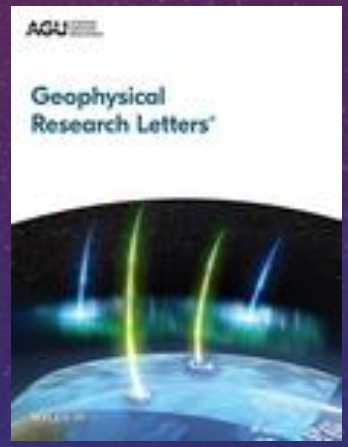
WINTER EURO-ALTANTIC CLIMATE MODES: FUTURE SCENARIOS FROM A CMIP6 MULTI-MODEL ENSEMBLE

Eleonora Cusinato[1], Angelo Rubino[1], Davide Zanchettin[1]

[1]Universita'Ca' Foscari, Dip. Scienze Ambientali, Informatica e Statistica



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VENETIARVM VNIVERSITAS IN DOMO FOSCARI

eleonora.cusinato@unive.it

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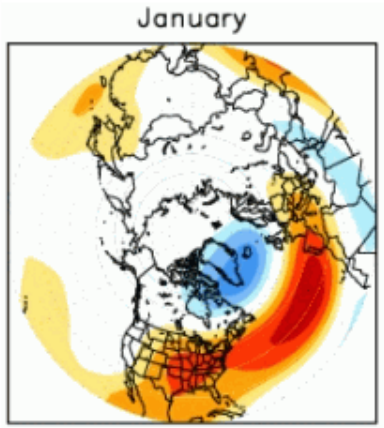
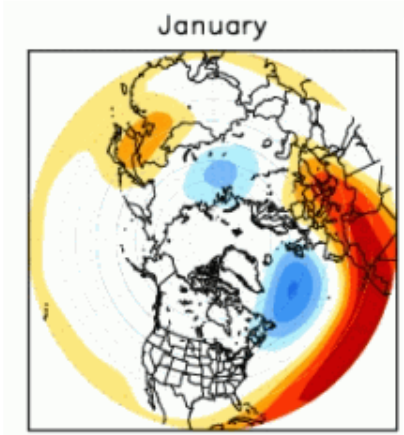
1. INTRODUTION: EURO-ATLANTIC CLIMATE MODES

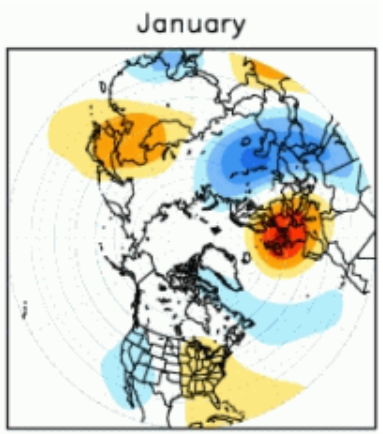
North Atlantic Oscillation (NAO)



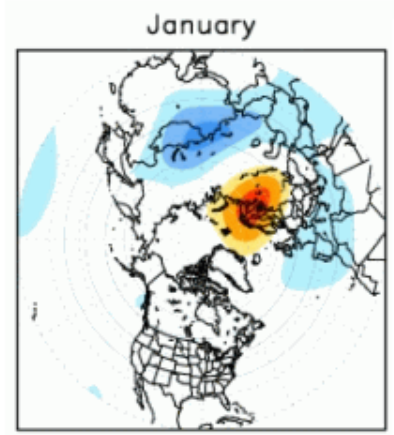
Eastern Atlantic pattern (EA)

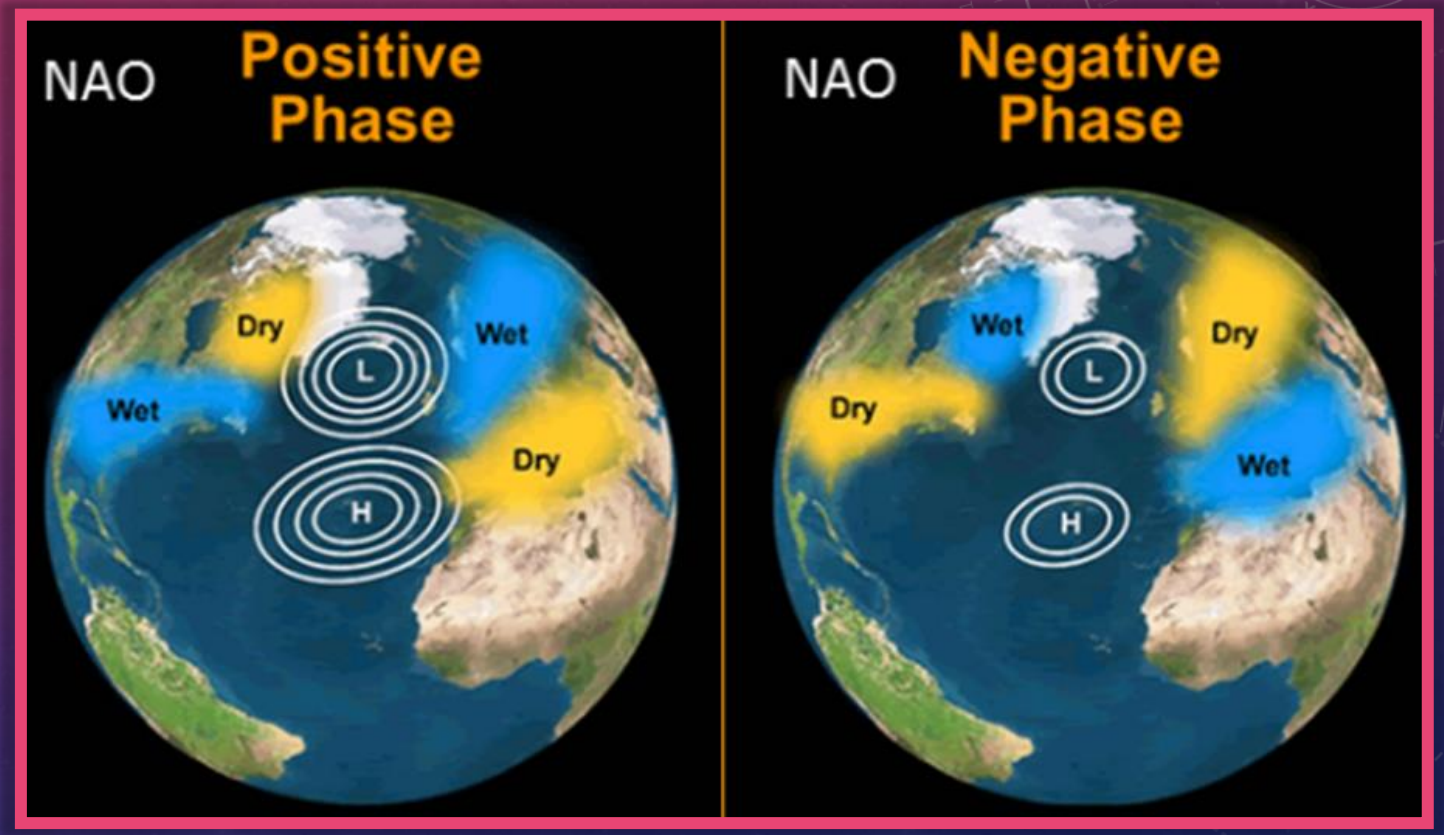


East Atlantic Western Russian pattern (EAWR)



