# Simulated Arctic sea ice and ocean change

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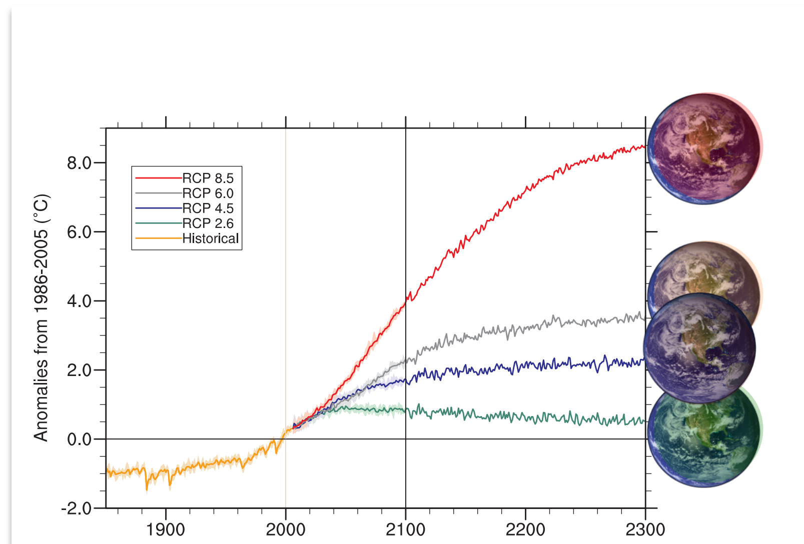
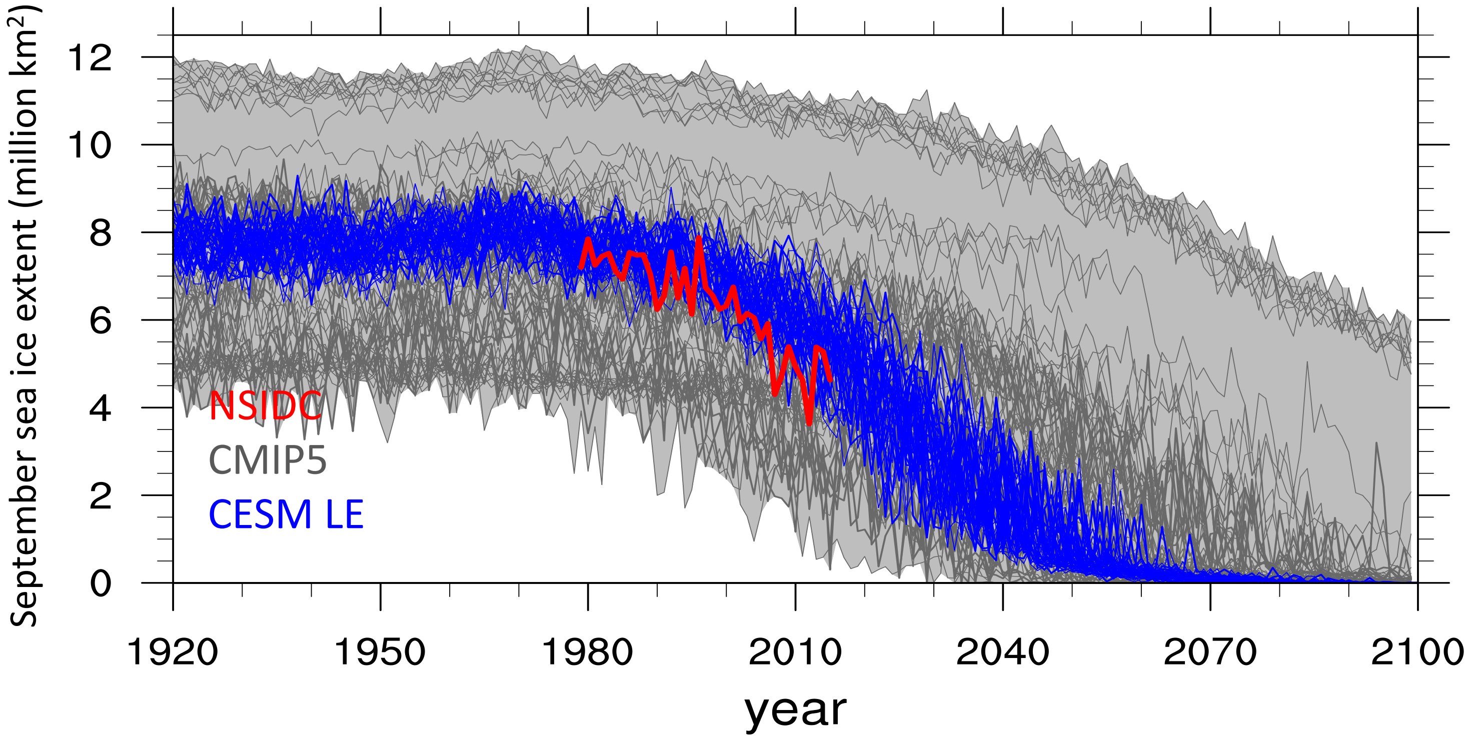
# Simulated Arctic sea ice and ocean changes

- Using results from free-running coupled global earth system models → Forced only by Greenhouse gas emission scenarios and solar forcing
- From CMIP5 (Climate Model Intercomparison Project) and CESM1.1 (Community Earth System Model) ensembles; also come figures from other recent large ensembles (CanESM, MPI)



# Simulated Arctic Sept sea ice extent changes




All CMIP5 models and CESM LE simulate a sea ice extent loss in September, in agreement with observations

But, there is a large spread between models
And no line matches the observations exactly
Why is that?

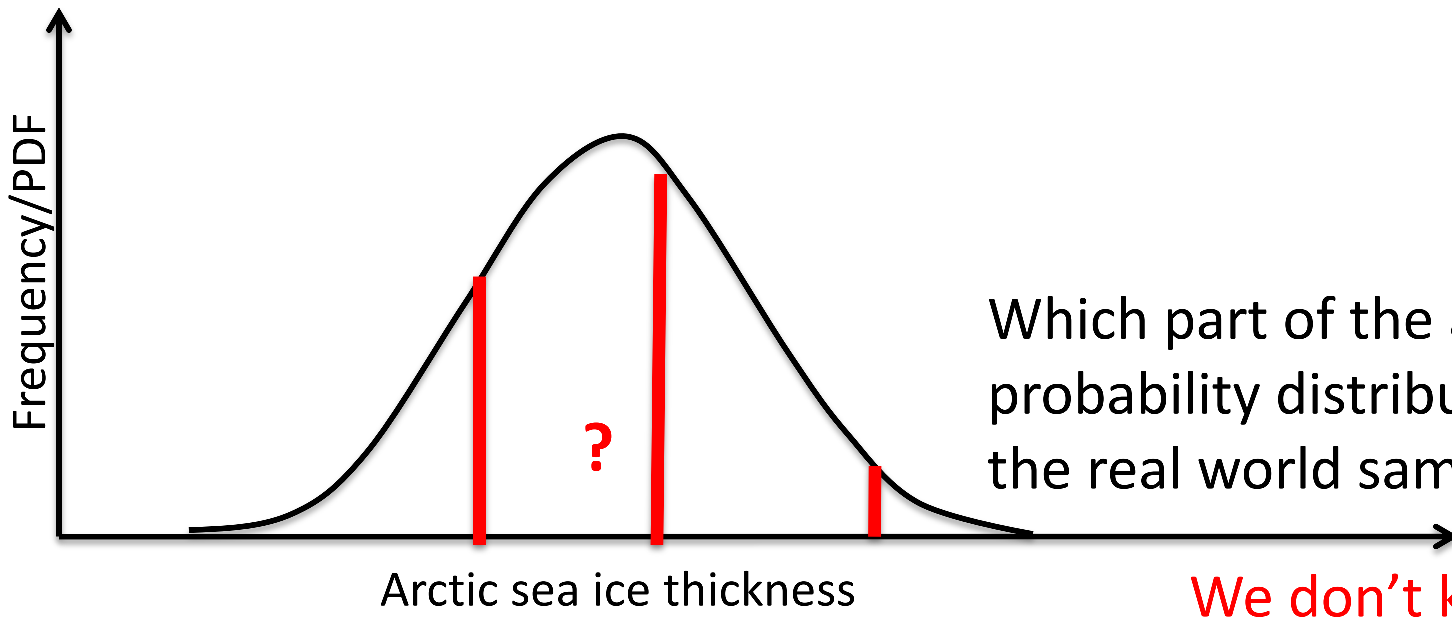
Model bias <u>and</u> Internal variability

