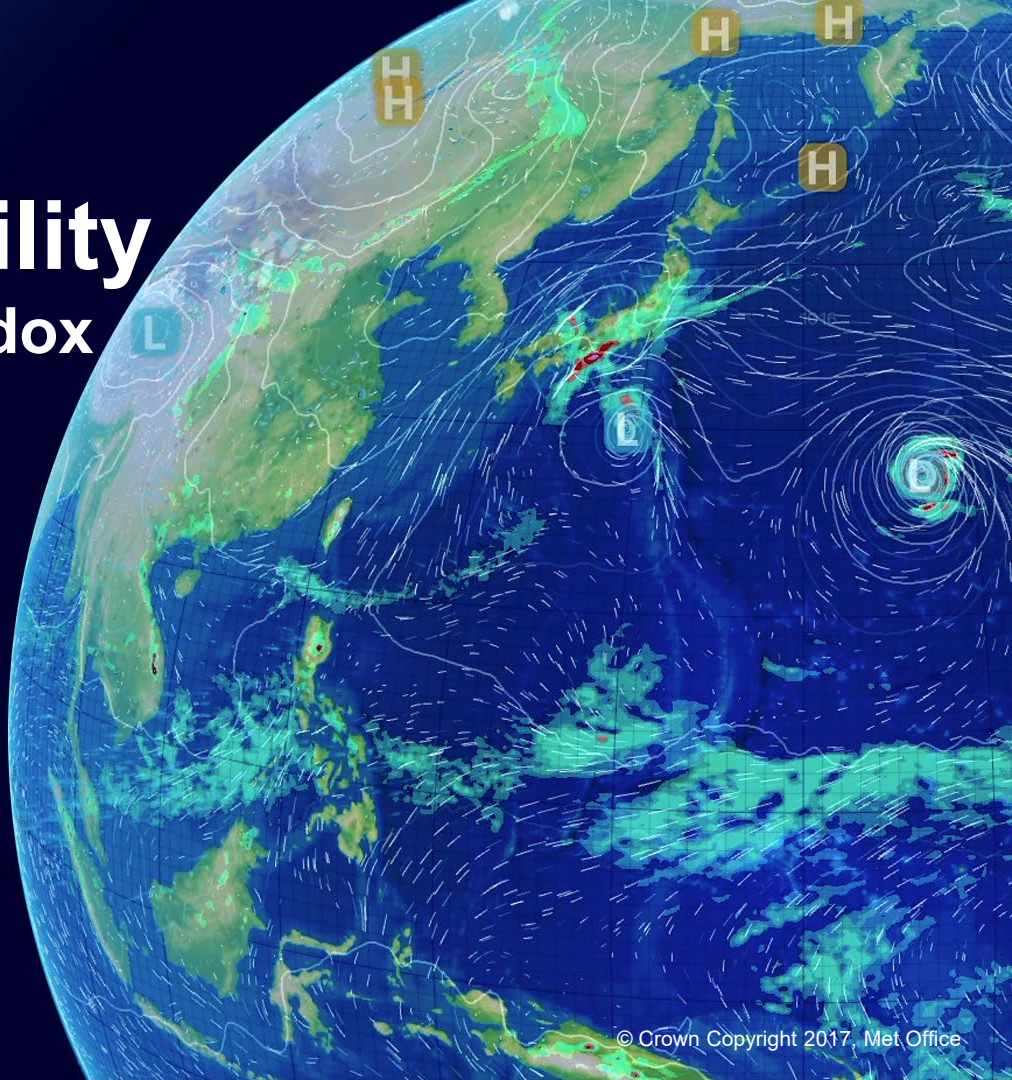
Met Office
Hadley Centre

Limits of predictability

and the signal-to-noise paradox



Leon Hermanson, Doug Smith

What are the limits of predictability?

