Soufiane Karmouche

Supplementary Material

Karmouche et al. (2023), *Earth Syst. Dynam.*, 14, 309–344, https://doi.org/10.5194/esd-14-309-2023, 2023.

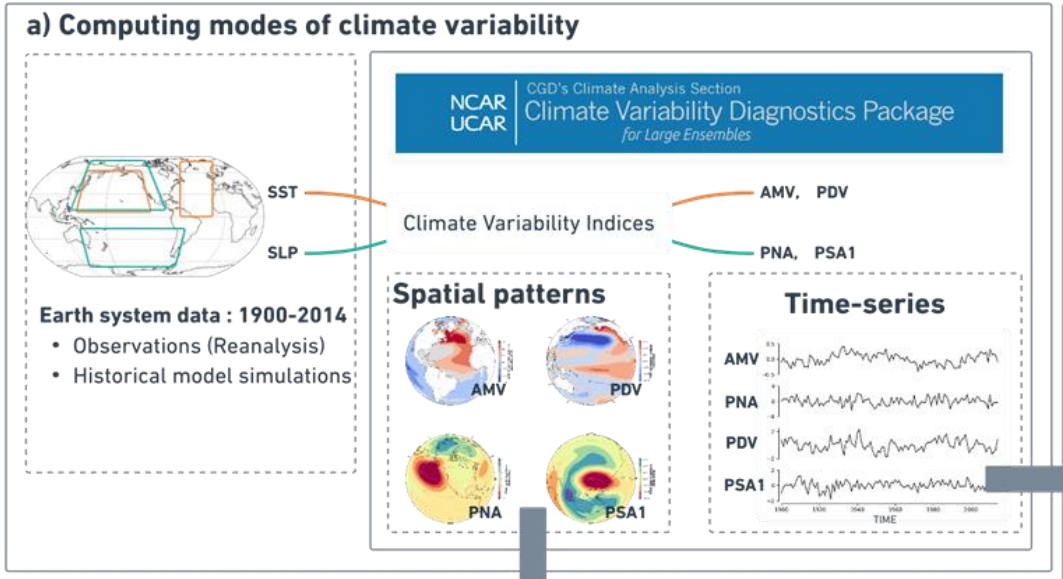
Methodology

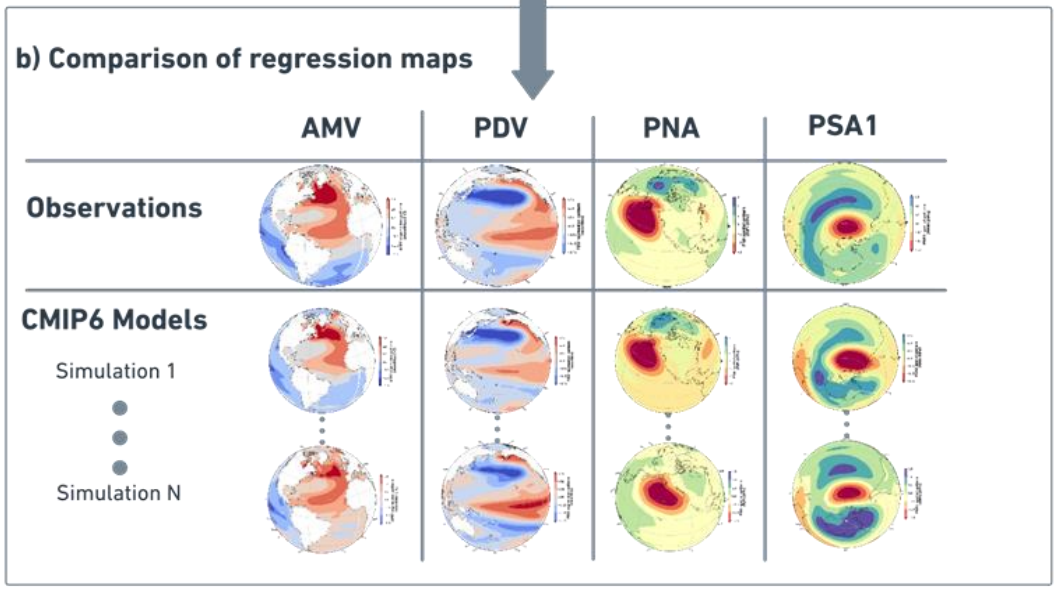
NCAR CVDP-LE for Climate Variability diagnostics
Phillips et al., 2020

