On the forced response and decadal predictability of the North Atlantic Oscillation

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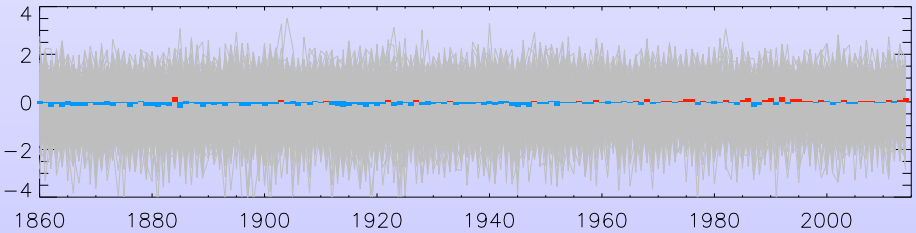
Climate model ensembles: CMIP6

Winter NAO, unsmoothed, historical

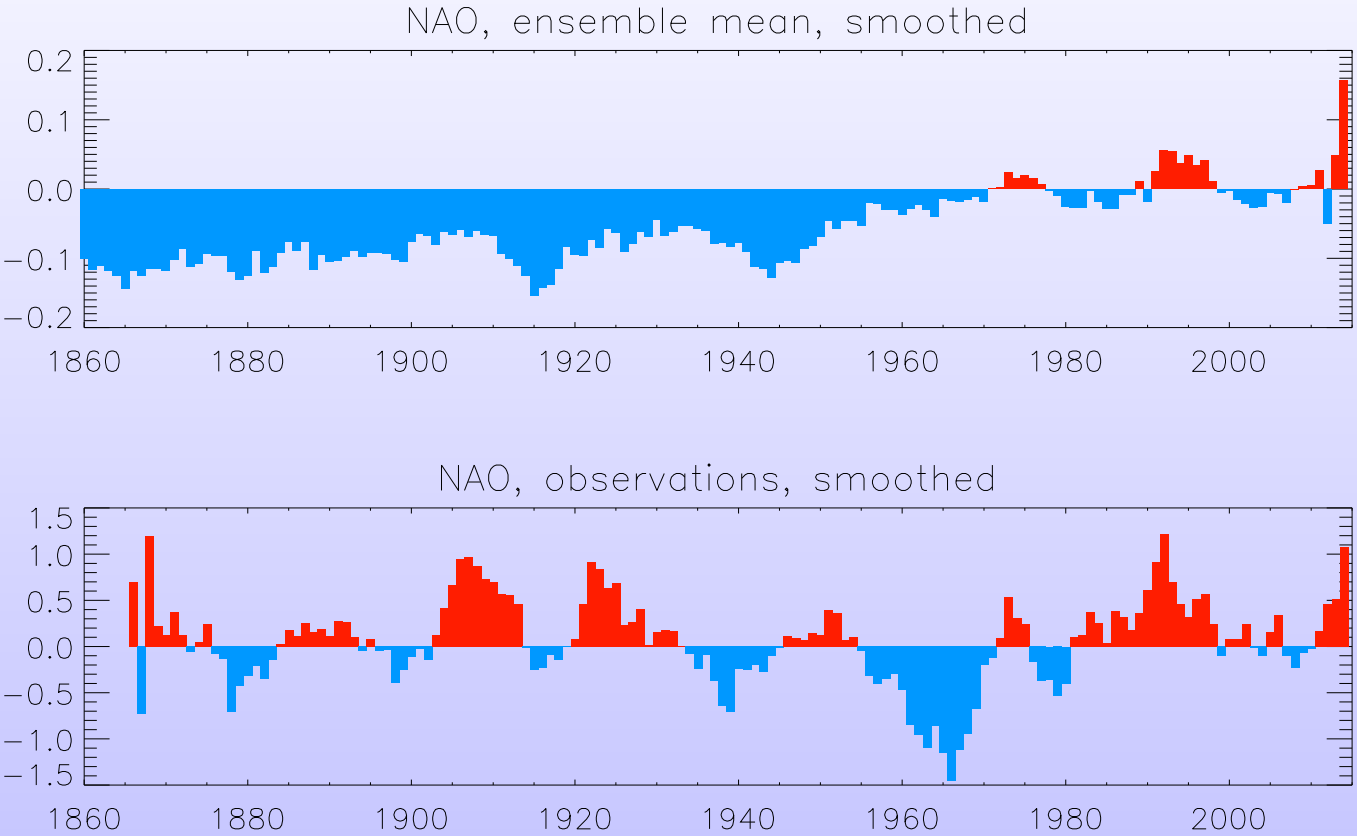


Simulations in this study: CMIP6

Model	Historical	Hist-nat	Hist-GHG	Hist-aer	piControl	Decadal
ACCESS-CM2	3	2	3	3	1	0
ACCESS-ESM1-5	10	3	3	3	1	0
AWI-CM-1-1-MR	5	0	0	0	1	0
AWI-ESM-1-1-LR	1	0	0	0	1	0
BCC-CSM2-MR	3	3	3	3	1	8
BCC-ESM1	3	0	0	0	1	0
CAMS-CSM1-0	2	0	0	0	1	0
CAS-ESM2-0	4	0	0	0	1	0
CESM1-1-CAM5-CMIP5	0	0	0	0	0	10
CESM2	10	3	3	2	1	0
CESM2-FV2	3	0	0	0	1	0
CESM2-WACCM	3	0	0	0	1	0
CESM2-WACCM-FV2	3	0	0	0	1	0
CIESM	3	0	0	0	1	0
CMCC-CM2-HR4	1	0	0	0	0	0
CMCC-CM2-SR5	1	0	0	0	1	5
CMCC-ESM2	1	0	0	0	1	0
CanESM5	10	10	10	10	1	0
CanESM5-CanOE	0	0	0	0	1	0
E3SM-1-0	4	0	0	0	1	0
E3SM-1-1	1	0	0	0	1	0
E3SM-1-1-ECA	1	0	0	0	1	0
EC-Earth3	8	0	0	0	0	10
EC-Earth3-AerChem	1	0	0	0	1	0
EC-Earth3-CC	0	0	0	0	1	0
EC-Earth3-LR	0	0	0	0	1	0
EC-Earth3-Veg	7	0	0	0	1	0
EC-Earth3-Veg-LR	3	0	0	0	1	0
