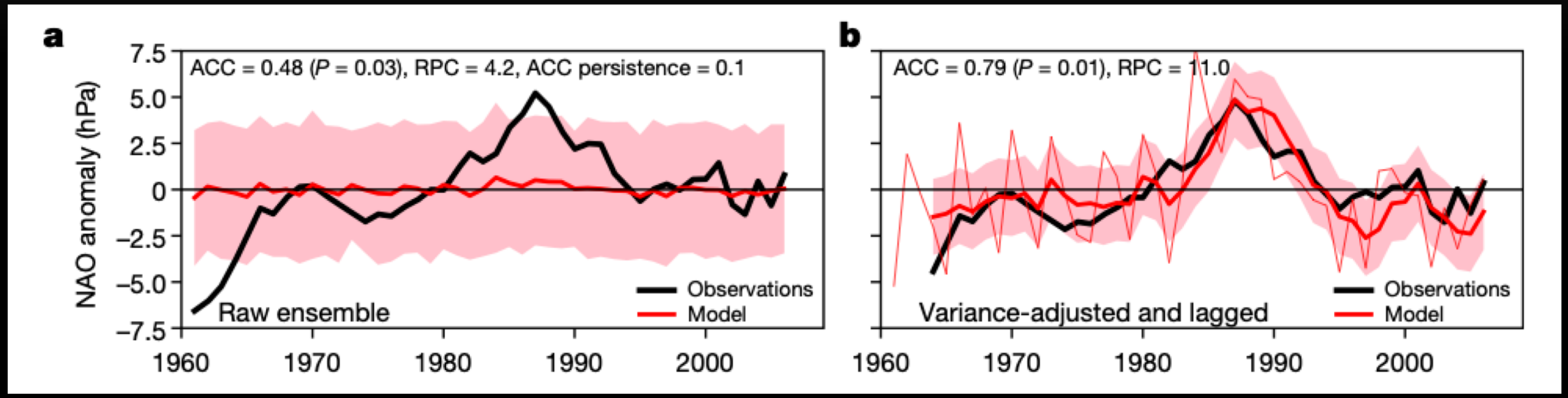
Challenges in near-term climate predictions

Signal-to-noise Ratio and Ensemble Size

Prediction of the NAO



Decadal predictions of the NAO. Left: observed (black) and predicted (years 2–9; red) 8-yr running mean NAO index. The red shading shows the 5%–95% confidence interval diagnosed from the individual ensemble members. Right : same as the left panel but the ensemble mean is adjusted to have the same variance as the observations (thin red) and smoothed (thick red).

The contrast between the strong ACC and weak signals of the ensemble mean is due to the underestimated predictable signals in models (by an order of magnitude).

Smith et al 2020

Ratio of predictable components (RPC)