Scandinavian pattern (SCA)





Red colours: High Pressure

Blue colours: Low Pressure

2. OBJECTIVE & RESEARCH QUESTIONS

To investigate the **presence of robust changes** in NAO, EA, EAWR and SCA in multi-model ensembles of **historical simulations** and simulations under the **ssp585 future scenarios** of anthropogenic forcing performed in the frame of the sixth phase of the Coupled Model Intercomparison Project (**CMIP6**, Eyring et al., 2016)

- How do CMIP6 climate models simulate observed features of winter NAO, EA, EAWR and SCA?
- How are the simulated temporal, spectral and distributional properties of these modes affected by future global warming conditions?

3. METHODOLOGY: DEFINITION OF CLIMATE MODES

- **Traditional approach**: Rotated Empirical Orthogonal Functions (EOF) or Rotated Principal Component Analysis (PC);
- **Caveats**: Uncertainties, linked to the variable covariance structure of the spatio-temporal data, in a multi-model framework *(e.g: Raible et al., 2014; Zanchettin et al., 2016);*
- **Alternative approach**: Box-based method *(Wallace and Gutzler, 1981; Stephenson et al., 2006):* Difference of the 500hPa geopotential height anomalies between the centres of action the modes are characterized of. Index is obtained by a linear combination of anomalies in such centres of action.

$$\mathbf{Index} = \beta_0 + \beta_n \mathbf{neg_n} + \beta_n \mathbf{pos_n}$$

$$NAO = -8.57 \times 10^{-5} - 0.015 \cdot neg1 + 0.017 \cdot pos1$$

$$EA = -0.005 \cdot neg1 - 0.009 \cdot neg2 + 0.054 \cdot pos1$$

$$EAWR = 2.857 \times 10^{-5} - 0.021 \cdot neg1 + 0.010 \cdot pos1 + 0.007 \cdot pos2$$

$$SCA = -5.714 \times 10^{-5} - 0.013 \cdot neg1 + 0.003 \cdot neg2 + 0.016 \cdot pos1$$

Z500 in winter (December-January-February) of:

- ERA –Interim reanalysis (= observations), 1980 – 2014;
- CMIP6 models, *historical* and *ssp585*

Univocal definition of the index across observations and models

Assumption: the centres of action do not change their spatial characteristics and relative weight in the *historical* and *ssp585* conditions.

Institution	Model	Simulations (*historical* and *ssp585*) r1i1p1f1	r2i1p1f1	r3i1p1f1	Reference
CSIRO (Australia)	ACCESS-CM2	X	X	X	Bi et al. (2020)
	ACCESS-ESM1-5	X	X	X	Ziehn et al. (2020)
AWI (Germany)	AWI-CM-1-1-MR	X			Semmler et al. (2020)
BCC (Beijing, Asia)	BCC-CSM2-MR	X			Wu et al. (2019)
CAMS (China)	CAMS-CSM1	X	x		Rong et al. (2019)
NCAR (USA)	CESM2-WACCM	X	x	X	Danabasoglu et al. (2020)
CMCC (Italy)	CMCC-CM-SR5	X			Cherchi et al. (2019)
CCCma (Canada Climate Center)	CanESM5	X	x	X	Swart et al. (2019)
EC-Earth-Consortium (Europe)	EC-Earth3	X			Massonnet et al. (2020)
	EC-Earth3-Veg	X	x	X	Wyser et al. (2020)
CAS (China)	FGOALS-f3-L	X			He et al. (2019)
	FGOALS-g3	X	x	X	Li et al. (2020)
FIO (China)	FIO-ESM2	X	x	X	Song et al. (2019)
NOAA-GFDL (USA)	GFDL-ESM4	X			Dunne et al. (2020)
CCR-IITM (India)	IITM-ESM	X			Krishnan et al. (2019)
INM (Russia)	INM-CM4-8	X			Volodin et al. (2018)
IPSL (France)	IPSL-CM6A-LR	X	x	X	Boucher et al. (2020)
MIROC (Japan)	MIROC6	X	x	X	Tatebe et al. (2019)
MPI (Germany)	MPI-ESM1-2-HR	X	x		Müller et al. (2018)
	MPI-ESM1-2-LR	X	x	X	Müller et al. (2018)
MRI (Japan)	MRI-ESM2-0	X			Yukimoto et al. (2019)
NCC (Norway)	NorESM2-LM	X			Seland et al. (2020)
	NorESM2-MM	X			Seland et al. (2020)
AS-RCEC (Thailandia)	TAIESM1	X			Lee et al. (2020)