- How far ahead we have predictability
- The spatial resolution of our predictability
- Initialisation errors and drifts
- Model biases, e.g. teleconnections
- Climate response to external forcings
- Finite ensemble size
- Ability to estimate prediction skill

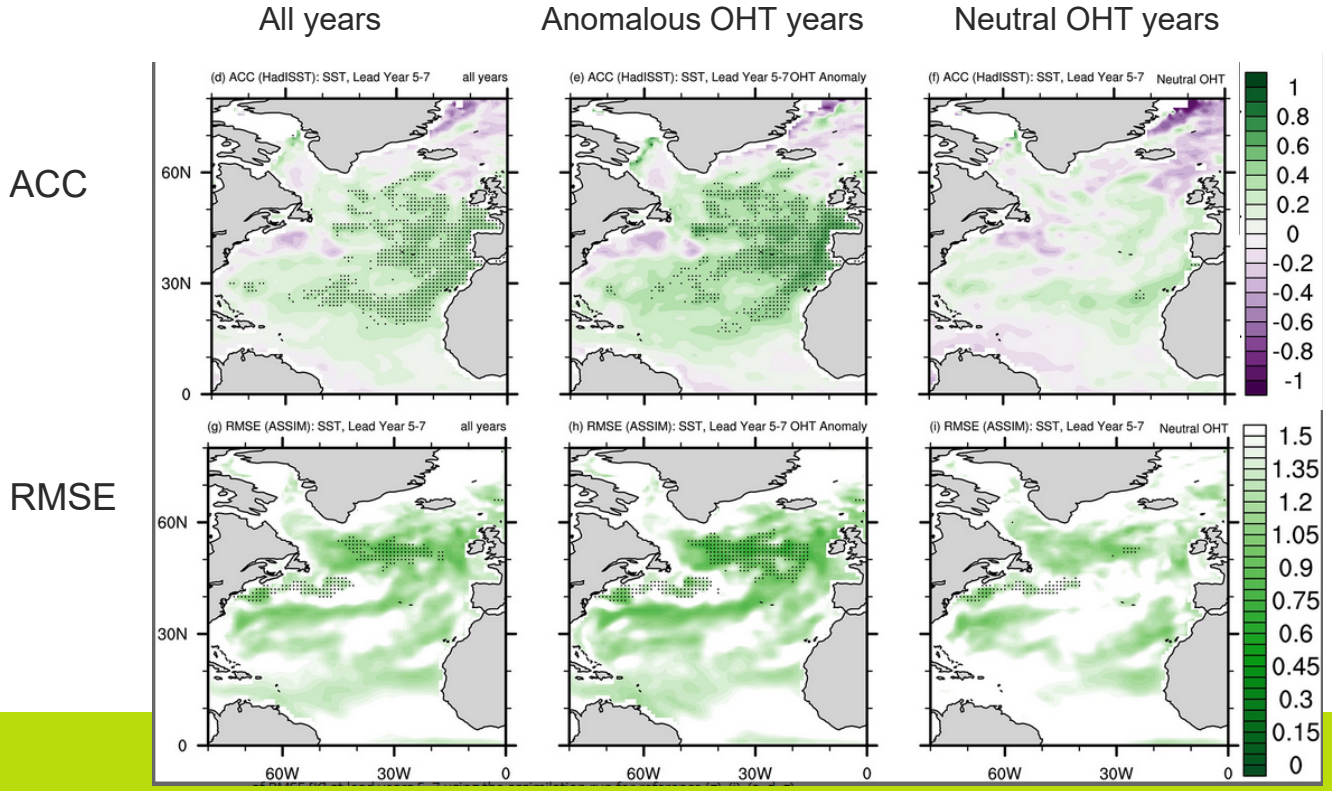
What limits does predictability have?

