Robustness and drivers of the Northern Hemisphere extratropical atmospheric circulation response to a CO_2-induced warming in CNRM-CM6-1

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Context

- Several studies have identified a **poleward shift** of the eddy-driven jet (*Kushner et al. 2001; Yin 2005; Vallis et al. 2015*).

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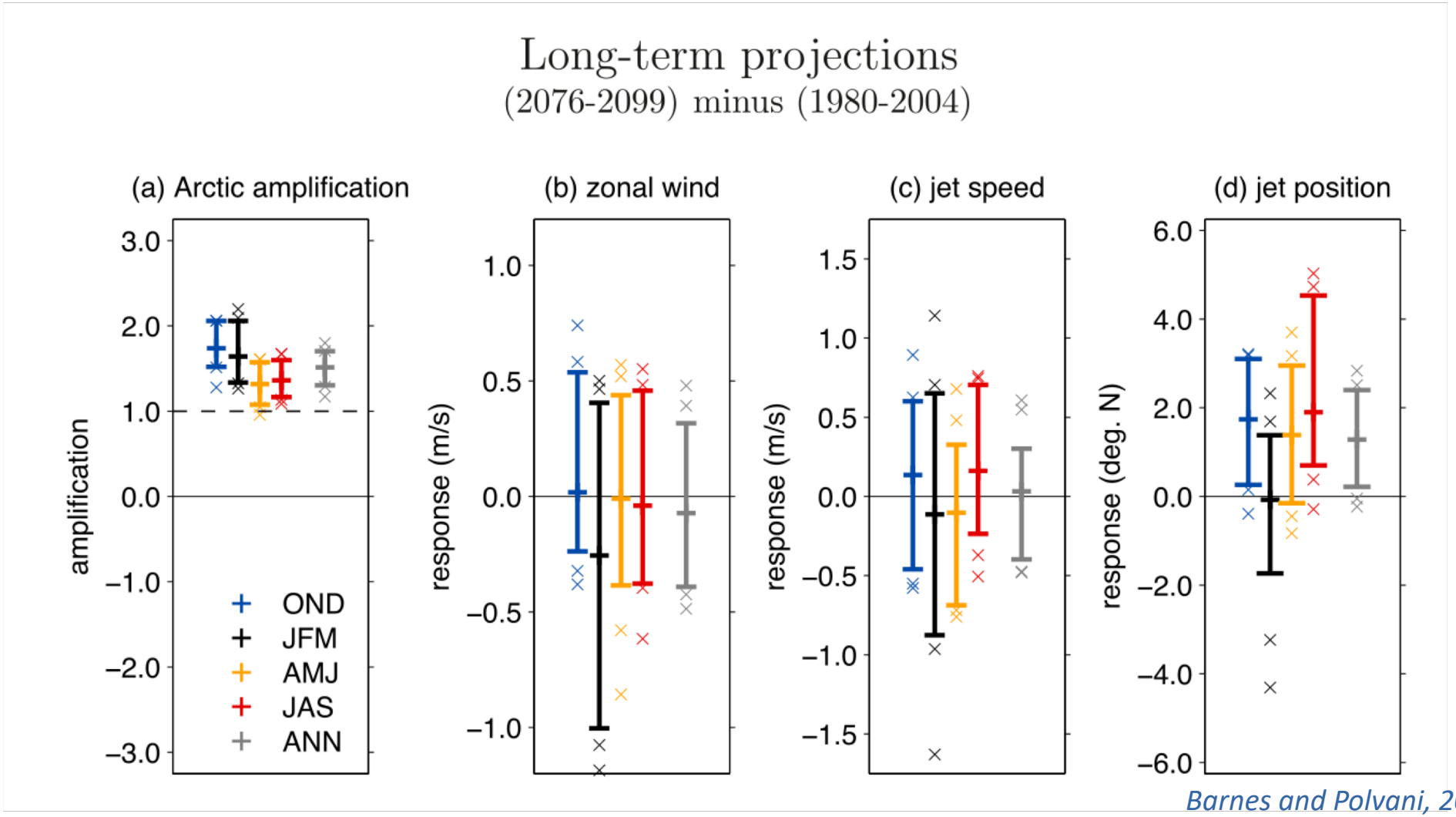
- This shift is **robust** in the Southern Hemisphere but strong **regional features** and **seasonal variability** are observed in the Northern Hemisphere (*Simpson et al. 2014; Barnes and Polvani 2015*).

Context



Barnes and Polvani, 2015

Large spread for the zonal wind, jet speed or jet position in JFM (black)

Context

- Several studies have identified a **poleward shift** of the eddy-driven jet (*Kushner et al. 2001; Yin 2005; Vallis et al. 2015*).
- This shift is **robust** in the Southern Hemisphere but strong **regional features** and **seasonal variability** are observed in the Northern Hemisphere (*Simpson et al. 2014; Barnes and Polvani 2015*).
- Potential drivers are : **Arctic Amplification**, **Tropical high troposphere warming**, **stratospheric vortex strength** (*Peings et al. 2018 ; Zappa and Shepperd 2017*).

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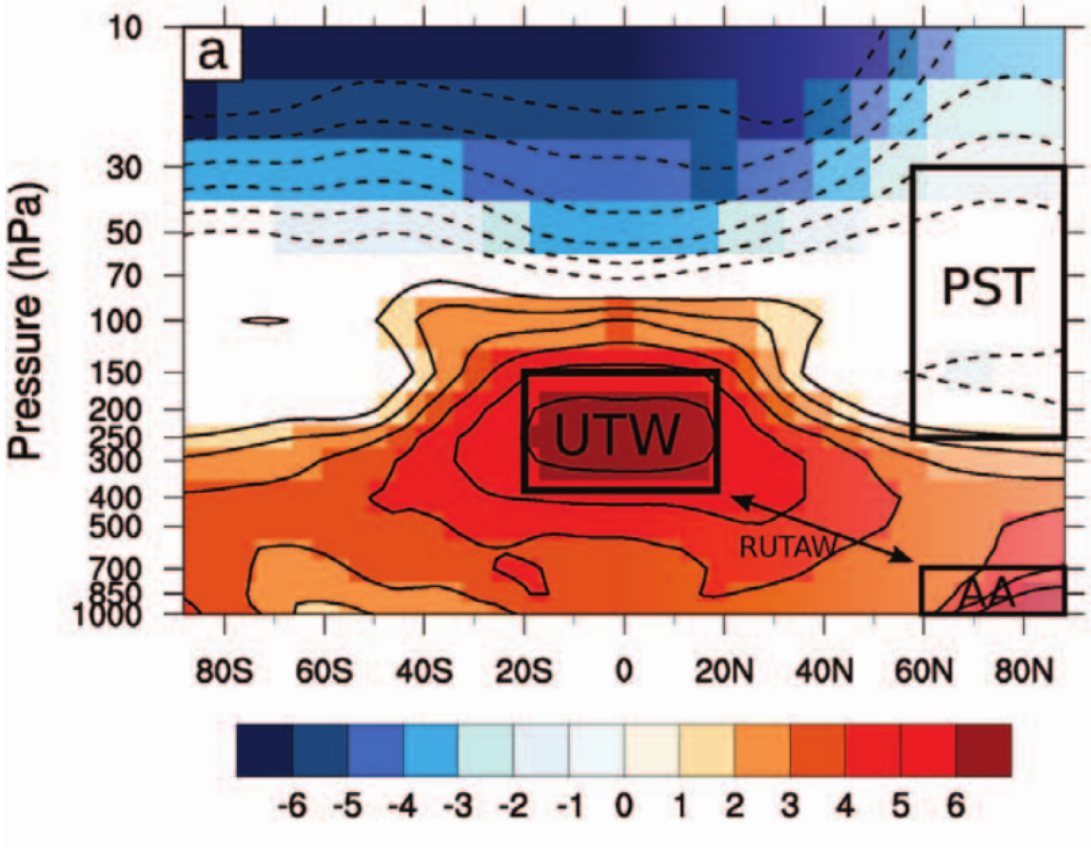
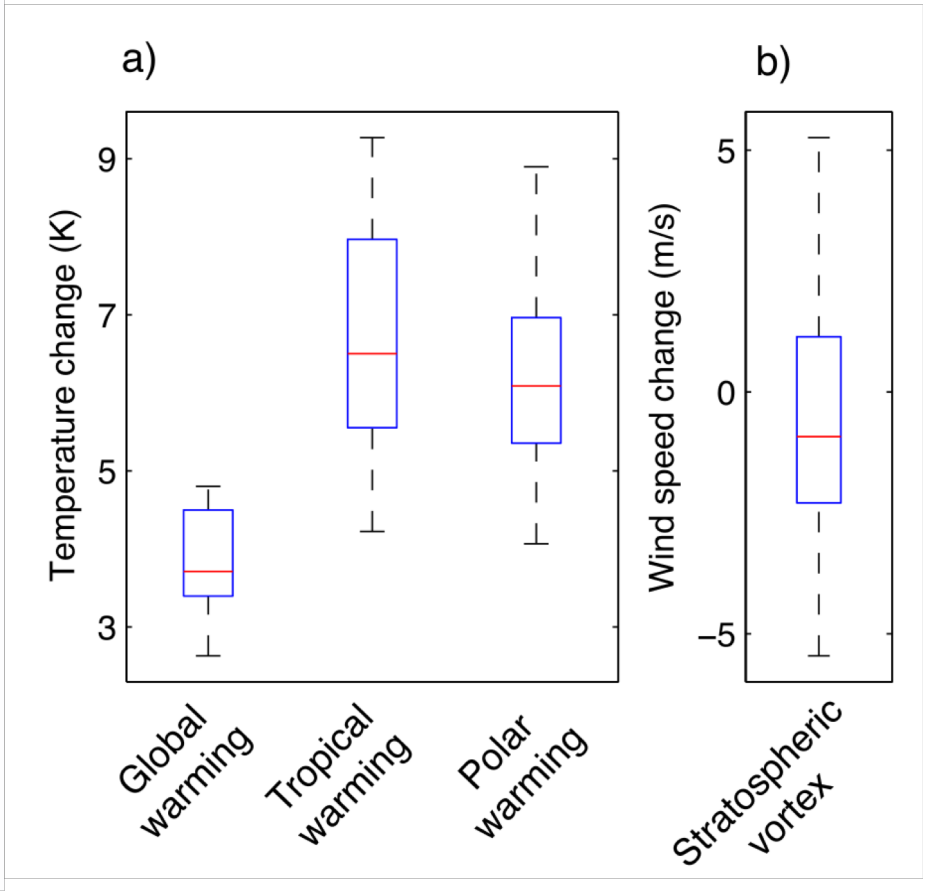