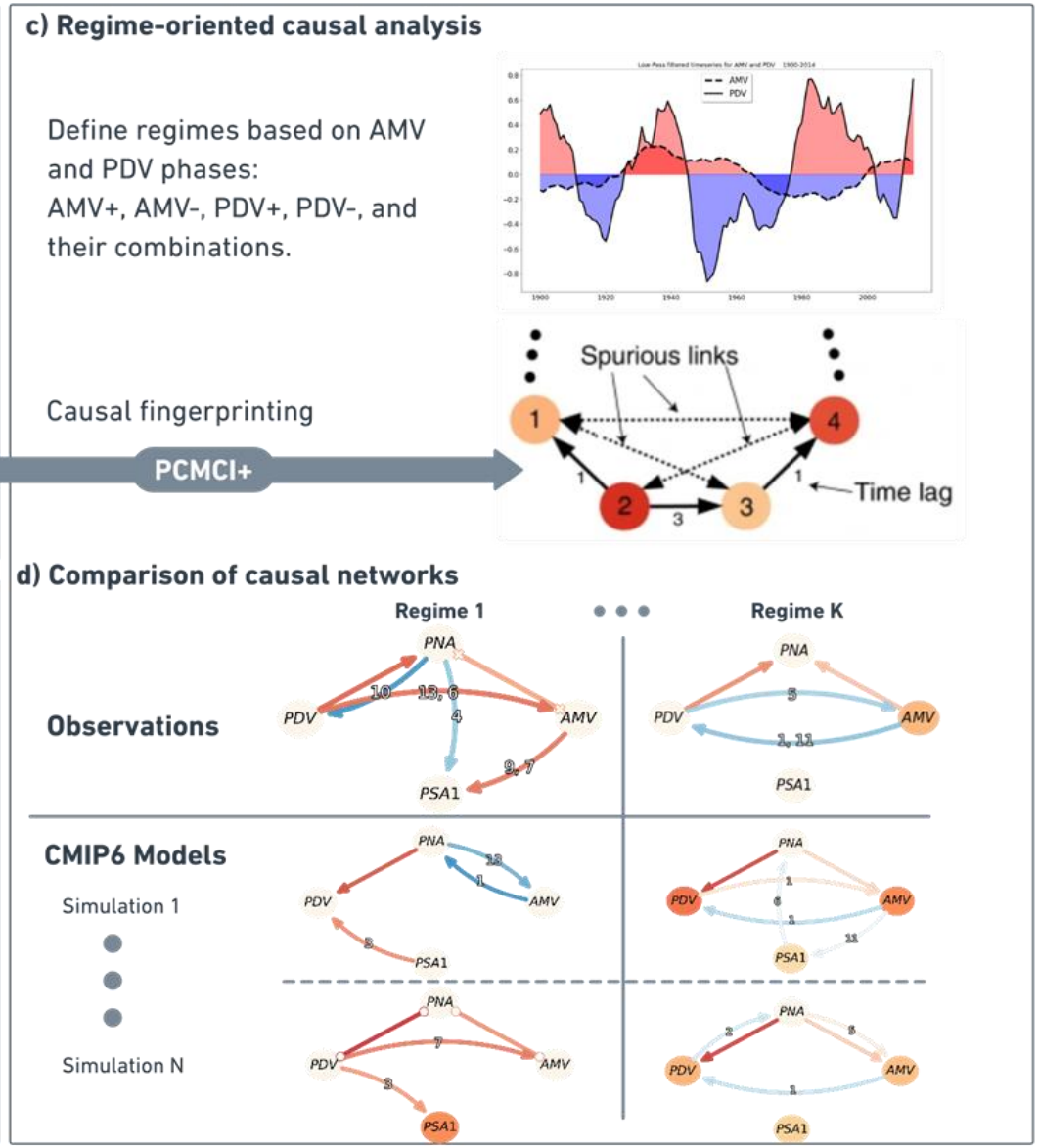
PCMCI+ for causal analysis
Runge, 2020

Reanalysis
ERSSTv5, SST
ERA20C_ERA5, PSL
1900-2014

CMIP6 Historical
12 Models
289 simulations total
1900-2014







Karmouche et al. (2023)

1) Teleconnections: Different regimes

1) Tropical Pacific drives same-sign tropical Atlantic.

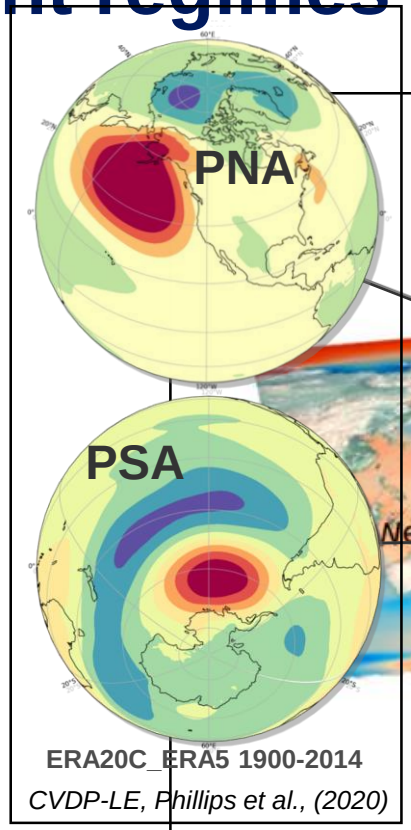
PDV**+** drives AMV**+**

Contributions from the tropical Walker circulation

.. **and extratropical teleconnections (PNA, PSA)**

2) Tropical Atlantic drives opposite-sign tropical Pacific.

- AMV**+** drives PDV**-**
- Mainly through the tropical Walker circulation

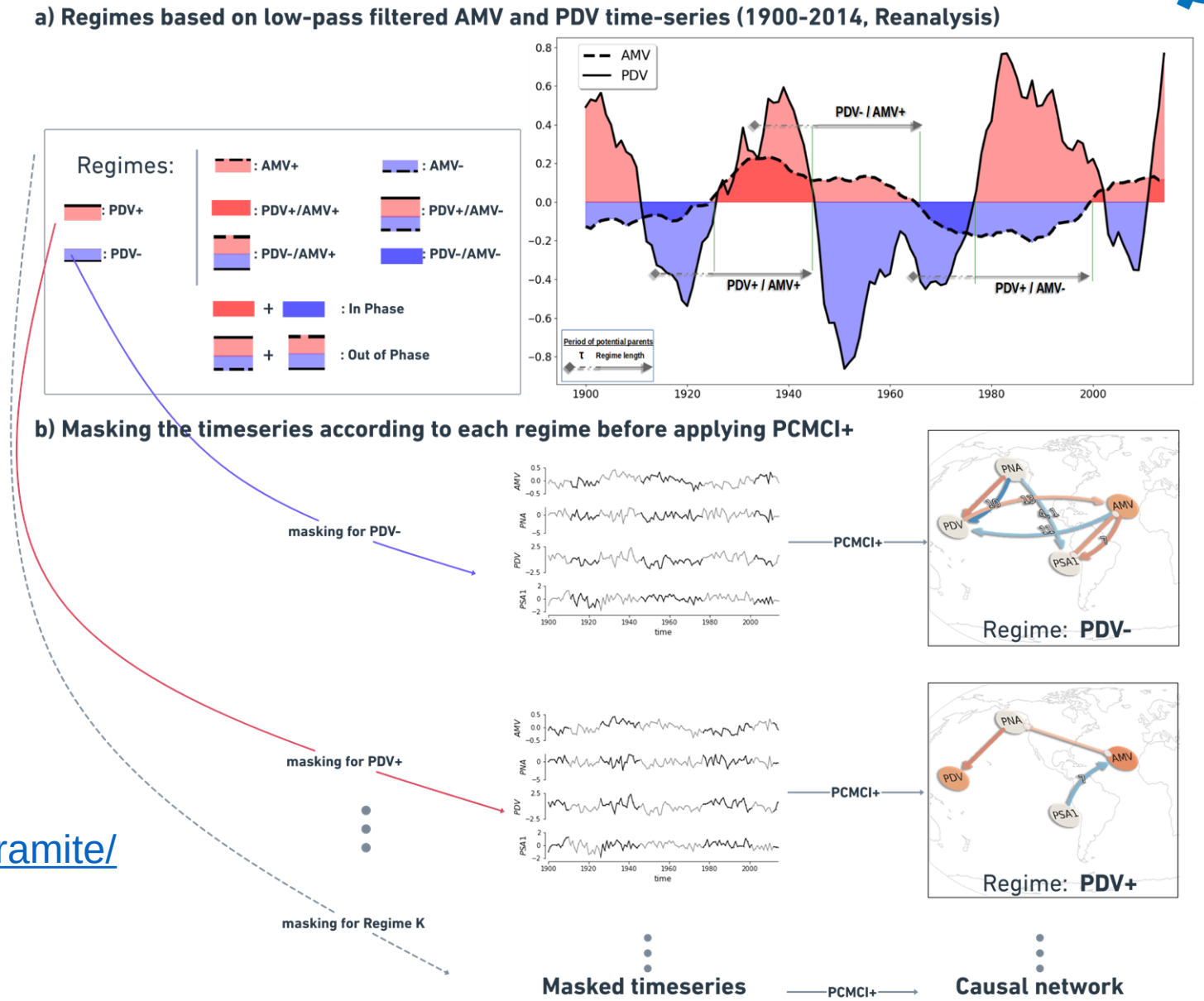


ERA20C_ERA5 1900-2014

CVDP-LE, Phillips et al., (2020)

Meehl et al. (2021)