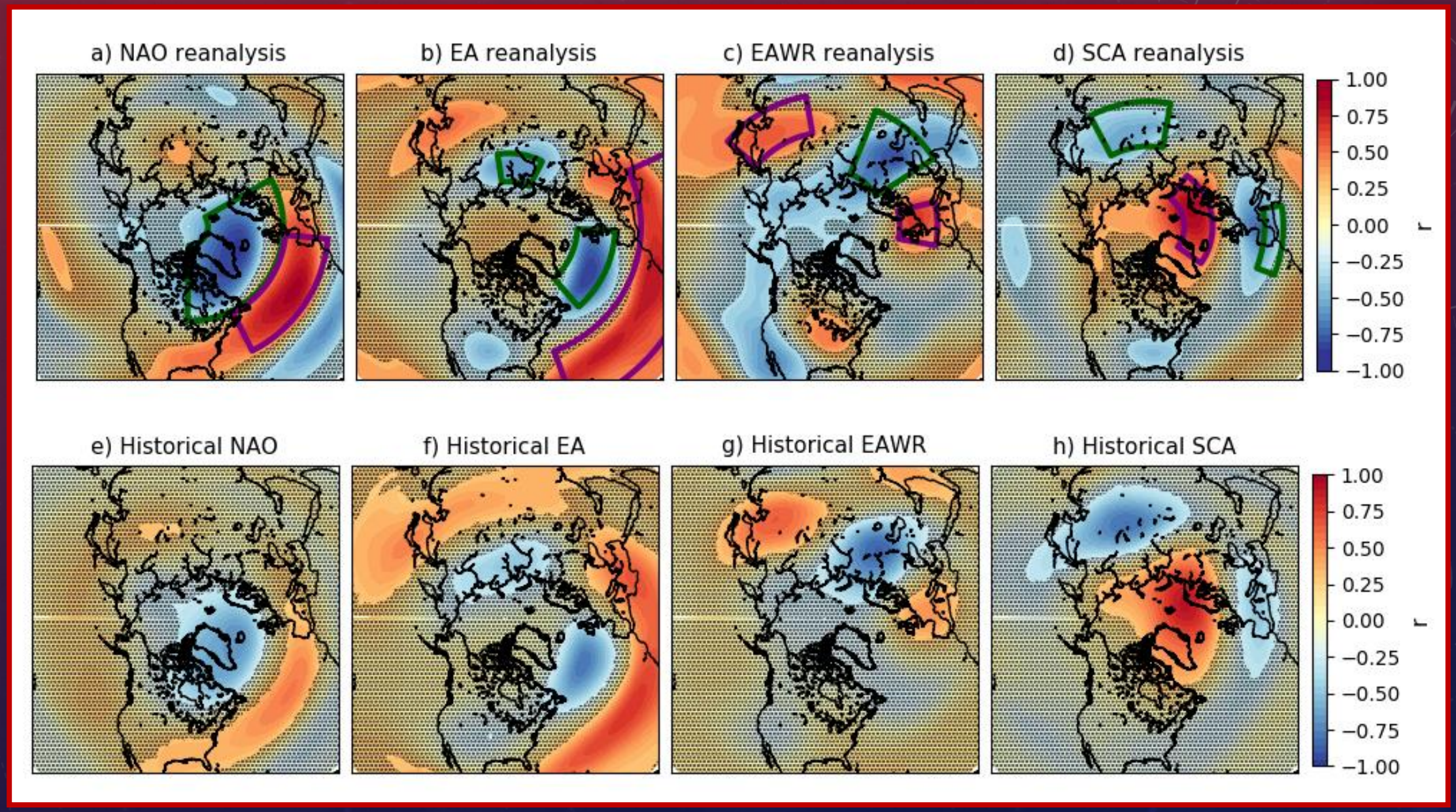
3. CMIP6

- Output: winter monthly averaged Z500, near-surface air temperature and precipitation;
- *Historical* simulations: 1851 – 2014;
- *ssp585* simulations: 2015 -2099;
- **Main analysis focus on 1960-1999 and 2060-2099.**