# What is Internal variability?

Real world climate = one dice

Real world is just one possible realization

Climate in each ensemble member = one dice each



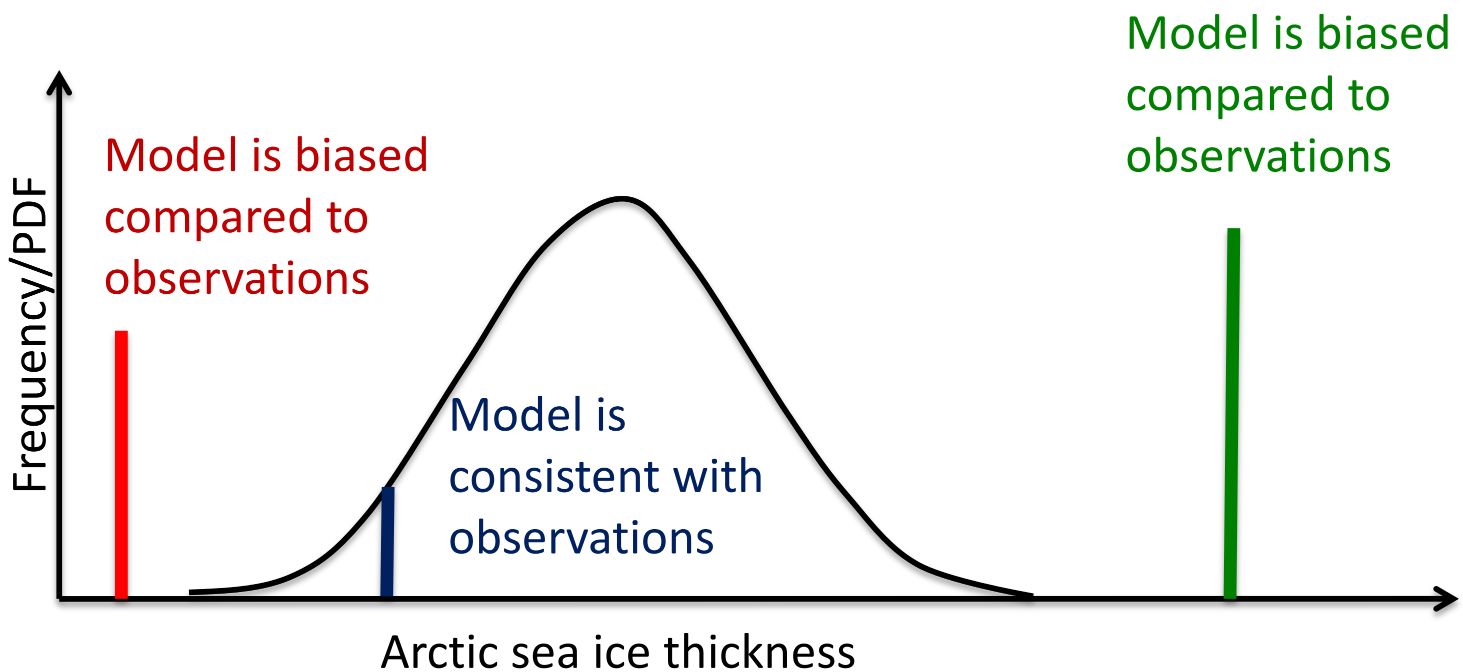

Which part of the actual probability distribution does the real world sample?

We don’t know

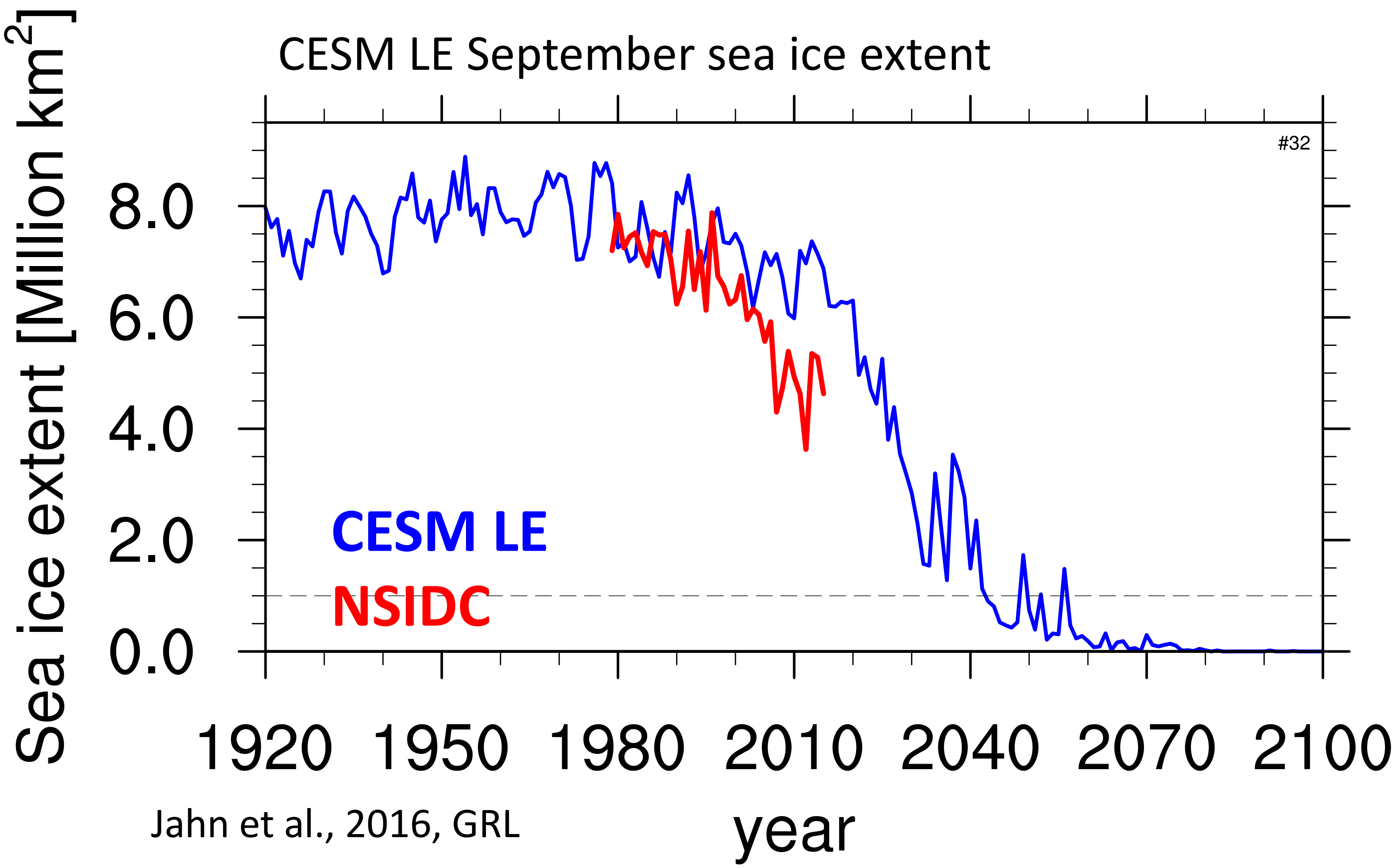
# What is a model bias?