- How far ahead we have predictability
- The spatial resolution of our predictability
- Initialisation errors and drifts
- Model biases
- Climate response to external forcings
- Finite ensemble size
- Ability to estimate prediction skill

Related to the signal-to-noise paradox

Limits on predictability lead time is complicated by "windows of opportunity"

ACC & RMSE skill maps for SST at lead 5-7 years

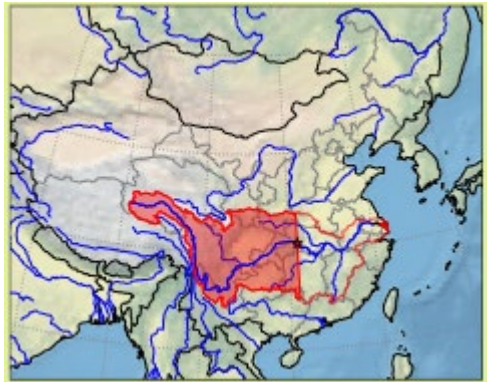


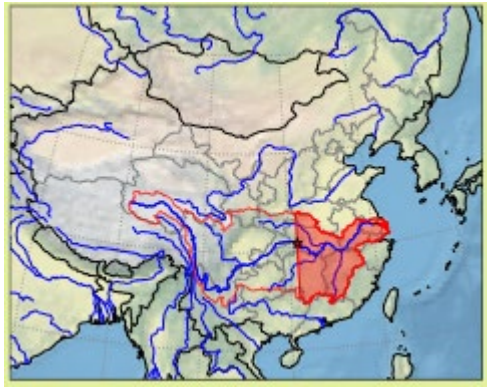
"hindcast skill estimates should be broken down into physical states to harvest their full potential"

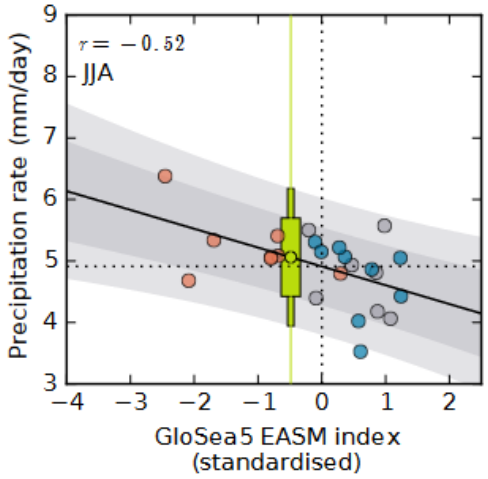
Borchert et al (2021, GRL)

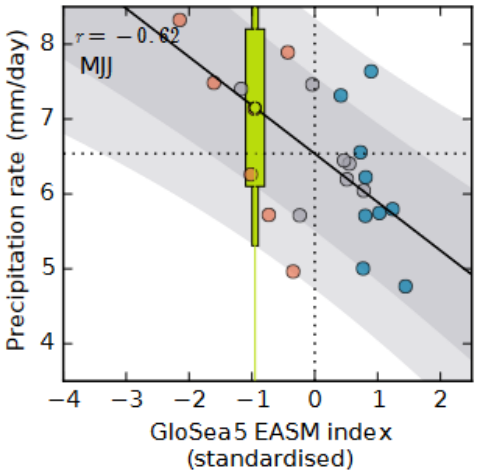
Want predictability at high spatial resolution? Link it to a climate index

- Met Office seasonal forecasts for Upper and Lower reaches of the Yangtze river
- Regression of the East Asian Summer Monsoon (EASM) index in the model to precipitation in the observations
- Copernicus projects for climate services based on decadal predictions are now using this method (See Nick's talk on Wednesday)



