Intermittent behavior in the AMOC-AMV relationship

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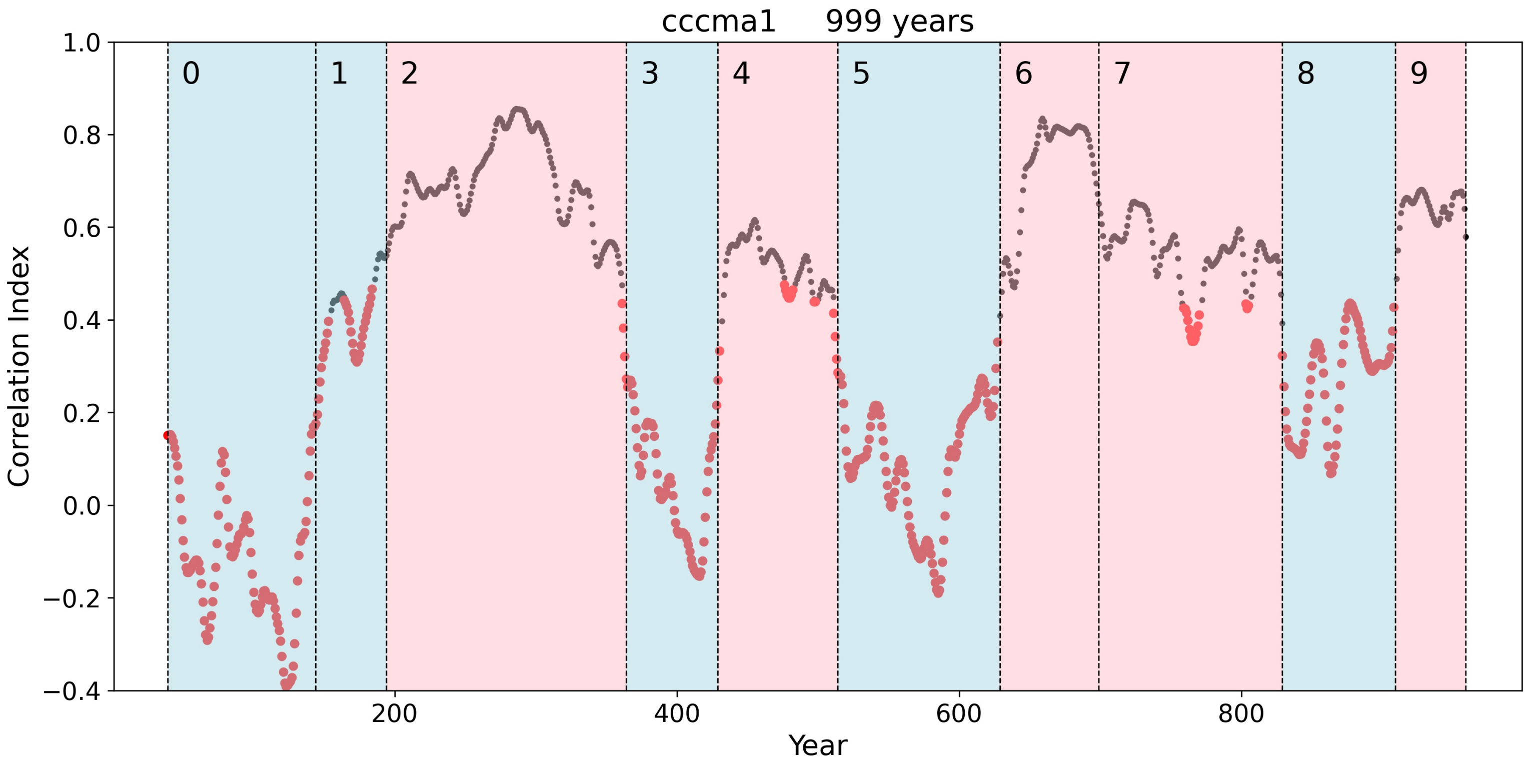
Denis Mattei (Univ. Modena), Paolo Ruggieri (Univ. Bologna), Luca Famooss Paolini (Univ. Bologna)



ICTP Workshop on AMV and TBI – August 2023, Trieste

The AMOC-AMV connection

- Well established physical basis (Bjerknes, 1964)
- Model-based evidence of non-stationarity in AMOC and AMV variability in pre-industrial runs
- Mavilia et al. (2018) and Moat et al (2019**)** show alternation of quasi-oscillatory and less regular/noisy phases in AMOC/AMV evolution in multi-century control simulations

On the spectral characteristics of the Atlantic multidecadal variability in an ensemble of…

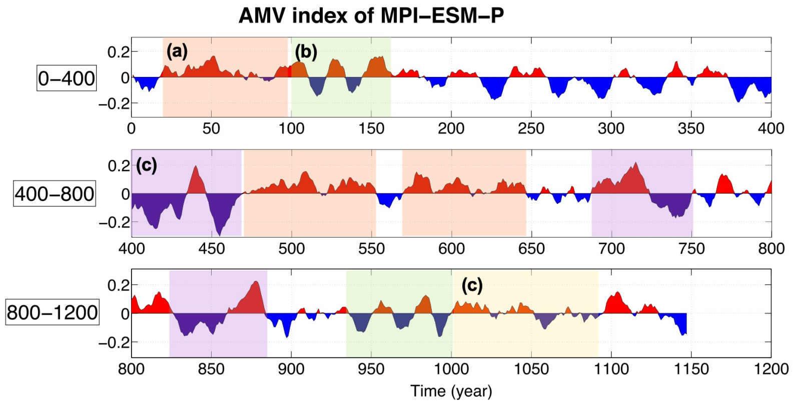


Fig. 4 AMV modulation shows epochs with different characteristics. (a) RED: mostly warm-skewed events; (b) GREEN: moderate, nearly-harmonic events; (c) PURPLE: intense events with longer periods; (d) YELLOW: sı

[Mavilia et al., 2018]

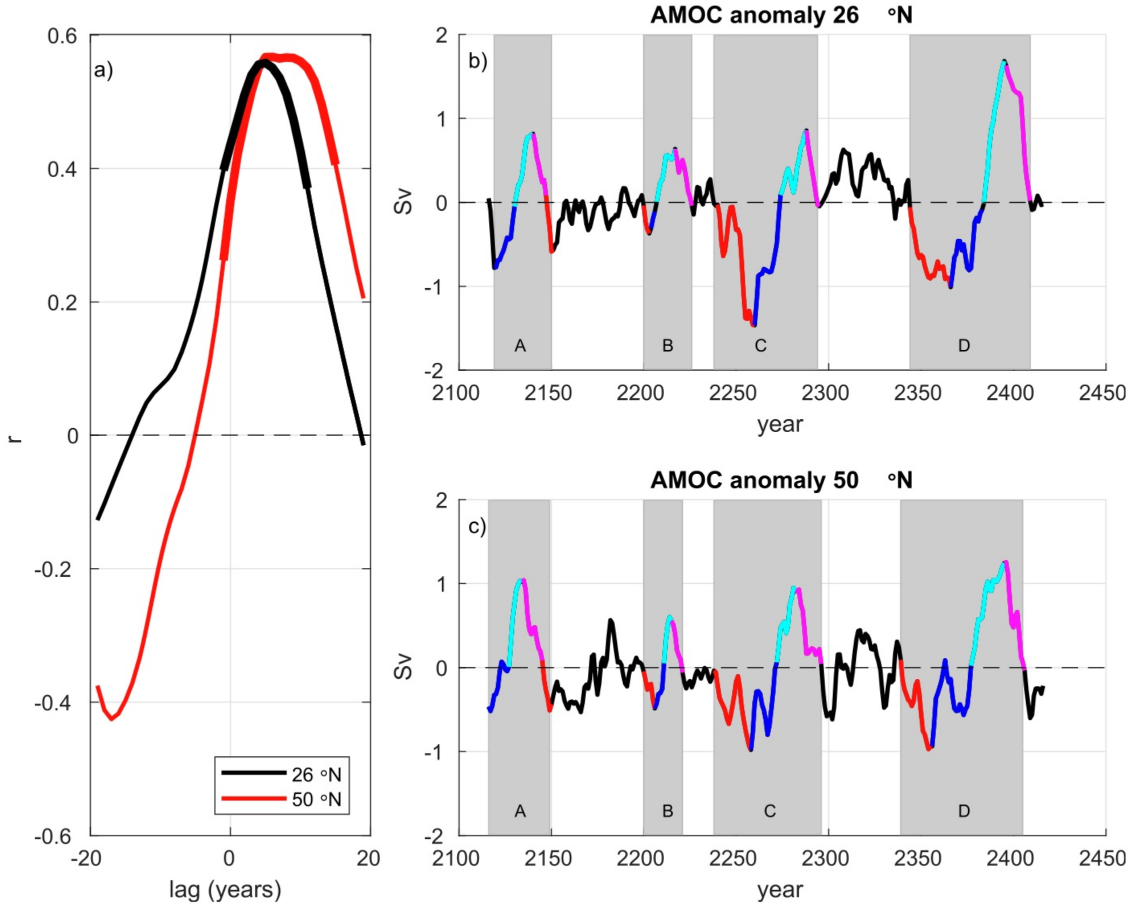


FIG. 3. (a) Lagged correlation between the AMOC anomaly (Sv) and the AMV (both 10-yr low pass filtered) indicating that the AMV lags the AMOC at 26°N (black) and 50°N (red). Thick lines indicate correlations are significant at the 95% level. Also shown is the AMOC anomaly at (b) 26°N and (c) 50°N. Events spanning a full AMOC cycle are indicated by letters A–D. Colors represent four different phases of the AMOC in each event: phase 1 (red), phase 2 (blue), phase 3 (cyan), and phase 4 (magenta).

[Moat et al., 2019]

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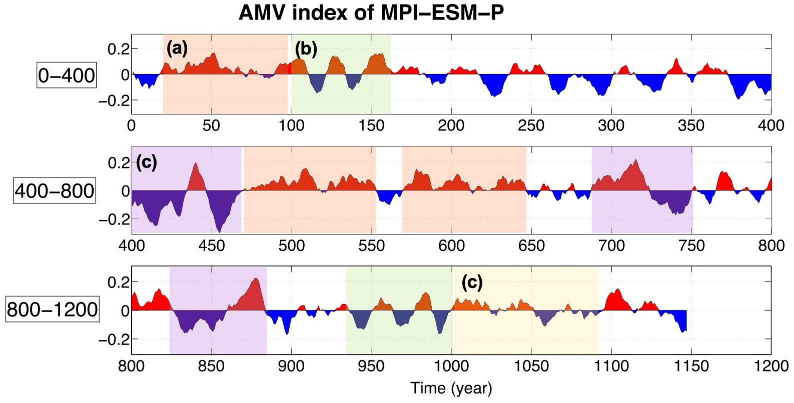