The model does not correctly simulate the feature of interest → suggests something is wrong or missing in the model

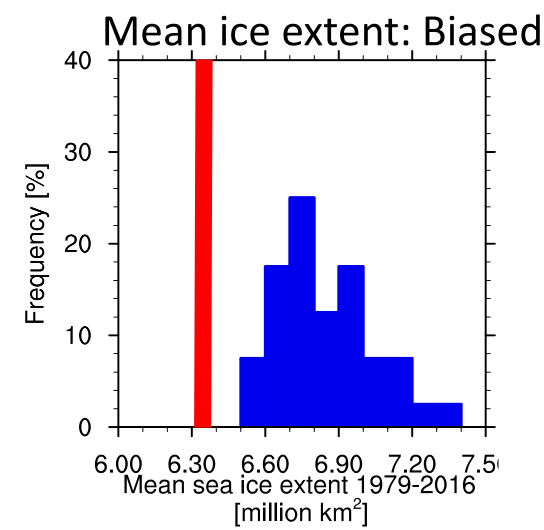
Internal variability makes detecting a bias difficult, as we need to compare with observations to detect a bias. But with ensembles, we can identify a bias.

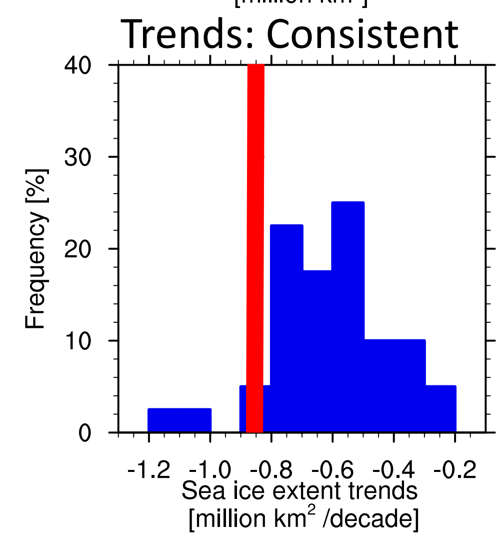


# Comparing one realization against many



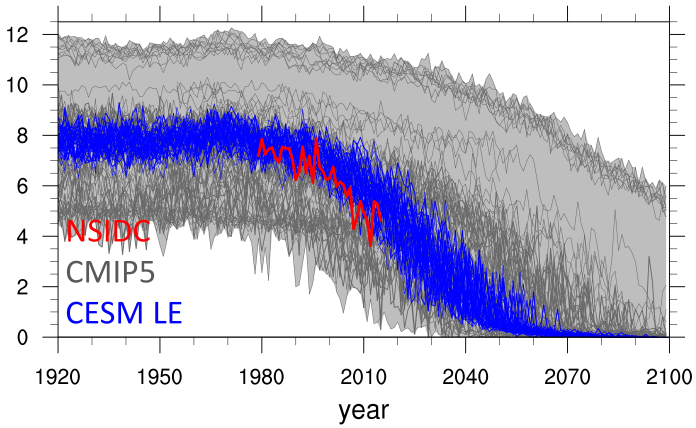

Jahn et al., 2016, GRL

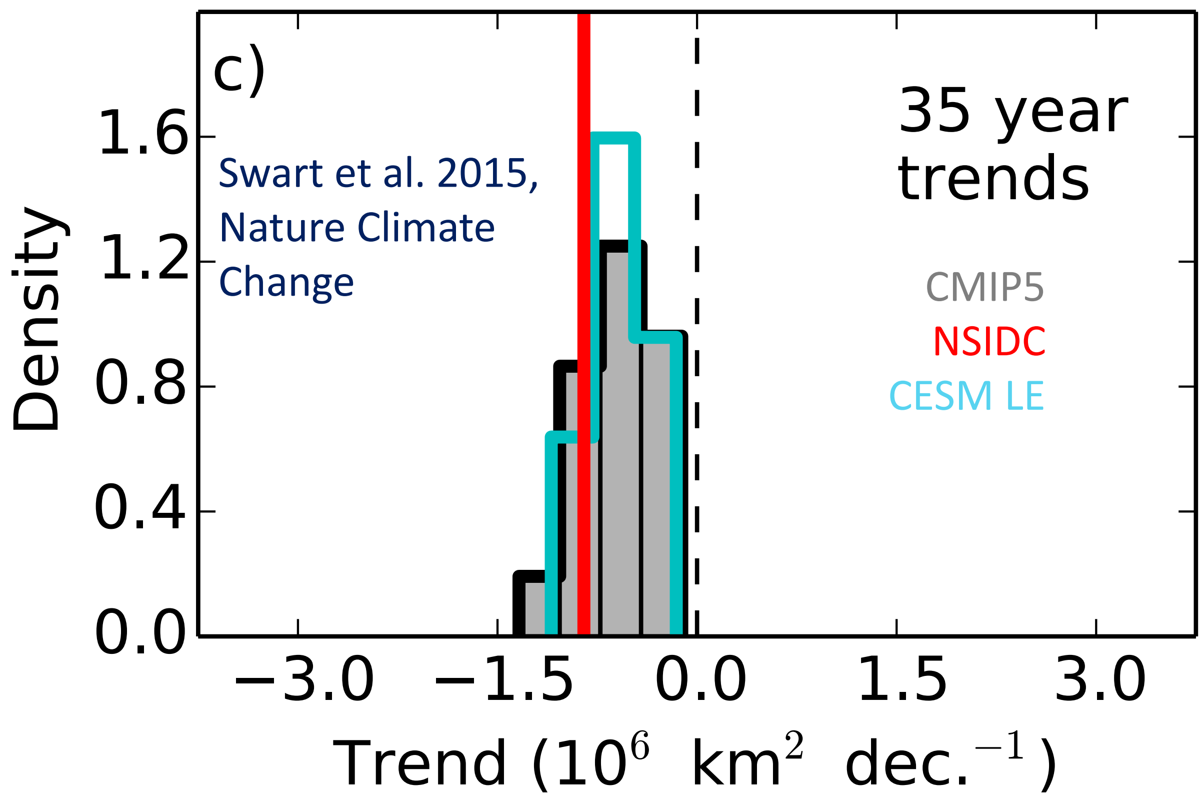



Are the observations within the model spread (i.e., consistent with observations) or outside the model spread (model bias)?

