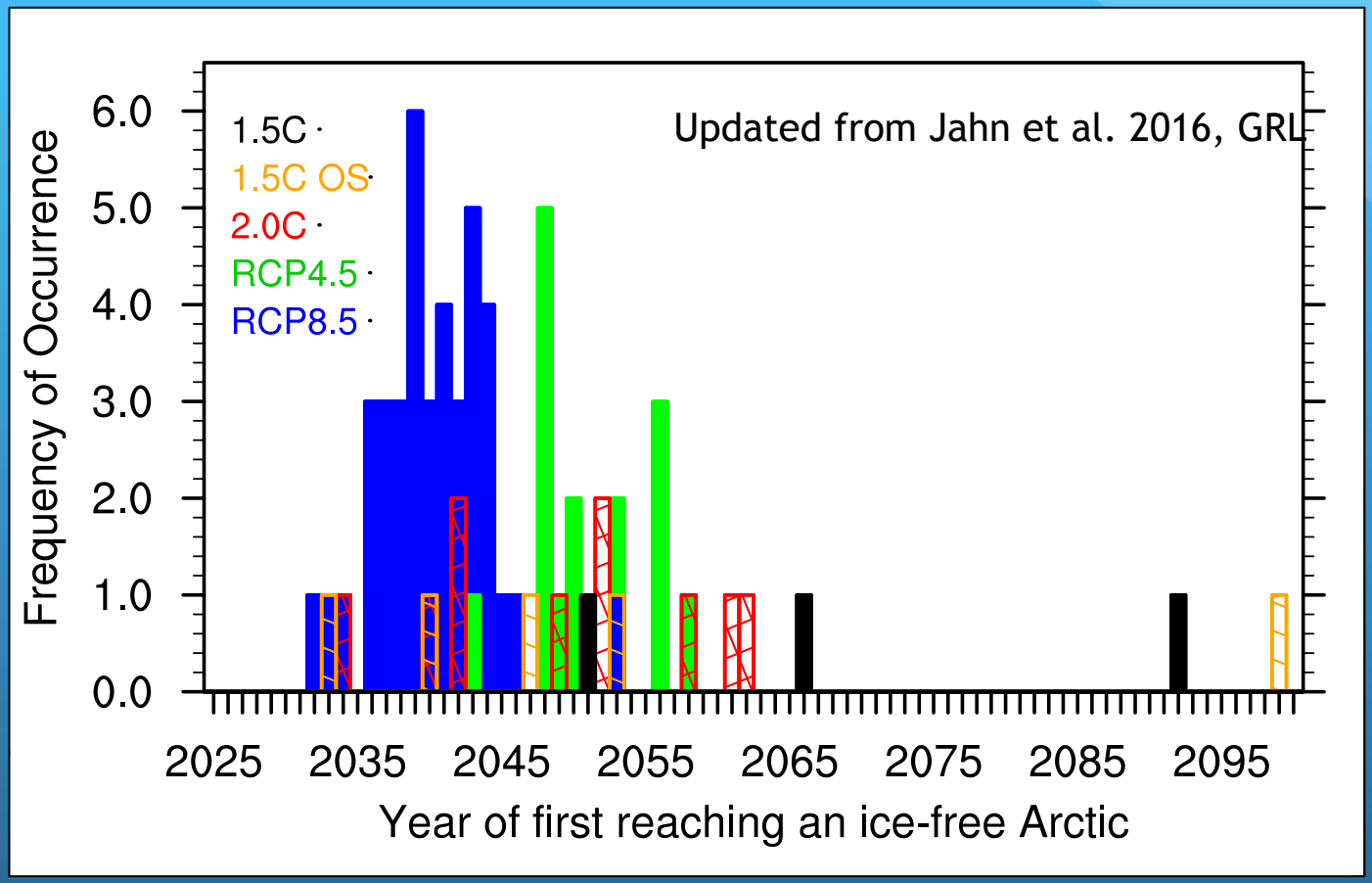
CESM compared to CMIP5 ensembles: CESM LE bootstrapped