FGOALS-f3-L	3	0	0	0	1	0
FGOALS-g3	6	3	3	3	1	0
FIO-ESM-2-0	3	0	0	0	0	0
GFDL-CM4	0	3	0	0	0	0
GFDL-ESM4	3	1	0	1	0	0
GISS-E2-1-G	10	0	5	5	1	0
GISS-E2-1-G-CC	1	0	0	0	0	0
GISS-E2-1-H	10	0	0	0	1	0
GISS-E2-2-G	0	0	0	0	1	0
IITM-ESM	1	0	0	0	1	0
INM-CM4-8	1	0	0	0	0	0
INM-CM5-0	8	0	0	0	0	0
IPSL-CM6A-LR	10	10	10	10	0	10
KACE-1-0-G	3	0	0	0	0	0
KIOST-ESM	1	0	0	0	1	0
MCM-UA-1-0	1	0	0	0	1	0
MIROC-ES2H	0	0	0	0	1	0
MIROC-ES2L	0	0	0	0	1	0
MIROC6	10	10	3	10	1	10
MPI-ESM-1-2-HAM	3	0	0	0	0	0
MPI-ESM1-2-HR	10	0	0	0	0	5
MPI-ESM1-2-LR	10	0	0	0	0	0
MRI-ESM2-0	5	5	5	5	1	7
NESM3	5	0	0	0	1	0
NorCPM1	10	0	0	0	0	10
NorESM2-LM	3	2	3	3	0	0
NorESM2-MM	3	0	0	0	0	0
SAM0-UNICON	1	0	0	0	0	0
TaiESM1	1	0	0	0	1	0

Forced signal (ensemble mean) in NAO: CMIP6 historical

NAO: smoothed over 7 winters



- Observations and model mean seem to partly agree after 1970.
- Note that the similarity is not just found for the positive NAO period in the 90s, but several wriggles seem to match.
- However, the amplitude of the ensemble mean is much lower – by a factor of 10 – than in observations.