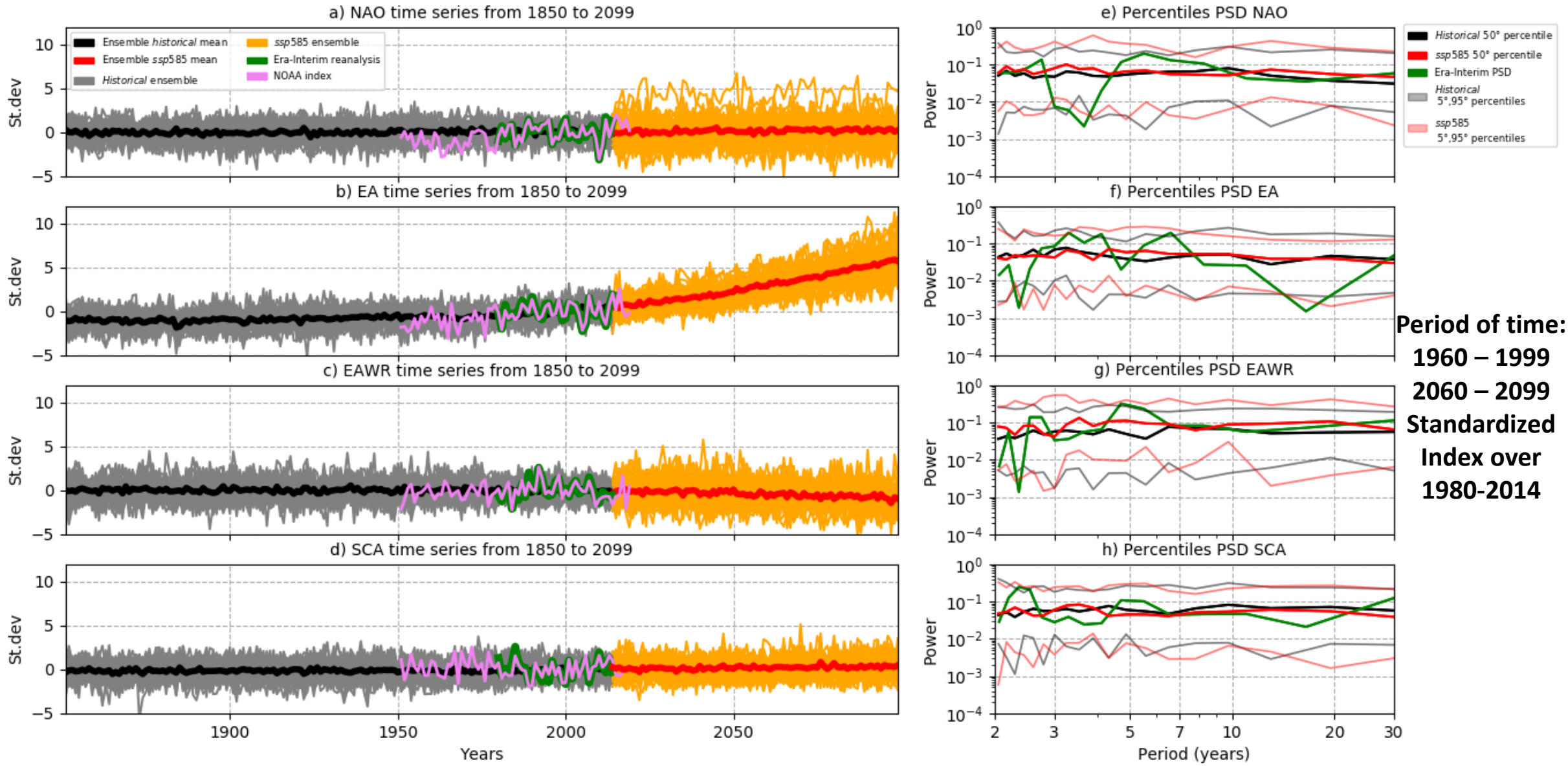
4. RESULTS – CMIP6 & OBSERVATIONS

Reanalysis: 1980-2014

CMIP6: 1960-1999



4. RESULTS – TEMPORAL & SPECTRAL FEATURES



Period of time:
1960 – 1999
2060 – 2099
Standardized Index over 1980-2014

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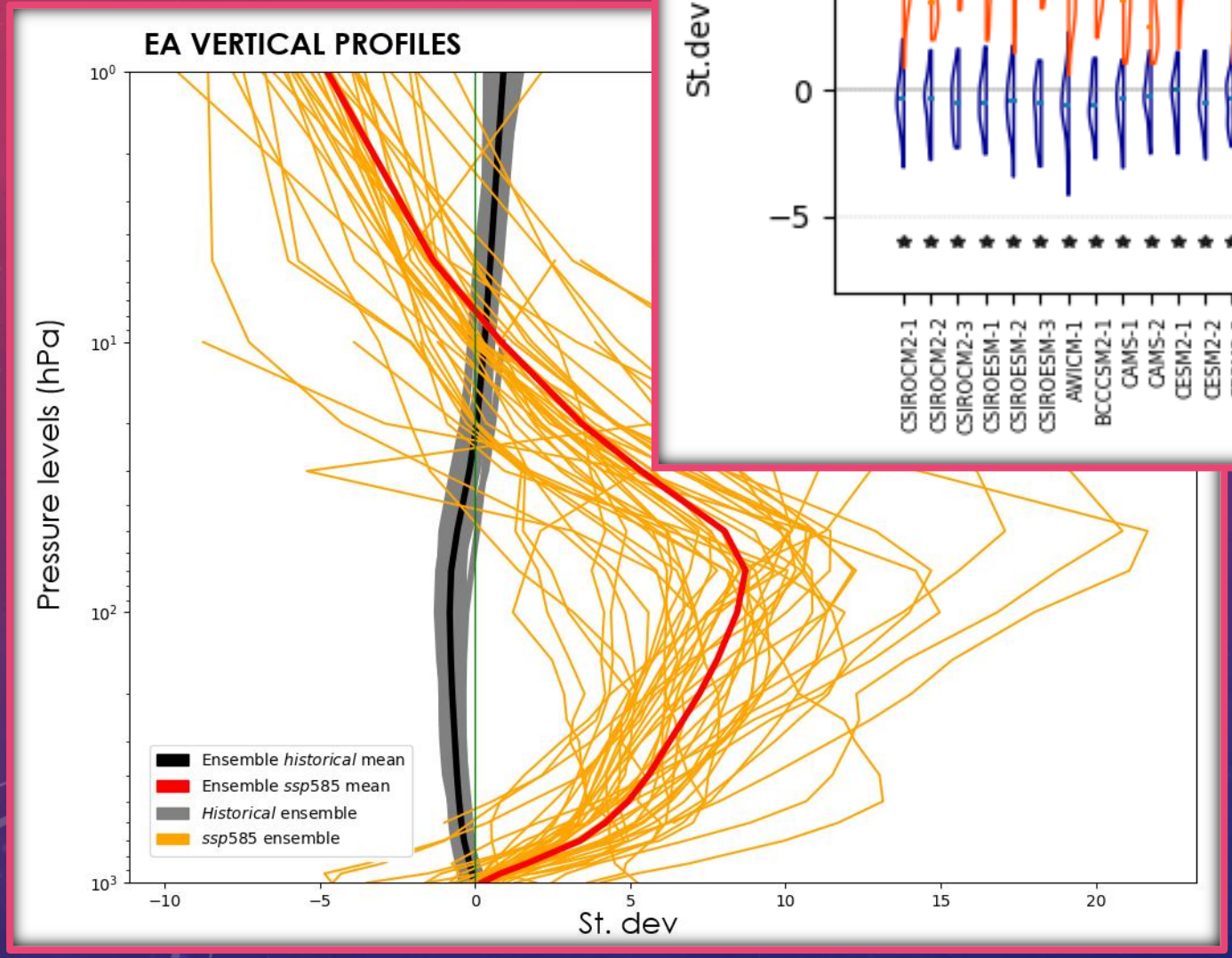