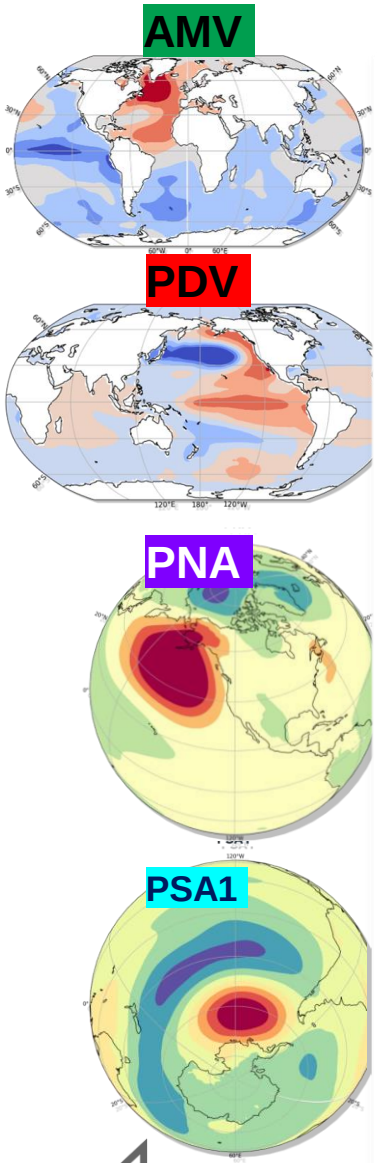
Methodology : Regime-oriented causal discovery setting

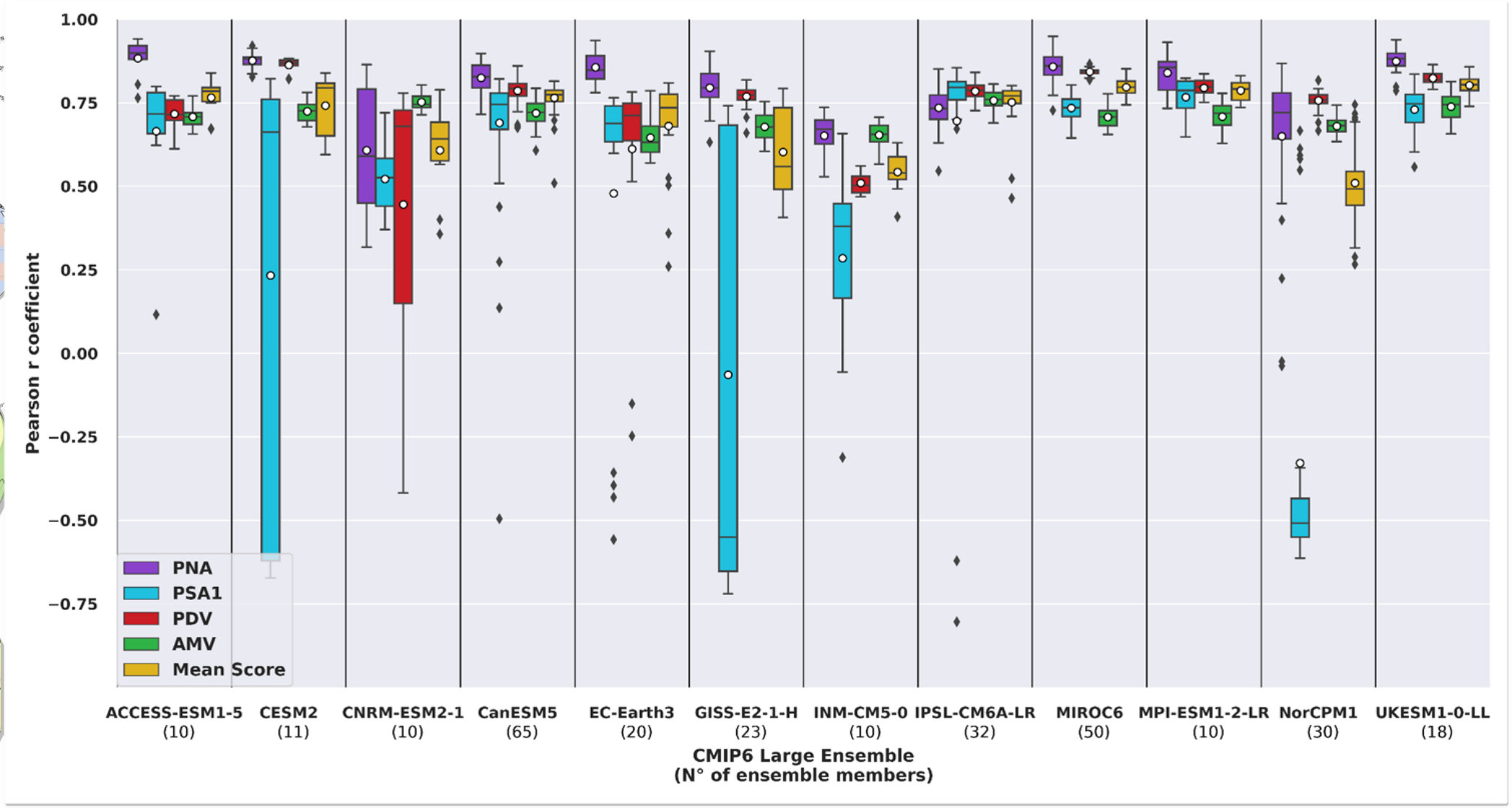


PCMCI+ (*Runge, 2020*) is part of the TIGRAMITE Package: https://github.com/jakobrunge/tigramite/

Karmouche et al. (2023)

Sanity Check: Pattern Correlations (OBS vs CMIP6 LEs)