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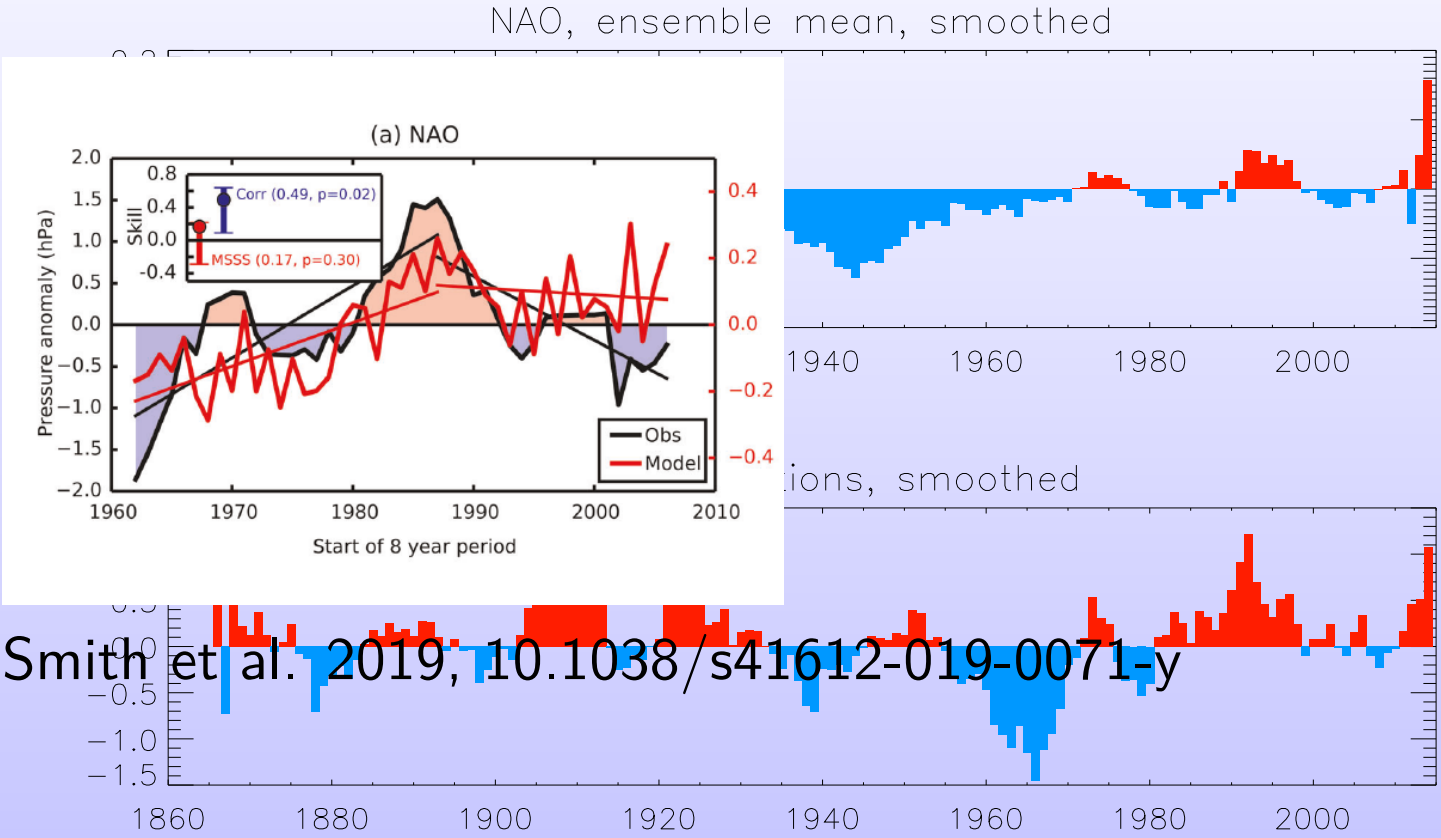