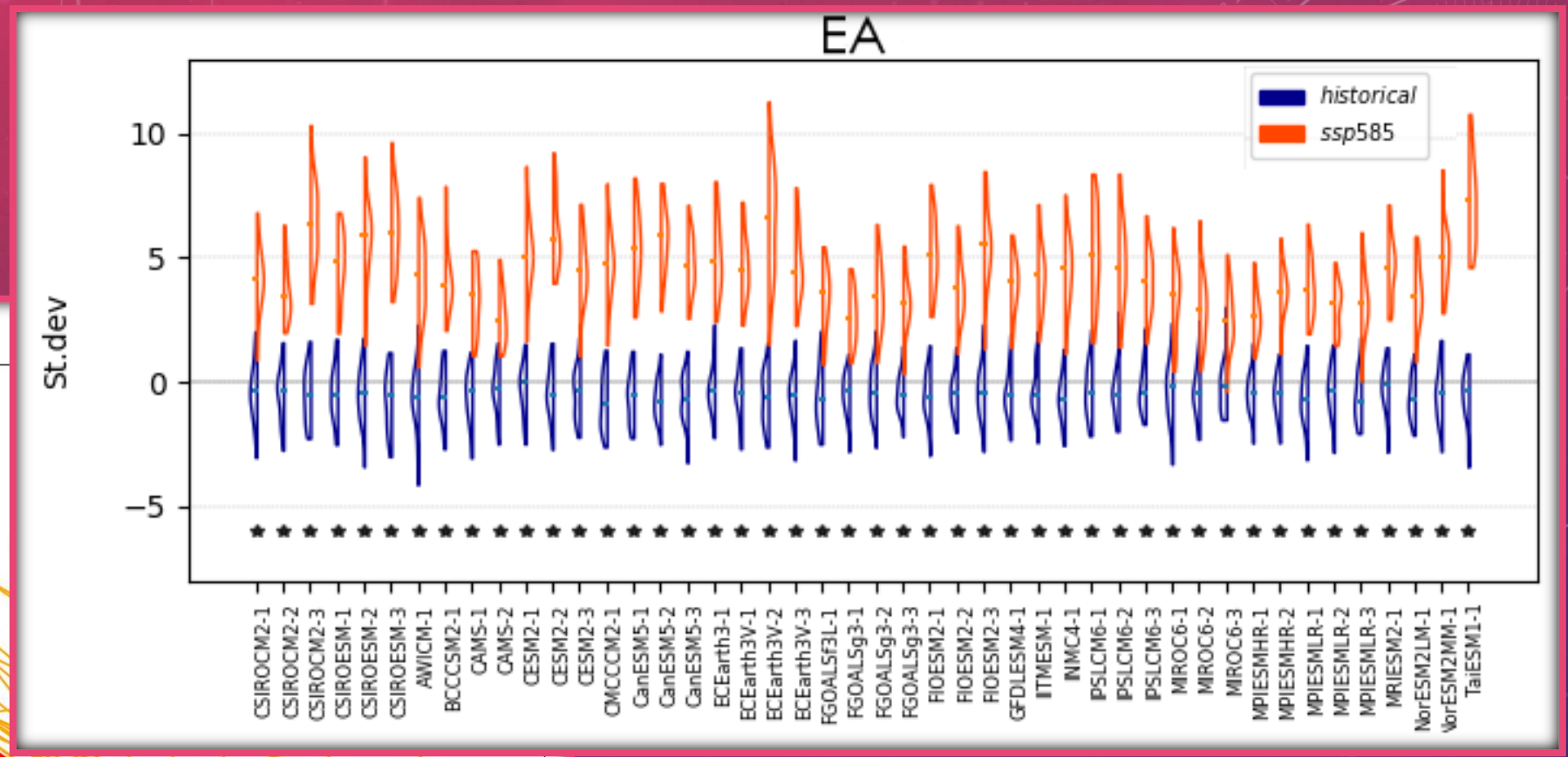
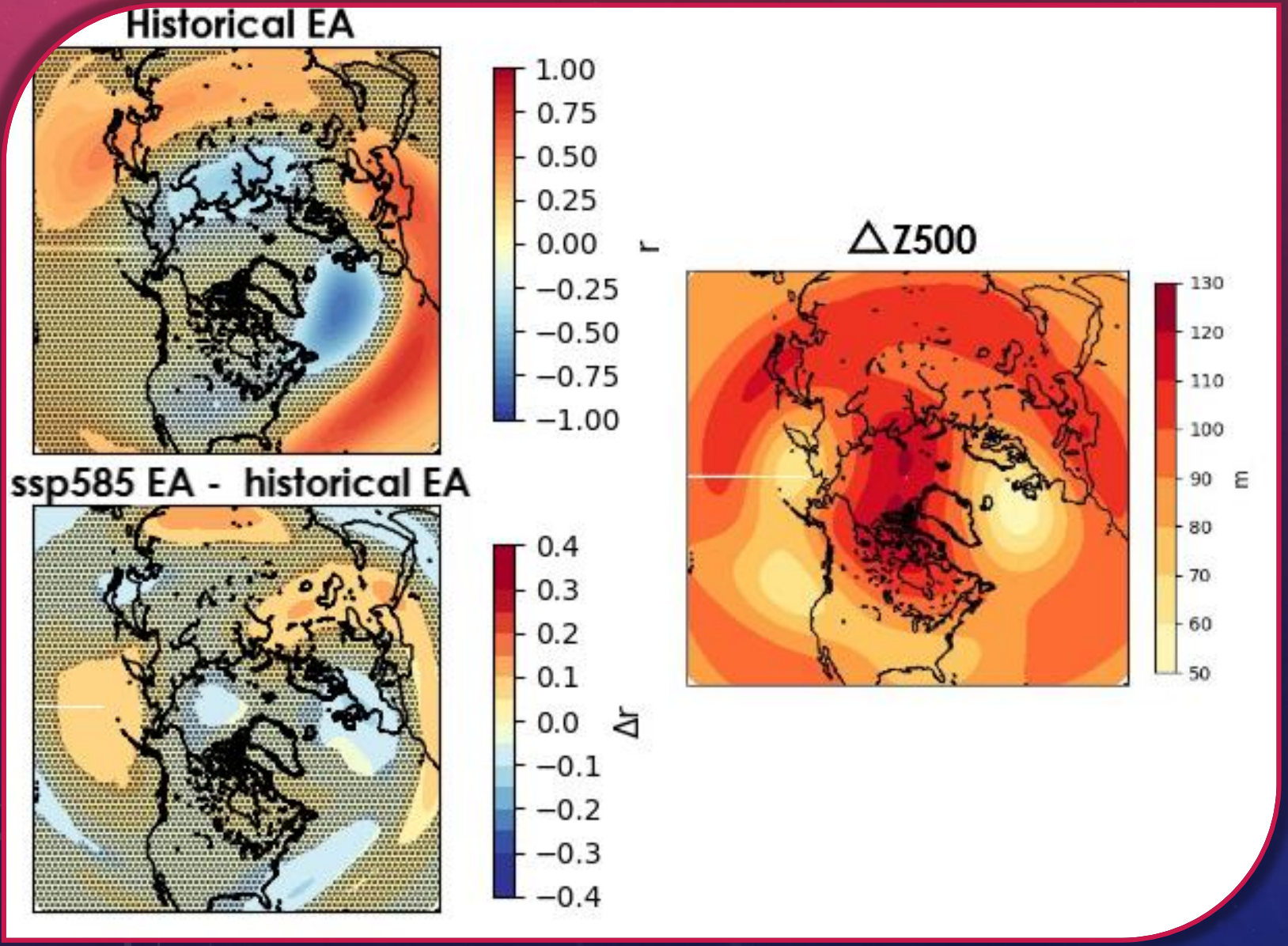




- Mann Whitney U test is used to identified significant differences ($p < 0.05$) between the historical and ssp585 distributions;
- Null hypothesis: no difference between the ensembles.