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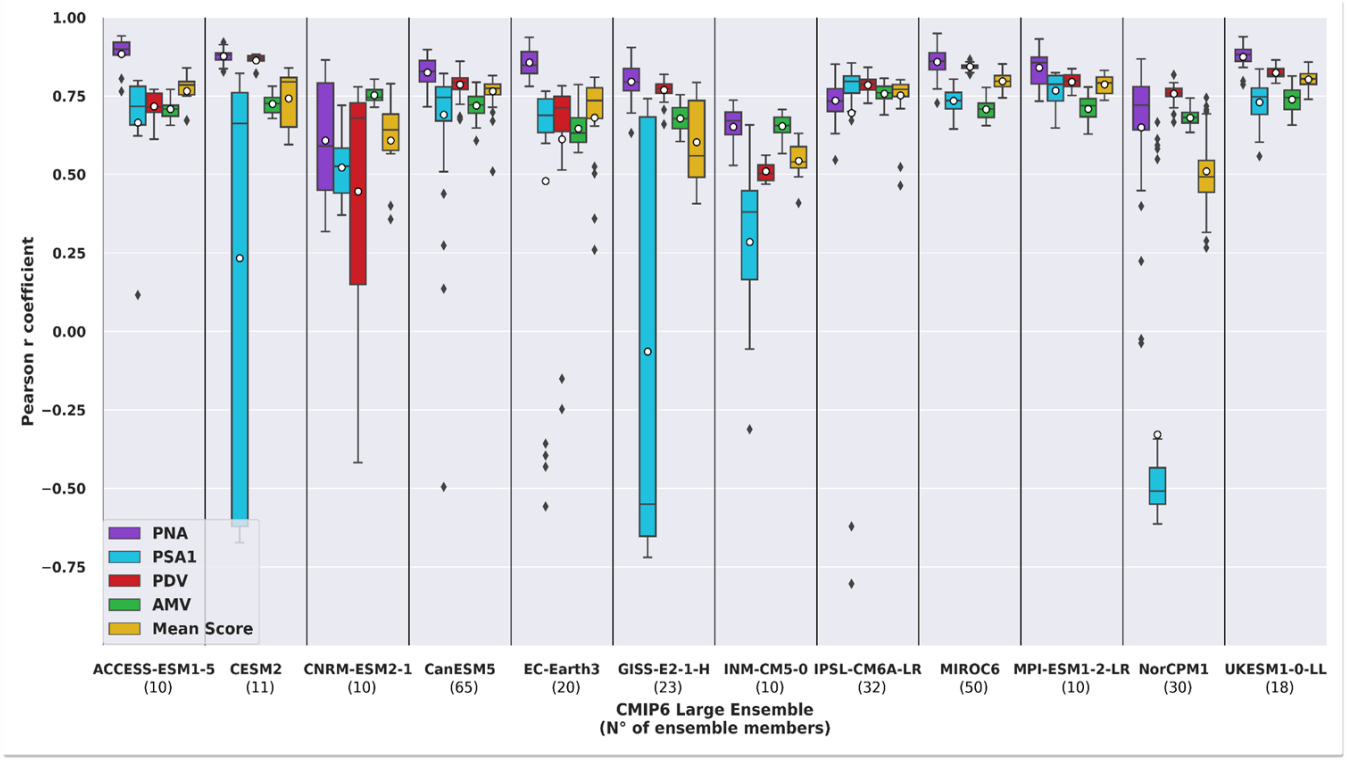
Sanity Check: Pattern Correlations (OBS vs CMIP6 LEs)

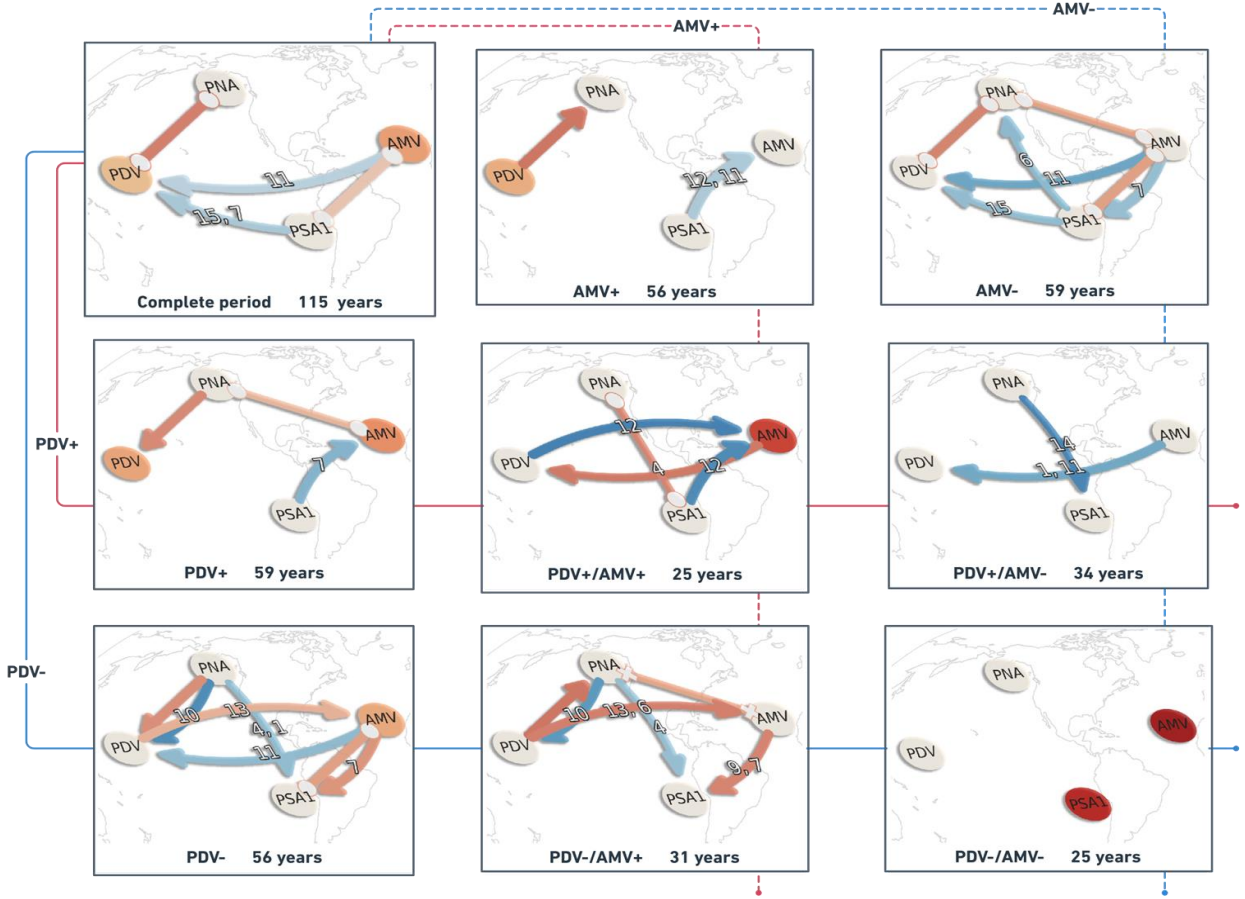
- Some models clearly fail to simulate the PSA1 patterns
(blue boxes)

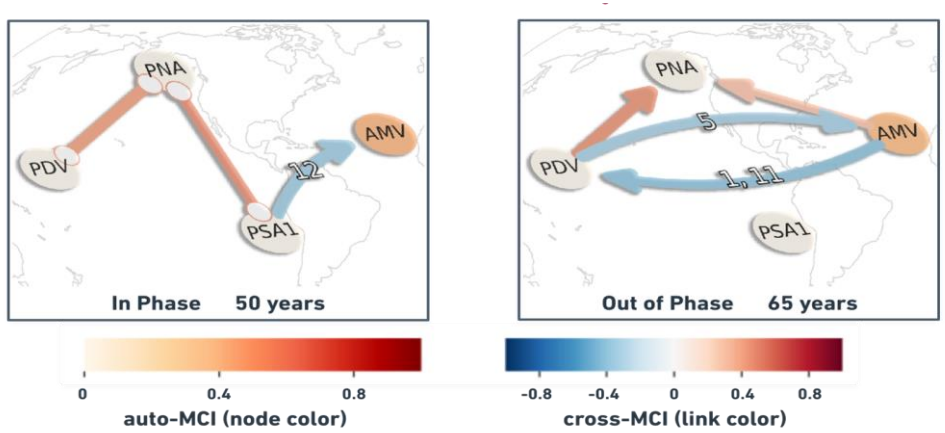
- One model shows large disagreement for PDV and PNA (purple and red boxes)

