# Externally forced and internal variability of tropospheric variability modes in the past millennium

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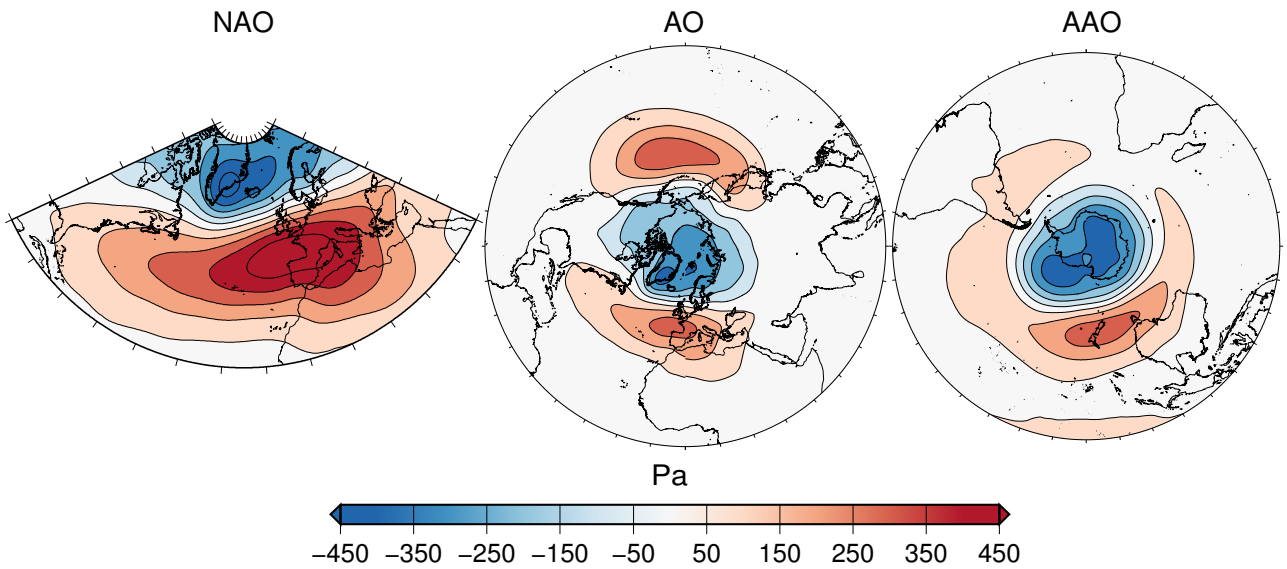
# *Variability Modes of SLP*



- The North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Antarctic Oscillation (AAO) are the dominant variability modes in winter in both hemispheres
- They are normally defined as the leading Eigenmodes (EOFs) of Sea Level Pressure variability in the respective winter season



# *Forced vs. Internal Variability*



- The evolution of these modes (in general of any climatic variable) has two components:
- A component due to internal (unpredictable) variability
- A component of response to the external (natural or anthropogenic) forcing
- Climate reconstructions and simulations can only agree in the forced component
- Should the NAO, AO or AAO reconstructions and simulations agree with climate simulations?

# *Simulations*



Two ensembles of simulations were analysed:

## MILLENNIUM ensemble

- Model: Earth System Model developed in MPI-M
- 3 "strong" forcing + 5 "weak" forcing + 1 control run
- Period 850–2005