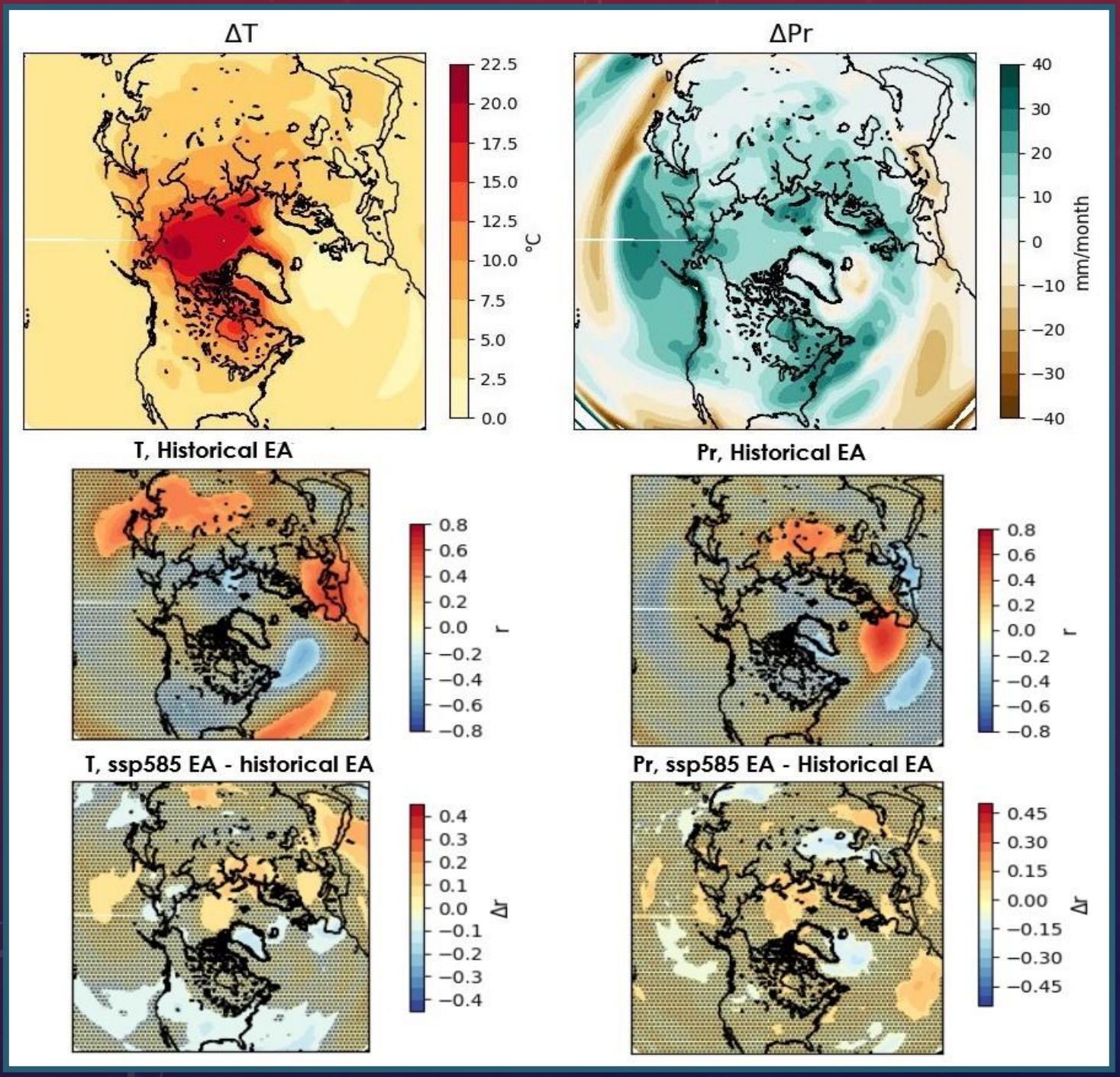
5. DISCUSSION



△ = ssp585 - historical

- Weakening of interannual-to-decadal variability;
- Ensemble-mean climatological changes in winter of the Z500 indicate a rise in the future vs historical;
- The rise of Z500 over the North Atlantic **could explain** the evolution towards a positive phase of EA.

5. EURO-MEDITERRANEAN CLIMATE



- 2.5 – 5°C warming;
- Drying over Mediterranean between -10 and -5 mm/month;
- Wetting over Europe between +10 and +5 mm/month;
- EA strengthening **may** contribute to enhance European warming and Mediterranean drying.

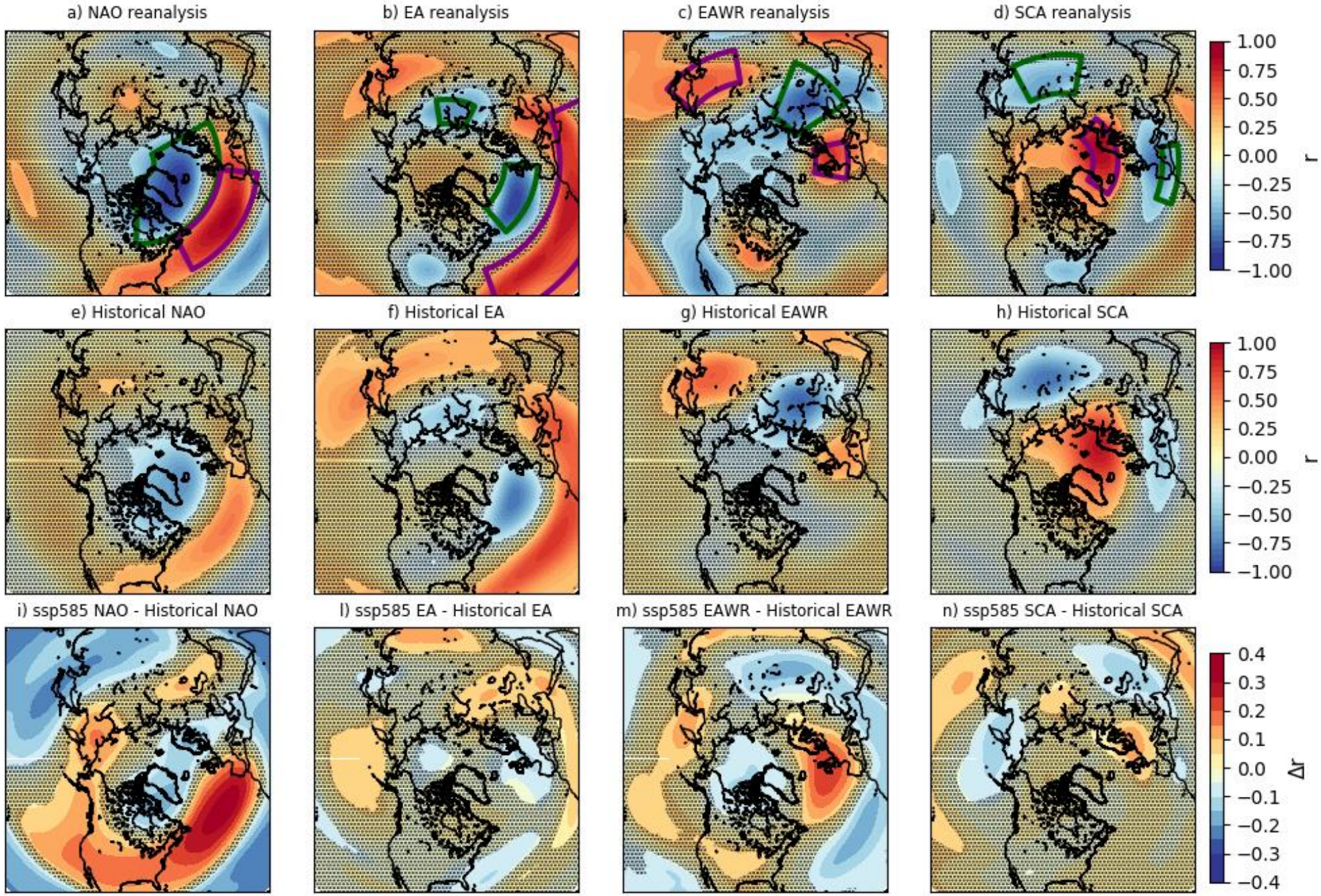
Historical: 1960 – 1999
ssp585: 2060 – 2099