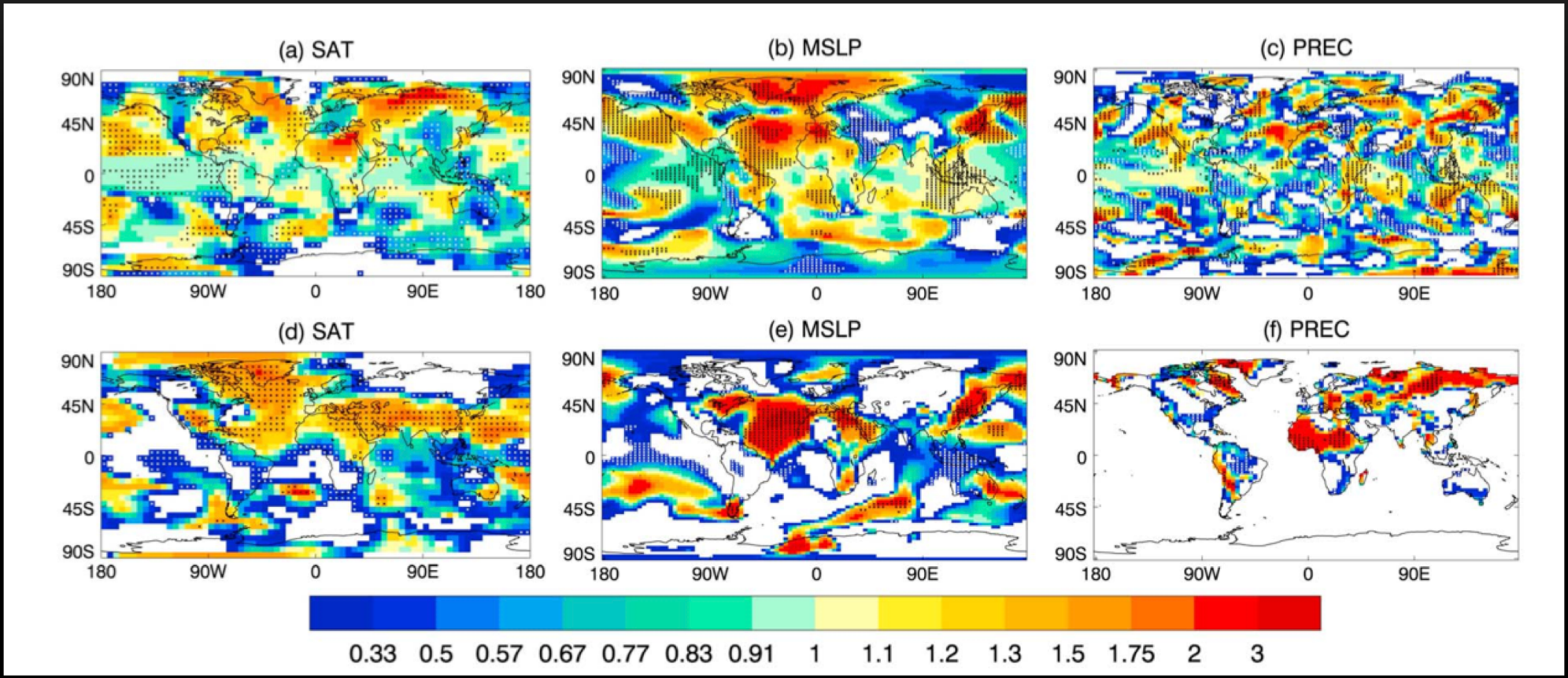
- The predictable component is sometimes underestimated in models, as in the example of the NAO prediction on the subseasonal to decadal (S2D) time scales. This can be assessed using the ratio of predictable components.

$$\mathrm{RPC} = \frac{\mathrm{PC_{obs}}}{\mathrm{PC_{mod}}} \geq \frac{r}{\sqrt{\sigma^2_{\mathrm{sig}}/\sigma^2_{\mathrm{tot}}}}$$

- The numerator, Pcobs, is the fraction of the observed variance that can be explained by model forecasts, diagnosed from the Pearson correlation (r) between observations and the ensemble mean of model hindcasts.
- The predictable component in the model may be estimated from the variance of the ensemble mean relative to the variance of individual ensemble members. σ^2_{sig} is the signal variance of the model ensemble mean in time and σ^2_{tot} is the average variance of individual members.
- Ideally, the RPC should be equal to one for a forecast system if the model perfectly reflects the actual predictability.

Eade et al. 2014

The Issue of Underconfidence



RPC for (a–c) seasonal hindcasts of December-January-February (DJF) means and (d–f) decadal hindcasts of 4 year annual means for years 2–5, for near-surface temperature (SAT, column 1), mean sea level pressure (MSLP, column 2), and precipitation (PREC, column 3). From Eade et al. 2014.

There are regions where the RPC is significantly greater than one. This is indicative of underconfidence, where the ensemble mean agrees relatively well with observations (high correlation) but ensemble members agree less well with each other (low model signal-to-noise ratio).

RPC Correction

The ensemble predictions can be adjusted so that 1) the ensemble mean has the same standard deviation as that of the observed predictable component (σ_{obs}*r); and 2) the standard deviation of the ensemble members with respect to their mean is equal to that of the observed unpredictable component.

$$\overline{Y_t}' = \left(\overline{Y_t} - \hat{Y}\right)\frac{\sigma_{obs} r}{\sigma_{sig}} + \hat{Y} \quad (2)$$

Adjusting the ensemble mean

where $\overline{Y}_t$ is the original hindcast ensemble mean value for a given start time t and $\hat{Y}$ is the average of these over all start times. We additionally transform each ensemble member (Y_{mt}') such that their variance about the new ensemble mean, i.e., the variance of the ensemble noise, becomes equal to the unpredictable variance of the observations, namely, $\sigma^2_{obs}\,(1 - r^2)$:

$$Y_{mt}' = \left(Y_{mt} - \overline{Y_t}\right)\frac{\sigma_{obs}\sqrt{(1 - r^2)}}{\sigma_{noi}} + \overline{Y_t}' \quad (3)$$