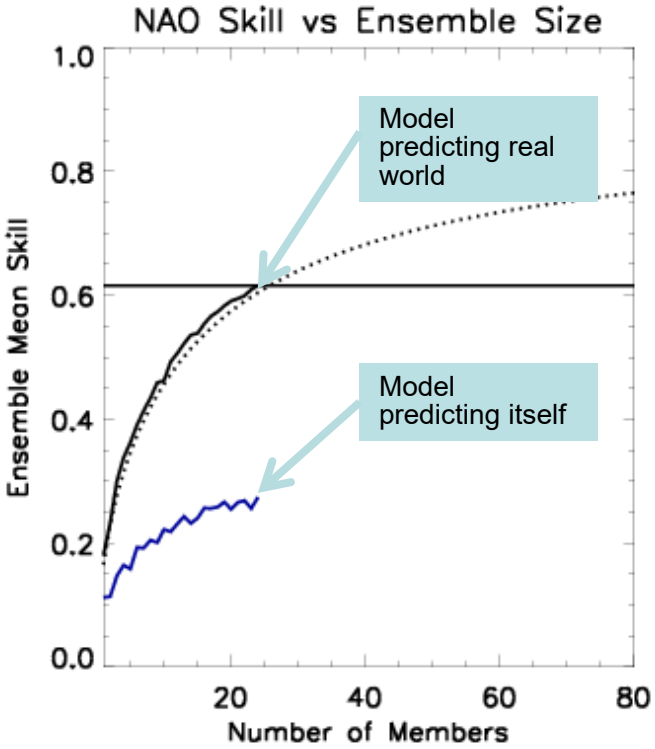






Bett et al (2020, JMR)

What is the signal-to-noise paradox?



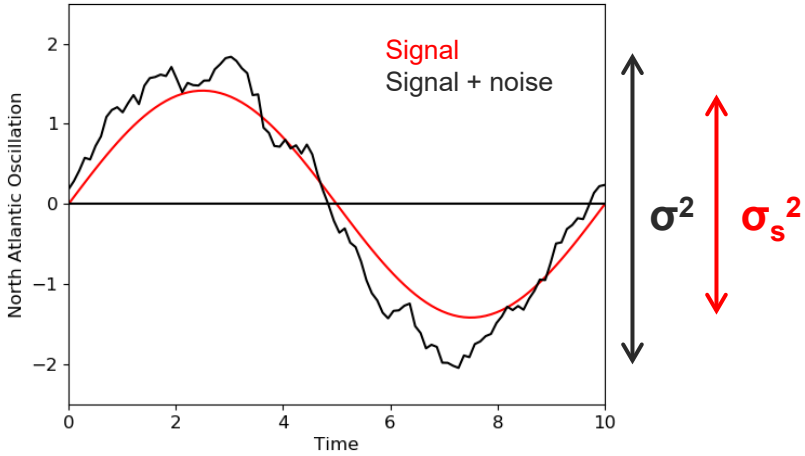
- Many studies have used the ability of a model to predict its own control as the upper limit of predictability
  - They represent themselves perfectly!
- Paradox: models predict the real world better than themselves
- Members are NOT alternate realisations of observations
- Need a very large ensemble to extract the predictable signal
- Measured by the ratio of predictable components (RPC)

Eade et al 2014, Scaife et al 2014, Dunstone et al 2016, 2018, Siegert et al 2016, Baker et al 2018, Scaife and Smith 2018