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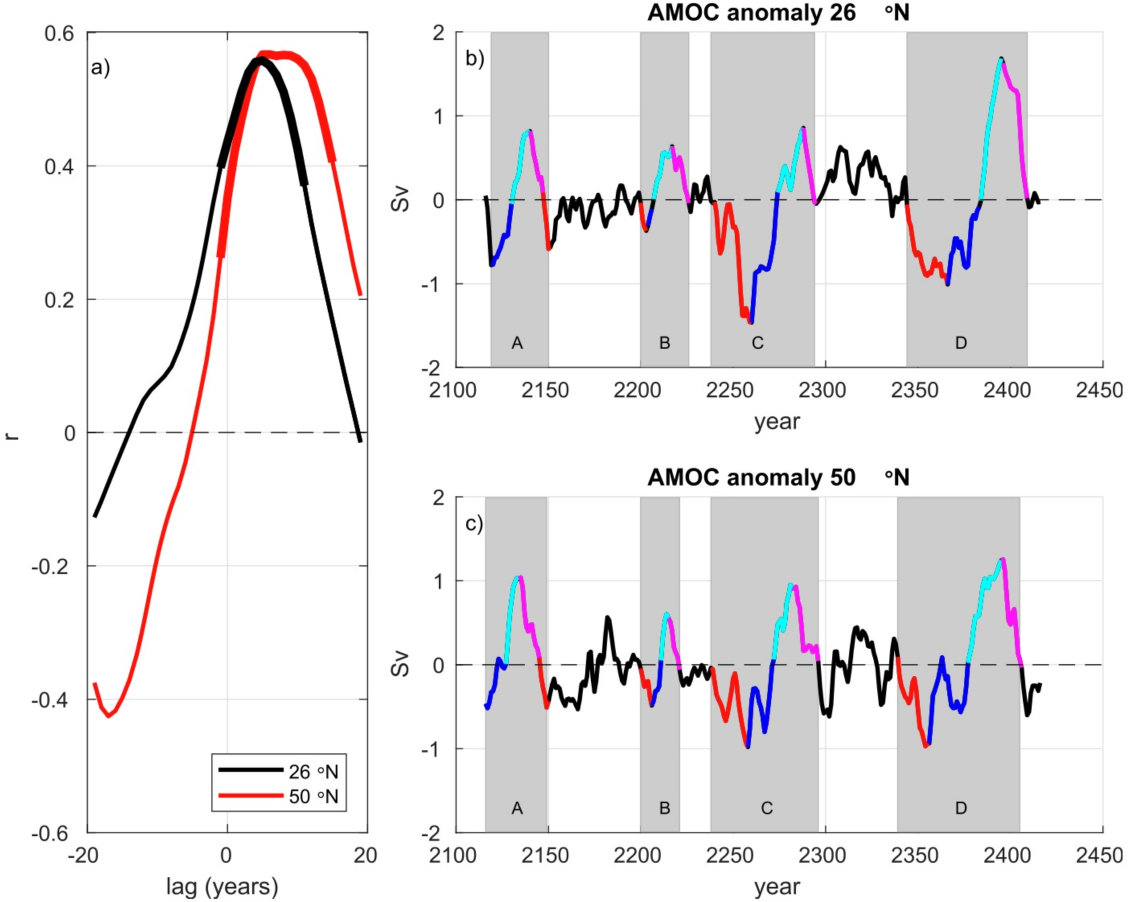

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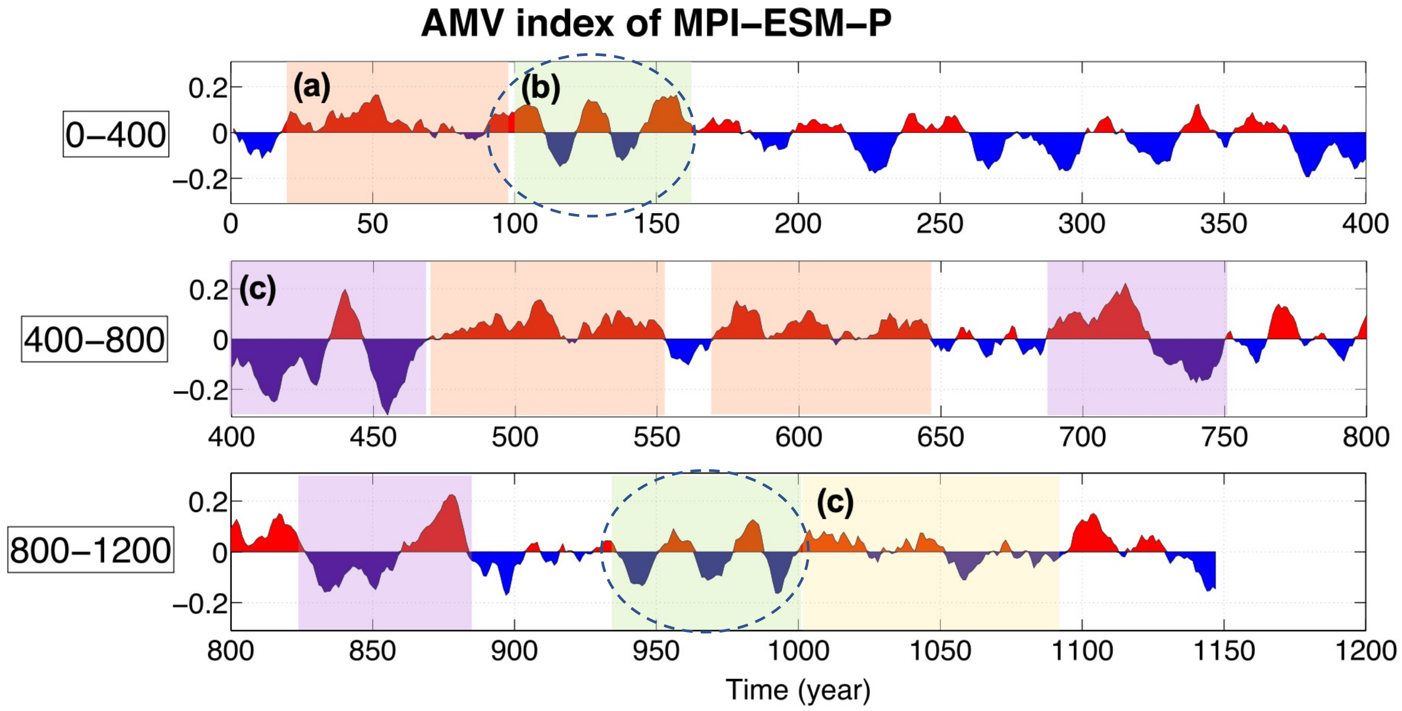
Nonstationary behavior in AMV

On the spectral characteristics of the Atlantic multidecadal variability in an ensemble of…



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AMV shows epochs with different characteristics:

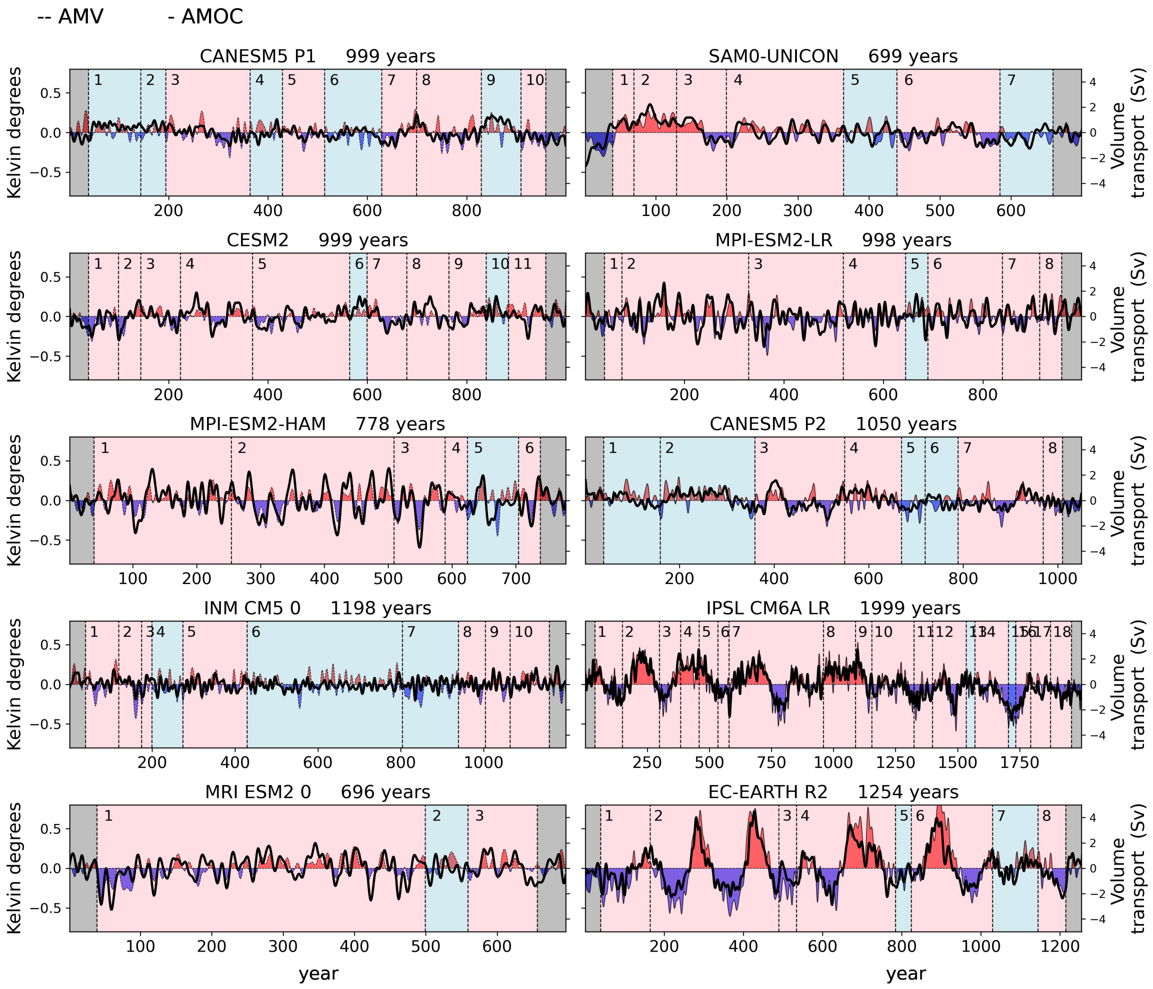
- (a) ***RED****: mostly warm-skewed events*
- (b) ***GREEN****: moderate, nearly sinusoidal events*
- (c) ***PURPLE****: intense and longer-period events*
- (d) ***YELLOW****: small amplitude events*

[Mavilia et al, 2018]

Aim : Assess the **stationarity of the AMOC-AMV relationship** in a multi-model set of CMIP6 multi-century pre-industrial climate simulations