- Overall, the **CMIP6 Large Ensemble (LE) models are able to simulate the observed spatial patterns** of the four modes (most boxers are narrow and high)



Reanalysis (Reference Causal Networks)

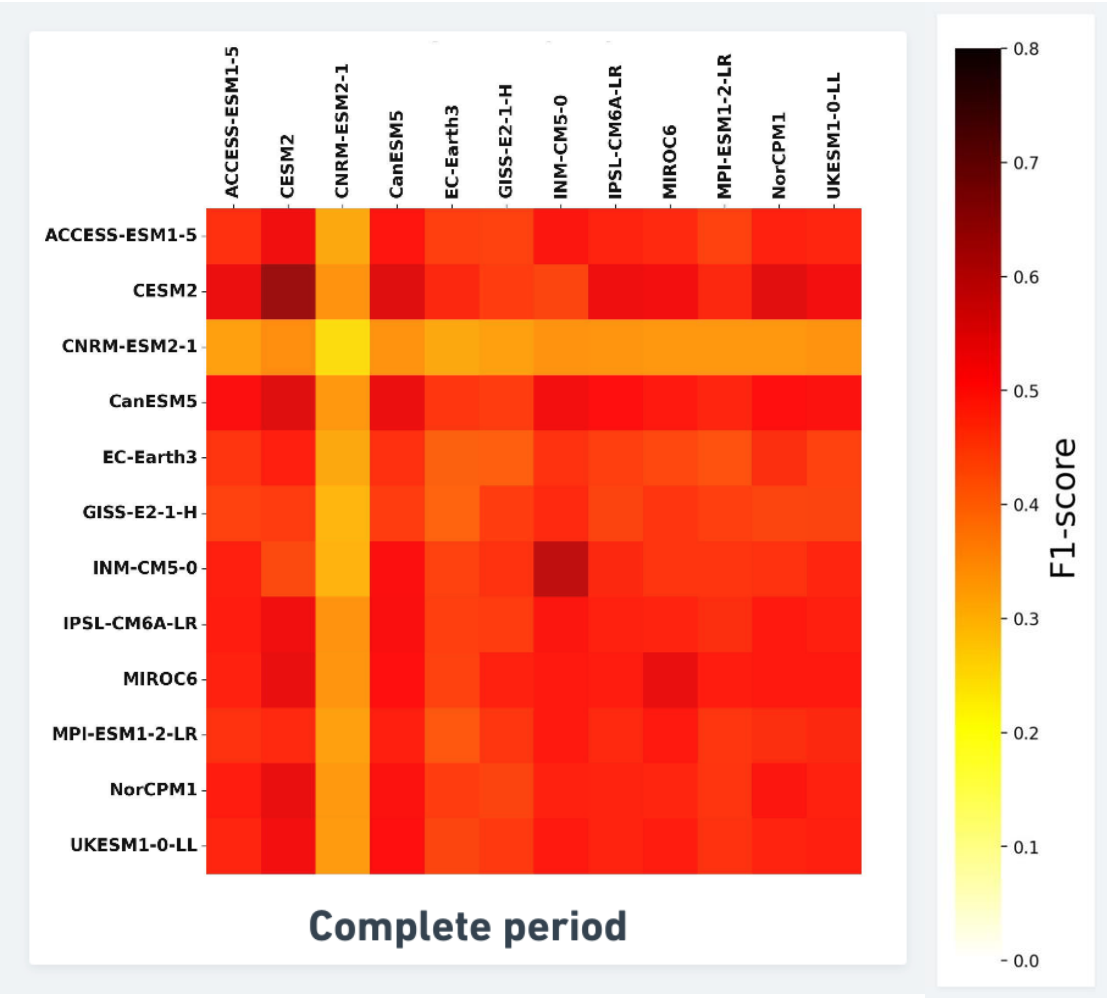


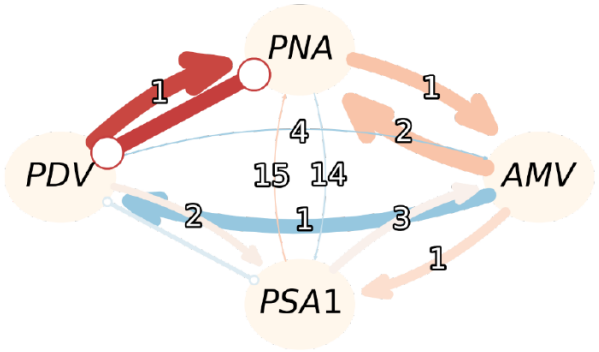


- Opposite-sign response (blue link) from AMV to PDV
- Atlantic and Pacific teleconnections to PNA during several regimes.

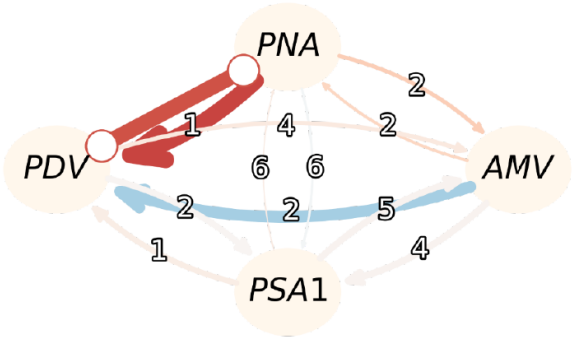
CMIP6 LE Intra- and inter-model comparisons

Complete Period

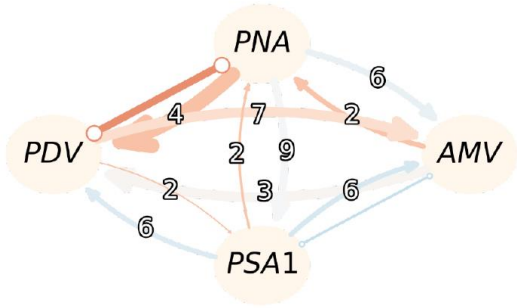




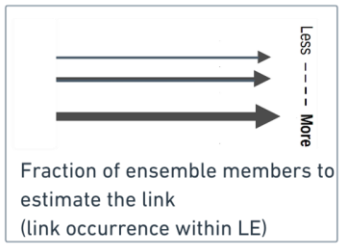
CESM2 (11)

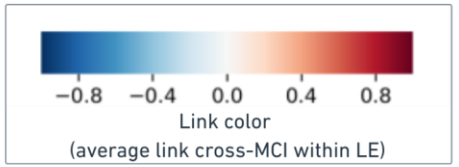


MIROC6 (50)



CNRM-ESM2-1 (10)