Peings et al. 2018

2066-2095 minus 1976-2005



Zappa and Shepperd 2017

2070-2100 minus 1960-1990

UTW : Upper-troposphere Tropical Warming
AA : Arctic Amplification
PST : Polar Stratospheric Temperature

Objectives

- Response of wintertime Northern Hemisphere mid-latitude atmospheric circulation to an abrupt quadrupling of the CO_2 concentration.

- **Evaluation of CNRM-CM6-1**: representation and sensitivity of the atmospheric circulation.

- Dissociate the role of **direct radiative forcing** from **indirect effects** (SST increase, Arctic sea ice loss, change in the SST pattern).

Experiments

	Experiment name	SST forcing	Sea ice forcing	CO2 forcing	Length
CMIP	piControl	(coupled)	(coupled)	pre-industrial	1500
CMIP	abrupt-4xCO2	(coupled)	(coupled)	quadrupled	1500
CFMIP	piSST	piControl	piControl	pre-industrial	390
CFMIP	a4SSTice-4xCO2	abrupt-4xCO2	abrupt-4xCO2	quadrupled	390
CFMIP	piSST-4xCO2	piControl	piControl	quadrupled	30
CFMIP	piSST-pxK	piControl + Δ	piControl	pre-industrial	30
CFMIP	a4SST	abrupt-4xCO2	piControl	pre-industrial	30
CFMIP	a4SSTice	abrupt-4xCO2	abrupt-4xCO2	pre-industrial	30

Differences showed in this study are computed over years 111-140

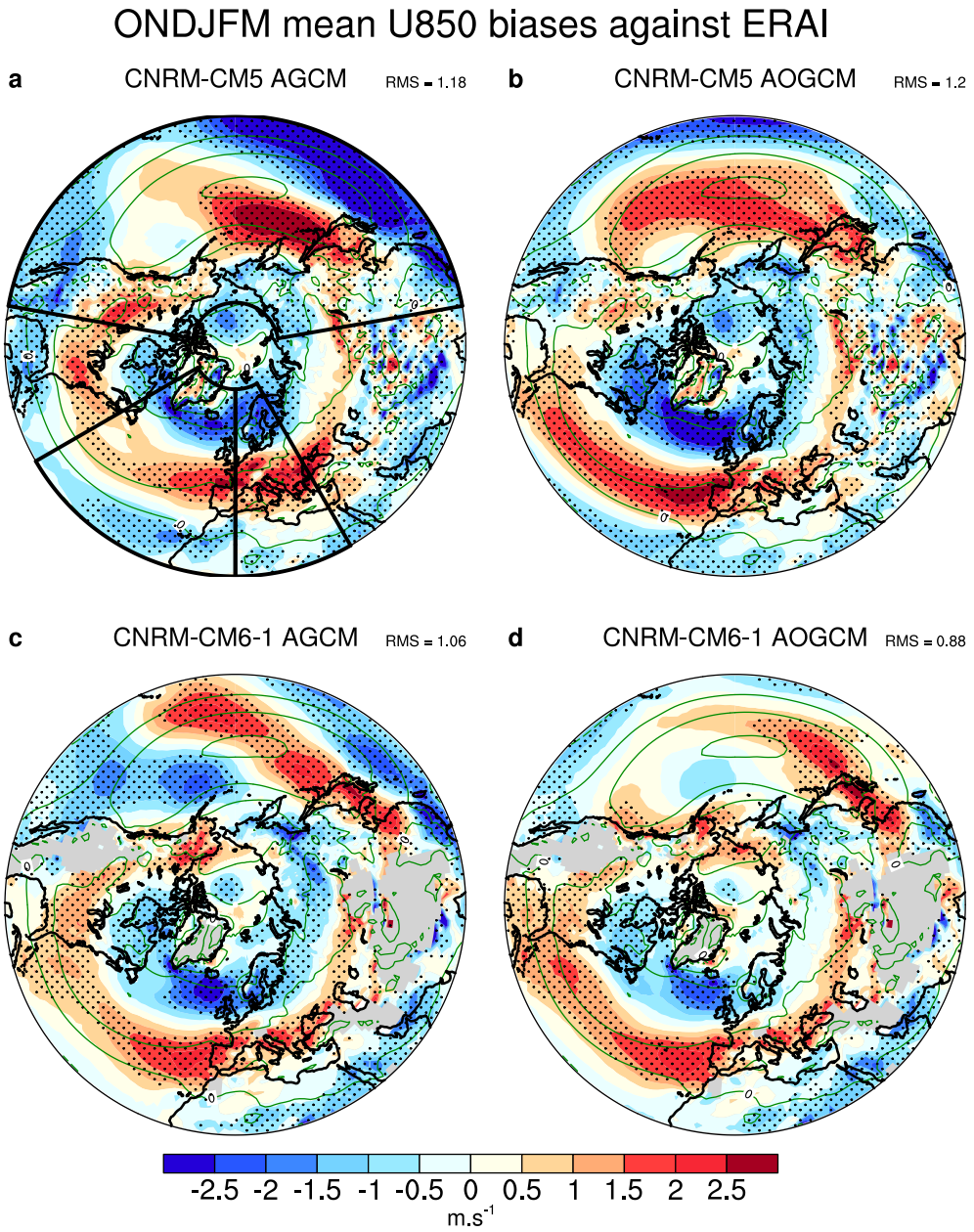
Experiments

- Total coupled = Total amip ?