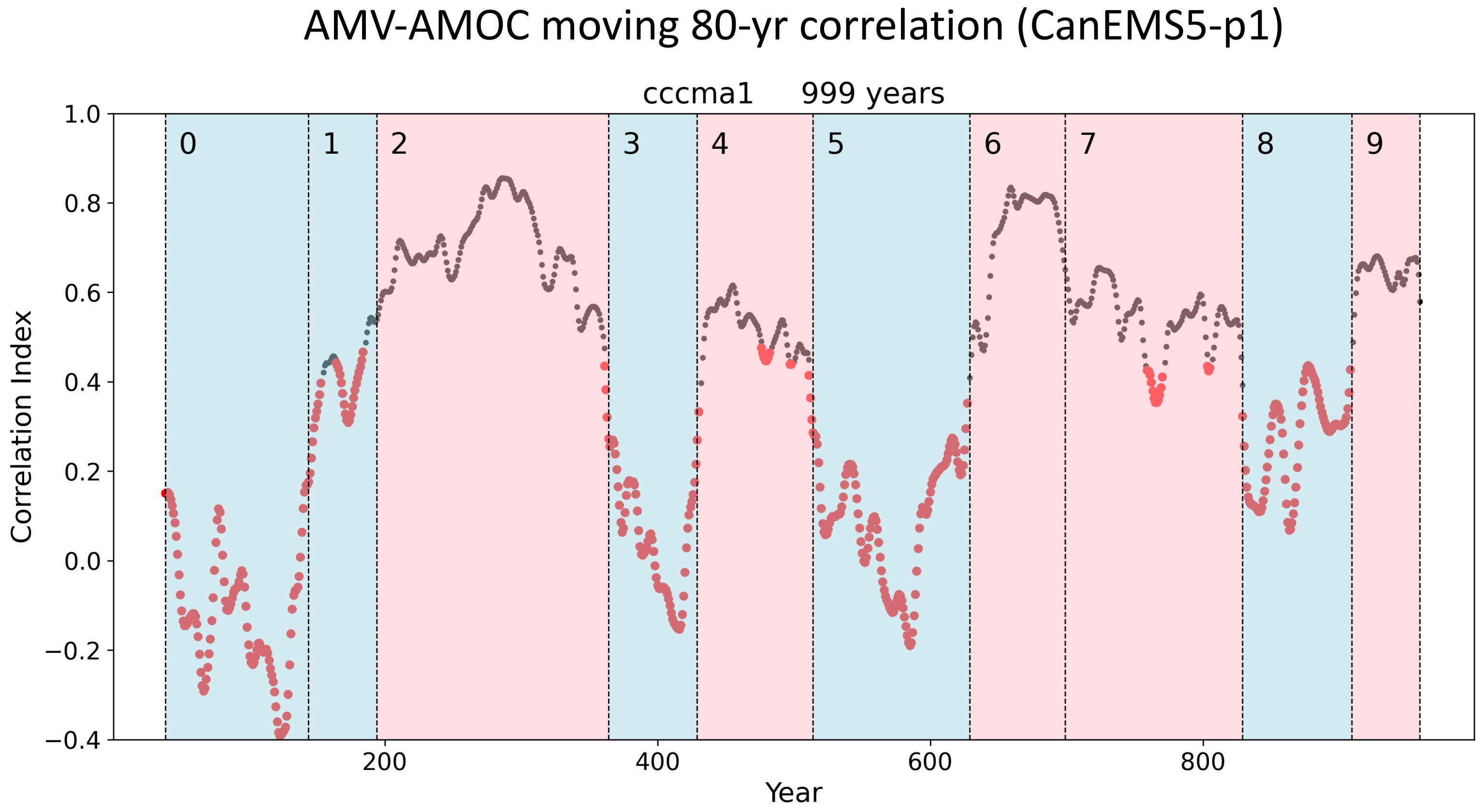
Model	Length (years)
CanESM5-p1	1000
CanESM5-p2	1000
CESM2	1200
EC-Earth3-r2	1255
INM-CM5-0	1200
IPSL-CM6A-LR	2000
MPI-ESM1-2-HAM	780
MPI-ESM1-2-LR	1000
MRI-ESM2-0	700
SAM0-UNICON	700

piControl CMIP6 simulations



AMOC & AMV index

A change-point detection method (*) is applied to 80-year running AMOC-AMV correlation to identify co-variability regimes in each model.



Methodology (details)

- Diagnose moving AMOC-AMV corr.
- Apply change-point detection method based on a PELT segmentation algorithm (Killick et al., 2012) to c(t) to identify discontinuities in the AMOC-AMV relation (vertical dash lines and numbers indicate the identified time segments)

CR	Correlated Regime
NCR	Non-Corr. Regime

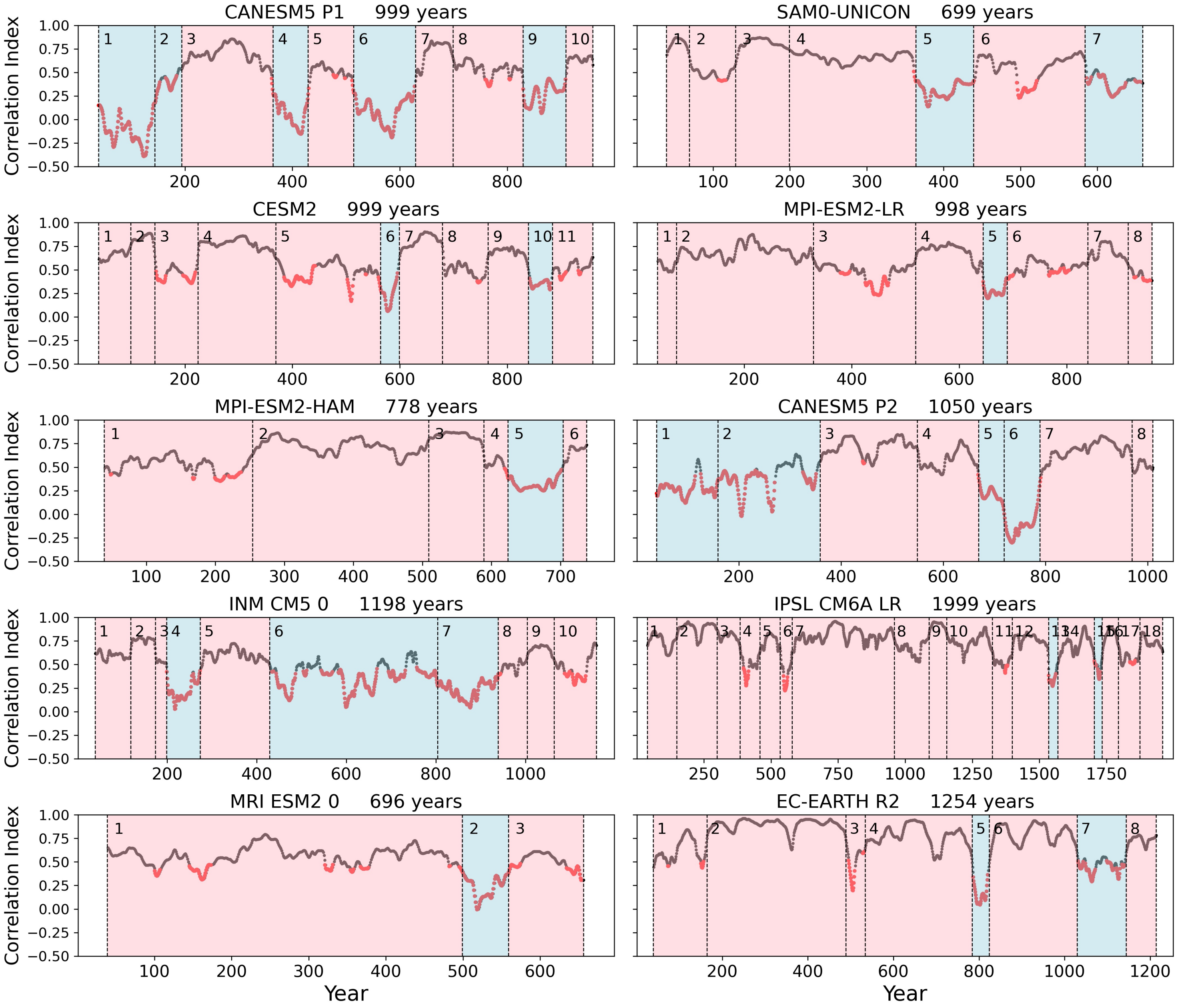
(*) R. Killick, P. Fearnhead, and I. Eckley. Optimal detection of changepoints with a linear computational cost. *Journal of the American Statistical Association*, 107(500):1590–1598, 2012.

After systematically applying this methodology to each selected model, we found:

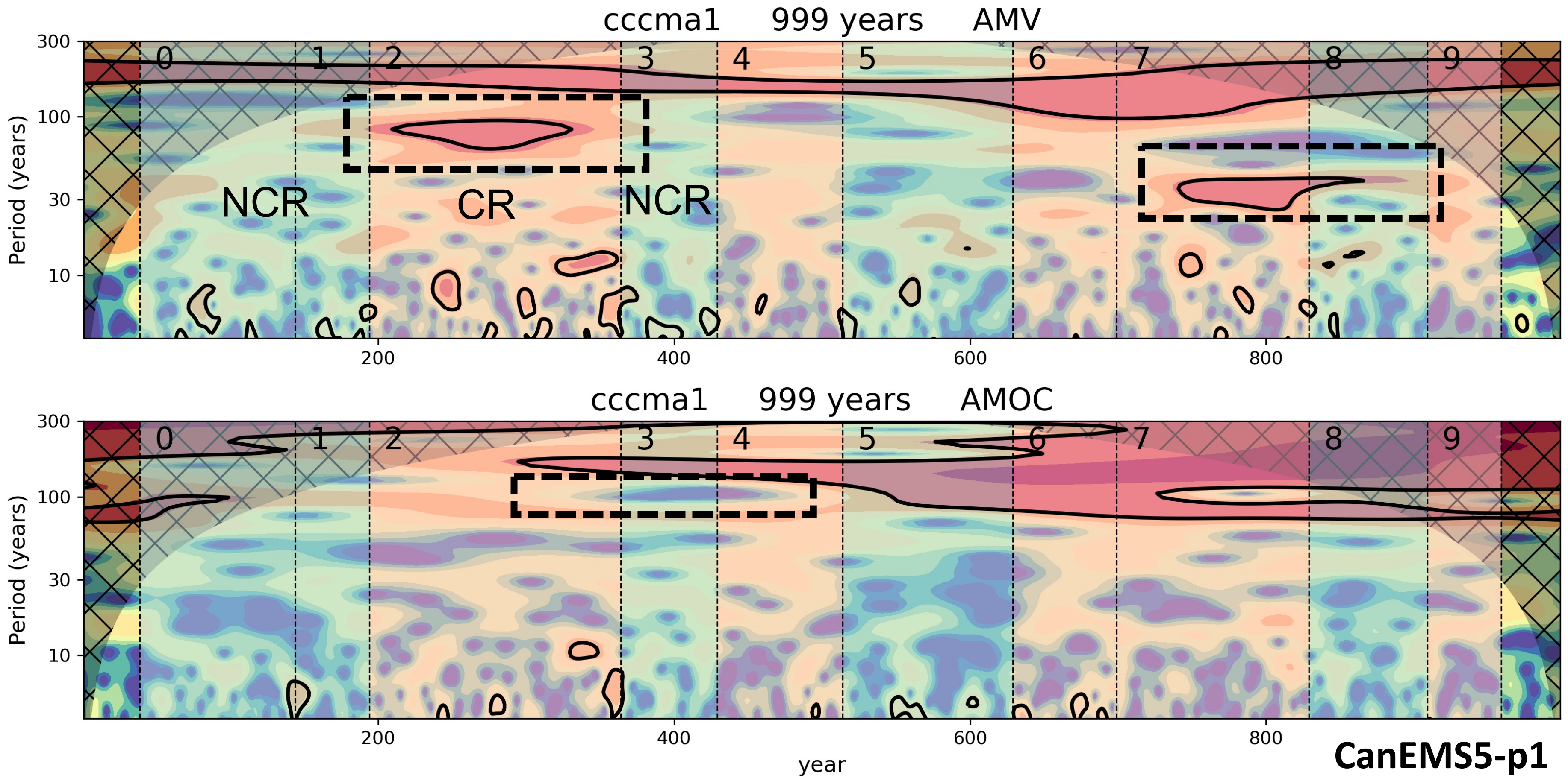
- All models feature, to different extent, **transitions between CR and NCR regimes**

- **The NCR regimes can have a duration ranging from a few decades up to several centuries**, and their inception and termination are generally marked by symmetrically rapid transitions from and towards a CR regime, respectively.