CMIP5 ensemble spreads are consistent with statistical expectation from CESM LE for smaller ensemble sizes

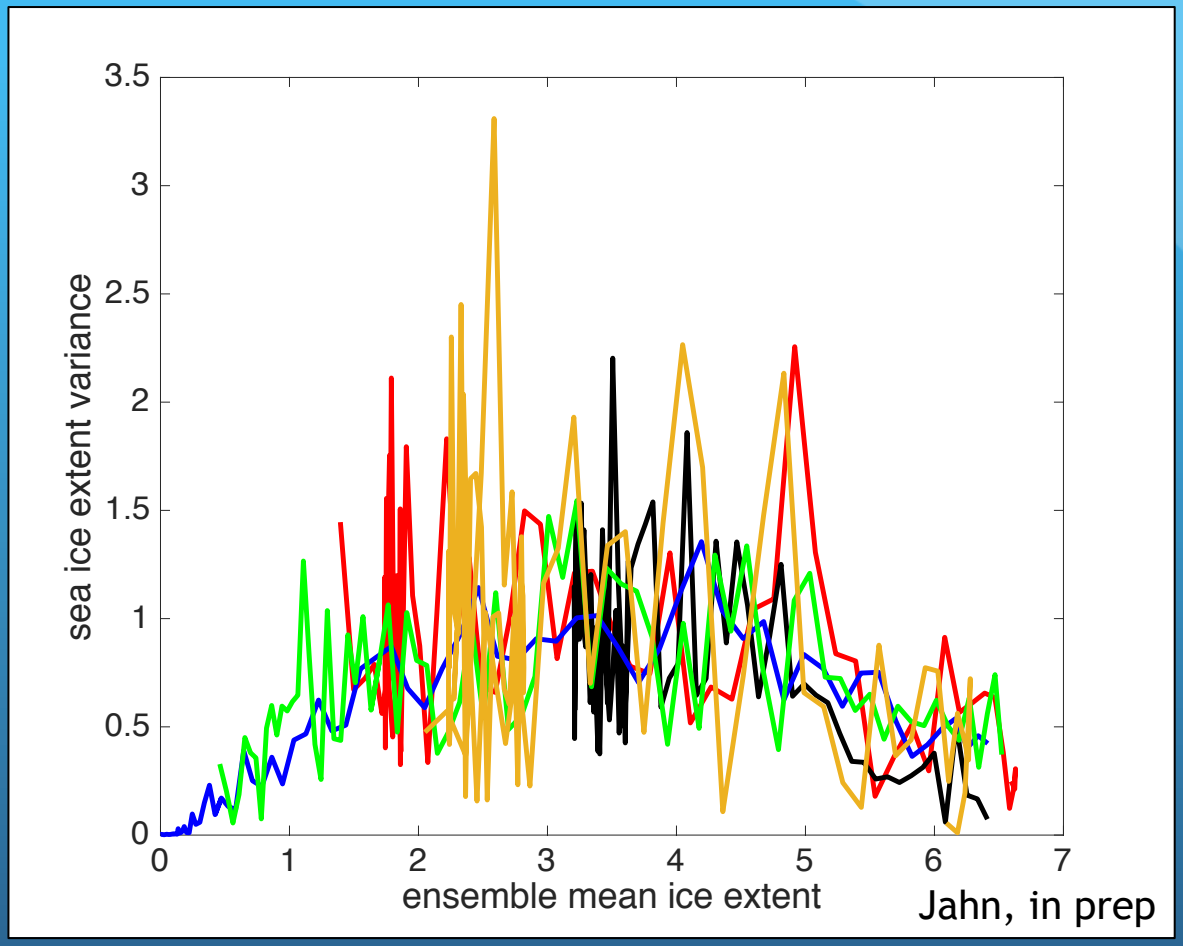
Jahn et al., 2016, GRL

When could the Arctic first be ice-free?