# Comparing one realization against many: CMIP5

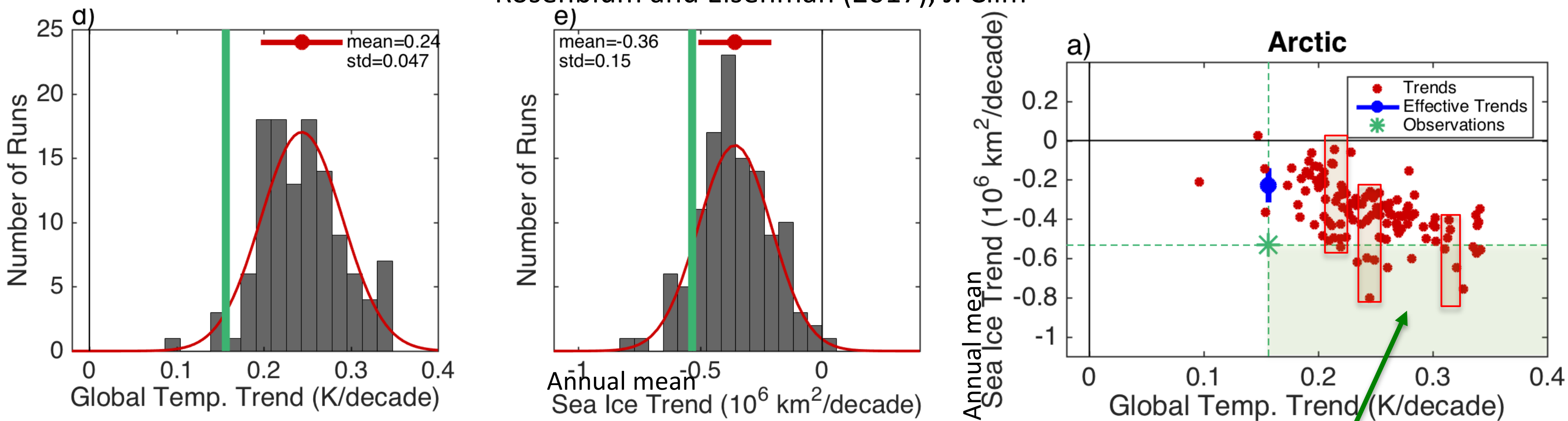


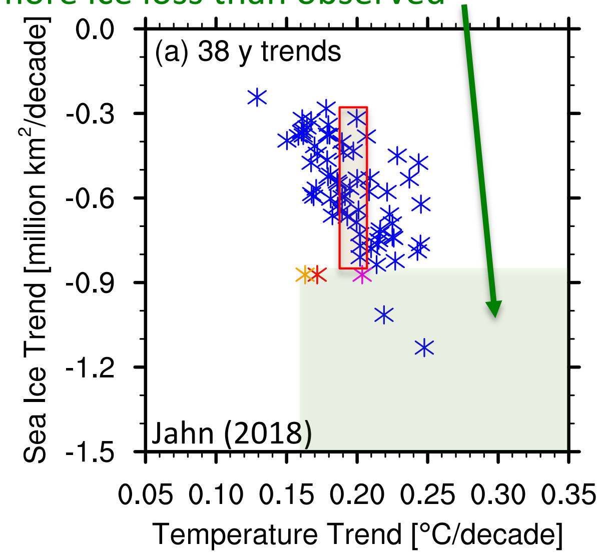

- **Observations are consistent with the CMIP5 35yr ensemble sea ice trends and the CESM LE trends**
- **Mean state in several models is biased**

# Finding signals in the noise

Rosenblum and Eisenman (2017), J. Clim



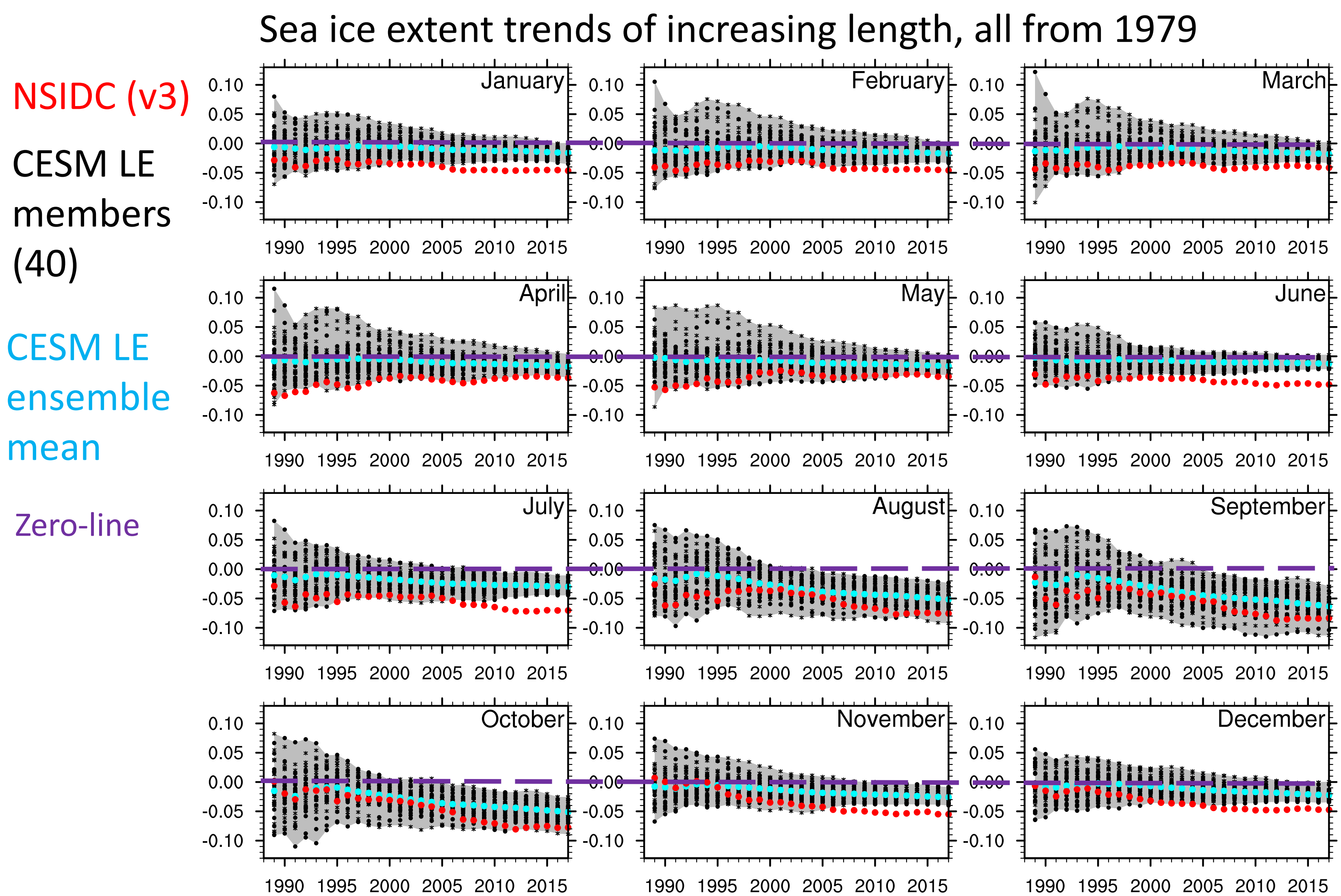

More warming than observed and more ice loss than observed




35 year CMIP5 sea ice trends (1979–2013) larger than observed only occur in CMIP5 model runs with larger than observed global warming trends
→ suggests that the sea ice sensitivity is too low in climate models