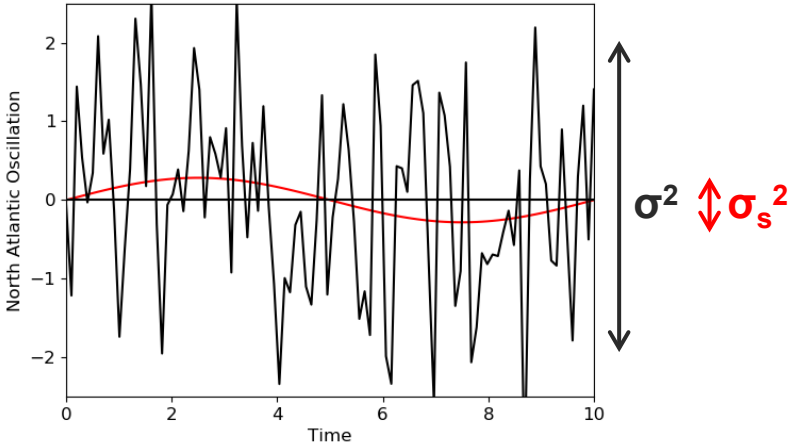
Scaife et al, ASL, 2016

A simple interpretation

Observations



Climate models



Climate models have the right amount of variability

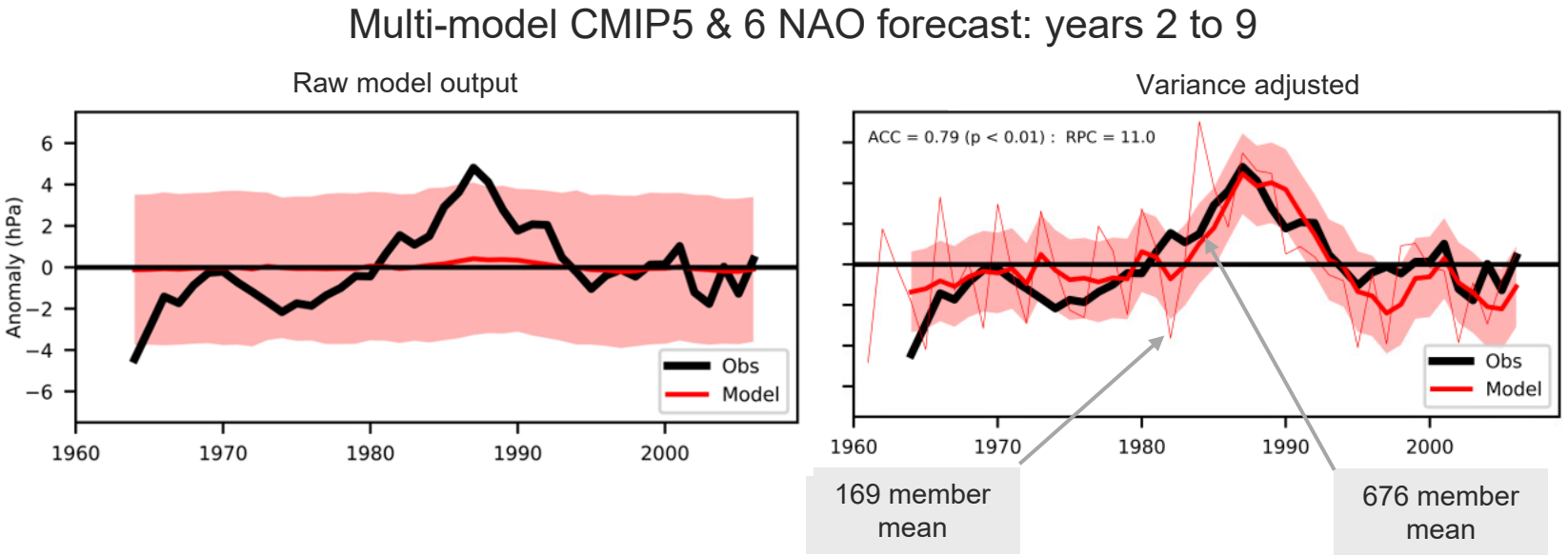
BUT

The *proportion* of variability that is predictable is too small