- **The relative fraction of CR- versus NCR-years is strongly model-dependent** with some models showing an almost equal partition between the two regimes (e.g.,**CanESM5 p1 and p2 and INM-CM5-0**), contrasting with models where the CR regime largely prevails (e.g, **IPSL-CM6-LR**).



Spectral fingerprints of AMOC/AMV decoupling episodes: Wavelet Transform analysis

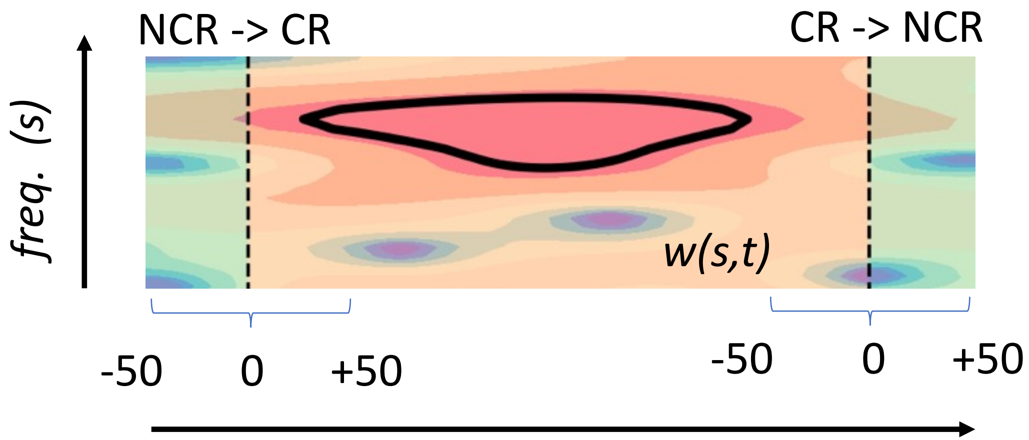


Some of the detected CR-NCR transitions appear to be associated with synchronous power peaks in the multidecadal range

- Introduce a spectral index ***L(t)*** defined as the **integral of the AMOC and AMV wavelet amplitudes (w), computed over the 30-100 year frequency range:**

$$L(t) = \int_{S0=30\,yr}^{S1=100\,yr} w(s,t)ds$$

- Compute a **composite of the *L(t)* index for all the CR-NCR and NCR-CR transitions, over a time window of ±50-year** width centered over each regime change-point, across all events and all models



$L(t)$: $t \in [-50, +50]$

Both AMV and AMOC exhibit a decay (increase) in the multidecadal (30-100 yr) spectral power when transitioning from CR to NCR (NCR to CR)

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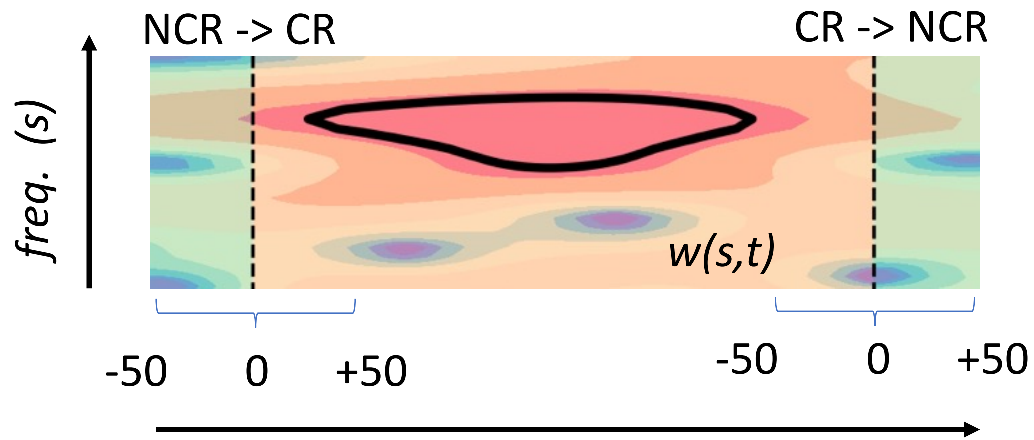

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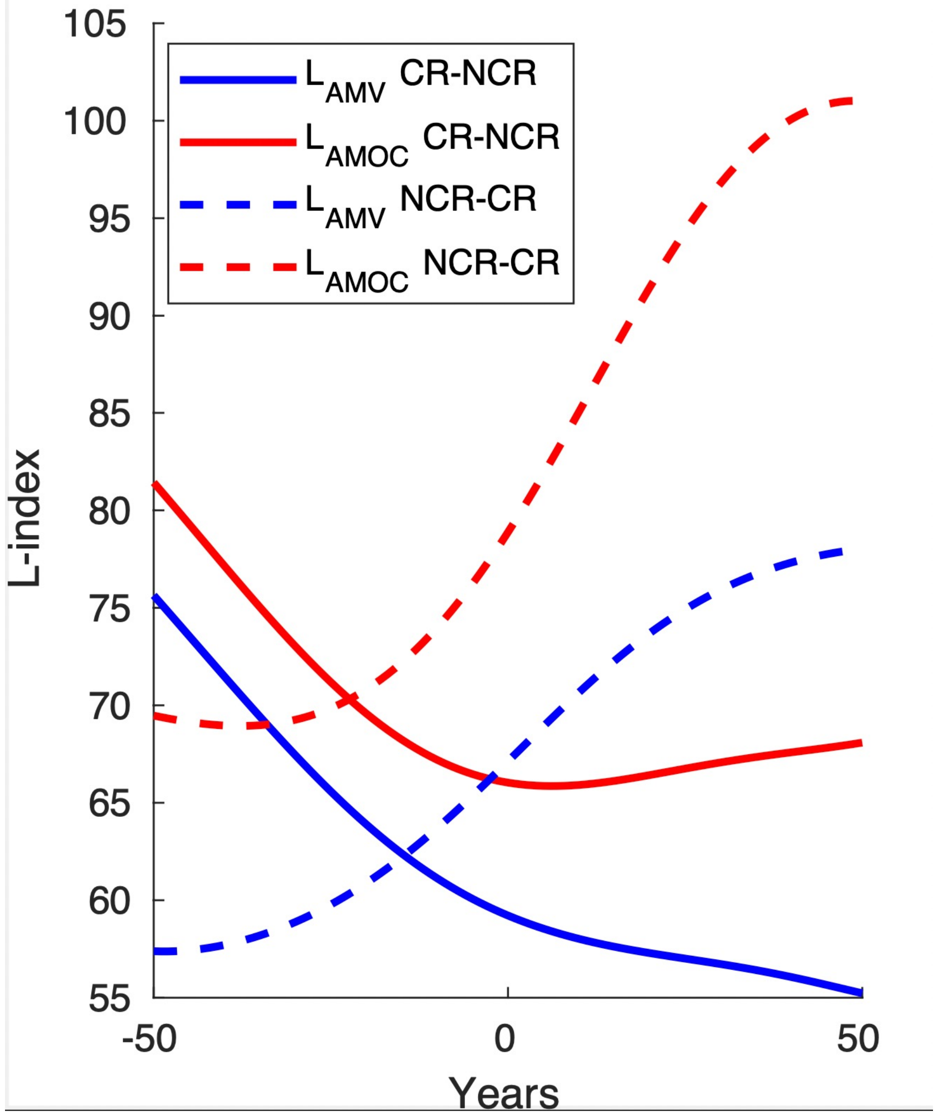