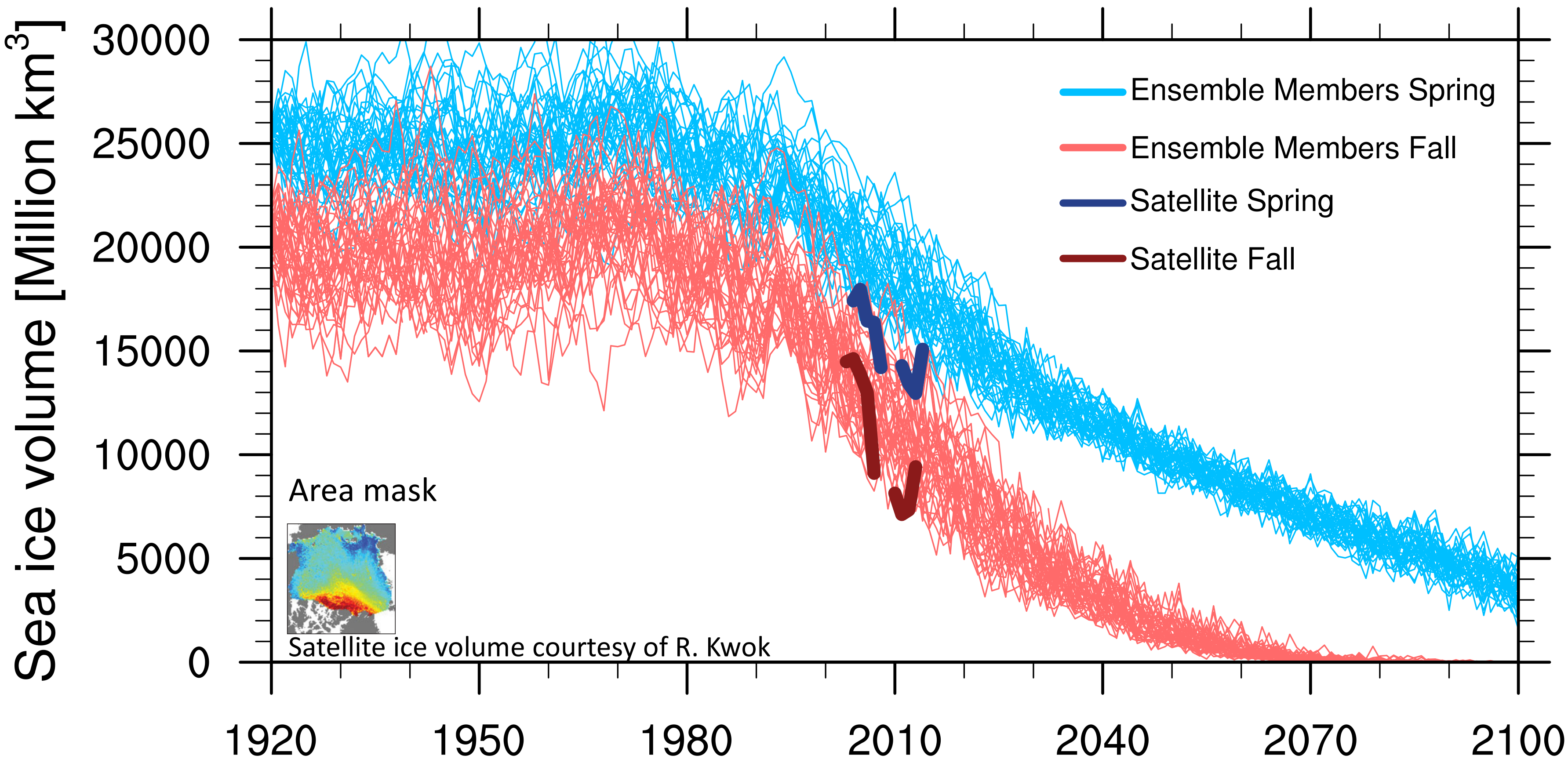
But: Both sea ice trends and global warming have a large imprint of internal variability as well → there are several possible sea ice trends for a given warming trend that occur in an ensemble, even for 38 yr trends

# Simulated Arctic sea ice trends: Sea ice extent is declining in all months, but largest decrease in summer and fall

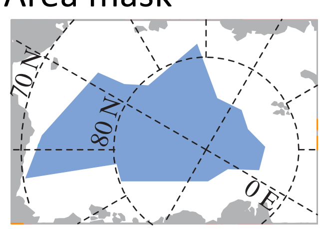



CESM LE trends have a low ice-loss bias in the winter and June and July

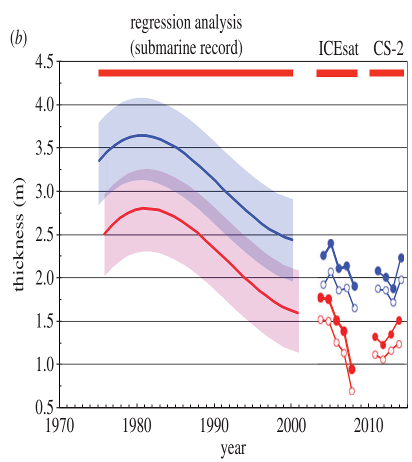
# Simulated Arctic sea ice change: Sea ice volume is also declining




Area mask




Kwok and Cunningham, 2015

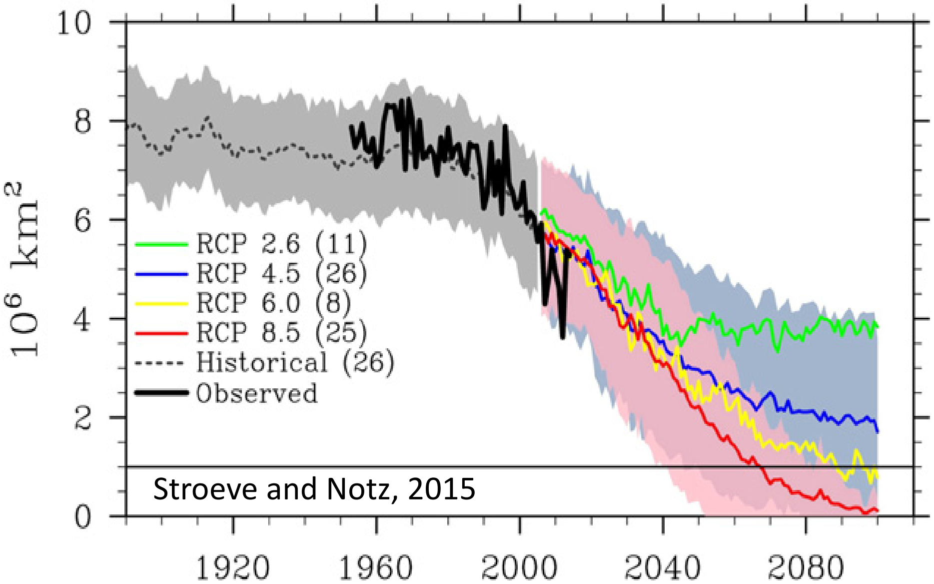



- Sea ice thickness started to decline already in 1980s, in agreement with submarine data
- The CESM LE winter/spring sea ice volume is too large compared to remote sensing data