Eade et al 2014, Scaife and Smith 2018

Scaife et al, ASL, 2016

Forecast signal is MUCH too weak

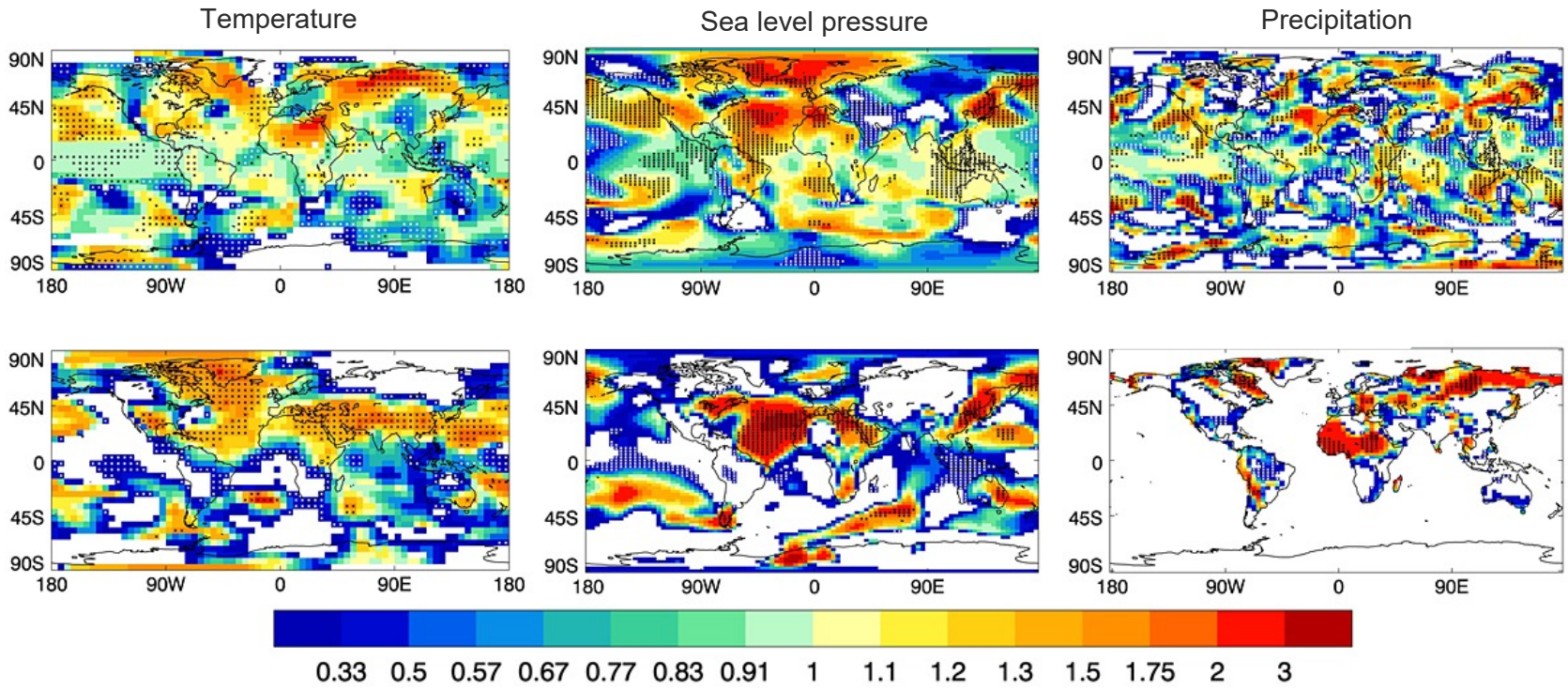


- Ratio of predictable components RPC = 11
- Signal is an order of magnitude too weak in climate model ensemble
- Need 100 times the number of ensemble members to extract the signal