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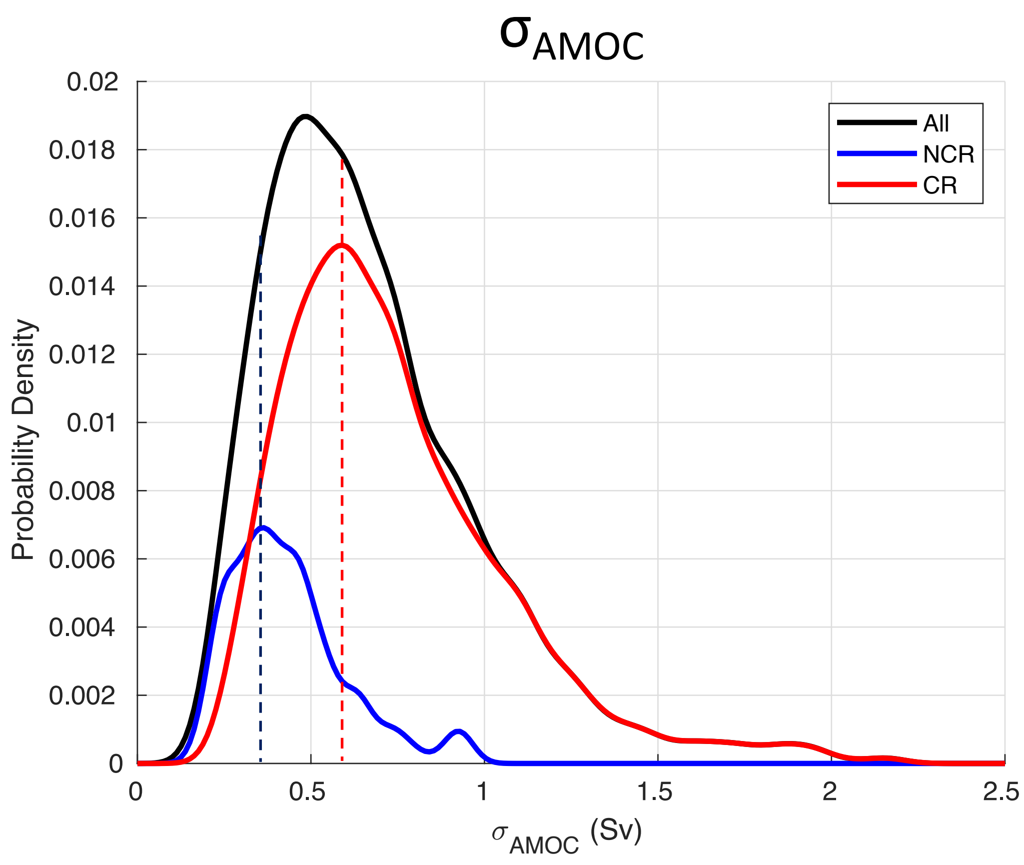
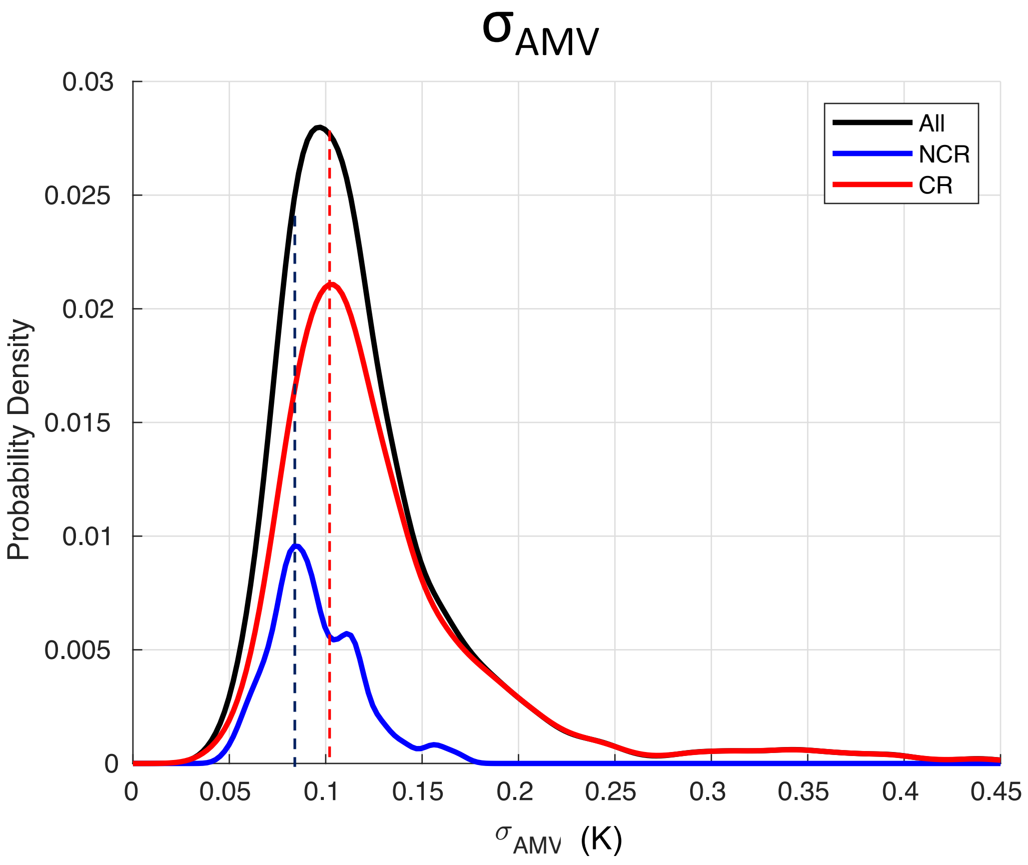
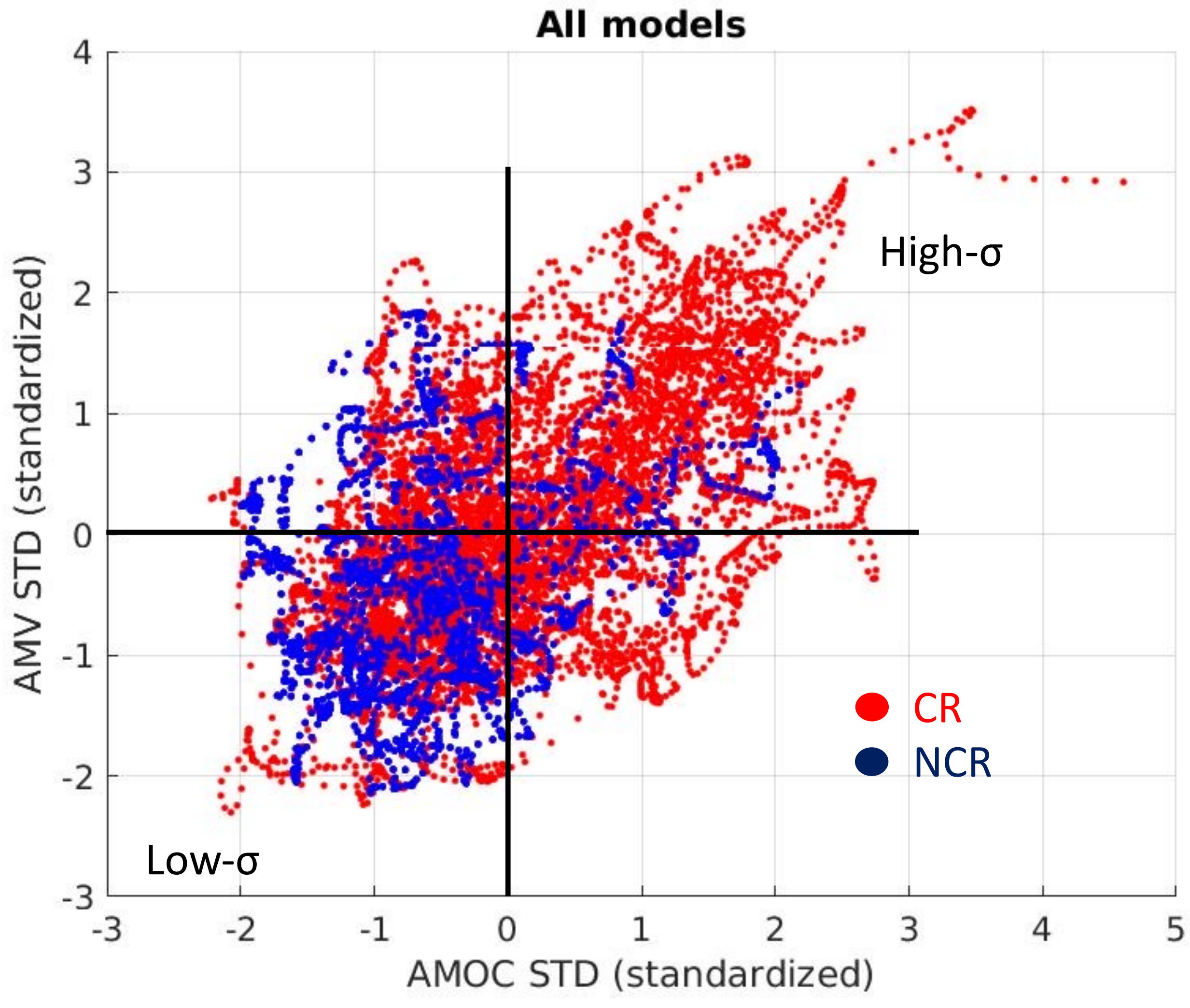
AMOC-AMV de/coupling vs variability

PDFs of moving standard deviation (σ)





NCR regimes are less frequent and show reduced variability, compared to CR



σ_{AMV}

σ_{AMOC}

- σ_{AMOC} and σ_{AMV} are significantly correlated (0.54) in the examined model population

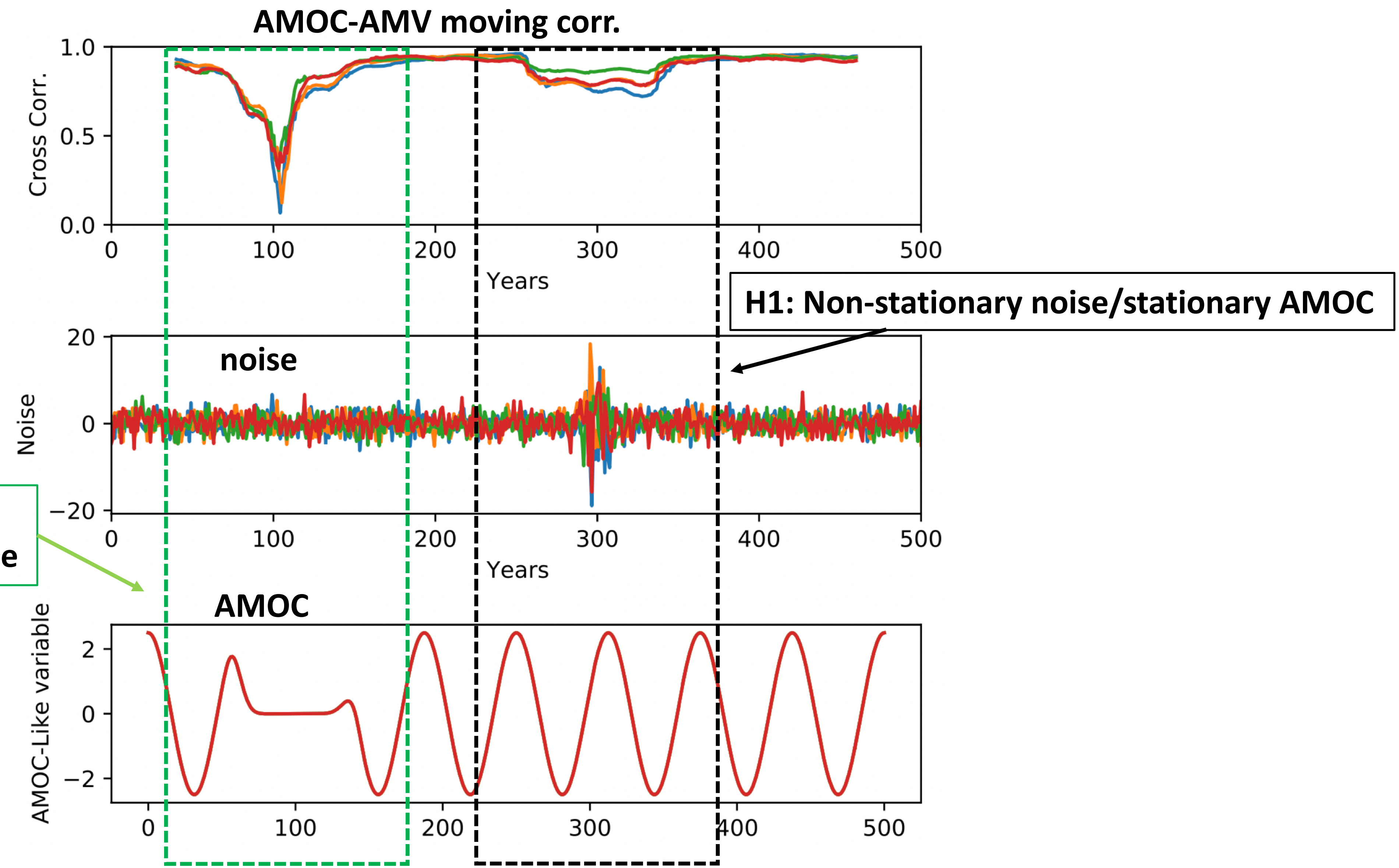
- **NCR regimes occur primarily in the low variability sub-space** (bottom-left corner in the σ_{AMOC} - σ_{AMV} diagram): the decoupling between the AMOC and AMV signals is more likely to occur when the amplitude of their variability is low.

- However the occurrence of low-σ/CR states (red points in the bottom-left corner of the scatter diagram) is not ruled out. On the other hand, high-σ/NCR states appear to be far less likely states.