6. CONCLUSIONS

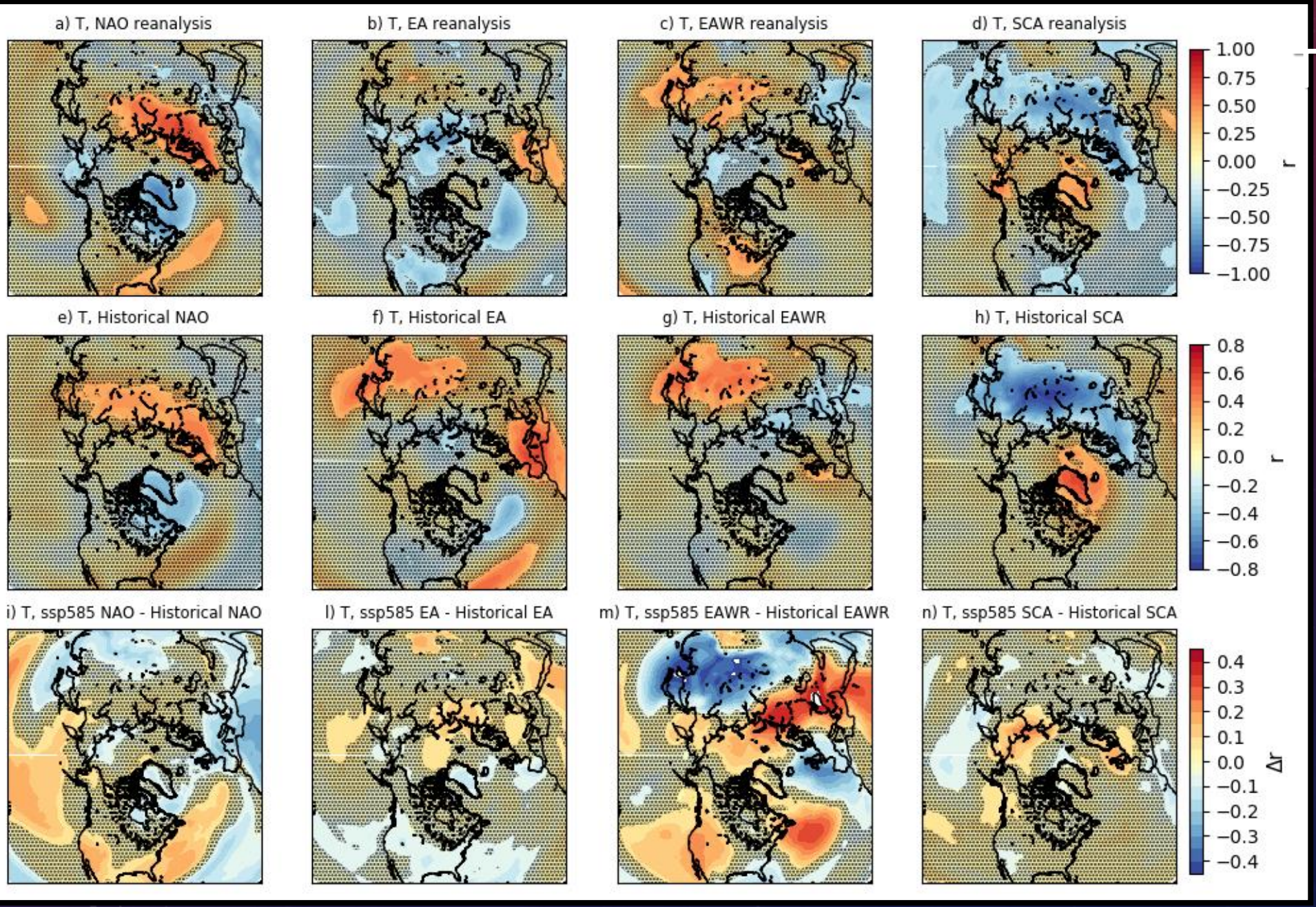
- **Capability** of CMIP6 to robustly simulate the observed spatial patterns of all modes;
- NAO, EAWR and SCA do not change substantially in the future with respect to historical conditions;
- **EA evolves toward a persistent positive phase** in the mid-troposphere;
- Weakening of interannual-to-decadal variability for all modes;

➢ **Projections of climate modes** under a future changing climate **could aid in the physical explanation of projected climate changes** in the Euro-Mediterranean region.