Based on CESM, first ice-free Arctic could occur by 2035 also under lower emission scenarios (1.5°C OS, 2.0° C) due to enhanced variance at intermediate sea ice extents, but overall uncertainty increases due to added scenario uncertainty

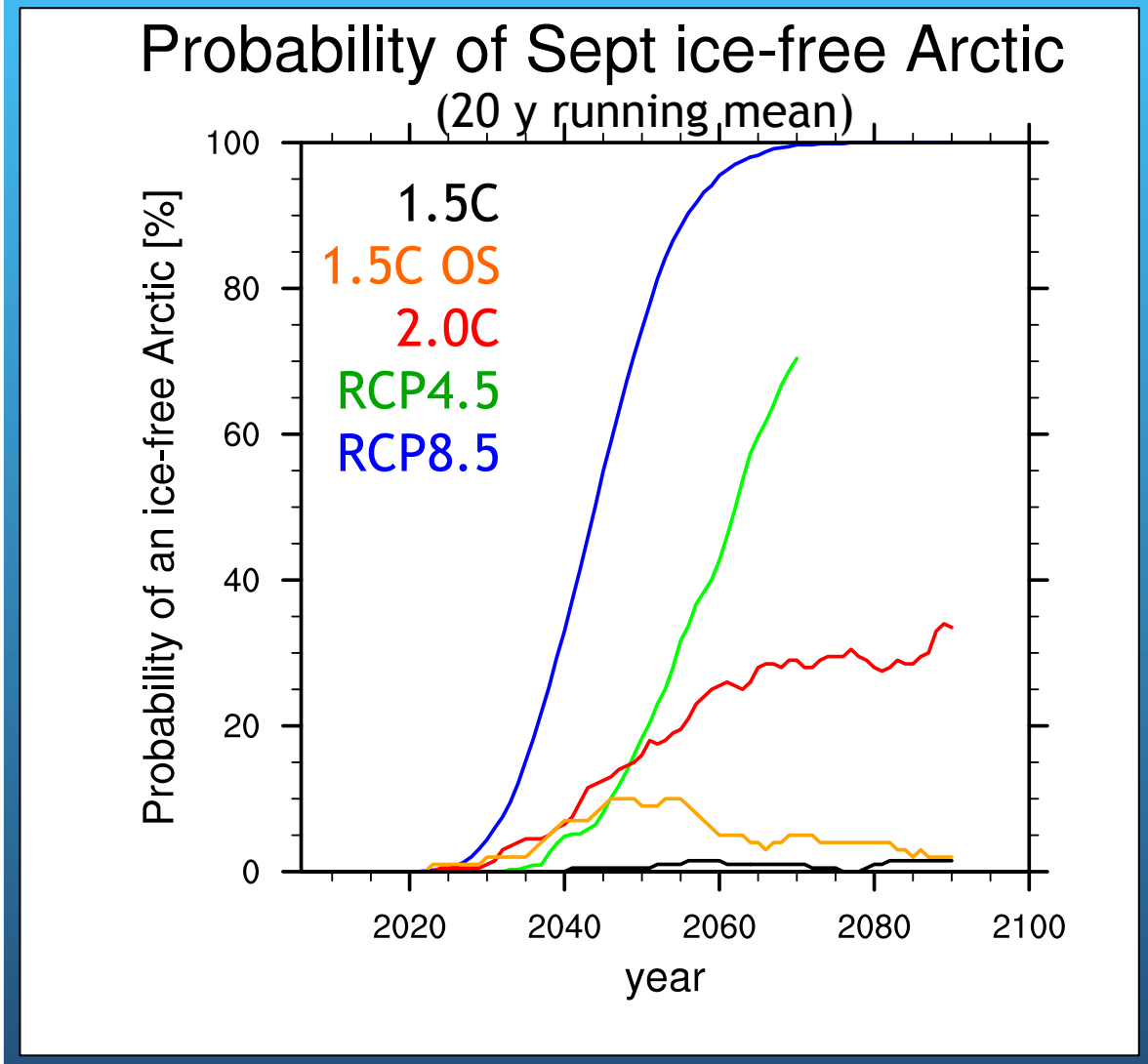
Changing Variance of Sept. sea ice extent