- Total amip = direct CO2 + sea ice loss + SST pattern + Uniform SST warming

Evaluation of CNRM-CM6-1

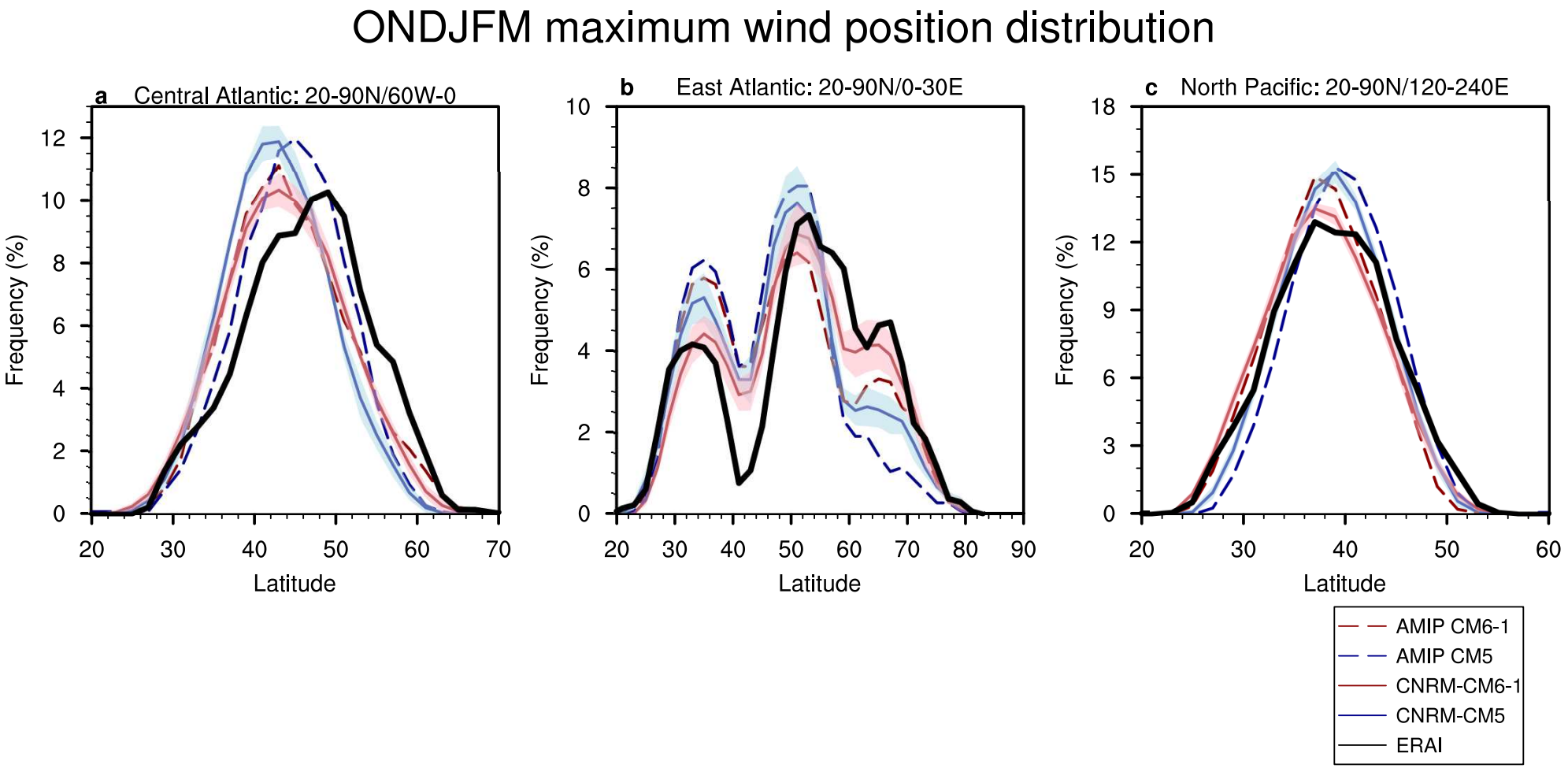
Biases of U850



- The jet is **too zonal** in both CNRM-CM models.

- Slight **decrease of the bias** between CNRM-CM5 and CNRM-CM6-1

Distribution of the jet position

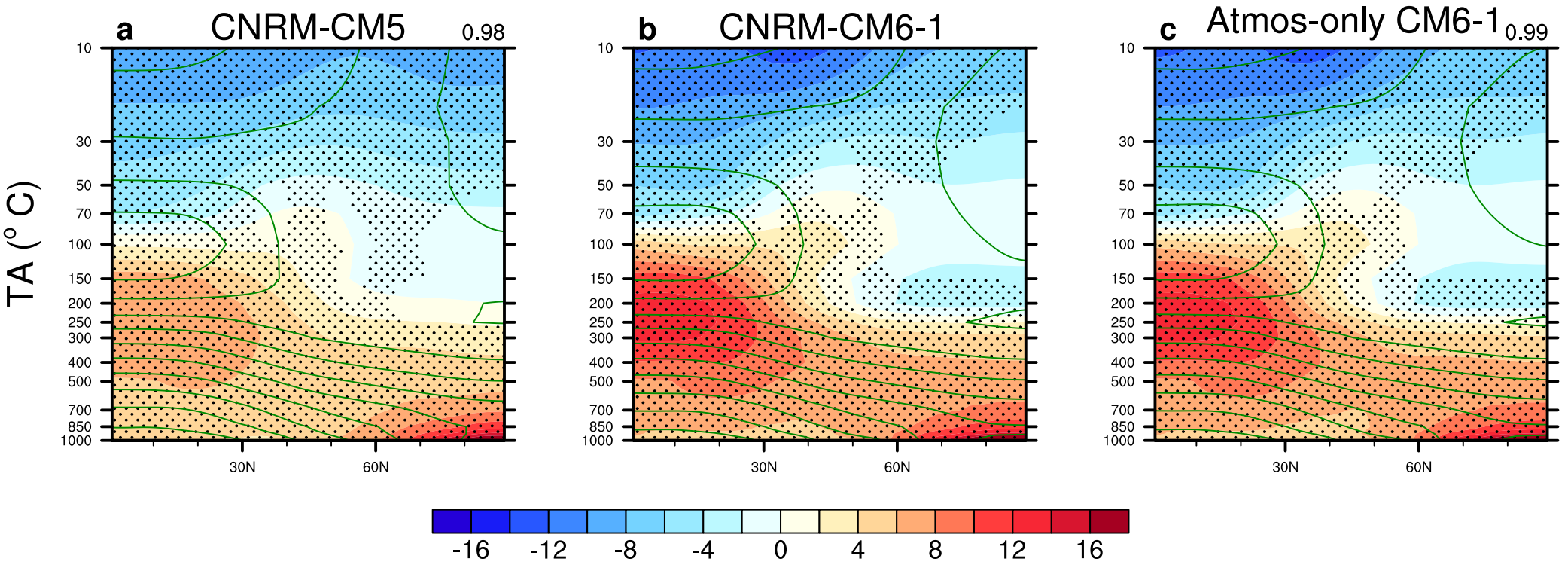


Evaluation of CNRM-CM6-1 : Summary

- The bias in U850 has been decreased
- However, the jet is **too zonal** in both versions (AGCM and AOGCM).
- There is a **better representation of blockings** in CNRM-CM6-1 compared to CNRM-CM5.
- There is a **better representation of the seasonal cycle of stratospheric vortex** (increased number of vertical levels in the stratosphere).

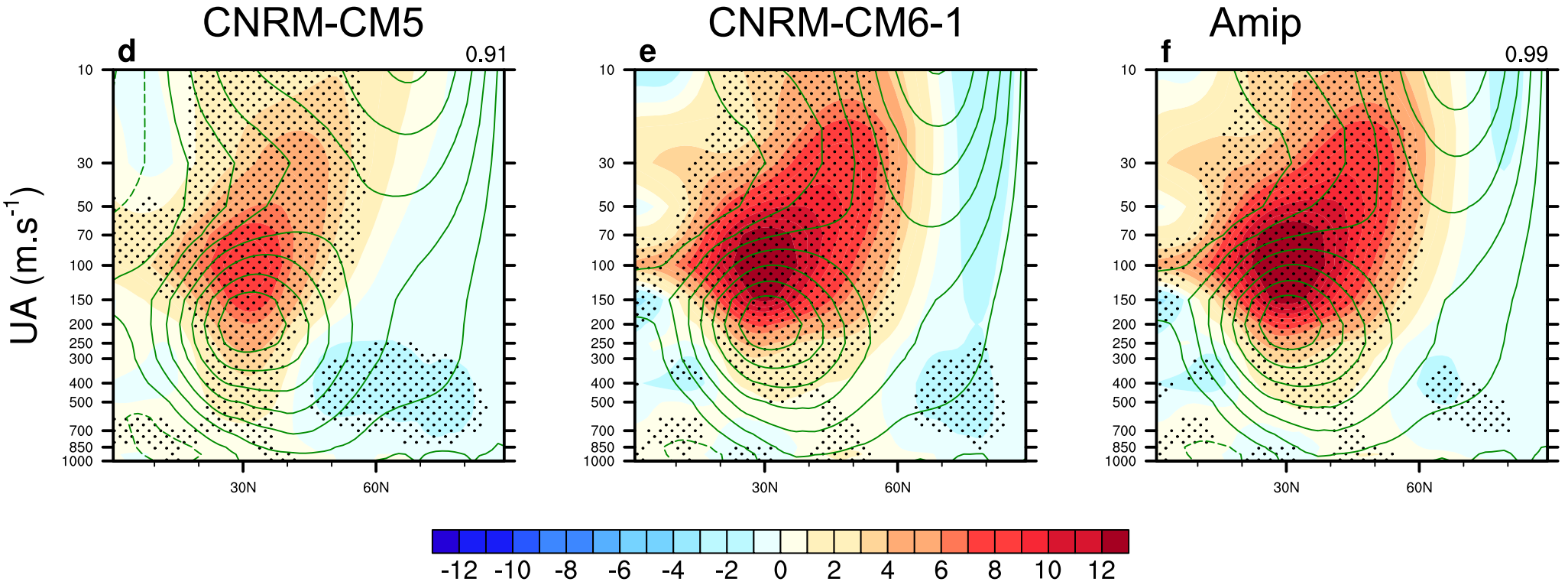
Assessment of the mid-latitude response in coupled and AGCM experiments

Zonal-mean temperature



- Stronger sensitivity of CNRM-CM6-1.
- Good reproducibility of Amip.