## CMIP5 Ensemble

- 4 Different models (only one run per model)
- Each model a control run
- "Similar" forcing (weak)
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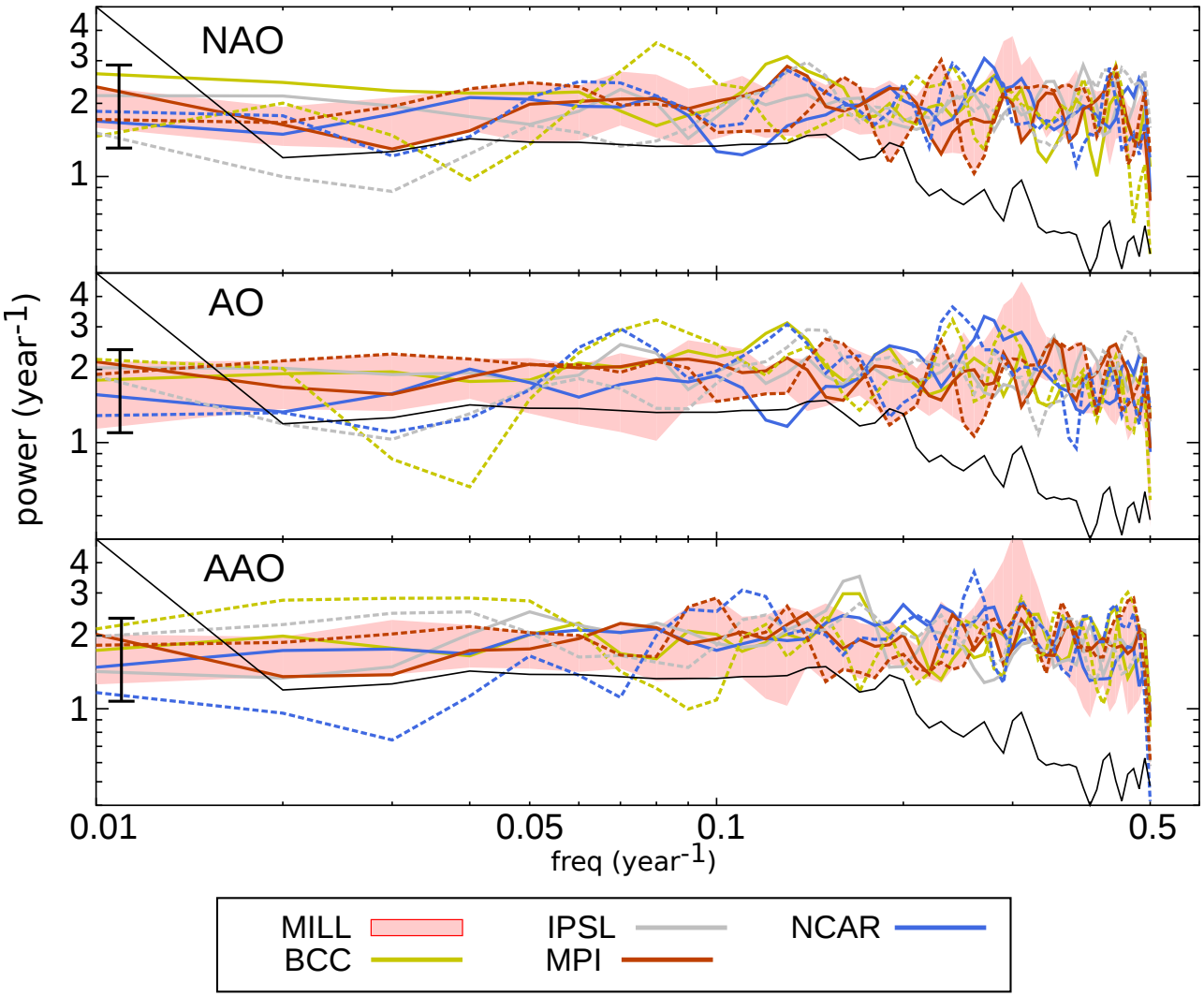
# *Spectral Analysis*



- The total variability of the series can be decomposed by Fourier analysis into their components at different frequency bands
- We look for the fingerprint of the external forcings in the variability spectrum of the NAO, AO and AAO indices
- Our approach is to compare the forced vs. unforced runs, to identify an increase in any frequency band attributable to the forcings

# Fourier Analysis Results





# *EOF Approach for Analysing Coherence*



We analysed the coherence of the series among the pool of simulations

## Main Argument:

*If the forcing modulates the dynamics, and because the simulations share the same forcing, they should also share their response. Otherwise, internal variability dominates over externally-controlled variance*

This inter-simulation analysis of coherence can be conducted through EOF analysis

# EOF Approach for Analyzing Coherence



- The EOFs of the "field":

$$f(s,t) = \text{Index}_s(t) \quad s = 1, 2, ..., N \quad \forall t$$

  are calculated for each index in the $N$ simulations
- The amount of variance of $EOF_1$ is a measure of the redundancy of the series
- The higher this value, the greater the signal-to-noise ratio
- The significance level for this variable has to be determined through Monte Carlo experiments

**Null Hypothesis:**

The amount of variance of $EOF_1$ is not statistically different from the case where the series are independent