Internal variability changes with the changing sea ice cover:

Higher between 5-2 million km^2, lower for higher and smaller sea ice extent → has implications for predictability

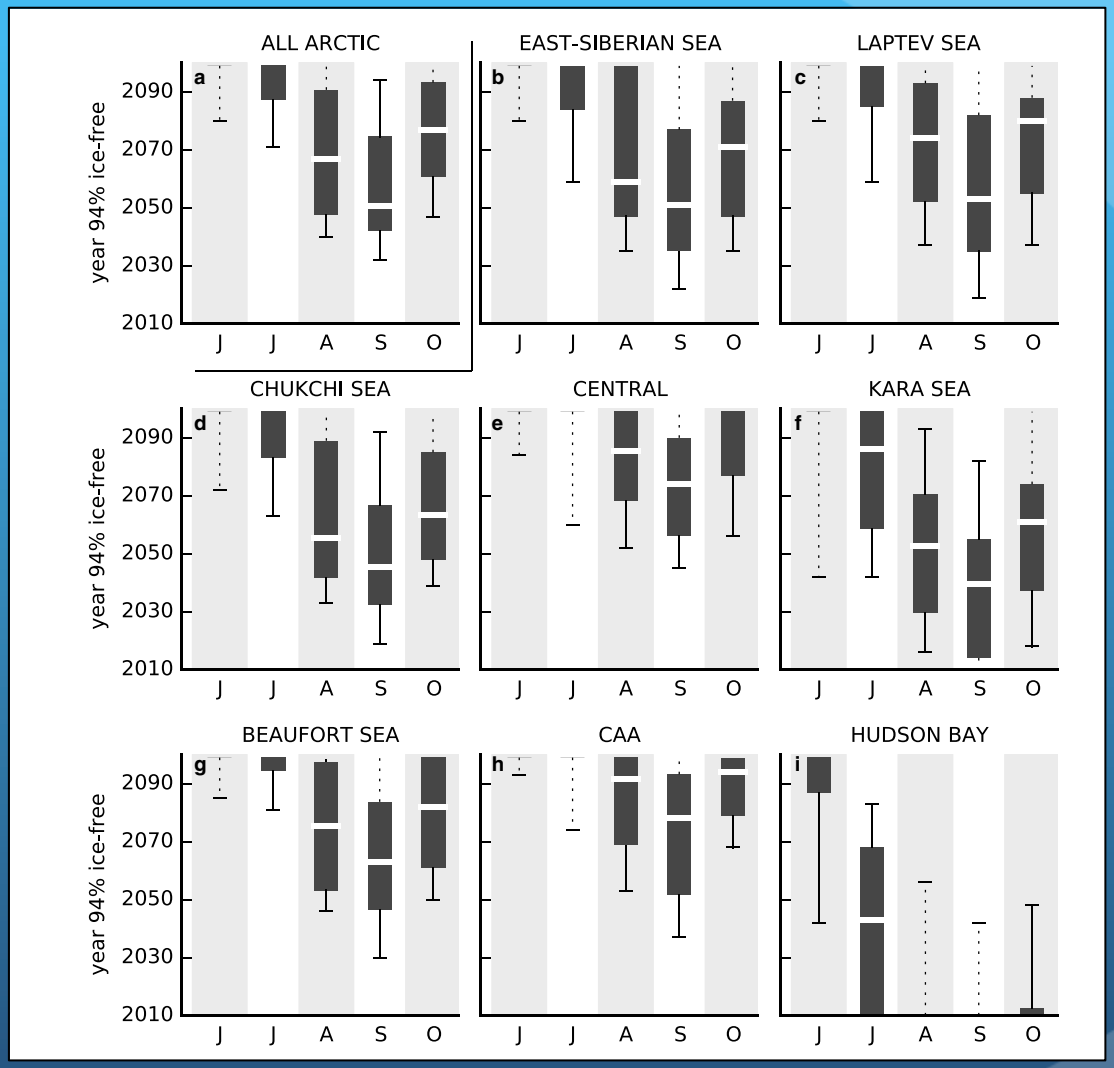
Different levels of probability of an ice-free Arctic in the later 21st century under different scenarios