Adjusting the ensemble variance

where Y_{mt} is the original ensemble member value and σ^2_{noi} is the original noise variance:

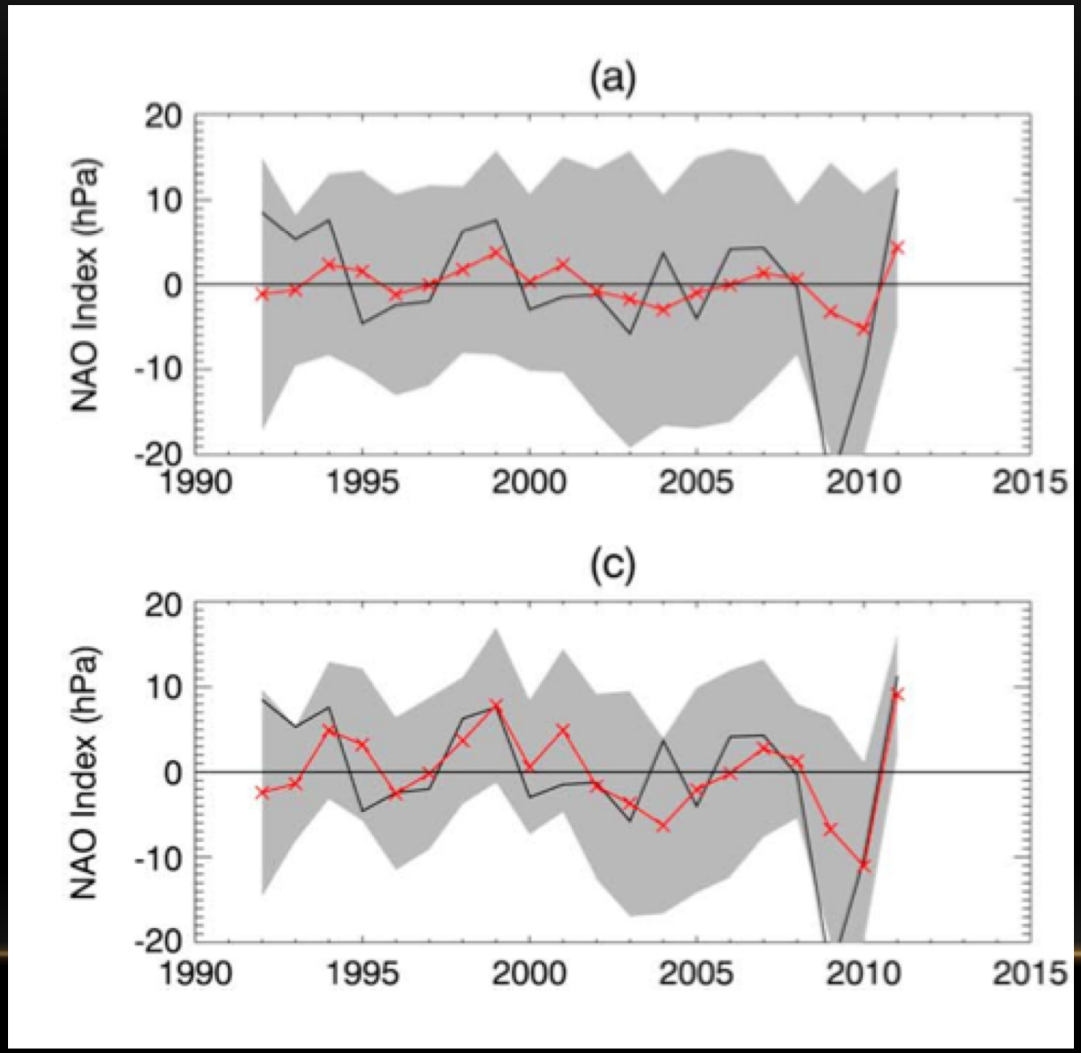
$$\sigma^2_{noi} = \text{Variance}\left(Y_{mt} - \overline{Y_t}\right) \quad (4)$$

This ensures that the total variance of the model is equal to σ^2_{obs}, with the predictable component now accounting for a fraction r^2 of this.