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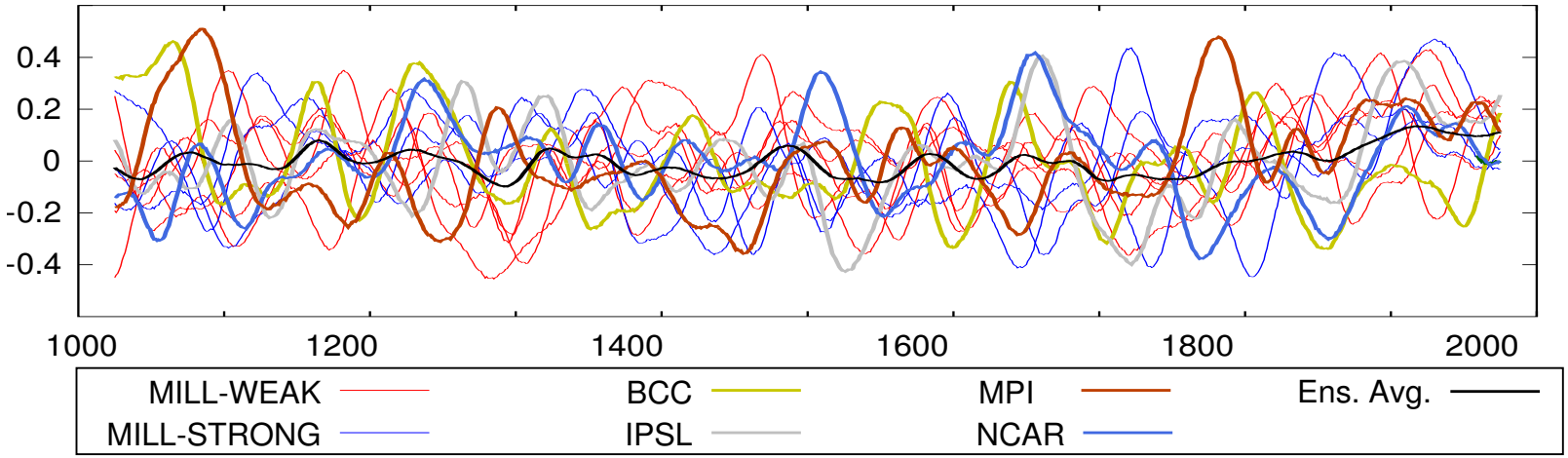
# *Example: NAO (51-year smoothed series)*





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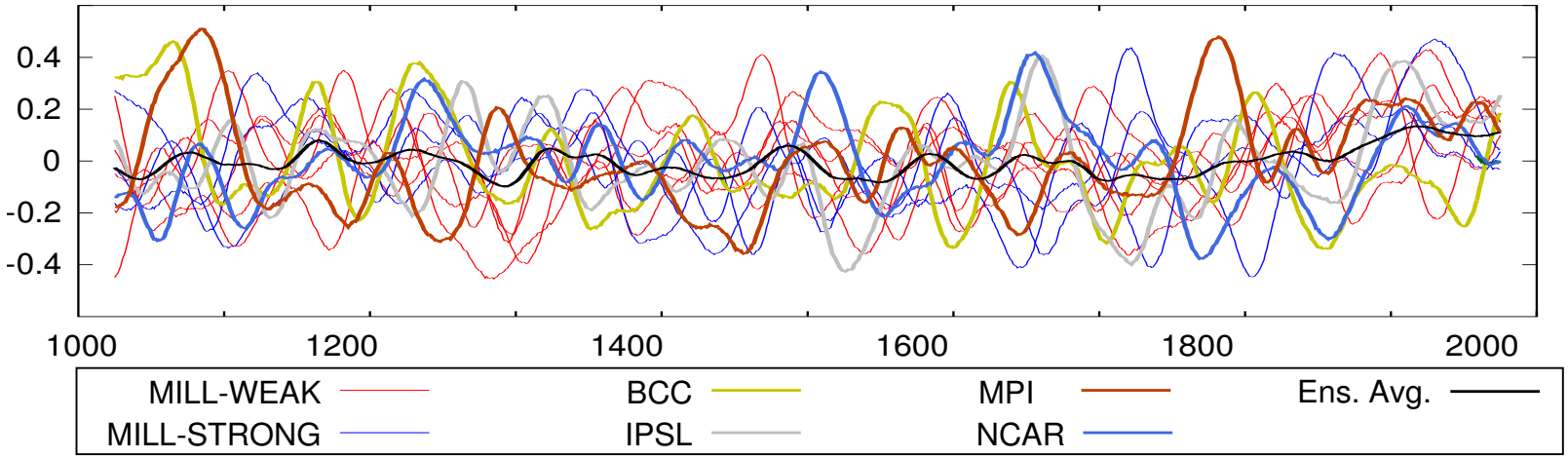