Smith et al. 2019, 10.1038/s41612-019-0071-y

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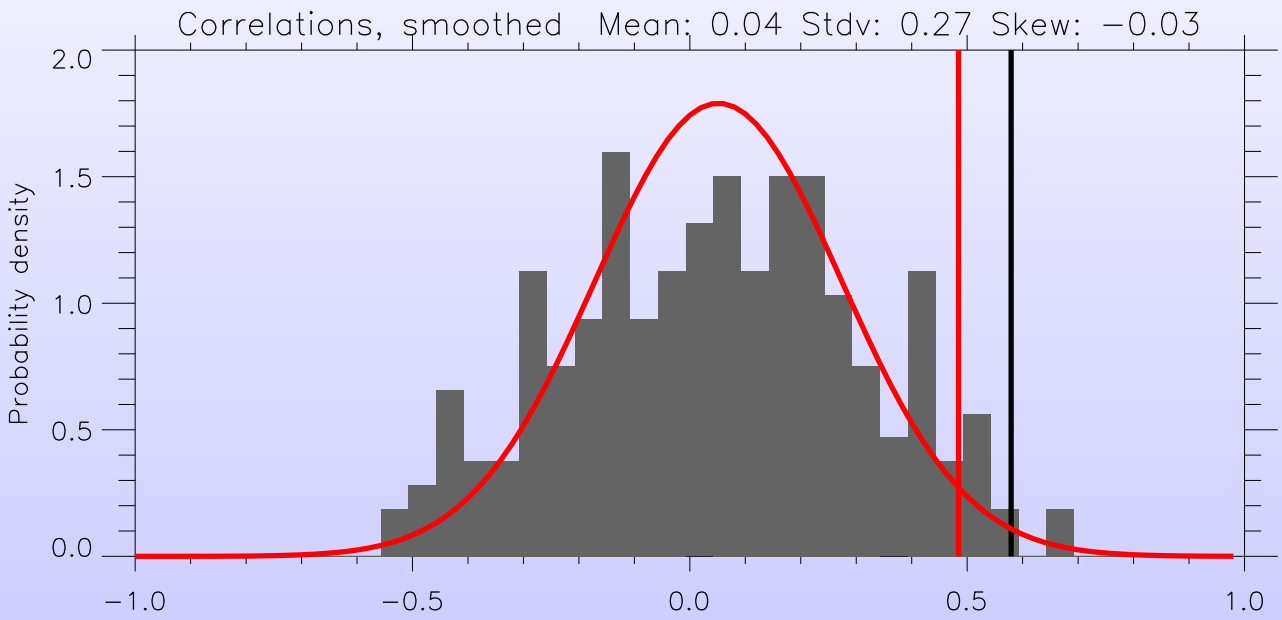
Correlations 1970-2015