Zonal-mean zonal wind



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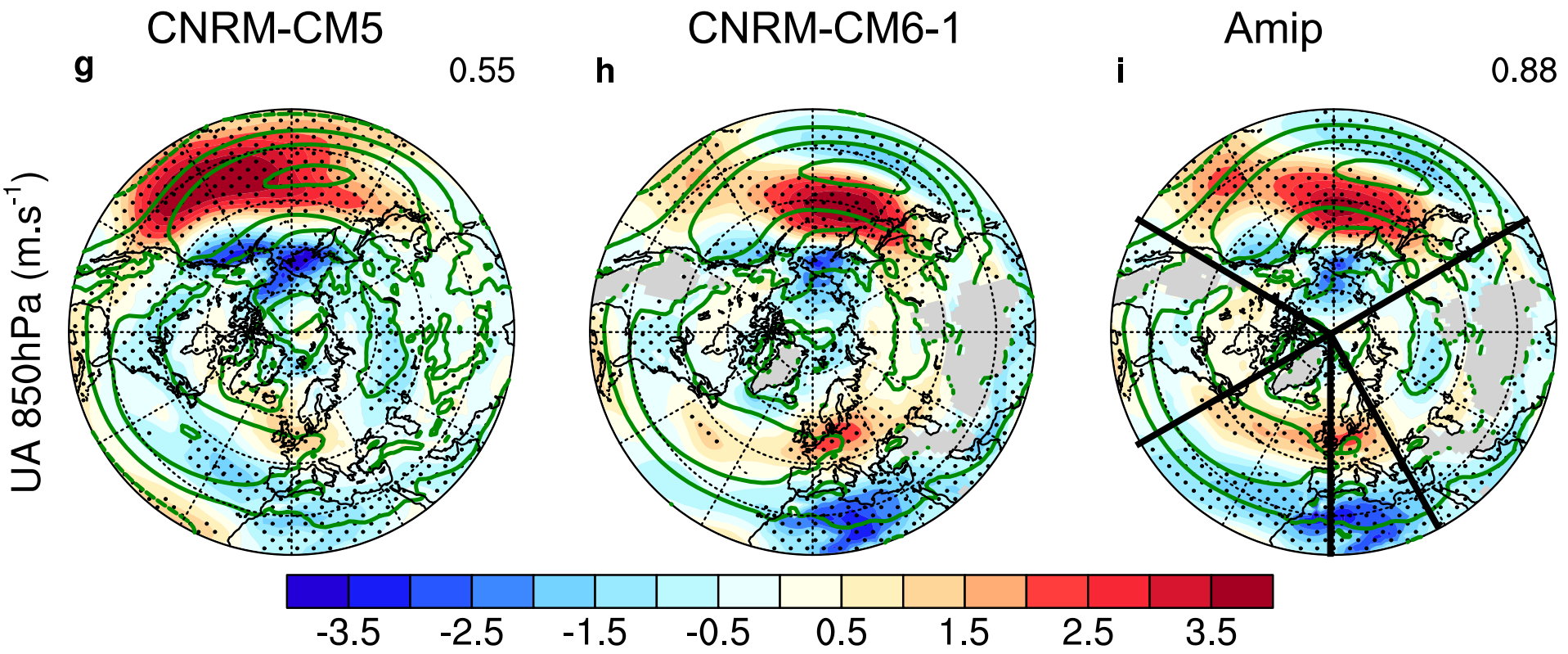
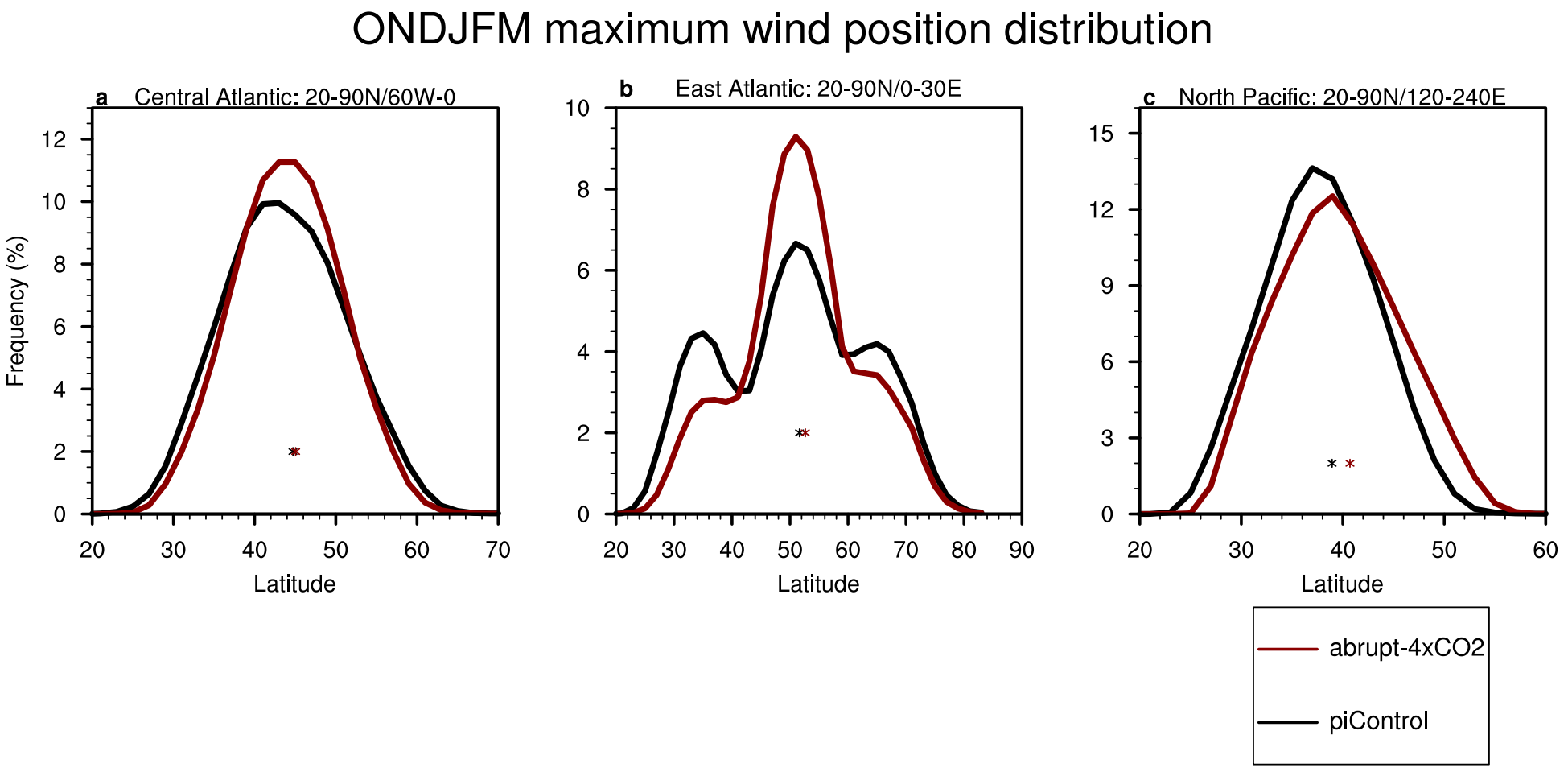
850 hPa Zonal wind



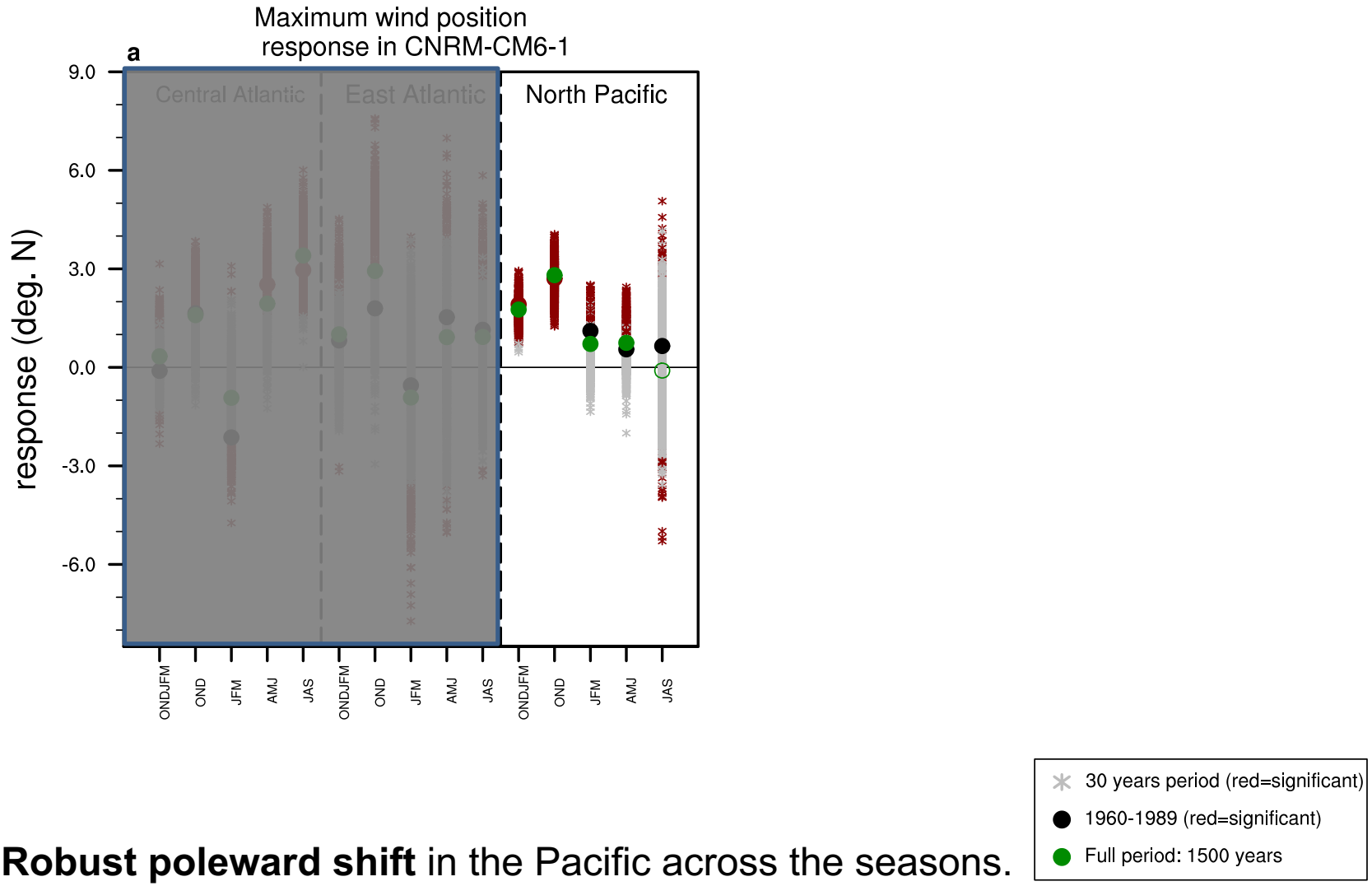
- Strong regional differences between CNRM-CM5 and CNRM-CM6-1.
- Good reproducibility of Amip, but differences in the Central Atlantic.