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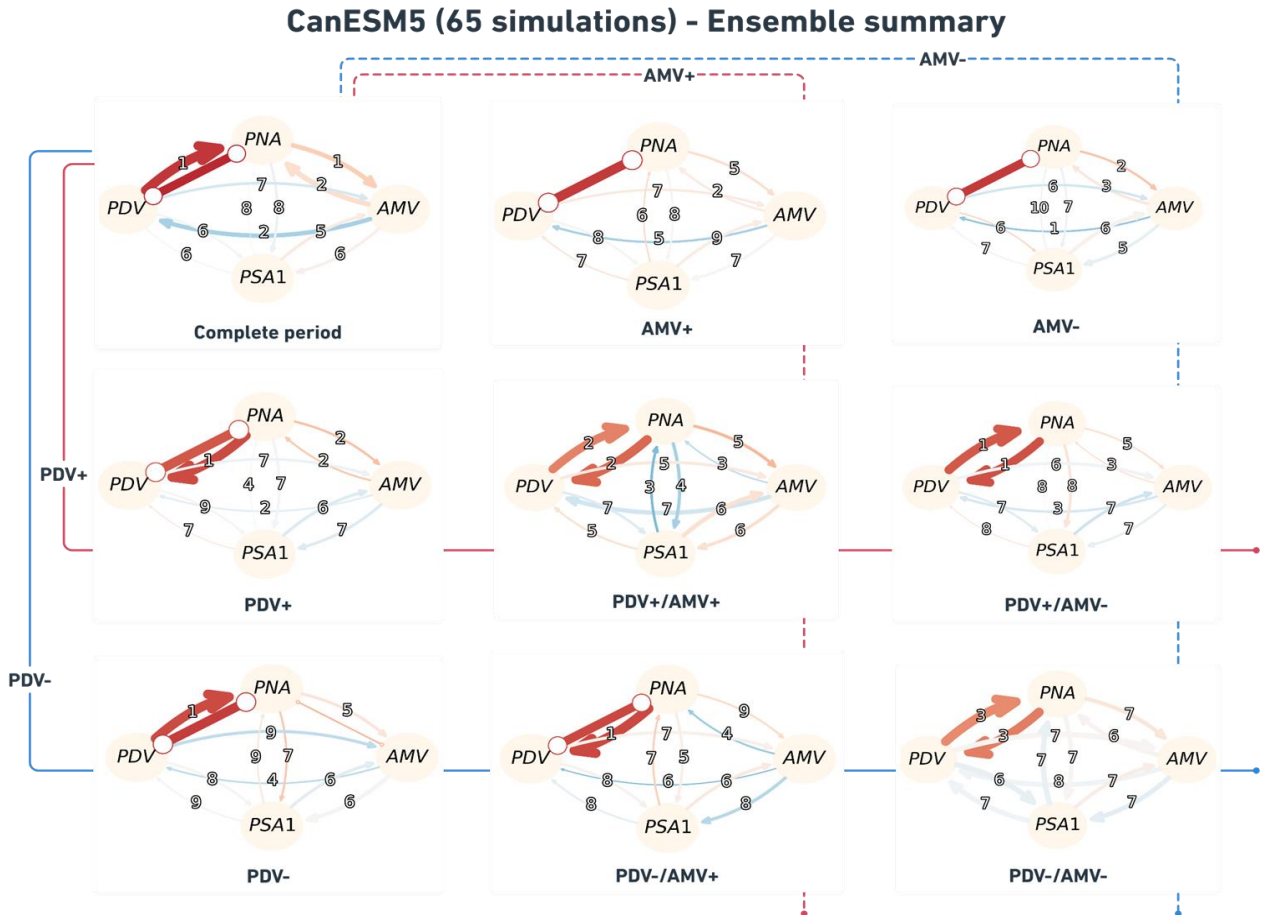
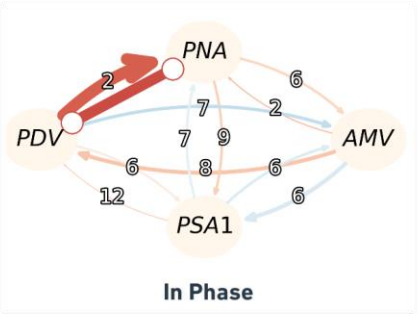
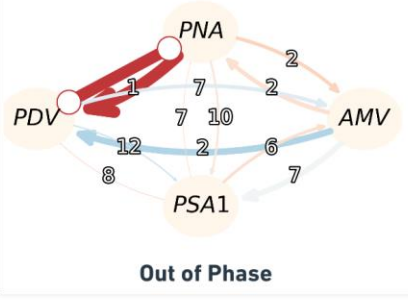
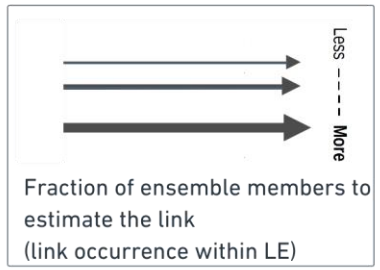
Karmouche et al. (2023)

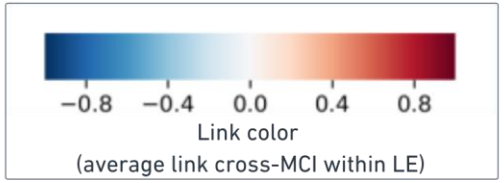
CMIP6 simulations – Model Summary CanESM5





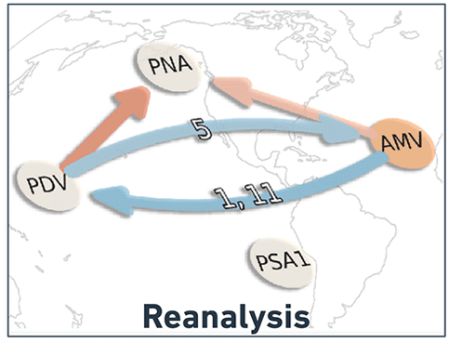




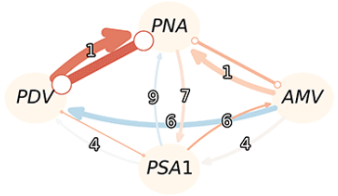


Out of Phase Regime

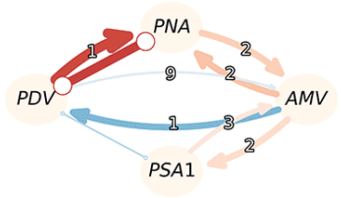
CMIP6 LE summary



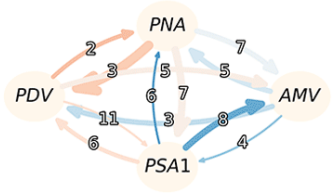
Reanalysis



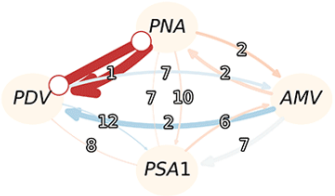
ACCESS-ESM1-5 (10)



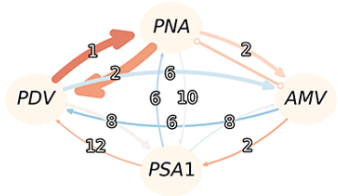
CESM2 (11)



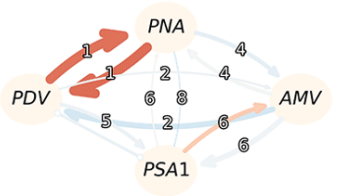
CNRM-ESM2-1 (10)