Eade et al. 2014

NAO Prediction with RPC Correction

Time series of the observed (black) and predicted (red) NAO index. (top) original prediction; (bottom) adjusted prediction. Grey shading represents the ensemble 5–95% range.

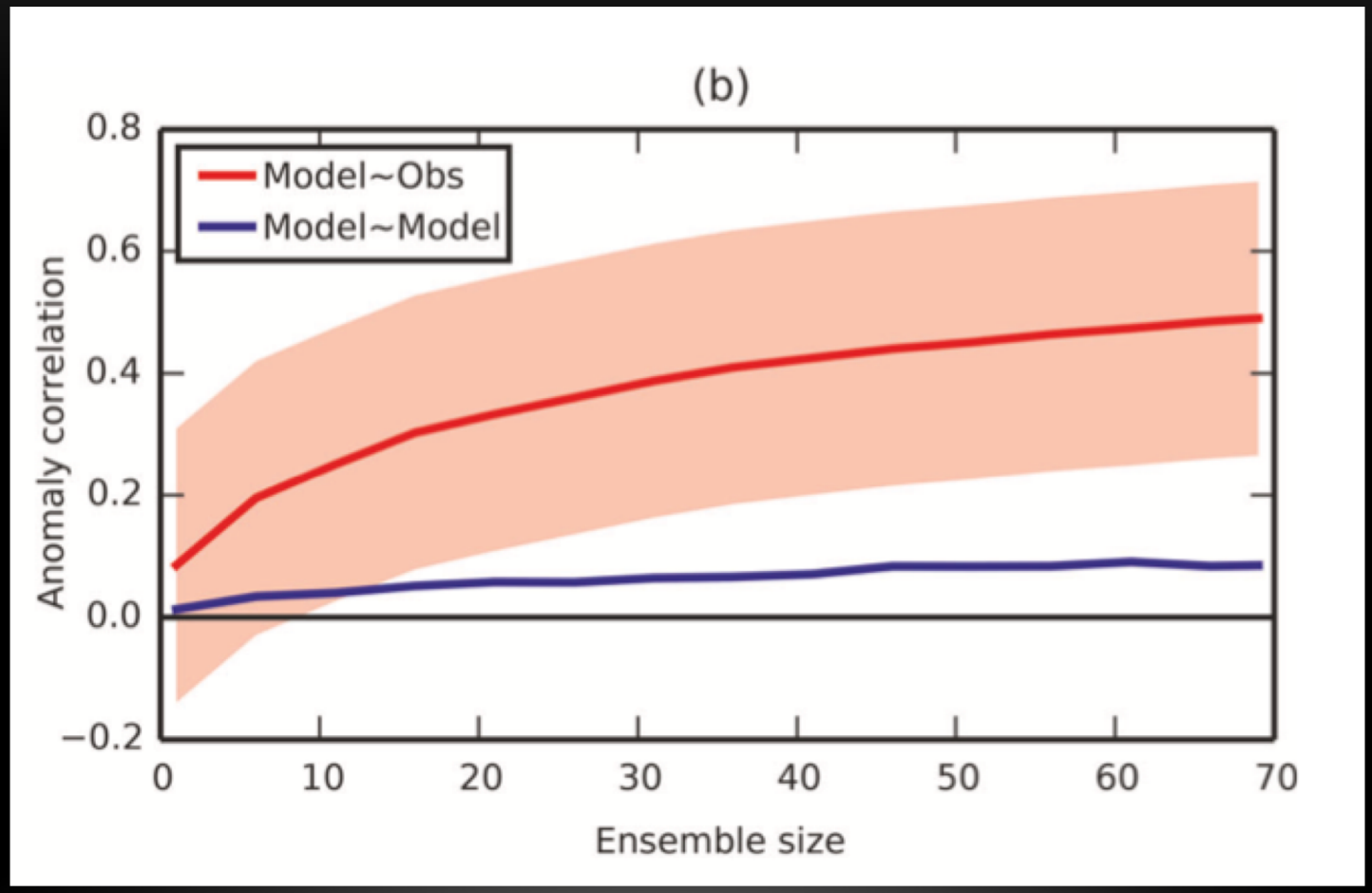


Original NAO prediction

Ensemble mean and ensemble spread with RPC correction

Eade et al. 2014

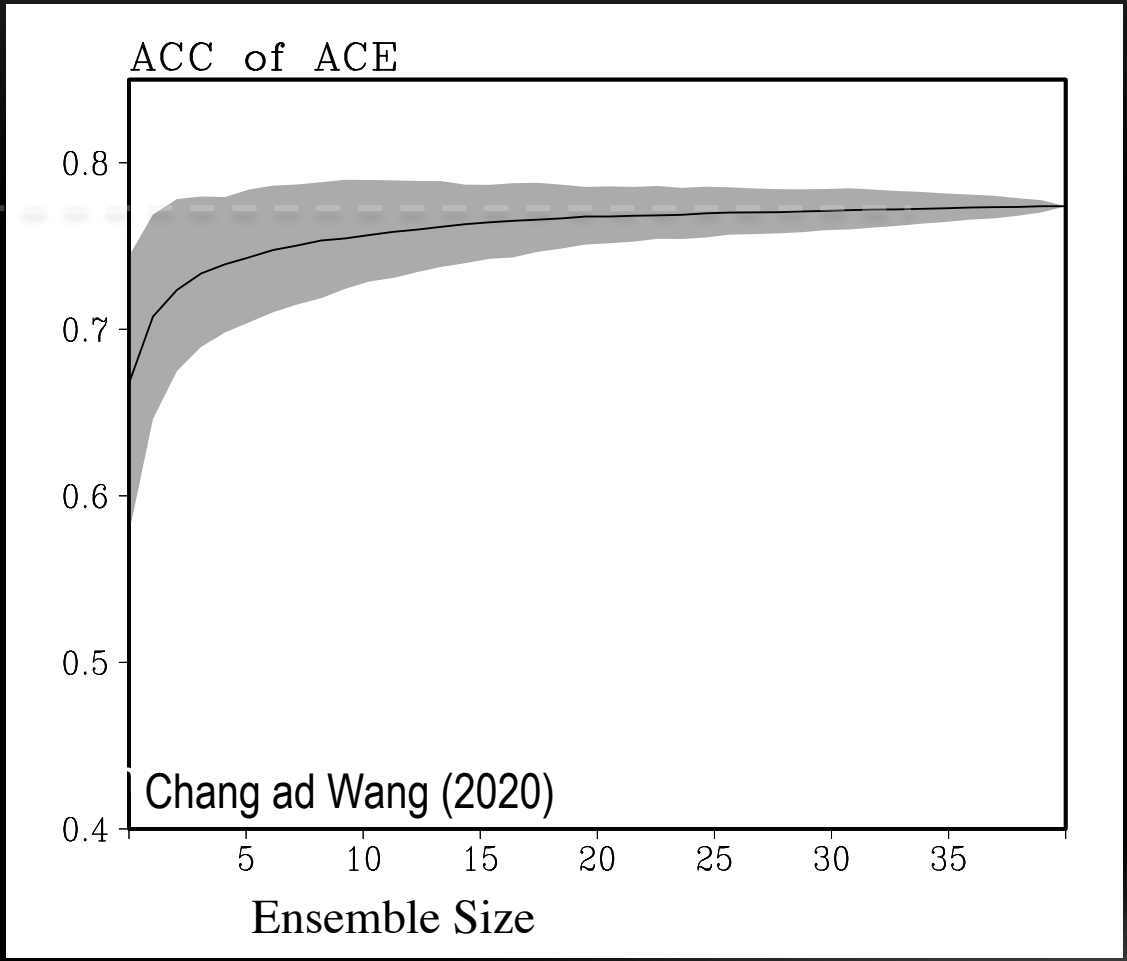
Prediction Skill (ACC) as a Function of Ensemble Size: NAO