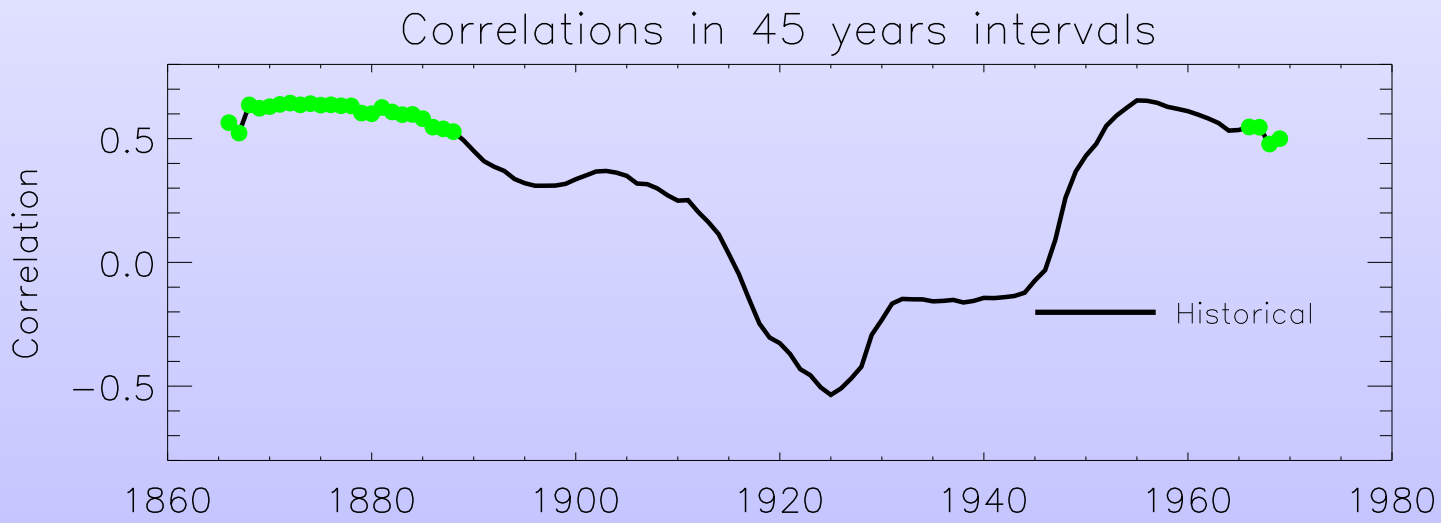


Histogram shows correlations between individual ensemble members and observations.

Vertical black line is correlation between ensemble mean and and observations.

On the temporal non-stationarity of correlations

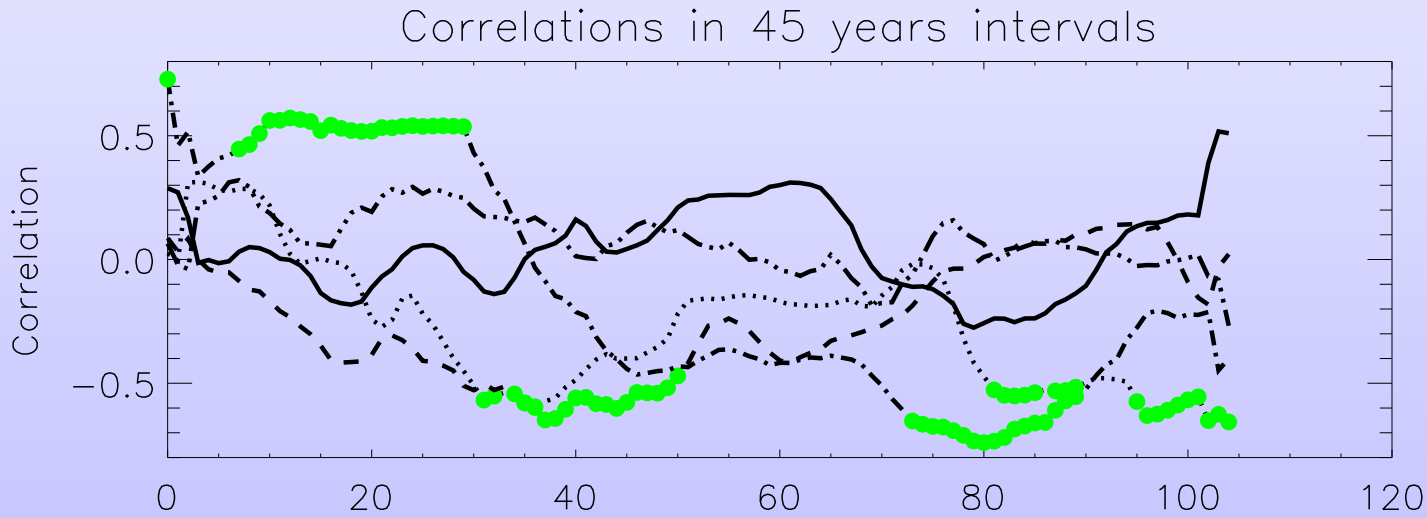
Correlations between ensemble mean and observation in 45 years periods as function of start year. Green symbols indicate correlations that are significantly different from zero.