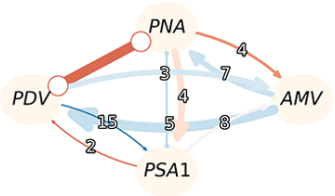
CanESM5 (65)



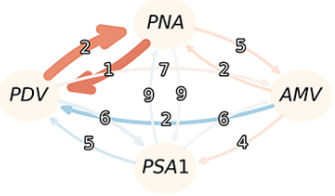
EC-Earth3 (20)



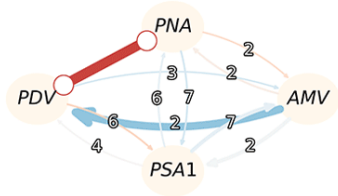
GISS-E2-1-H (23)



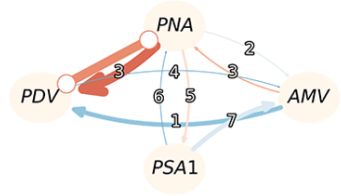
INM-CM5-0 (10)



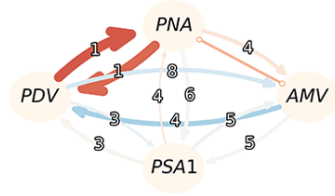
IPSL-CM6A-LR (32)



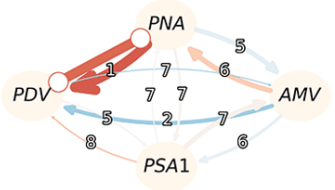
MIROC6 (50)



MPI-ESM1-2-LR (10)



NorCPM1 (30)

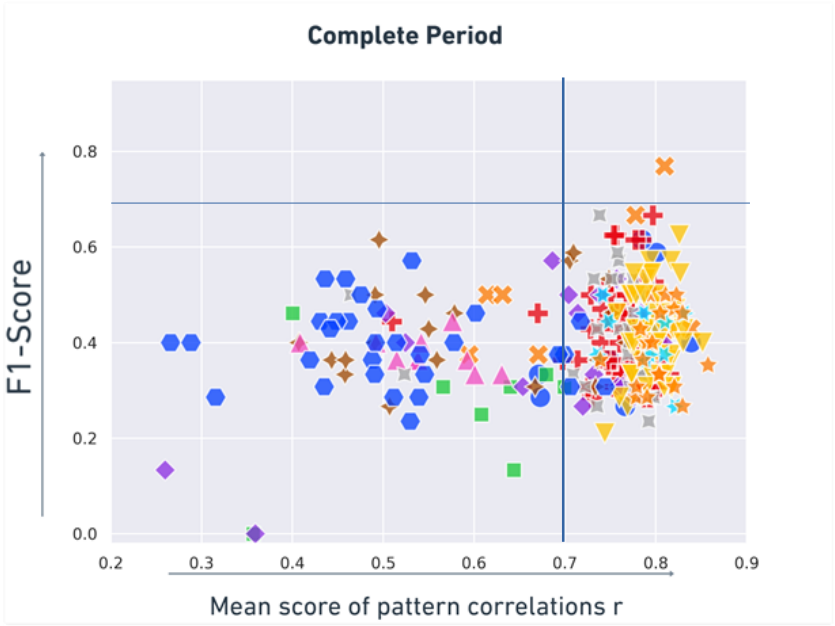


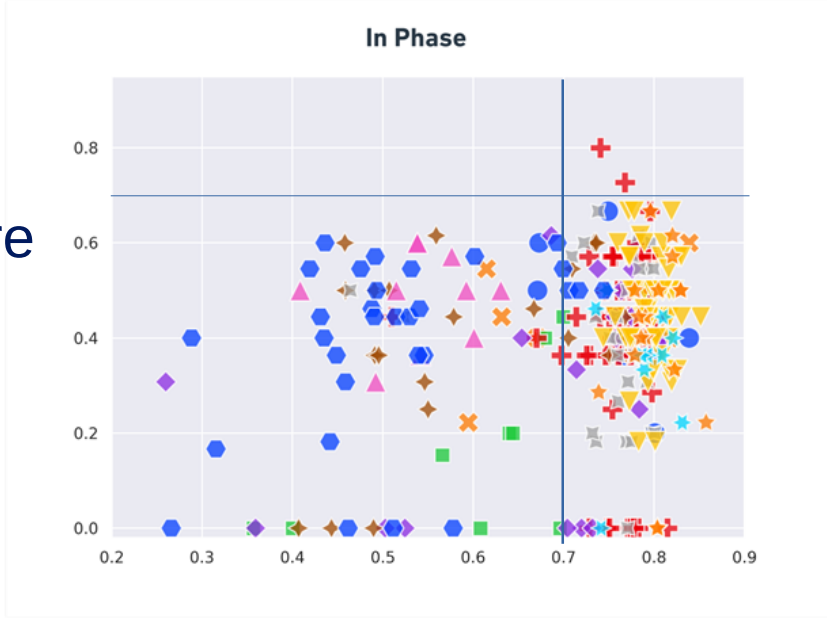
UKESM1-0-LL (18)