Two hypotheses for the NCR regimes

Assume linearity:
AMV ∝ AMOC + *noise*

H2: Suppressed AMOC variability/stationary noise



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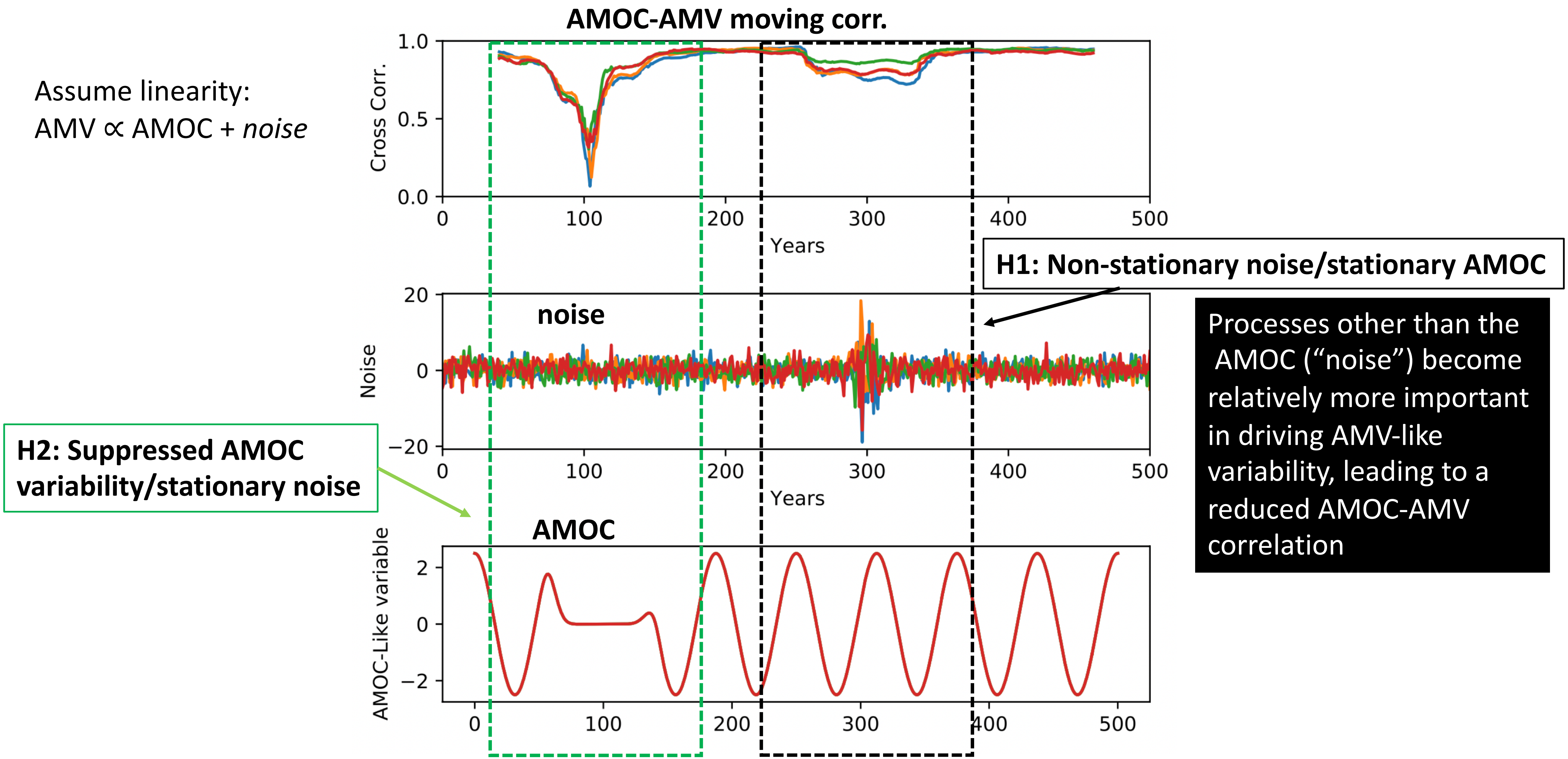

Processes other than the AMOC ("noise") become relatively more important in driving AMV-like variability, leading to a reduced AMOC-AMV correlation

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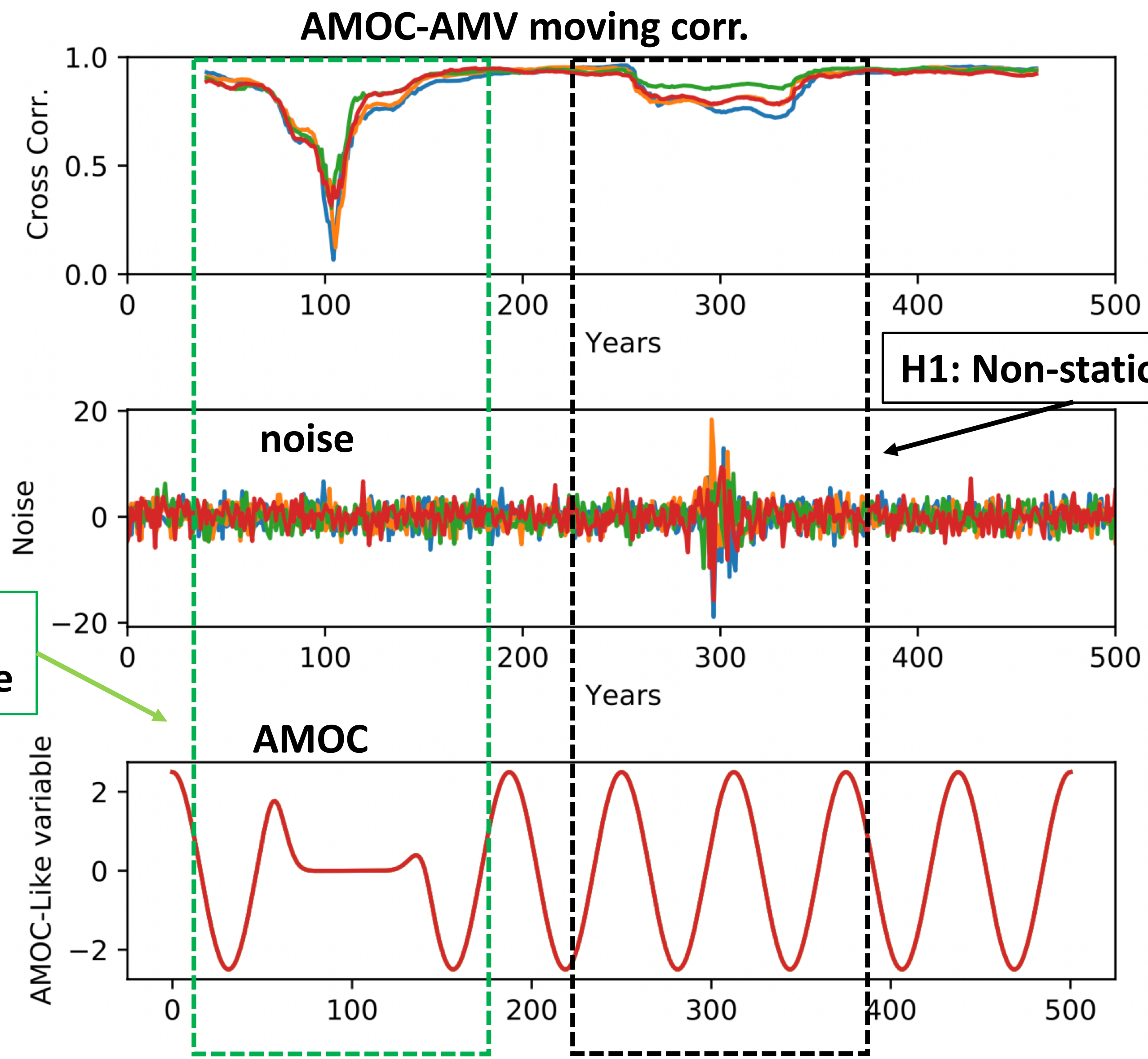

H1: Non-stationary noise/stationary AMOC

Processes other than the AMOC ("noise") become relatively more important in driving AMV-like variability, leading to a reduced AMOC-AMV correlation

H2: Suppressed AMOC variability/stationary noise

AMOC variability is suppressed, the fraction of AMV explained by AMOC is therefore reduced and the relative weight of noise on the AMV becomes larger, leading to a drop in AMOC-AMV correlation.

Conclusions

- **Spontaneous breakings of the AMOC-AMV connection** are found in a suite of CMIP6 multi-century control simulations that can last from **several decades to centuries**
- There are indications that these events are associated with a consistent **non-stationarity in the power spectra** of the AMV and AMOC signals over the **multidecadal frequency band**
- Decoupling between the AMOC and AMV is **more likely to occur under low variability (σ_{AMOC} and σ_{AMV}) conditions**.
- The evidence of long-term modulations in the AMOC-AMV covariability, has implications for the predictability in the North Atlantic regional climate. The **potential transition from strongly to weakly coupled AMOC-AMV regime** may impact the predictive ability of initialized decadal predictions over the Atlantic sector.

Geophysical Research Letters®

RESEARCH LETTER

10.1029/2022GL098771

Intermittent Behavior in the AMOC-AMV Relationship

Alessio Bellucci[1], Denis Mattei[2], Paolo Ruggieri[3], and Luca Famooss Paolini[4,5]

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Key Points:

- Spontaneous breakings of the Atlantic meridional overturning circulation-Atlantic multidecadal variability (AMOC-AMV) connection are found in a suite of multi-century control simulations from the 6th phase of the Coupled Model Inter-comparison Project
- The inception and demise of these AMOC-AMV de-coupling events can be abrupt in scale and last several decades or centuries
- Decoupling between AMOC and AMV is more likely to occur when their respective variance is low

Supporting Information:

Supporting Information may be found in the online version of this article.

Abstract The connection between the Atlantic meridional overturning circulation (AMOC) and the Atlantic multidecadal variability (AMV) is inspected in a suite of pre-industrial integrations from the 6th phase of the Coupled Model Inter-comparison Project (CMIP6), using a change-point detection method to identify different AMOC-AMV co-variability regimes. A key finding of this study is that models robustly simulate multi-decadal windows where the AMV and the AMOC are essentially uncorrelated. These regimes coexist with longer periods with relatively high correlation. Drops and recoveries of correlation are found to be often abrupt and confined in a temporal window of the order of 10 years. Phenomenological evidence suggests that the no-correlation regimes may be explained by drops in the variance of the AMOC: a less variable meridional heat transport leads to a suppressed co-variability of the AMV, leaving a larger role for non-AMOC drivers, consistent with a non-stationary AMOC-stationary noise interpretative framework.

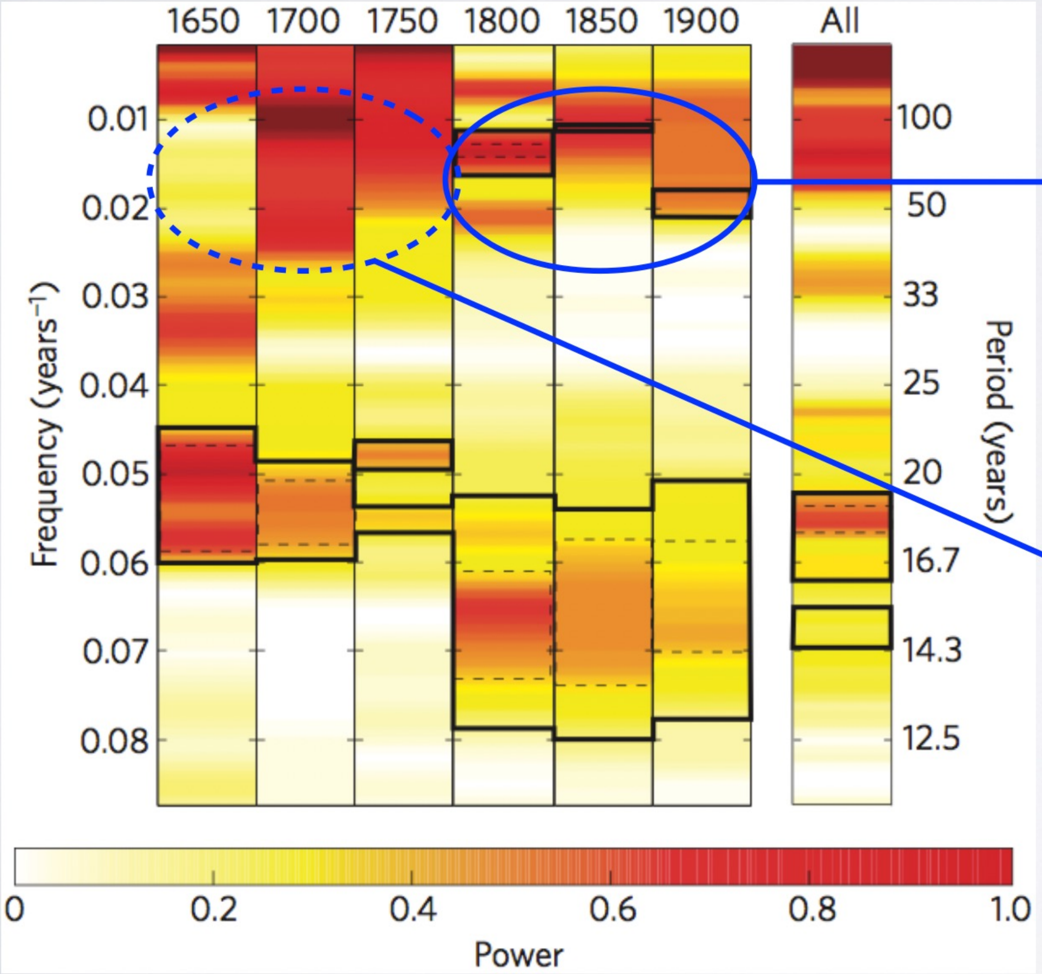
Bellucci, A., Mattei, D., Ruggieri,P., & Famooss Paolini, L. (2022). Intermittent behavior in the AMOC-AMV relationship. *Geophysical Research Letters*, *49*, e2022GL098771. https://doi. org/10.1029/2022GL098771