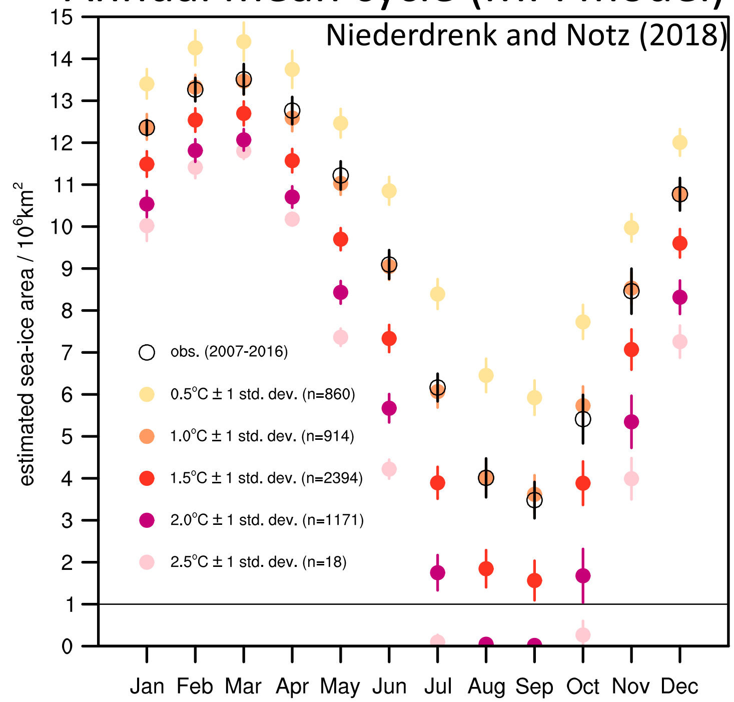
# What does the future hold for Arctic sea ice?

**More ice loss is to be expected, in all months. But how much depends on emission scenario**

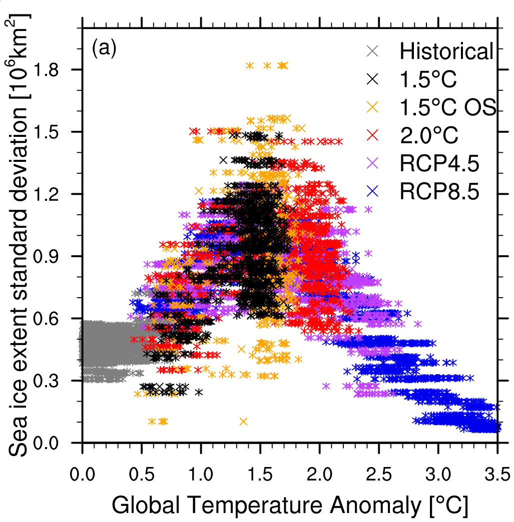
September ice loss (CMIP5 models)




Annual mean cycle (MPI model)




September sea ice extent standard deviation (CESM LE)

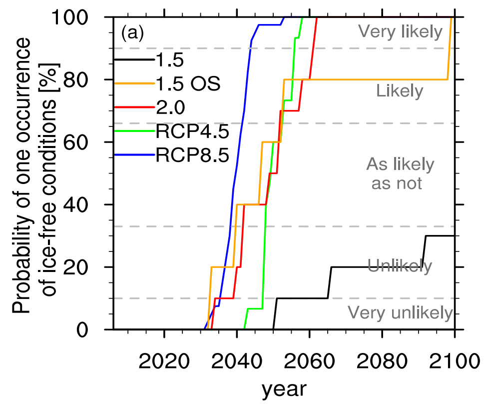



Year-to-year variability can be expected to increase, based on models

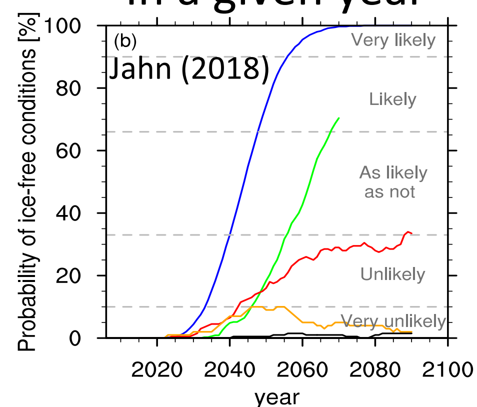
# Will we seen an Ice-free Arctic Ocean?

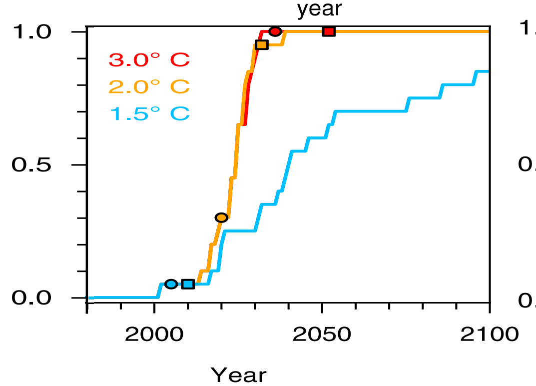
## Probabilities of Sept. ice-free conditions