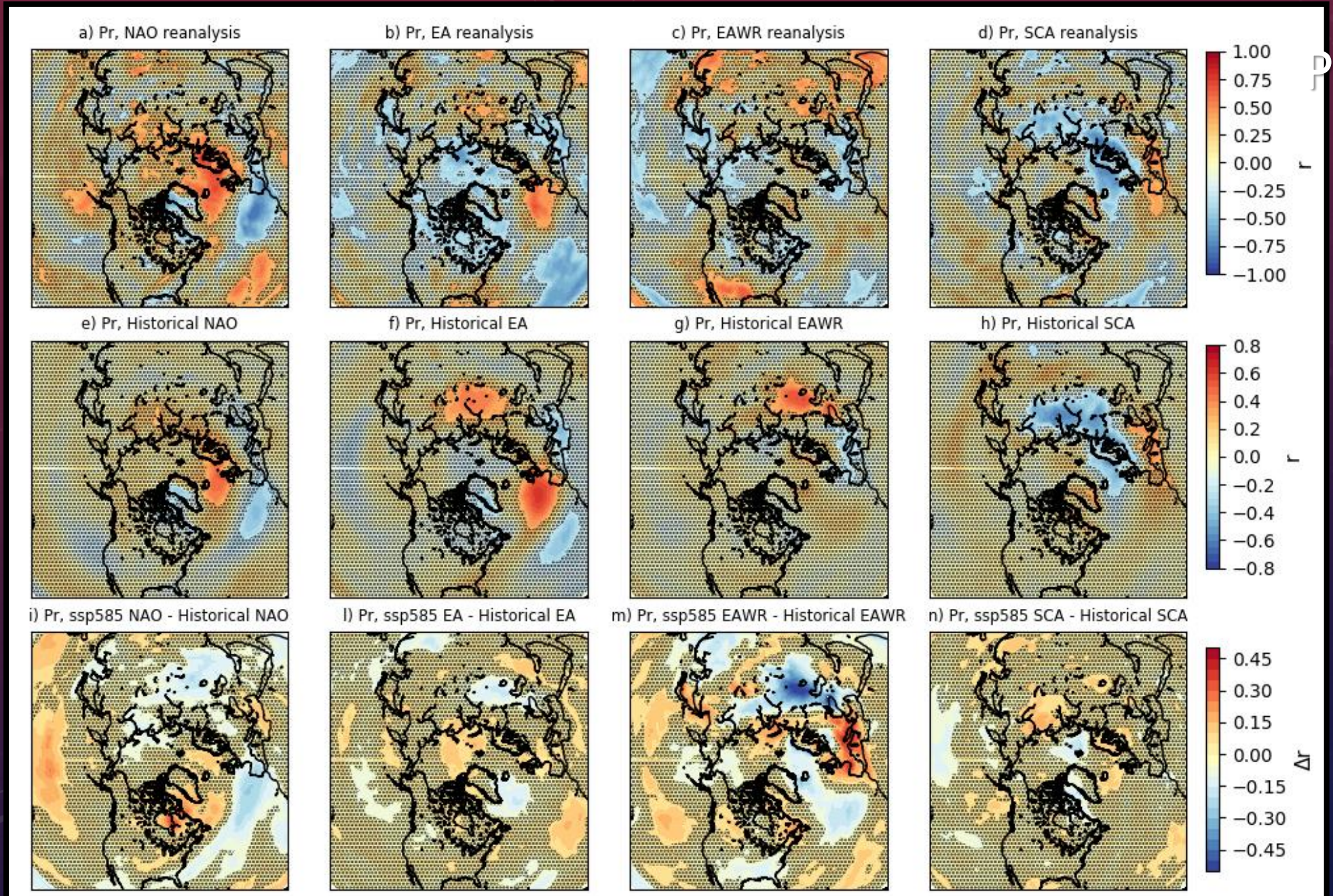
APPENDIX 1– INTERANNUAL VARIABILITY

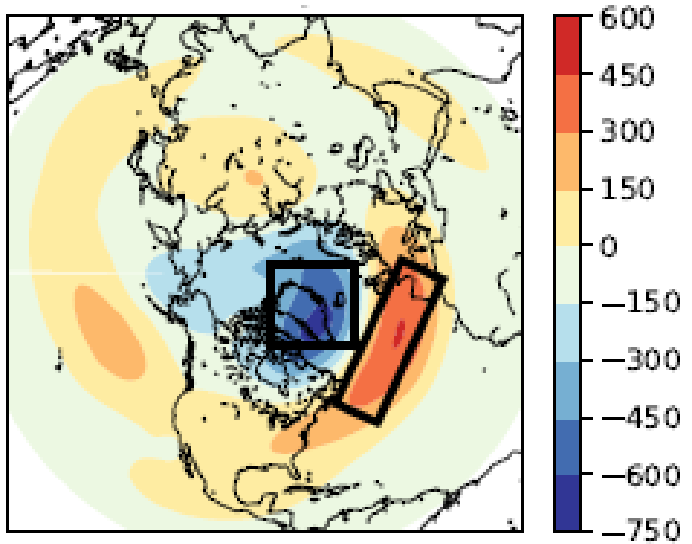


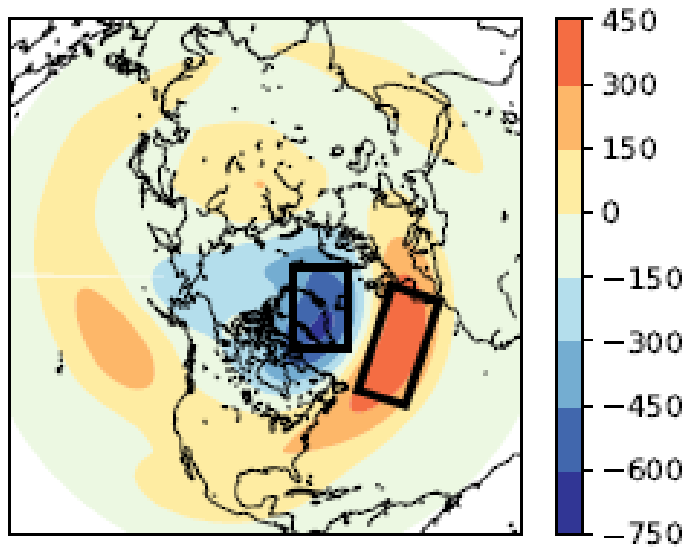
APPENDIX 2– TEMPERATURE & INDICES



APPENDIX 2– PRECIPITATION & INDICES







2) Multi-linear regression model:

$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \ldots + \beta_n \cdot x_n$ Z500 anomalies of the set of modified boxes (predictor x) and NOAA index (response variable y). Output:

Indices time-series for each set of boxes.

1) Simple linear regression model:

$y = \beta_0 + \beta_1 \cdot x_1$ Era-Int Z500 anomalies (response variable y) and NOAA index (predictor x).

Output: Identification of **start boxes;**

$$\mathbf{NAO} = \beta_0 + \beta_1 \mathbf{neg1} + \beta_2 \mathbf{pos1}$$

Standardized index over 1980-2014