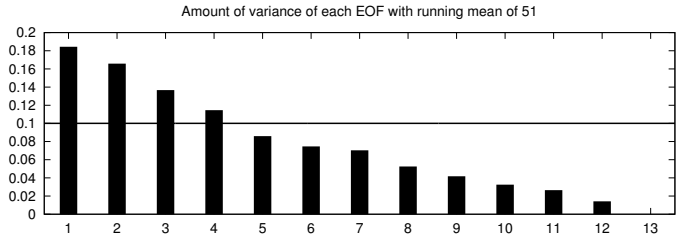


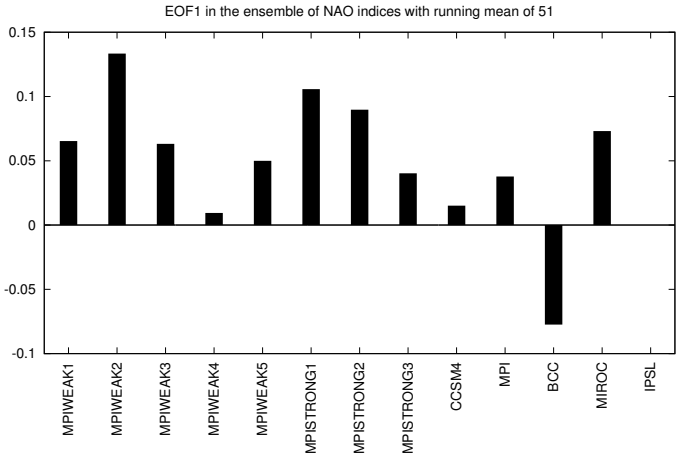

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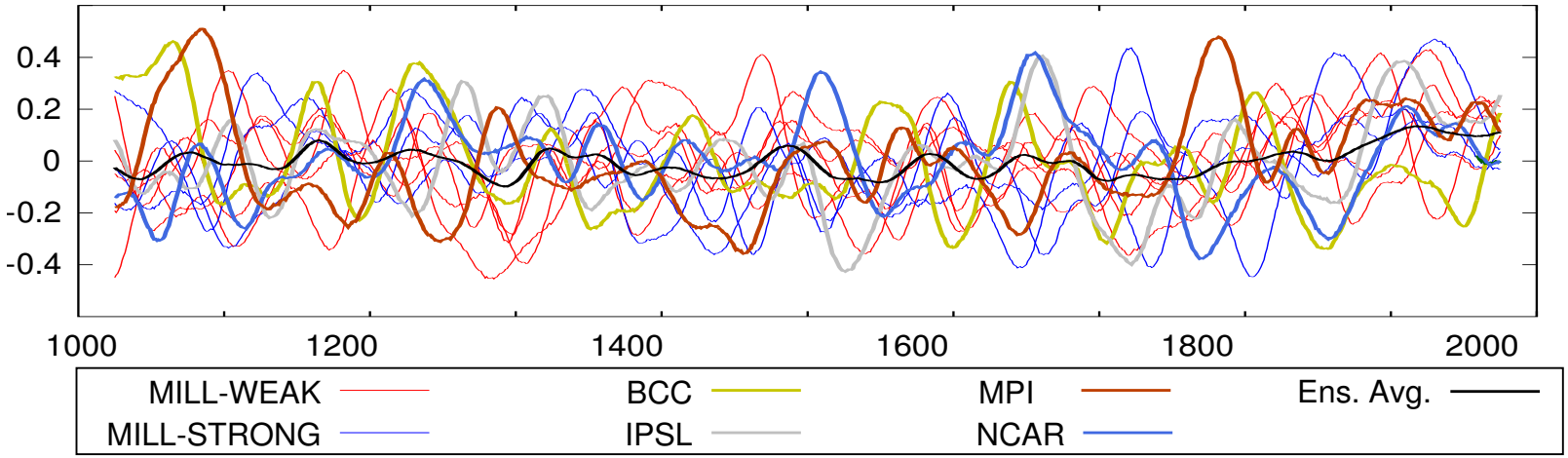