CMIP6 historical

On the temporal non-stationarity of correlations

Correlations between ensemble mean and observation in 45 years periods as function of start year. Green symbols indicate correlations that are significantly different from zero.

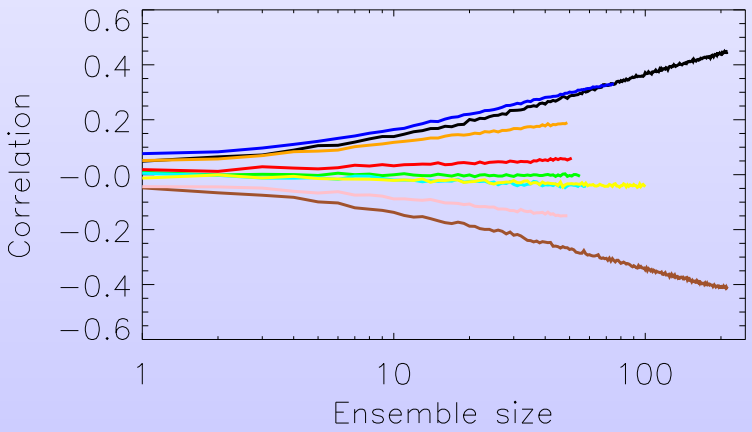


Ensemble members and observations are obtained by drawing independent numbers from a Gaussian distribution.

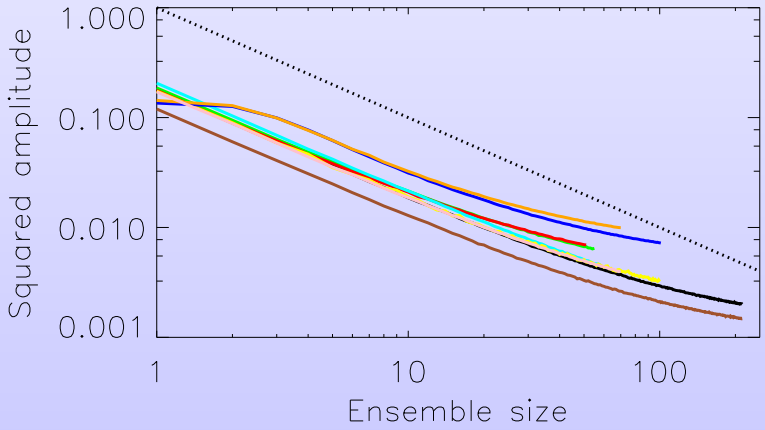
Other ensembles: Ensemble mean as function of ensemble size

Period is: 1970–2004

The correlations with observations



The squared amplitude



historical
hist−nat
hist−GHG
hist−aer
MPI−GE
decadal
historical 1925−1969
decadal red
historical red

- The amplitude converges towards zero for all ensembles.
- Only in the historical CMIP6 and the initialized forecasts do we see increasing and significant correlations.

Conclusions

- For the forced NAO signal in CMIP6 we find significant correlation (0.57) with observations for the period after 1970. This is in agreement with the results reported by Smith et al. (2019, 2020) with ensembles of decadal forecasts.
- The signal in the models is strongly underestimated (factor of 10), and therefore large ensembles are needed.
- However, in earlier periods of the same length (45 years) insignificant and even negative correlations are found.
- This kind of apparent non-stationarity in the correlations can easily be due to chance as we demonstrated with both the pre-industrial control ensemble and pure random numbers.
- No significant correlations between the forced NAO signal and observations found in single-forcing CMIP6 experiments or in MPI-GE.

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