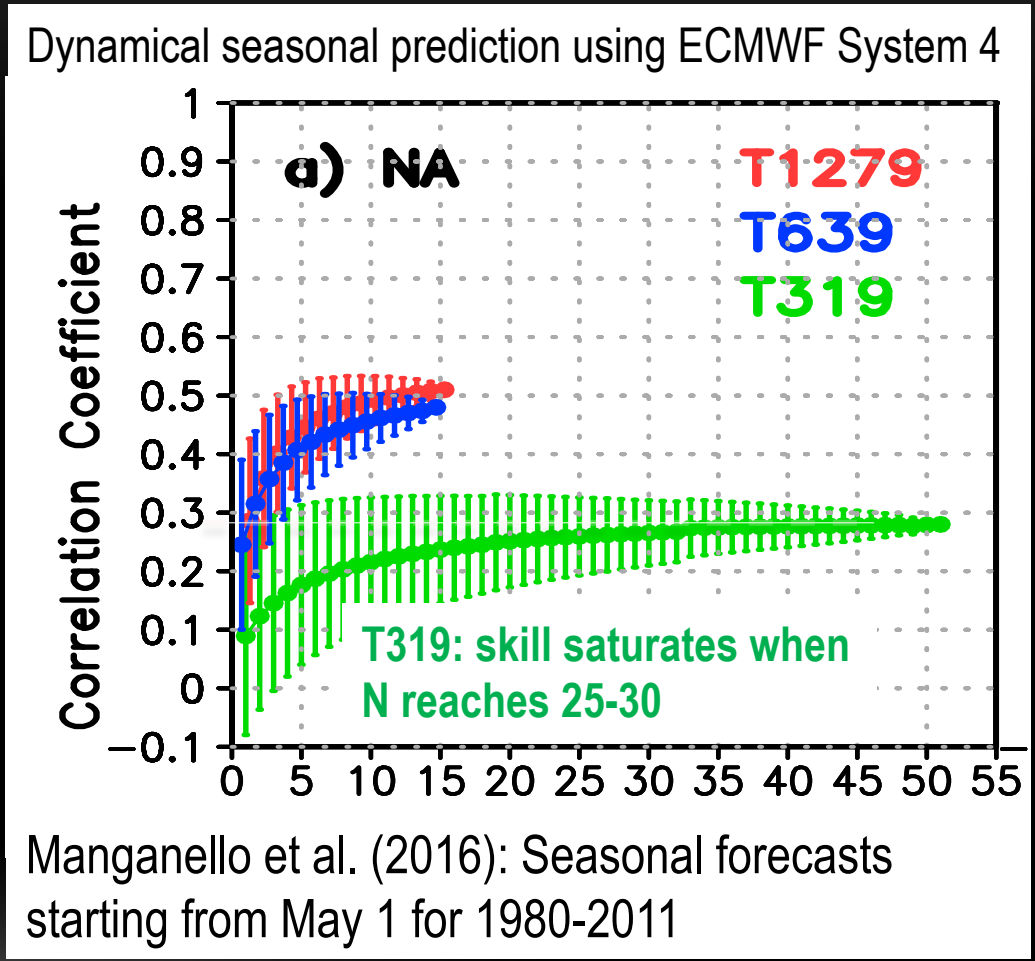


ACC as a function of ensemble size for model ensemble mean forecasts of the observations (red curve with 5–95% confidence interval shaded), and for model ensemble forecasts of an independent ensemble member (blue curve, averaged over all possible combinations) for the NAO prediction.

Smith et al. 2019

Prediction Skill (ACC) as a Function of Ensemble Size: Tropical Cyclones





In the TC hybrid prediction (left), the model skill increases sharply when the ensemble size is increased from 1 to 5, and saturates when the ensemble size is 15-20, indicating the optimal ensemble size is 15-20. The behavior is similar to the dynamic prediction by high-resolution models (right).

References

- Athanasiadis, P.J., Yeager, S., Kwon, YO. et al. Decadal predictability of North Atlantic blocking and the NAO. Nature npj Clim Atmos Sci 3, 20 (2020). https://doi.org/10.1038/s41612-020-0120-6
- Chang, C., & Wang, Z. (2020). Multiyear Hybrid Prediction of Atlantic Tropical Cyclone Activity and the Predictability Sources, *Journal of Climate*, *33*(6), 2263-2279.
- Eade, R., D.M. Smith, A.A. Scaife, E. Wallace, N. Dunstone, L. Hermanson and N. Robinson, 2014: Do seasonal to decadal climate predictions underestimate the predictability of the real world? Geophys. Res. Letts., 41, 5620-5628, DOI: 10.1002/2014GL061146
- Kushnir, Y. et al., 2019: Towards operational predictions of the near-term climate. Nature Climate Change, Vol 9, pp 94-10
- Smith et al. 2019: Robust skill of decadal climate predictions, Nature npj Climate and Atmospheric Science (2019)2:13 ; https://doi.org/10.1038/s41612-019-0071-y
- Smith, D. M., et al, 2020, North Atlantic climate far more predictable than models imply, Nature, 583, 796-800, doi:10.1038/s41586-020-2525-0