Additional Slides

Non-stationarity in the past AMV

coral-based proxy record of Atlantic SST, *Saenger et al.* [2009]

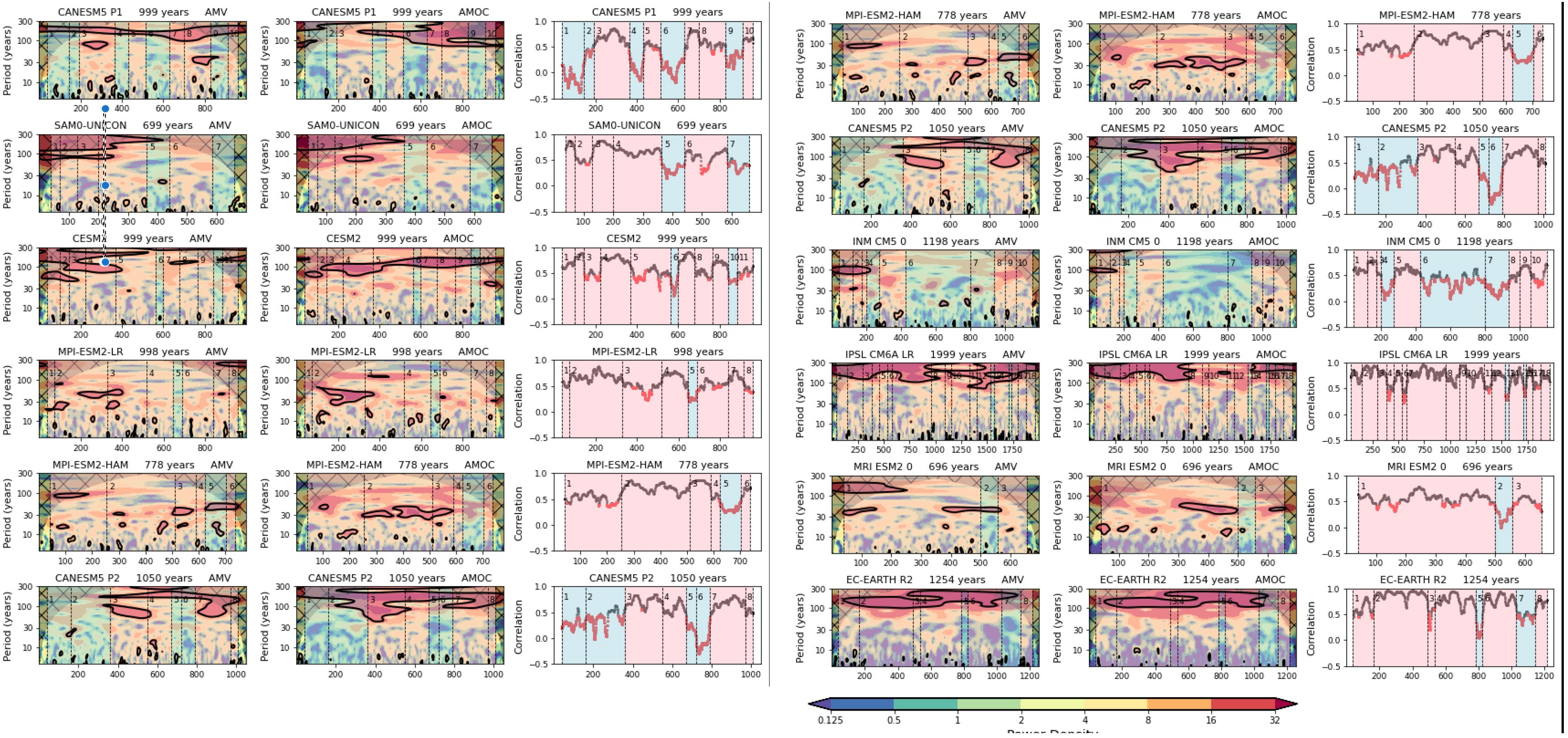
Power spectrum for 200-year bins and for the entire record



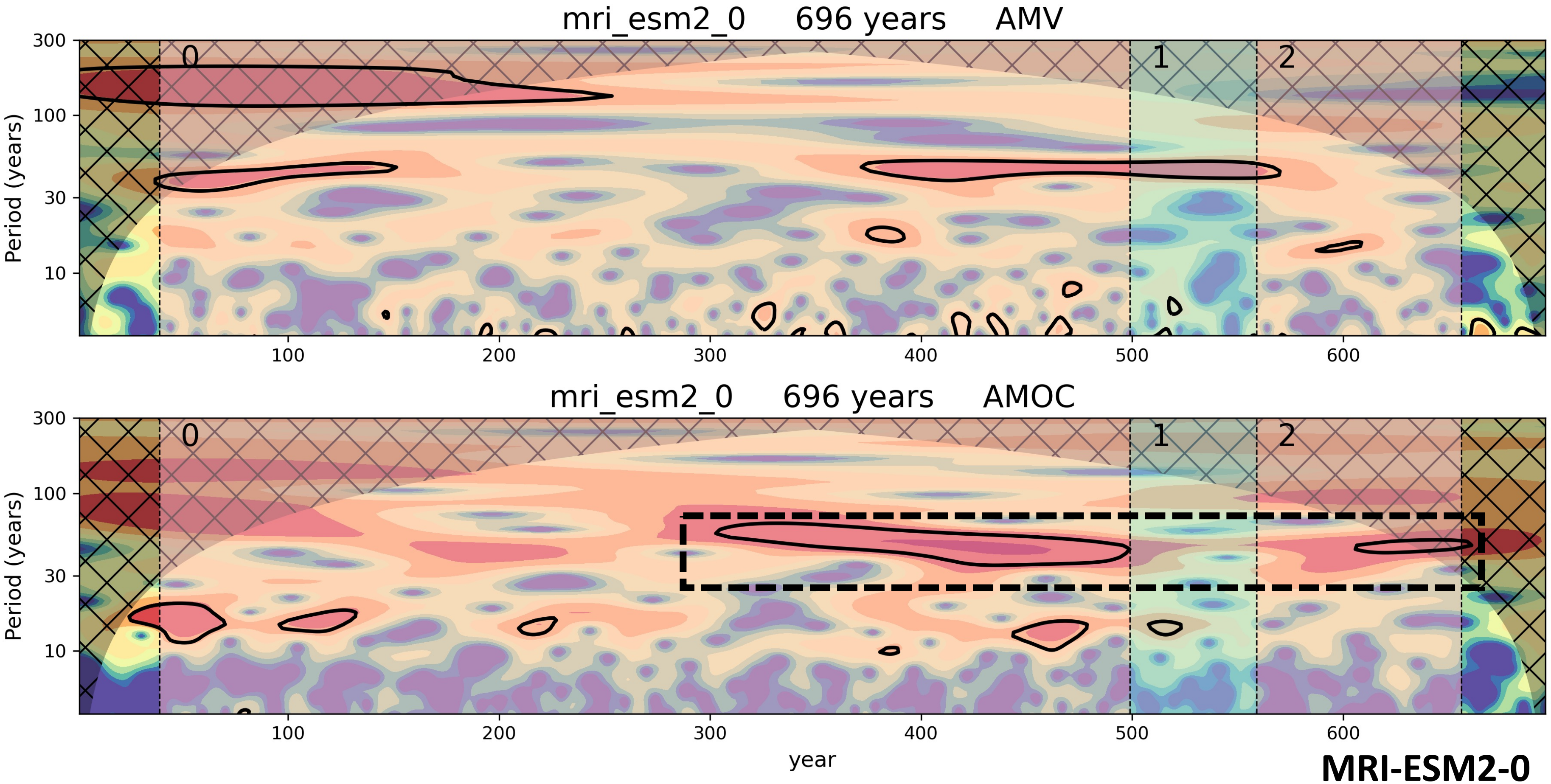
Some periods show multidecadal power similar to the currently observed AMV…

…whereas no significant multidecadal power is evident in other past epochs

Spectral fingerprints associated with AMOC/AMV decoupling episodes: Wavelet analysis