Jet position response



- **Poleward shift** in the Pacific.
- **Squeezing of the variability** in the Atlantic (especially at the east).

Seasonality and significance of the jet position response



- **Robust poleward shift** in the Pacific across the seasons.
- **No shift in the Atlantic for NDJFM and JFM**: strong internal variability.
- **The poleward shift is robust in OND** for both Atlantic and Pacific (consistent with *Barnes in Polvani 2015*).

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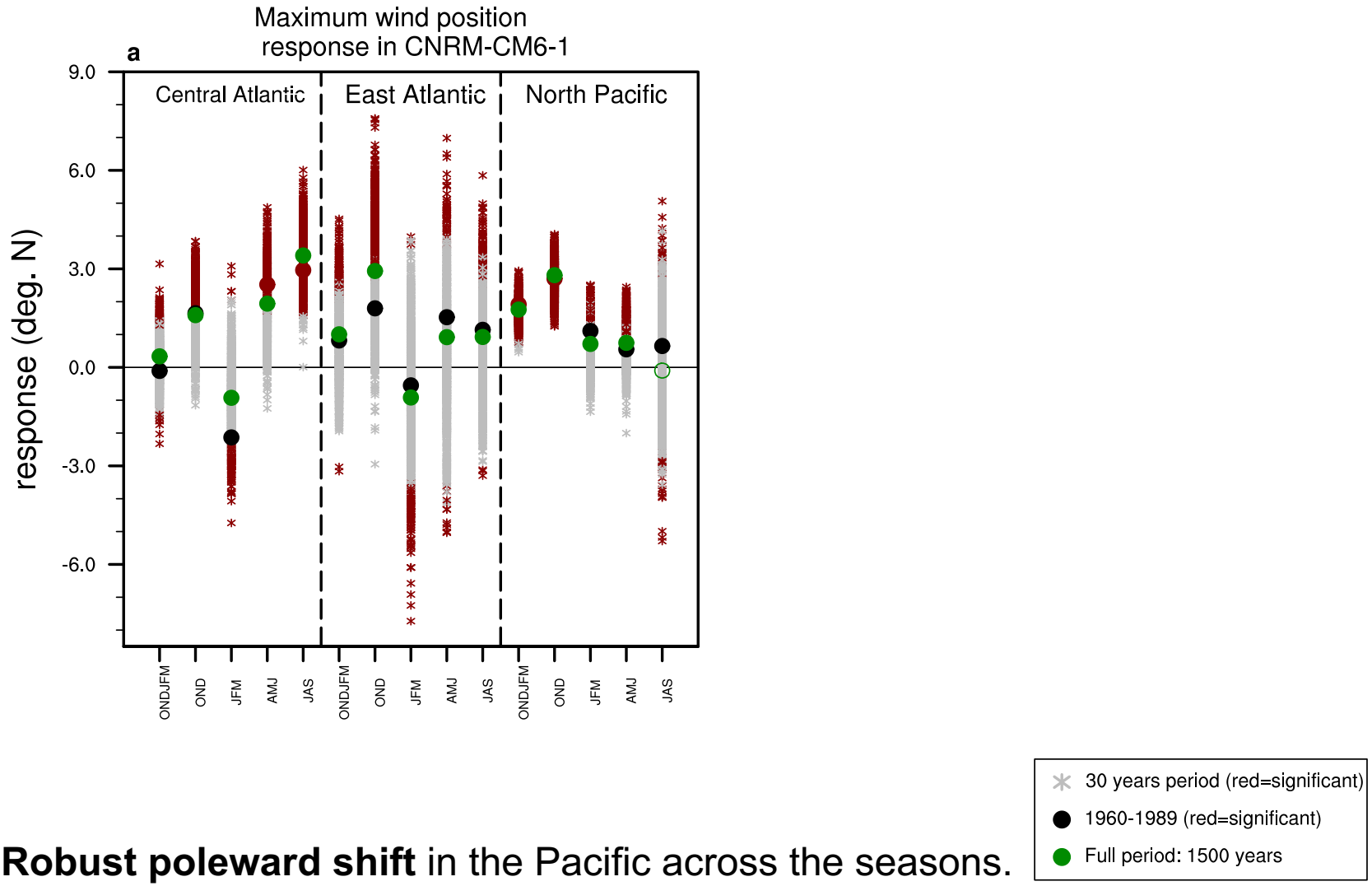

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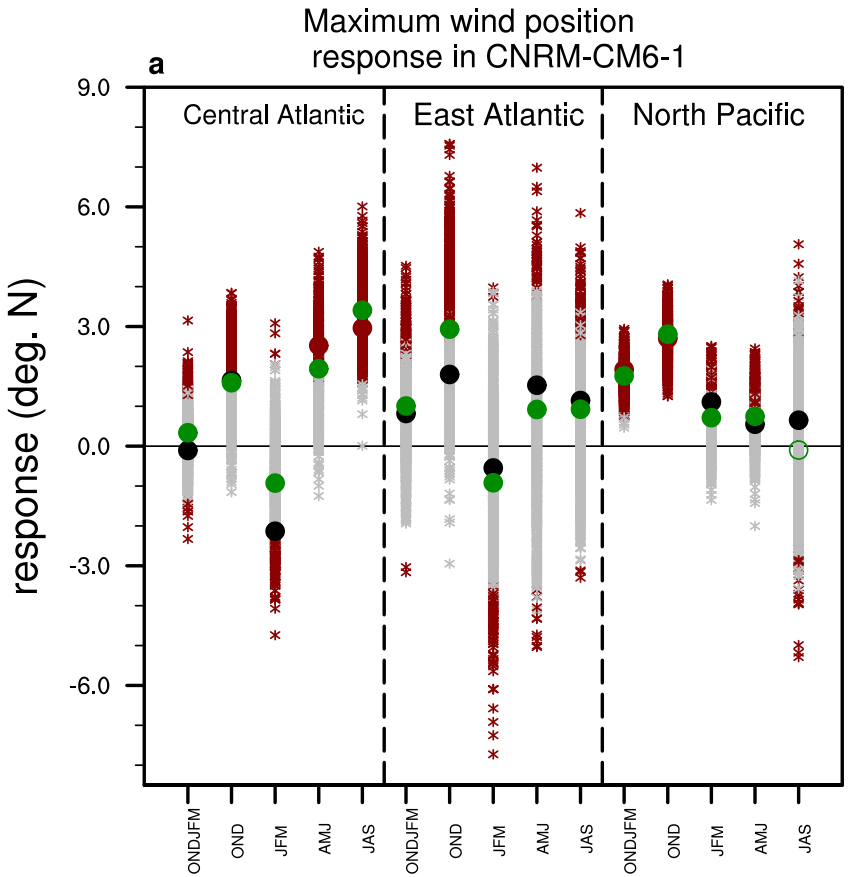