An ice-free Arctic has a low probability for the 1.5C scenario (~1%), but it has a 100% probability for the RCP8.5, >70% for RCP4.5, ~35% for <2 degree warming

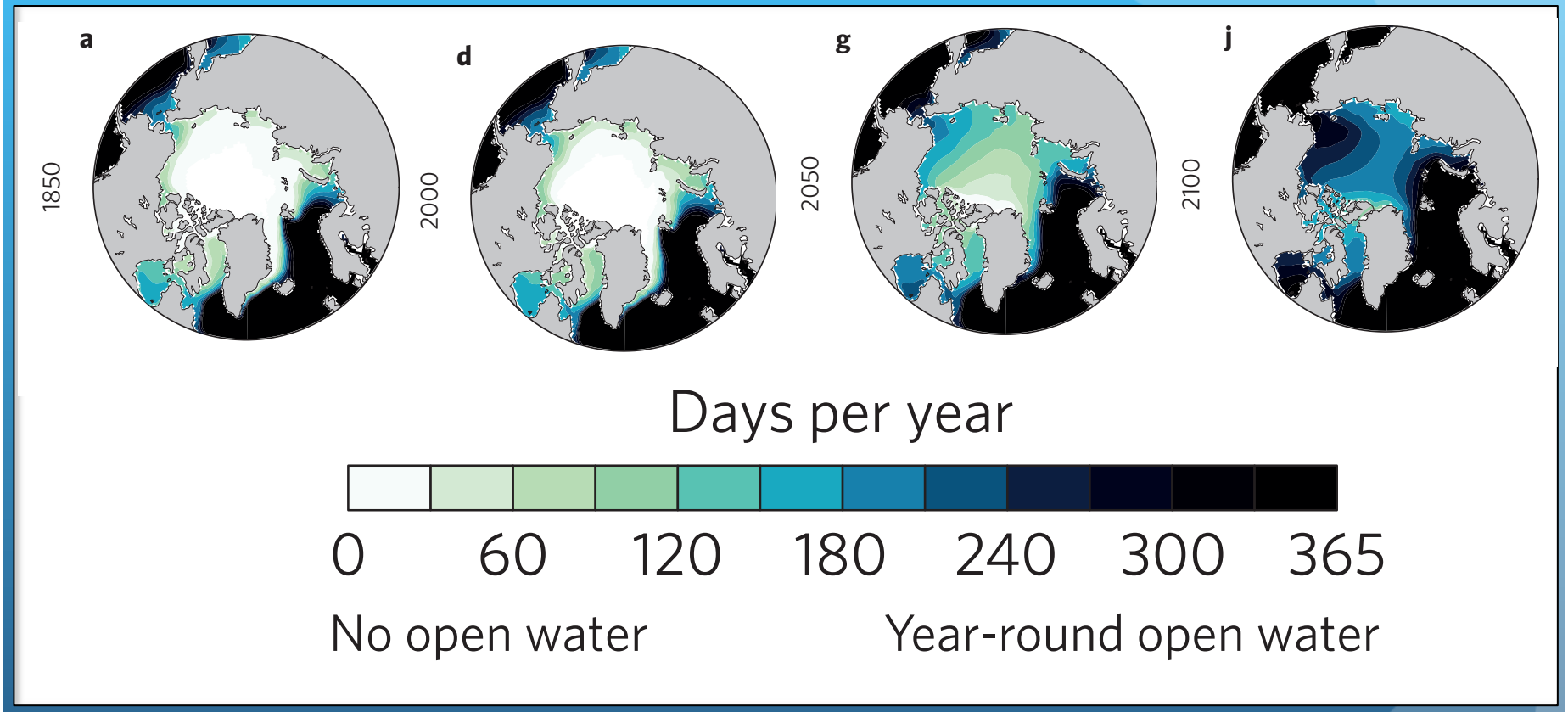
Adapted from Sanderson et al., 2017 (Earth System Dynamics)