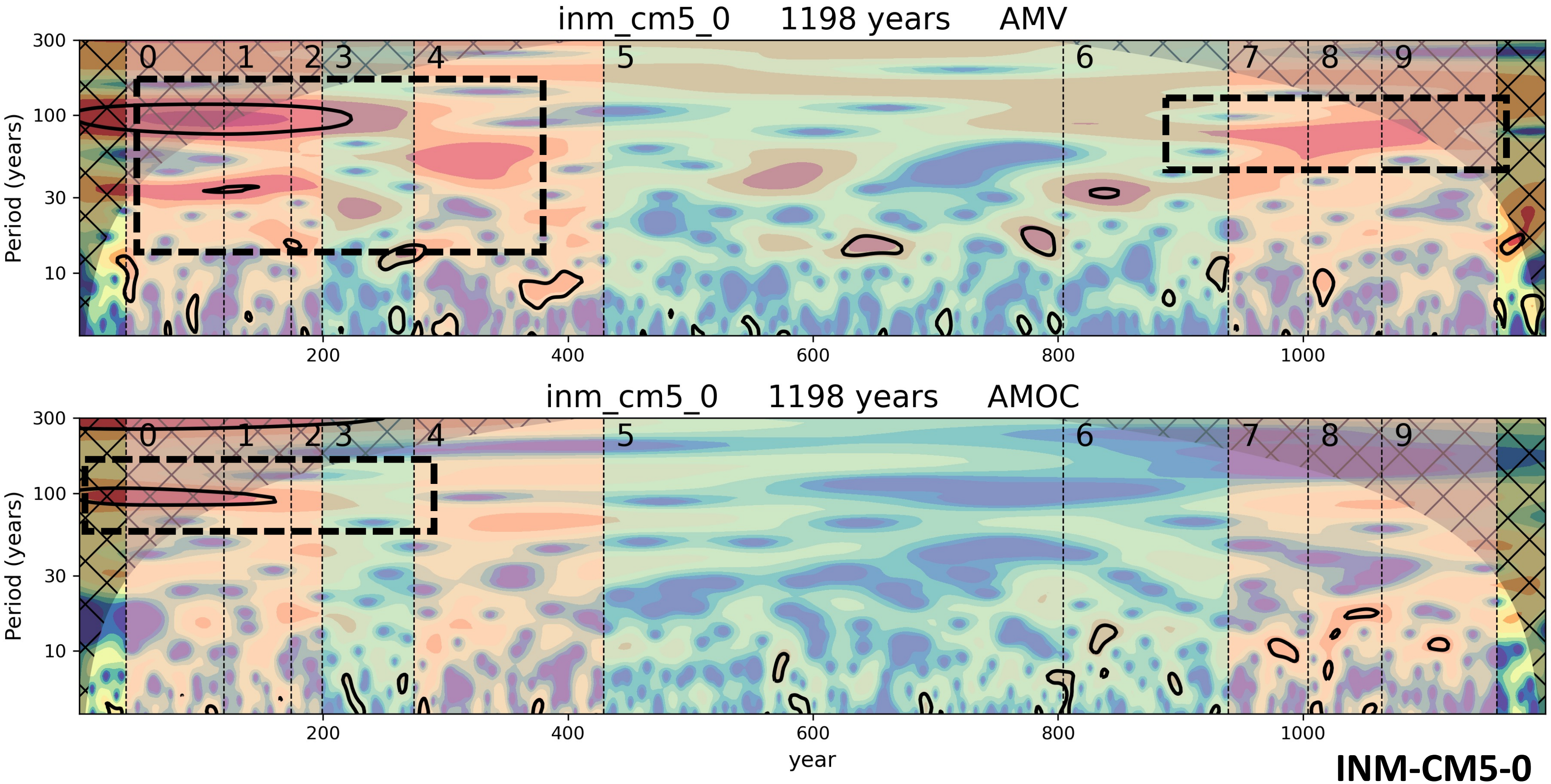


Wavelet Transform: MRI-ESM2-0



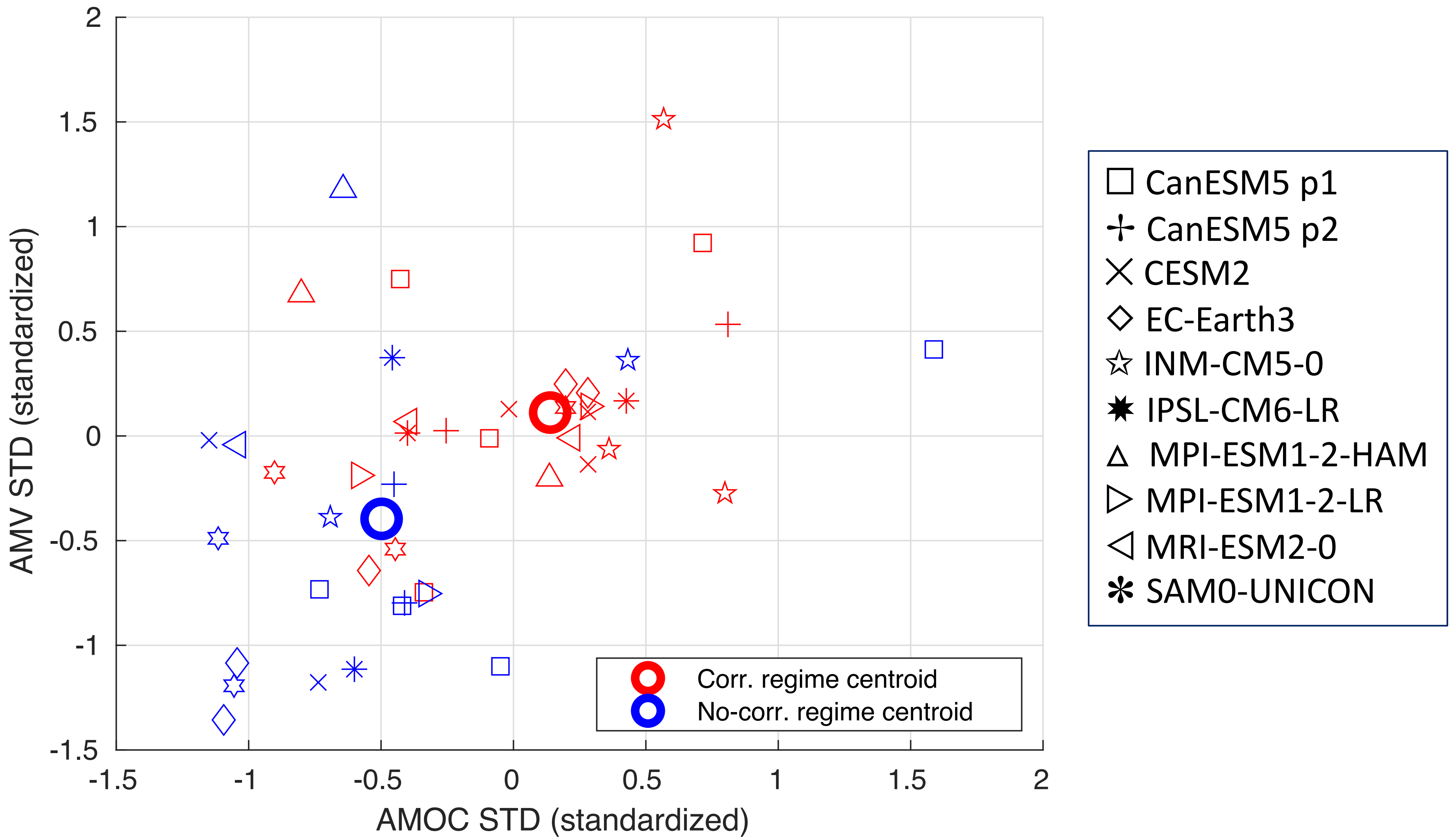
MRI-ESM2-0

Wavelet Transform: INM-CM5-0



INM-CM5-0

Centroids of CR and NCR regimes identify two distinct populations.

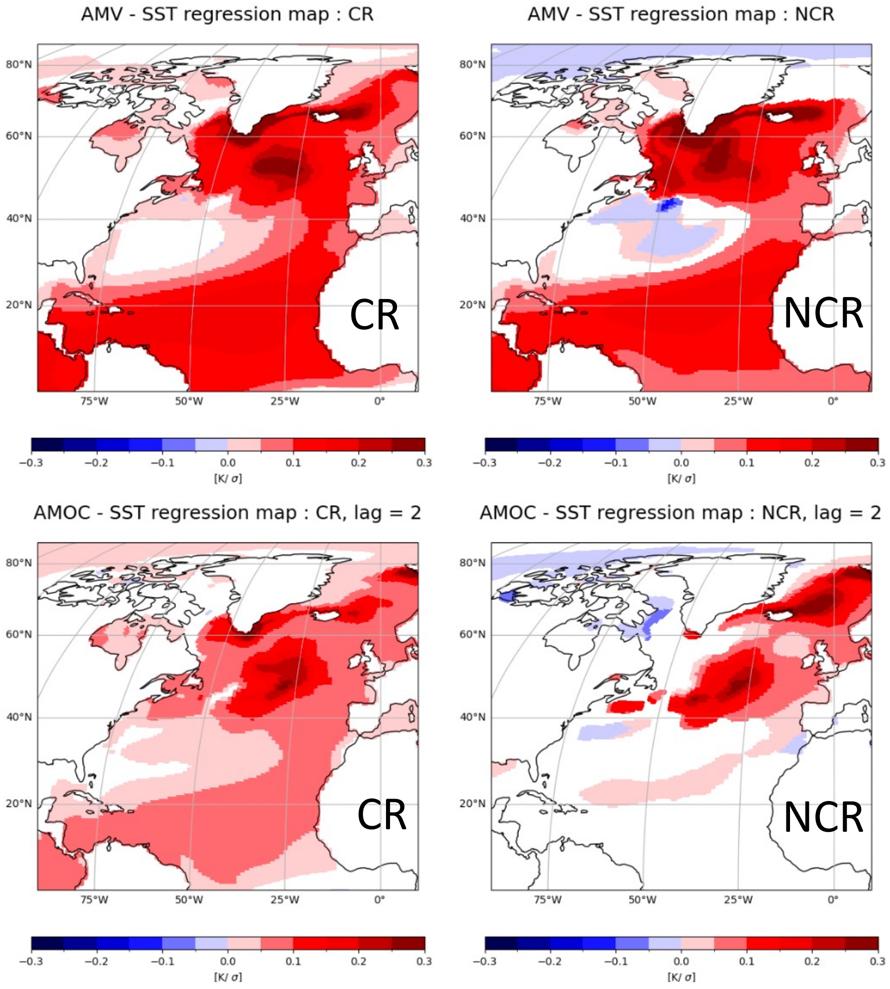


Regression patterns (AMV/SST & AMOC/SST)

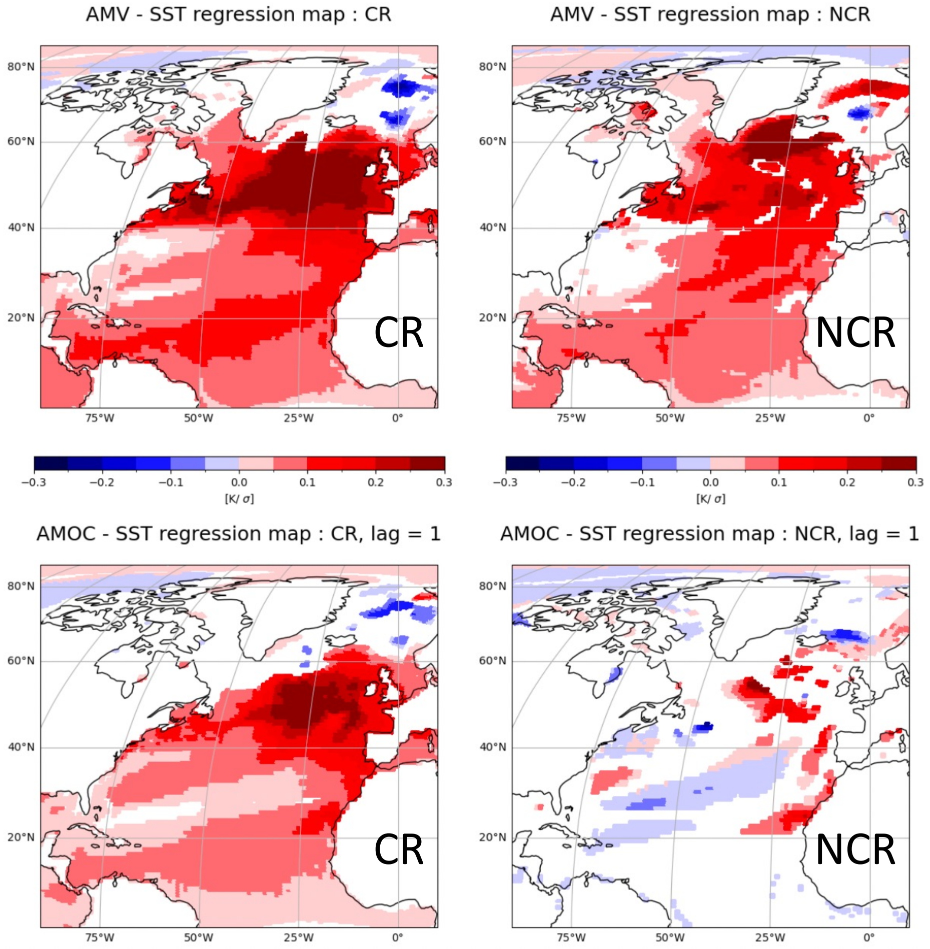
CESM1-LME

AMV/SST

AMOC/SST



CanESM5P1



[Ventrucci et al. (in prep.)]