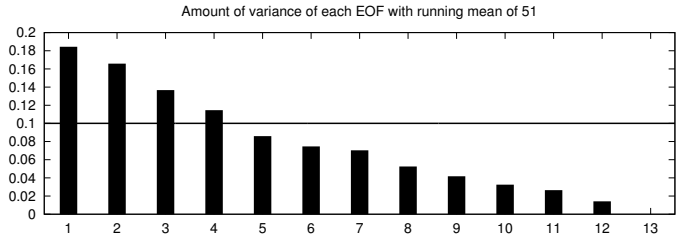


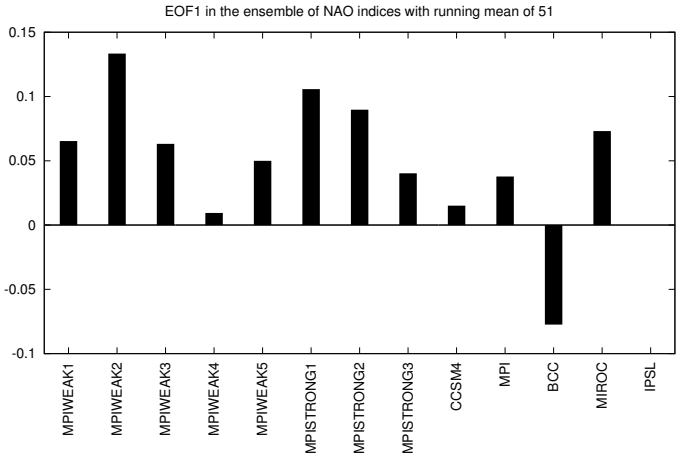


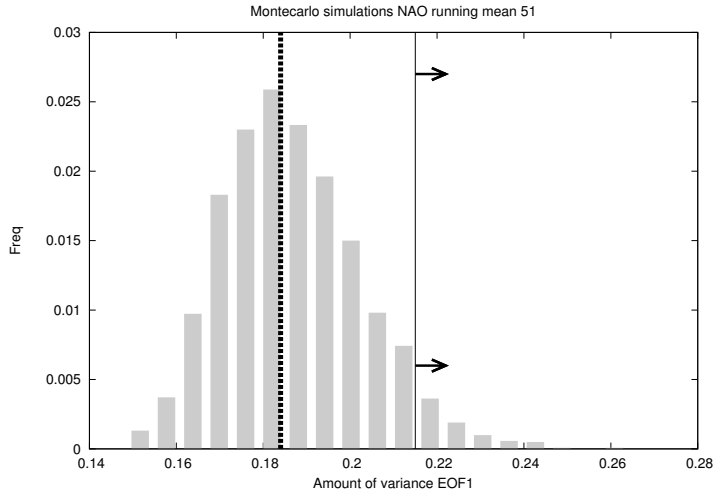

# Whole Picture



We analysed the series using three windows sizes to smooth the series for the three indices prior to the calculations:

| Window | NAO | AO | AAO |
|---|---|---|---|
| 1 | 9.99 (10.21) | 10.23 (10.24) | 9.97 (10.23) |
| 51 | 17.66 (21.49) | 20.11 (21.76) | 17.90 (22.02) |
| 101 | 25.29 (27.18) | 24.58 (28.79) | 21.93 (29.63) |

In no case the amount of variance represented by $EOF_1$ is significantly (at the 95% confidence level) larger than it could be expected by chance

# *Main conclusions*



- Our analysis shows that forced runs with state-of-the-art climate models present similar variability as control runs in all frequency bands
- We are not able to reject the *Null Hypothesis* of the independent evolution of the indices among the simulations
- Thus, long-term variability of these modes in these simulations is dominated by internal variability over than external forcings
- A coherent variability of these indices between simulations and reconstructions should not be expected

# Thank you very much!

# *Significance Test in Climate Change Scenarios*



We have repeated this analysis to a set of (five) climate change projections. In this case, the modes do respond coherently to the external forcing.

| Window | NAO | AO | AAO |
|---|---|---|---|
| 1 | **29.1 (29.1)** | **33.0 (30.0)** | **29.7 (28.5)** |
| 31 | **87.9 (81.5)** | **86.0 (79.9)** | 73.1 (76.2) |
| 51 | **94.1 (79.0)** | **92.5 (80.9)** | **81.4 (74.1)** |