Regional ice-free projections



Laliberté et al., 2016, GRL

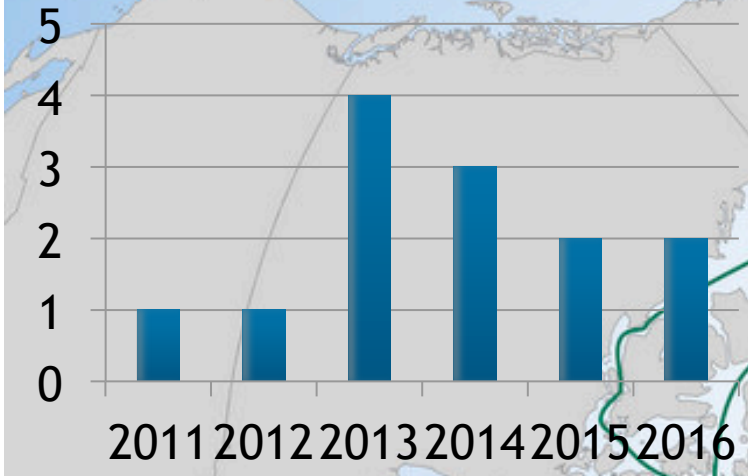
Projection of # of open water days (CESM LE)



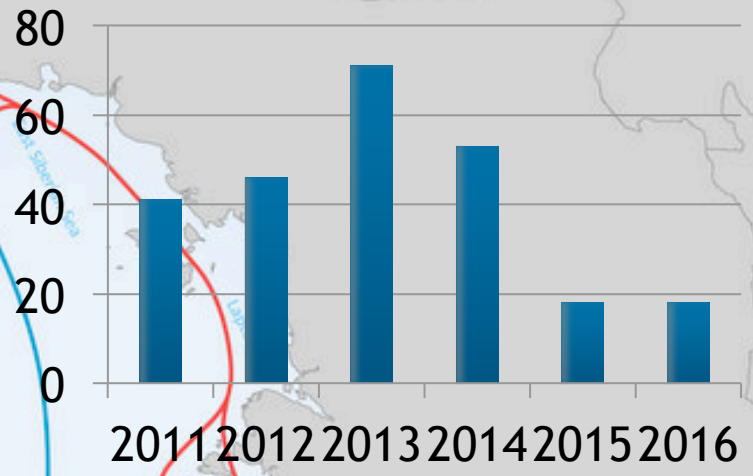
Barnhard et al., 2015

Number of cargo and commercial cruise ships through NWP

R. K. Headland and colleagues (2017)



Number of cargo ships through NSR http://www.arctic-lio.com/nsr_transits



Arctic Shipping Routes

- North-West Passage (NWP)
- Northern Sea Route (NSR)
- Transpolar Sea Route (TSR)
- Arctic Bridge Route (ABR)