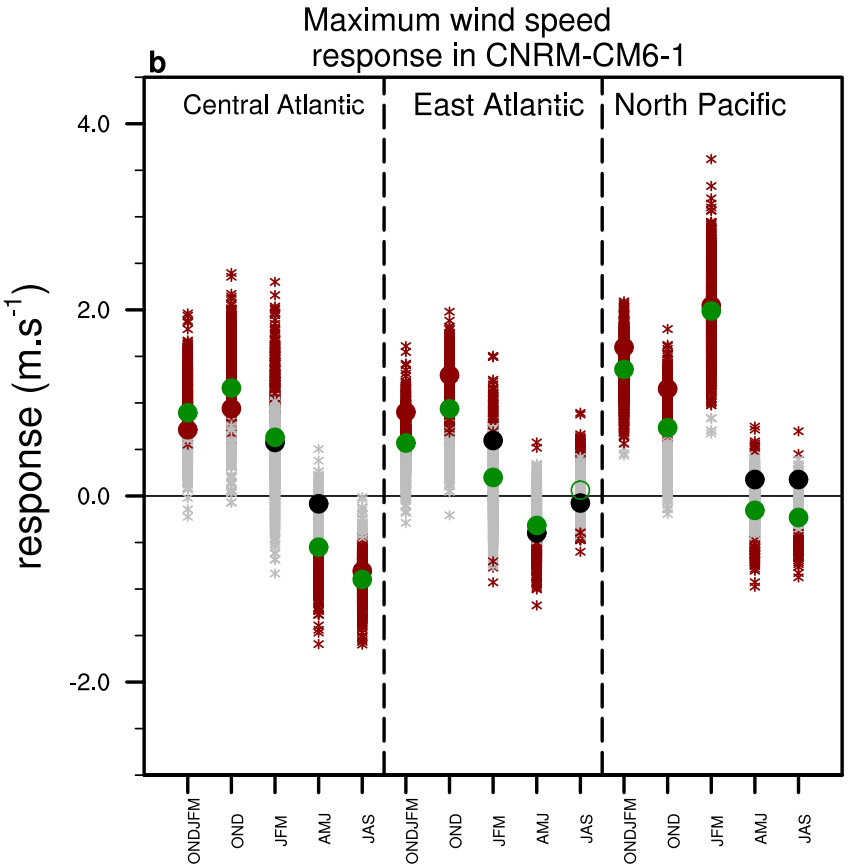

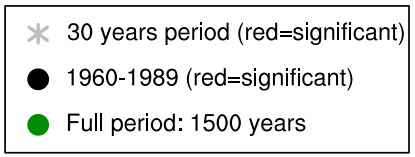

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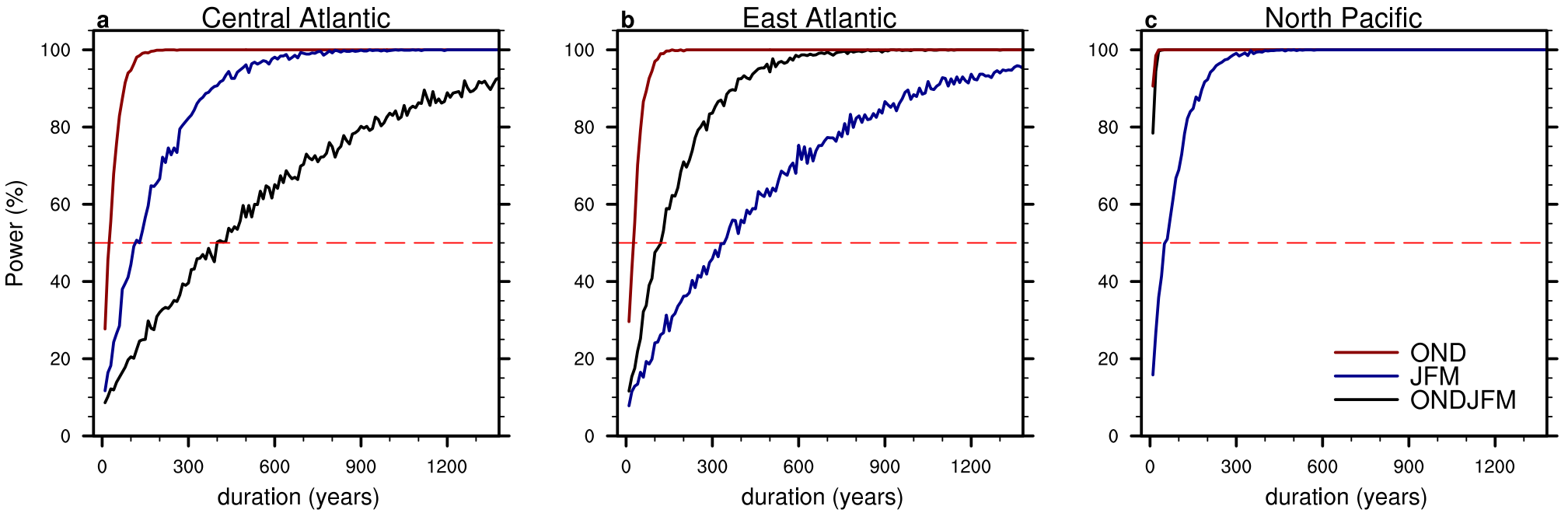
Robustness of the jet position response

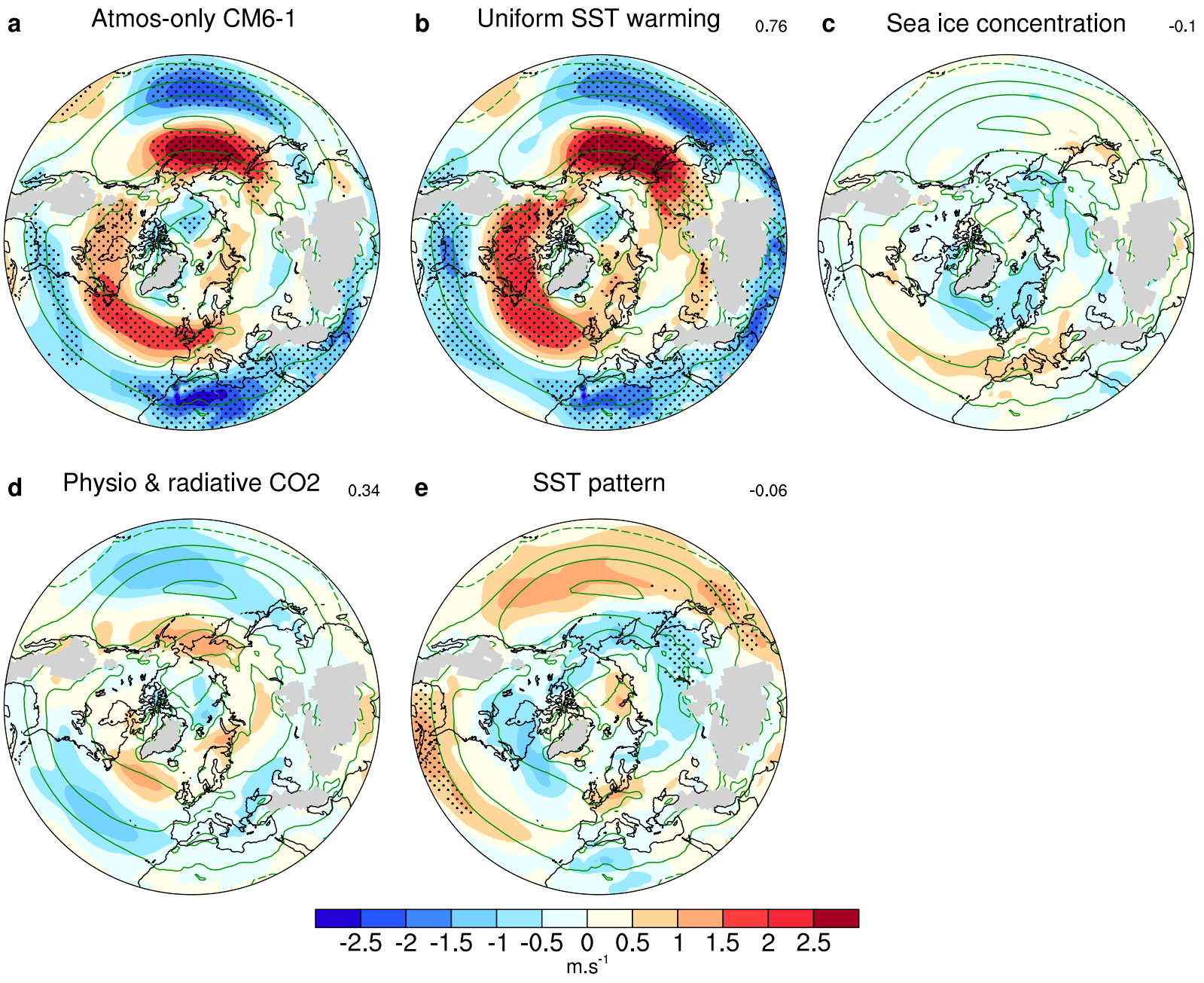


- Significance is reached **much faster in OND** than in ONDJFM and JFM: A dozen of years are needed.

- **Internal variability** is important in the Atlantic compared to the Pacific in which robustness is found for almost each seasons.