Smith et al 2020

Scaife et al, ASL, 2016

Signal to noise paradox: a widespread issue

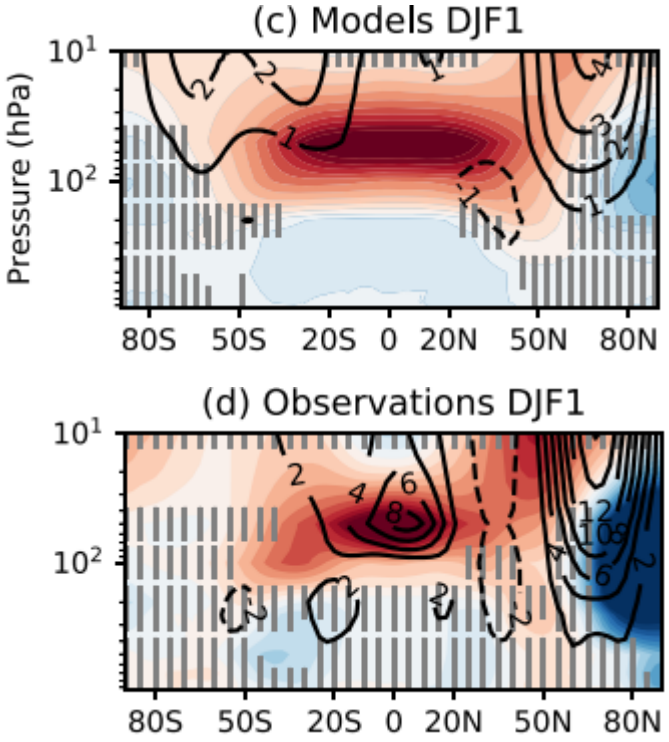


- Red areas are geographically widespread over multiple time scales
- Especially serious for precipitation and pressure
- Atmospheric circulation signals too weak

Eade et al 2014

Response to external forcing: volcanoes and solar

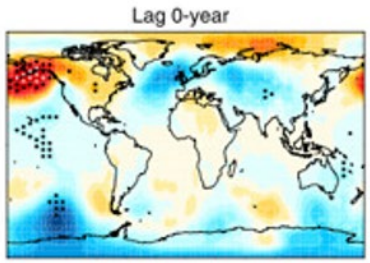
Volcanoes

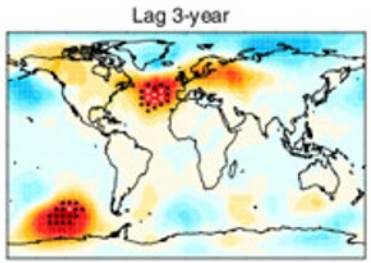


Hermanson et al 2020, Gray et al 2013

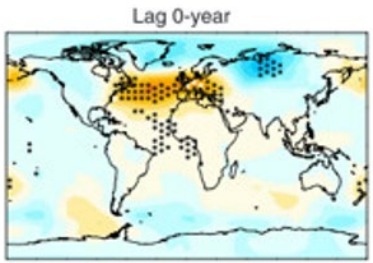
Solar

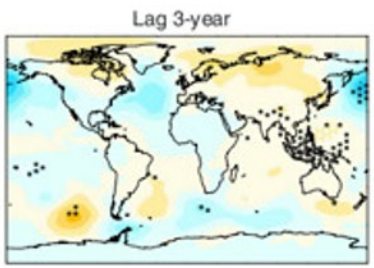
Observations





Models





Model response is too weak, and not lagged

The signal-to-noise bias therefore exists in historical simulations and climate projections: Klavans et al 2021, Zhang and Kirtman 2019, Sevellec and Drijfhout 2019, Zhang et al 2021

Estimating limits of predictability

- Correlation coefficients are unaffected by the signal-to-noise paradox
  - The correlation skill grows with ensemble size
- Root mean squared error and mean squared skill score under-estimate skill in areas with high RPC
- Measures dependent on the spread of ensembles will be misleading:
  - Brier skill score, reliability diagrams, etc.
- What can be done?
  - Always use the largest ensemble possible, include other models and lagged forecasts if possible
  - Post process: Adjust the variance and ensemble spread

Conclusions

- The limits of predictability can be extended through windows of opportunity and clever use of climate indices
- The signal-to-noise paradox limits our predictability
  - Good news: Climate is much more predictable than we thought!
  - Bad news: Our models are seriously deficient
- It has been shown in multiple models over timescales from months to many years
- Correlation skill scores are unaffected, but RMSE, MSSS and probabilistic measures are impacted
- Interim solution: Variance adjusted very large multi-model ensembles