Ships through Panama Canal: ~14,000 a year

The Arctic Institute | Center for Circumpolar Security Studies

Future shipping projections

Under RCP8.5 the TSR is open for up 4-8 months of the year

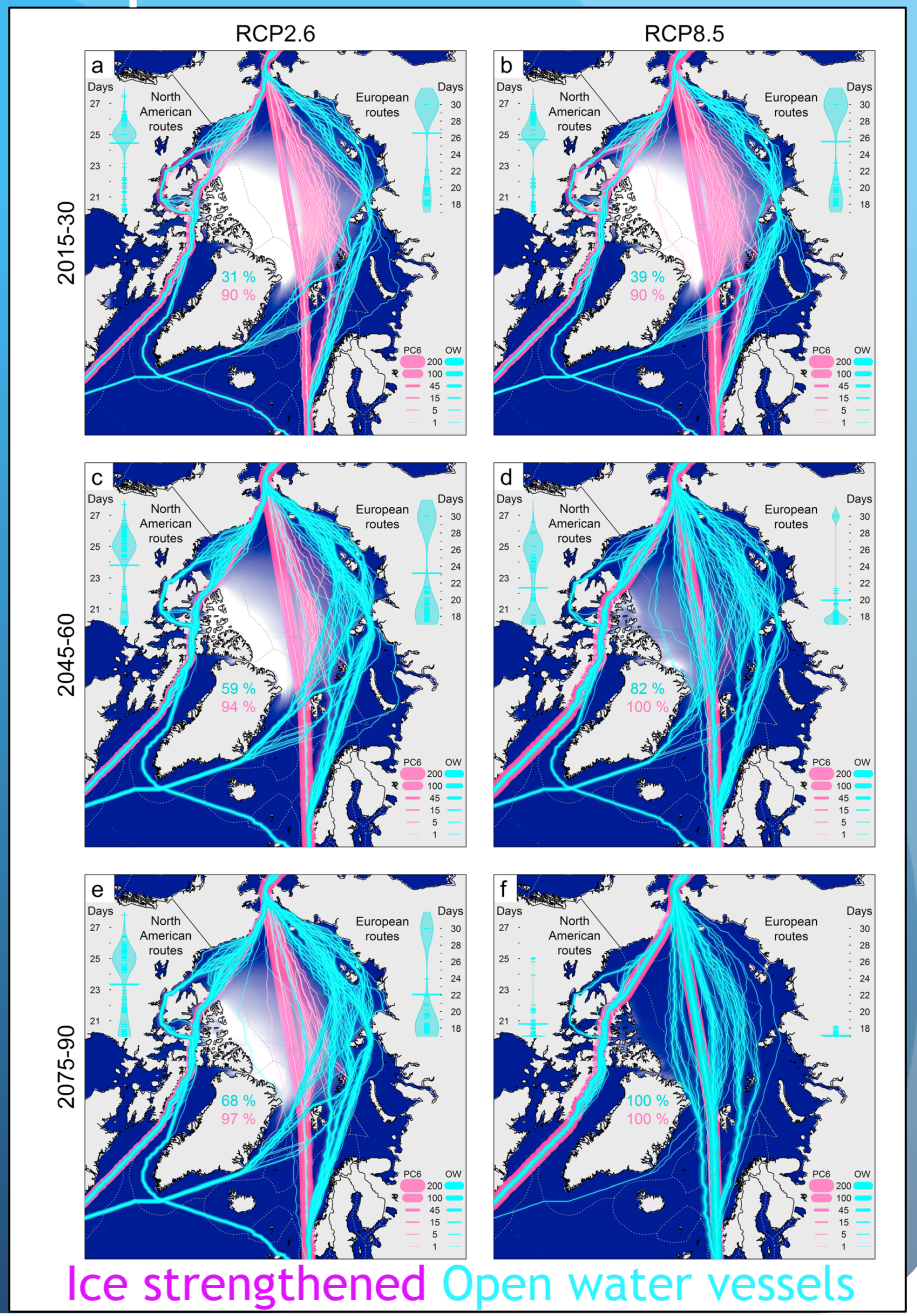
This can reduce average travel time to Asia from Europe with open water from 26 days to:

- 17 days by late century for RCP8.5
- (22 days by late century for RCP2.6)

For North America, reduction is from 25 days to 20-22 days for the NWP, but having to take the NSR or TSR can make it 24 days or more.

Melia et al, 2016, GRL

September trans-Arctic routes



Summary

- Arctic sea ice is projected to decrease over the 21st century – how much depends largely on future emissions
- In the next 1-2 decades, internal variability is more or as important and scenario differences for sea ice loss in a given year
- We can not predict the first year the Arctic will be ice-free with an uncertainty range of less than 20 years
- But the likelihood of an ice-free Arctic in the summer in the later half of the 21st century increases the larger the warming is, with frequent ice-free Arctic summers likely for a warming of 2 C, infrequent for a 1.5C warming, and guaranteed ice-free multi-month periods under RCP8.5 (4C warming)
- Open water days will increase, opening up the Arctic for increased shipping, with the TSR passable for open-water vessels in the second half of the century under RCP8.5, and threating polar bear survival