Breakdown of the AGCM response

850 hPa zonal wind breakdown

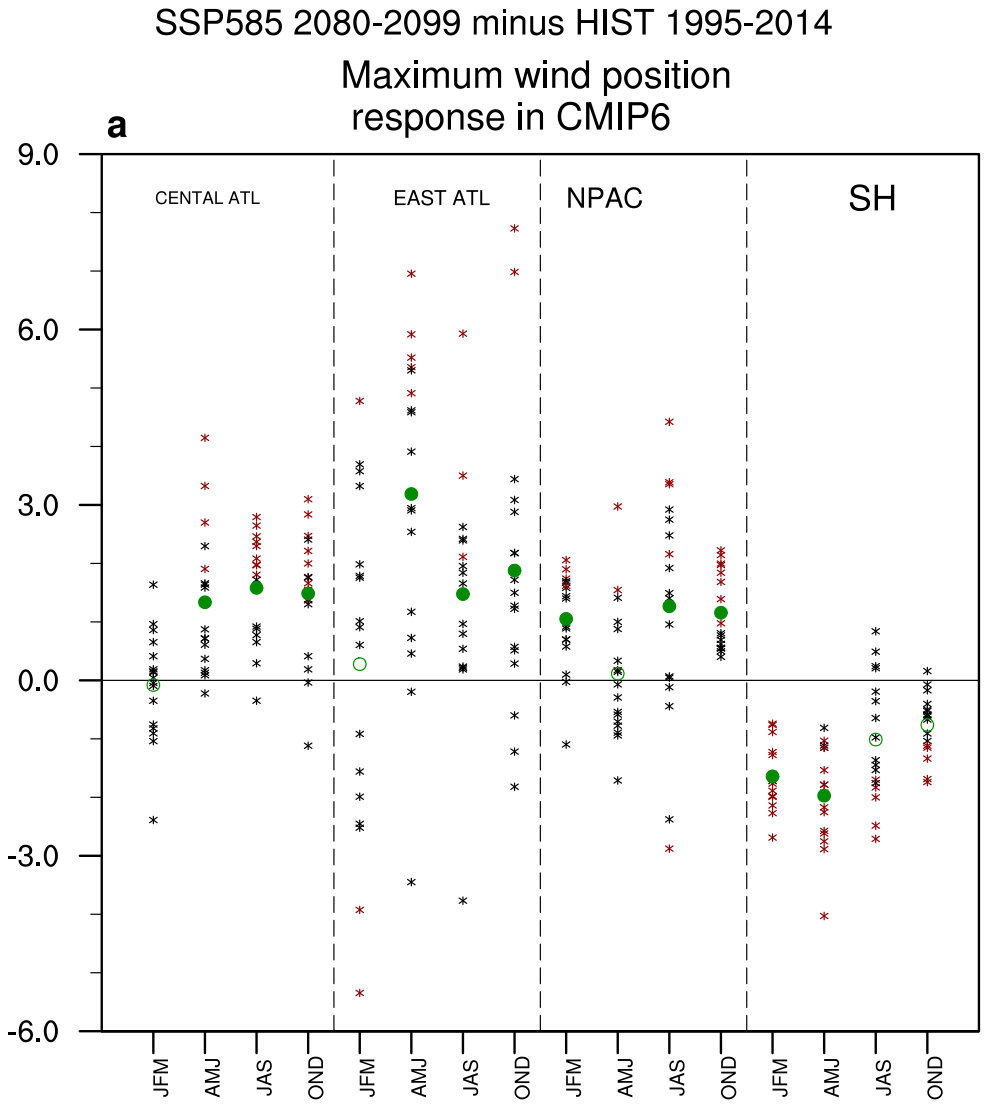


Conclusions

- CNRM-CM6-1 performs better (weaker biases, better representation of blockings, etc.) and has a **stronger sensitivity** than CNRM-CM5.
- **Robust poleward shift** in the Pacific and **squeezing of the variability** in the Atlantic.
- The **uniform SST warming** is the dominant factor to explain the poleward shift.

Perspectives

- Looking at other CMIP6 models.



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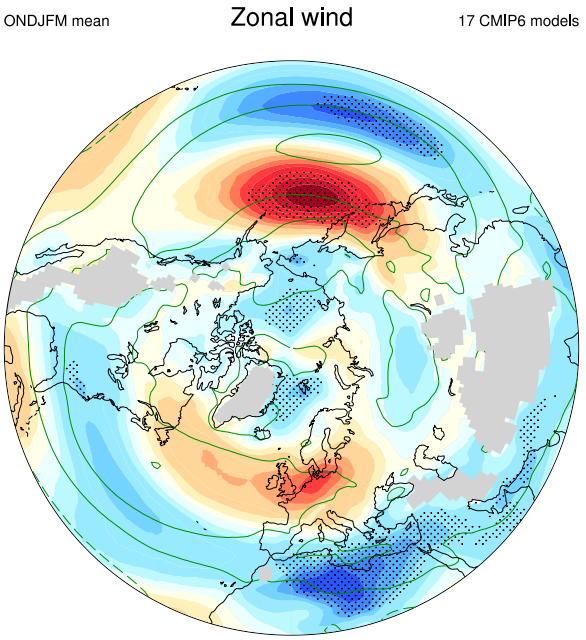

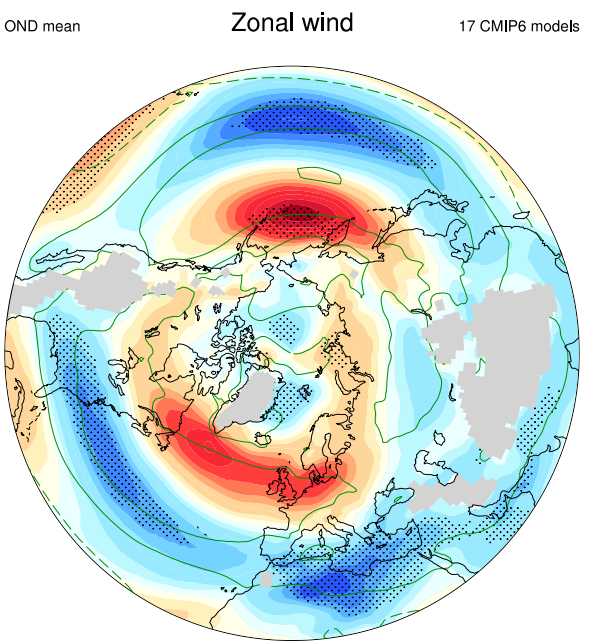

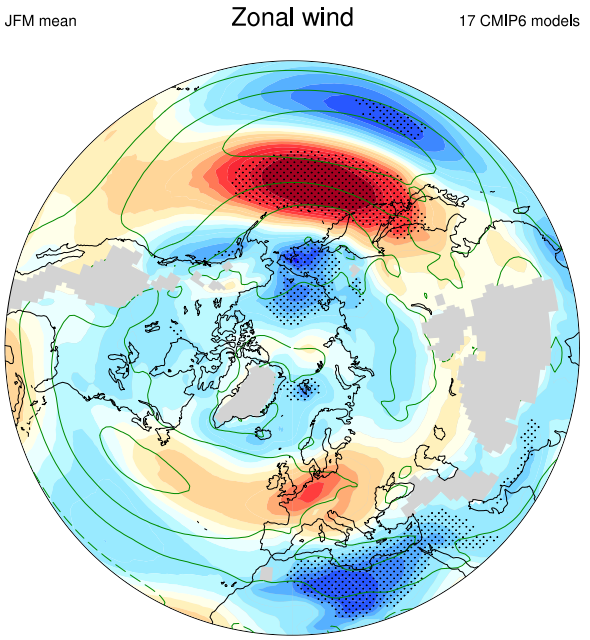

- Analyze storm-tracks, blockings and sinuosity responses in CMIP6 models.

Experiments

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	a4SST	abrupt-4xCO2	piControl	pre-industrial	x	30
	a4SSTice	abrupt-4xCO2	abrupt-4xCO2	pre-industrial	x	30
	amip	obs.	obs.	obs.	x	36
	amip-p4K	obs. +4K	obs.	obs.	x	36
	amip-lwoff	obs.	obs.	obs.		36
	amip-p4K-lwoff	obs. +4K	obs.	obs.		36