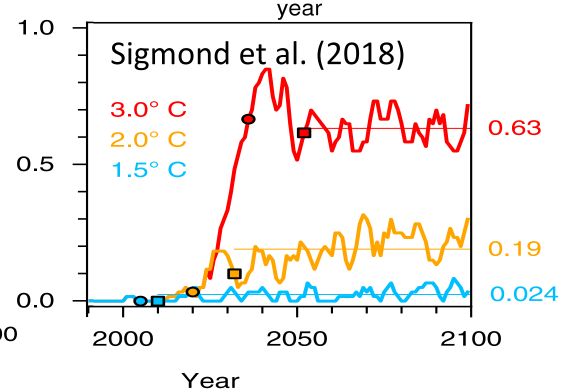
One occurrence



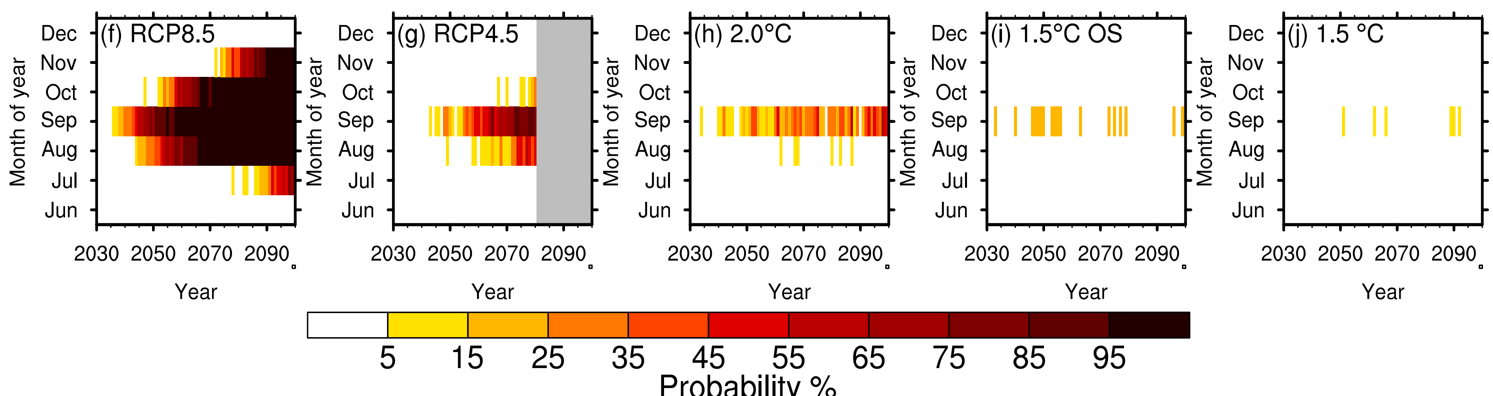

In a given year



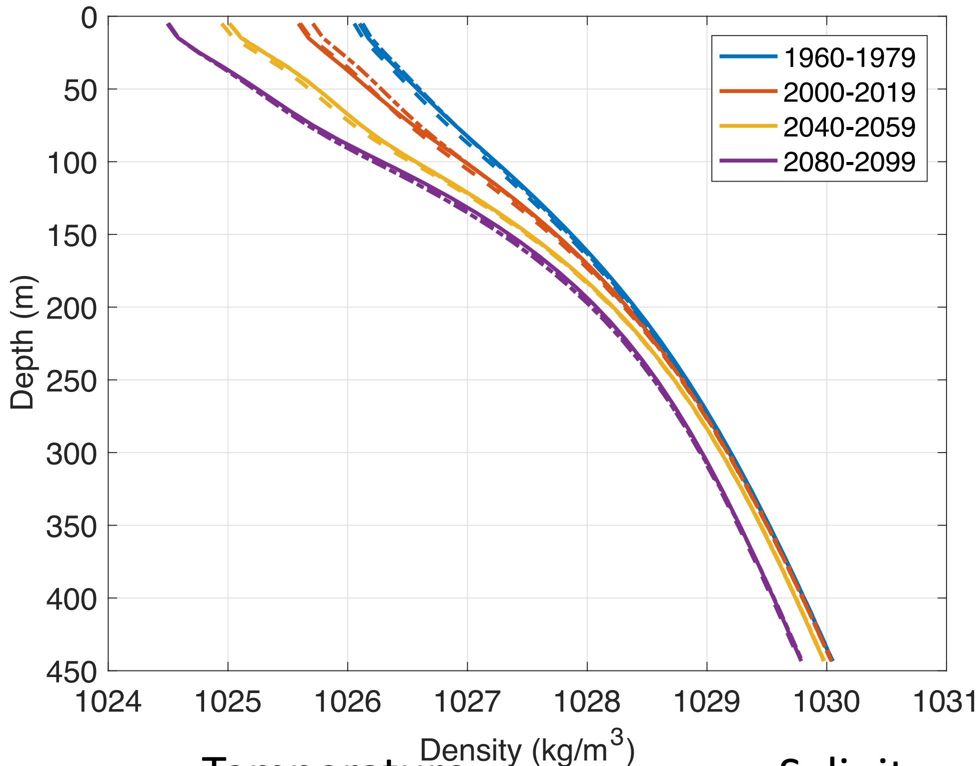



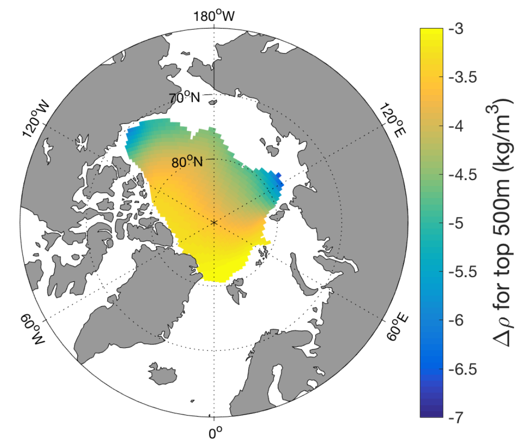

## Probabilities of ice-free conditions in a given year



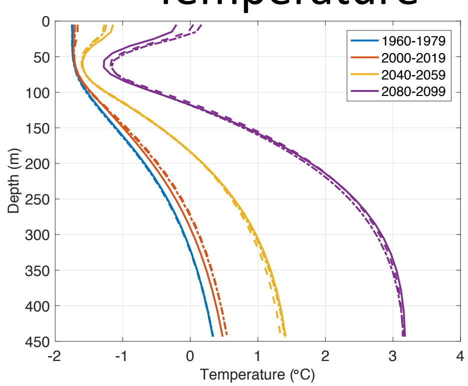

Jahn (2018)

# Density profile over the central Arctic (ocean depth > 500 m, from CESM LE)

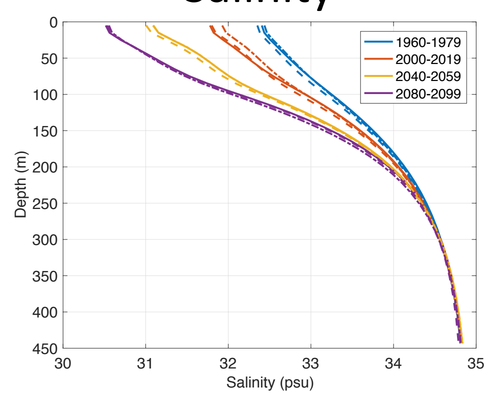



Temperature




Salinity

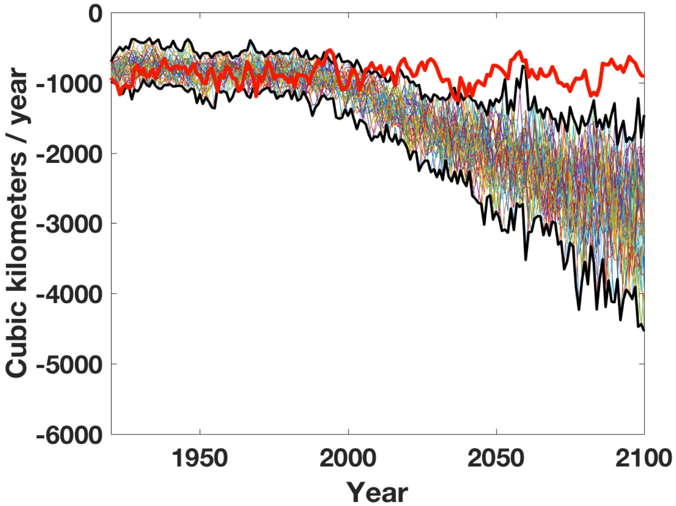



- Surface ocean is getting less dense.
- Late 20th century density change is driven by salinity
- 21st century change is from freshening and warming, with warming impact getting more and more important as ice is lost