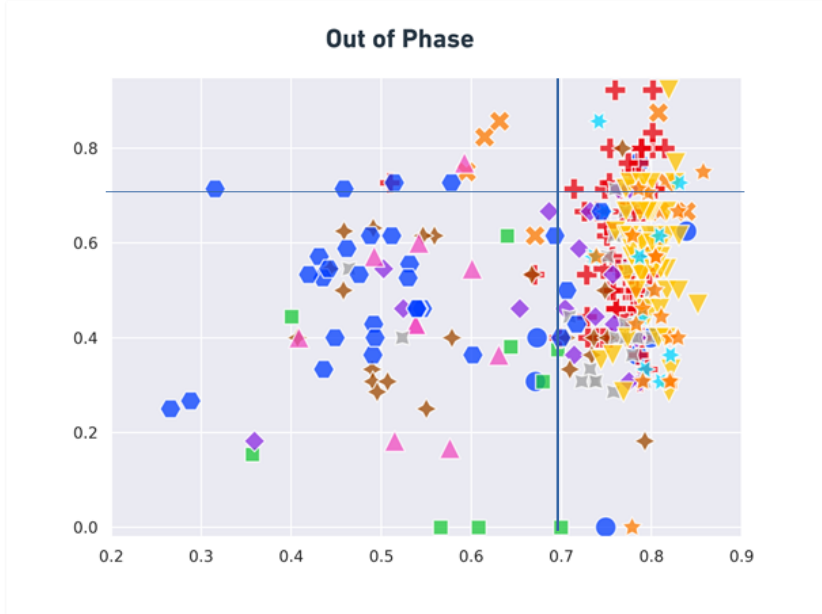
Spatial Patterns vs Causal Fingerprints

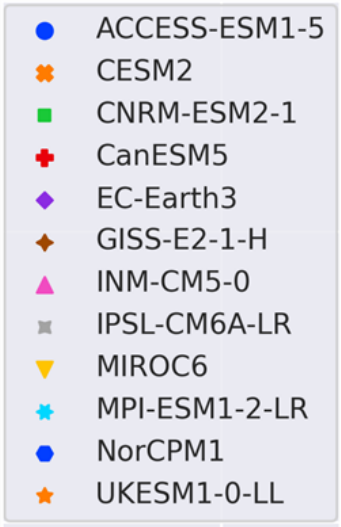
CMIP6 compared to Reanalysis

Mean score of pattern correlations **vs** F1-score

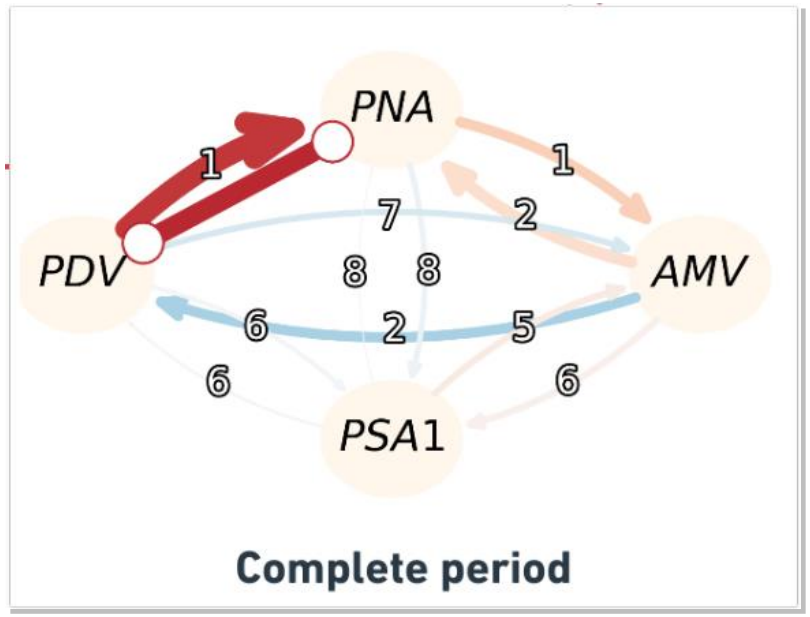


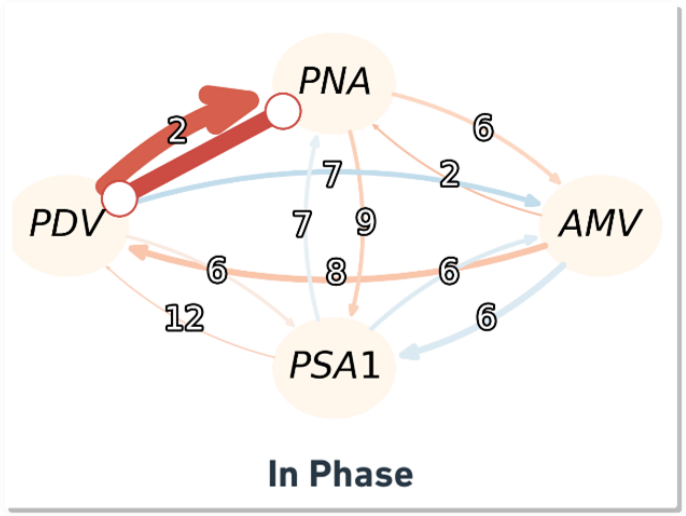


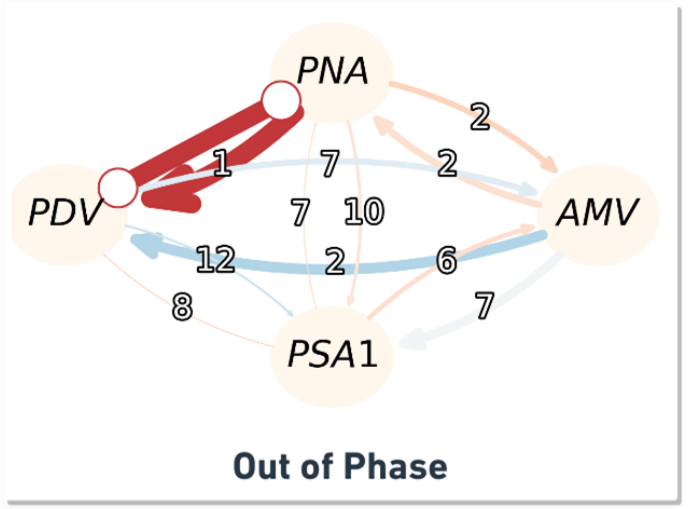


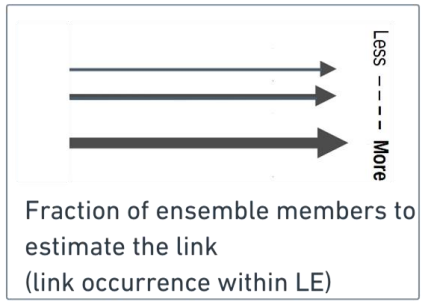


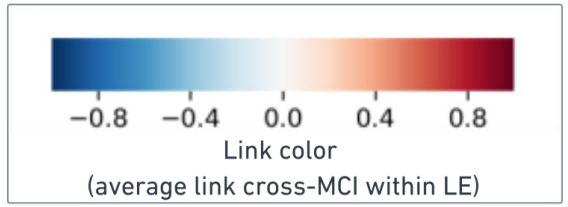
CMIP6 LE model (CanESM5, 65 members)











- Clear red PDV – PNA links detected in most simulations
- A good fraction detect blue AMV → PDV links

CMIP6 models

Table 1. CMIP6 Large Ensemble historical simulations used in the analysis

Dataset		Components		N° realisations used	References
CMIP6 LE	Institute	Atmosphere model	Ocean model		
ACCESS-ESM1-5	CSIRO	HadGAM2	ACCESS-OM2	10	Ziehn et al. (2019)
CESM2	NCAR	CAM6	POP2	11	Danabasoglu (2019)
CNRM-ESM2-1	CNRM	Arpege 6.3	NEMO3.6	10	Seferian (2018)
CanESM5	CCCma	CanAM5	NEMO3.4.1	65	Swart et al. (2019)
EC-Earth3	EC-Earth	IFS cy36r4	NEMO3.6	20	Döscher et al. (2022)
GISS-E2-1-H	NASA	GISS-E2.1	HYCOM Ocean	23	Kelley et al. (2020)
INM-CM5-0	INM	INM-AM5-0	INM-OM5	10	Volodin et al. (2019)
IPSL-CM6A-LR	IPSL	LMDZ	NEMO-OPA	32	Boucher et al. (2018)
MIROC6	JAMSTEC, AORI, NIES,R-CCS	CCSR AGCM	COCO4.9	50	Shiogama et al. (2019)
MPI-ESM1-2-LR	MPI-M	ECHAM6.3	MPIOM1.63	10	Wieners et al. (2019)
NorCPM1	NorESM Climate modeling Consortium	CAM-OSLO4.1	MICOM1.1	30	Bethke et al. (2019)
UKESM1-0-LL	Met Office Hadley Centre	MetUM-HadGEM3-GA7.1	NEMO-HadGEM3-GO6.0	18	Tang et al. (2019)