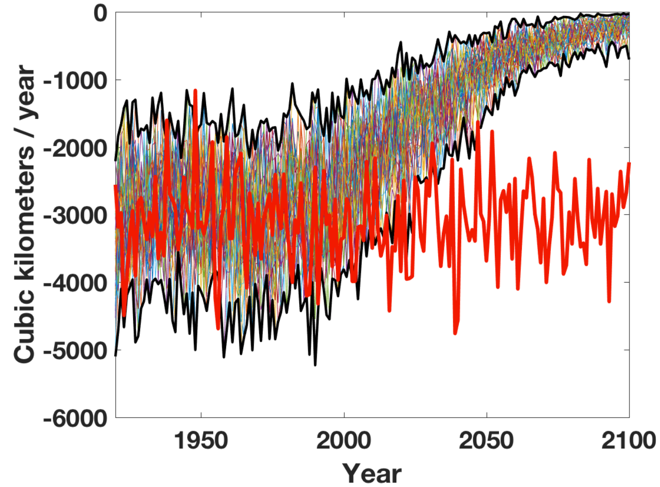
Courtesy of Patricia DeRepentigny, CU Boulder

# Arctic Freshwater export (based on CESM LE)

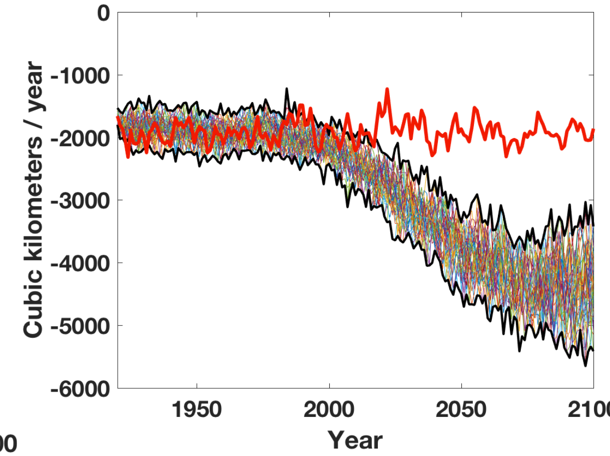
Fram liquid



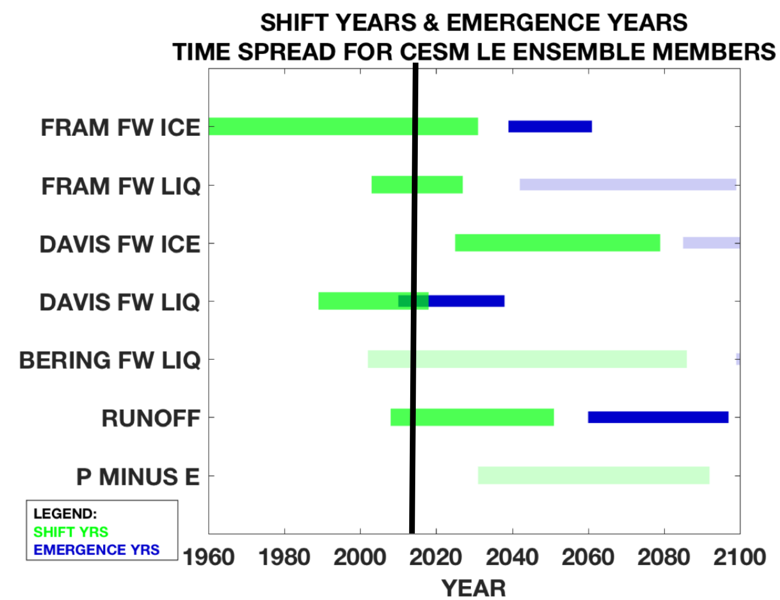

Fram solid




Davis Strait liquid



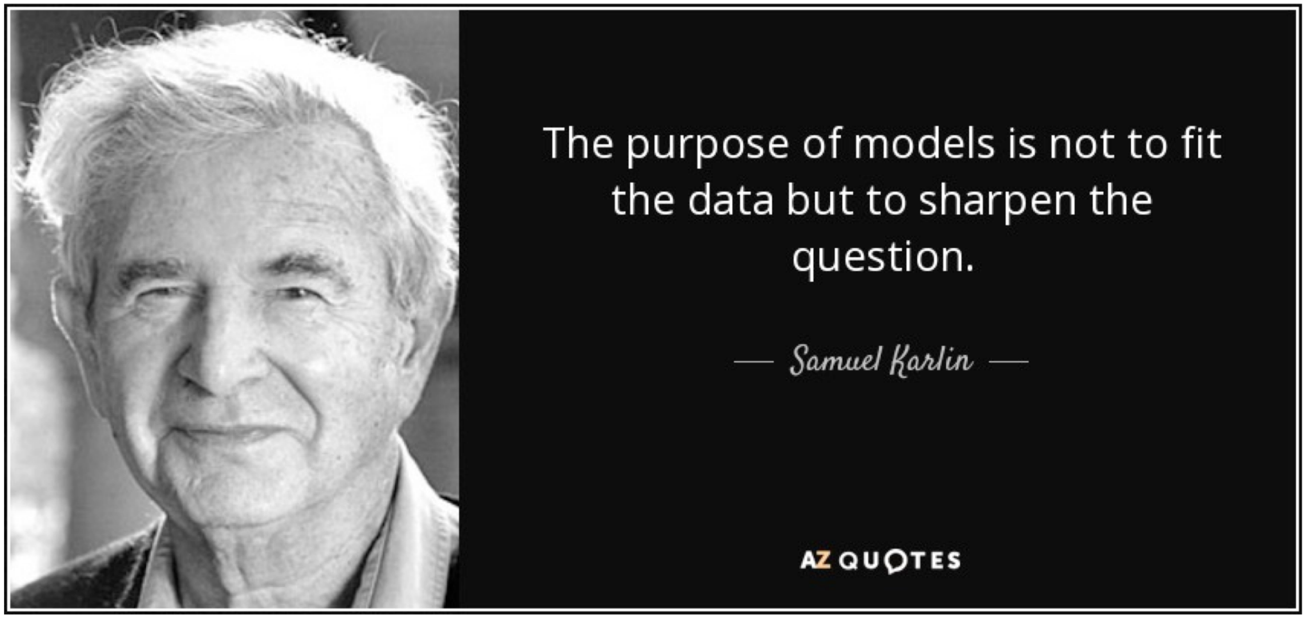

- A detectable shift of these FW exports compared to pre-industrial internal variability does not occur in all members before ~2030
- A clear emergence from the background state into a new regime does not occur until the end of the 21$^{st}$ century in all members.
- For observations, this means just because we haven't seen a shift (e.g., Davis Strait liquid) it wont be changing in the (near) future




Courtesy of Rory Laiho, CU Boulder

Laiho and Jahn, in preparation

# Final thoughts




- Model simulations help us place observations into a longer term context
- Model biases tells us something about processes and relationships we do not (yet) understand/know (well enough)
- Model simulations tell us something about the possible future evolution of climate we can not otherwise predict, due to the nonlinear climate system