Differences showed in this study are computed over years 111-140

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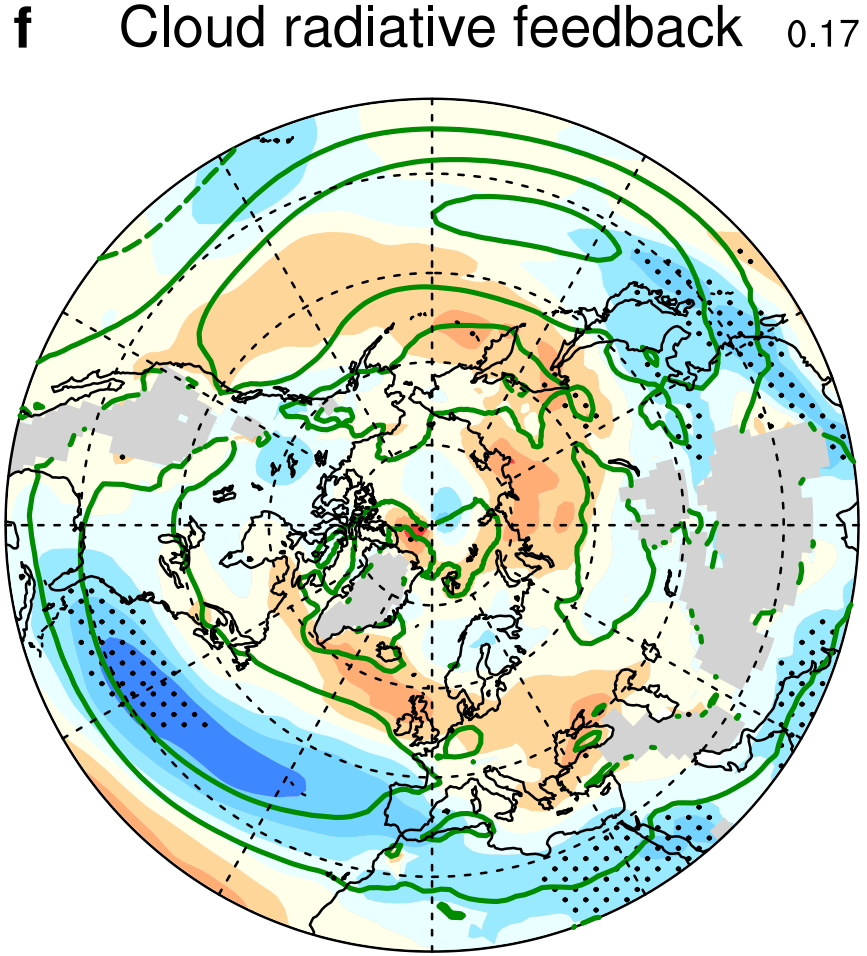
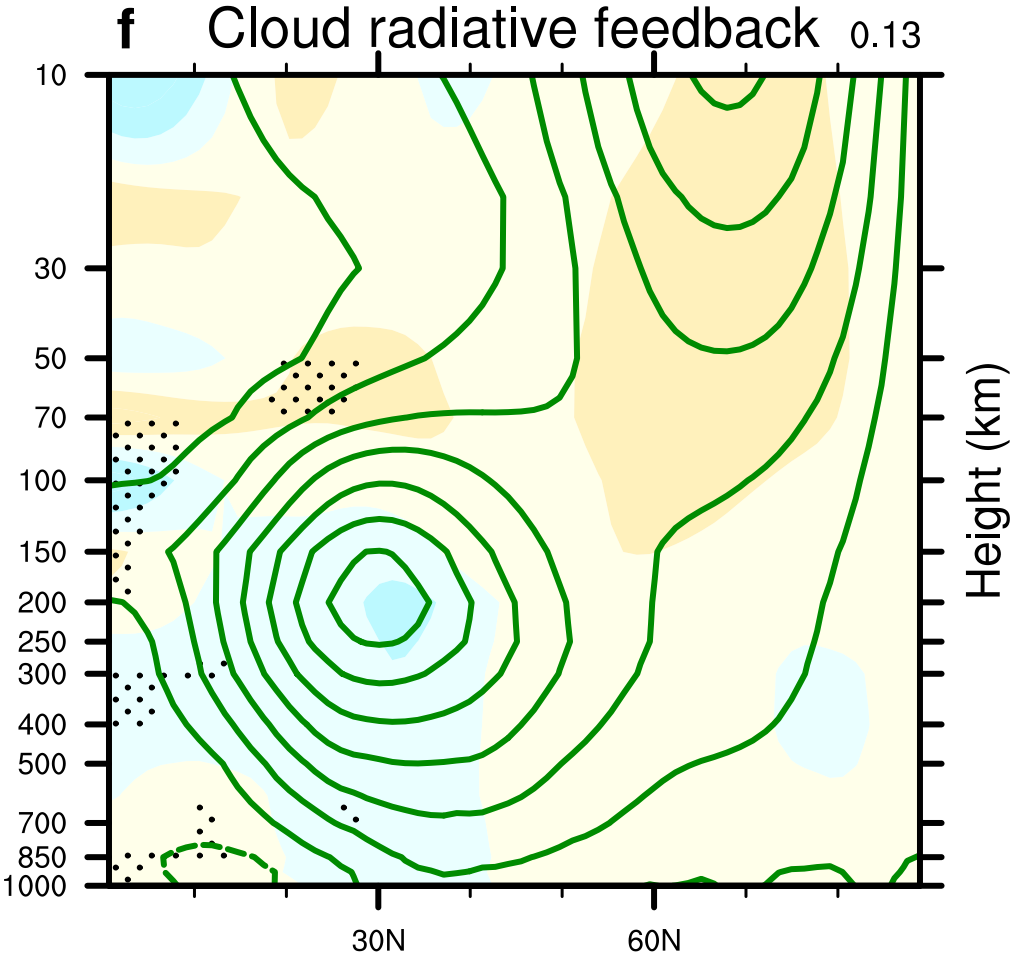
- **Role of clouds ?** Is the poleward shift **enhanced** by the cloud radiative heating as suggested by previous studies ? (*Ceppi and Hartmann 2015; Voigt and Shaw 2016; Li et al. 2019*).

Role of clouds ?

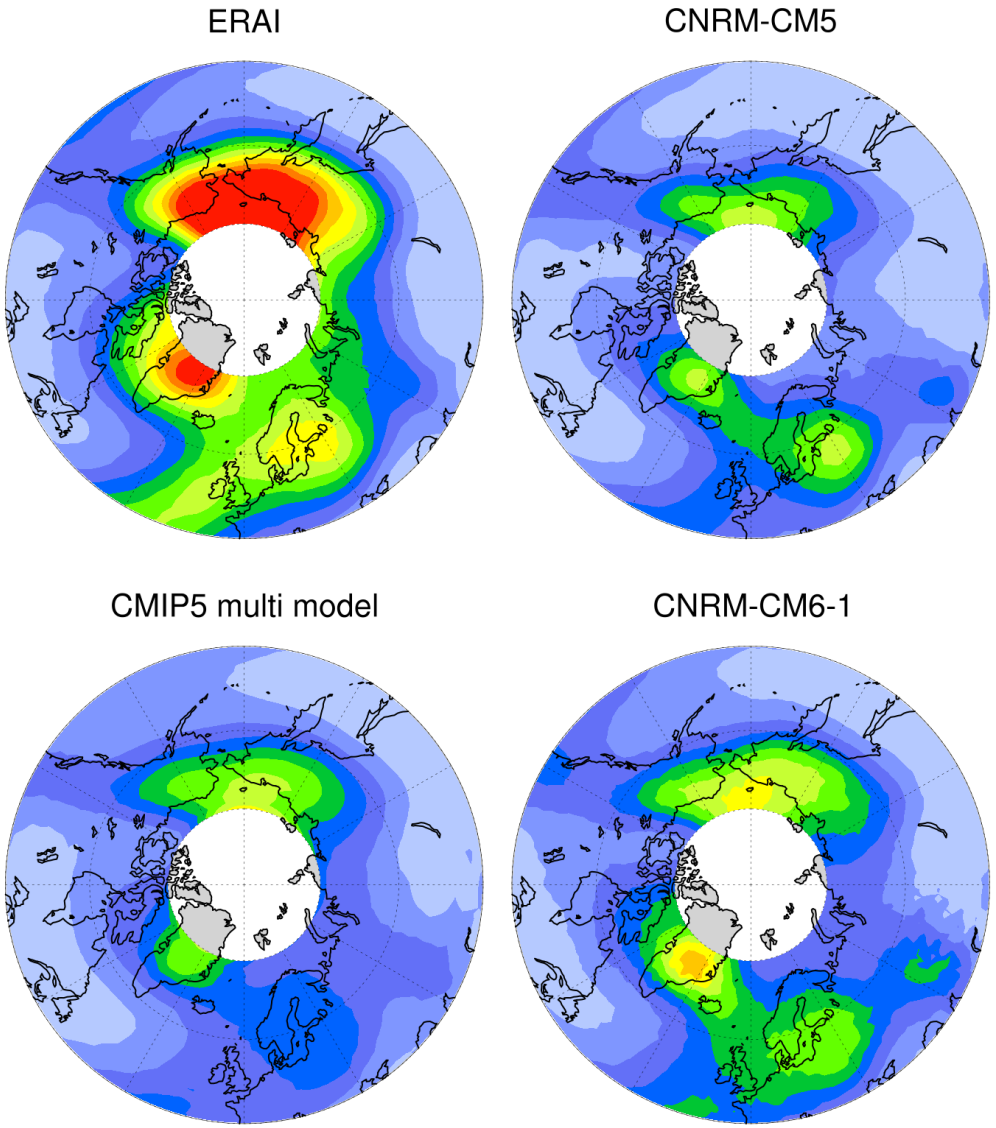
U850

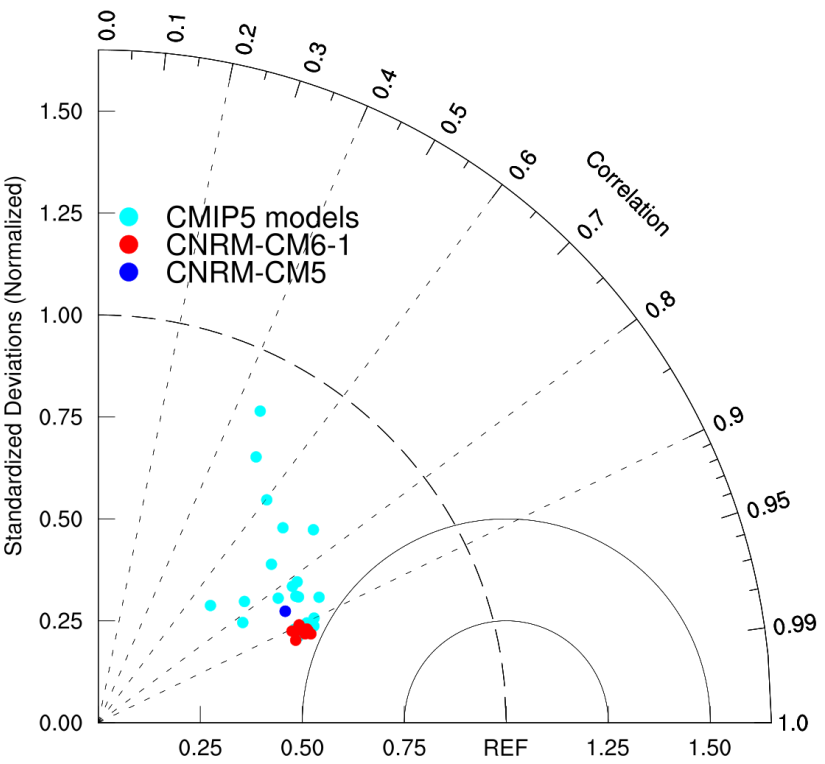


Zonal-mean zonal wind



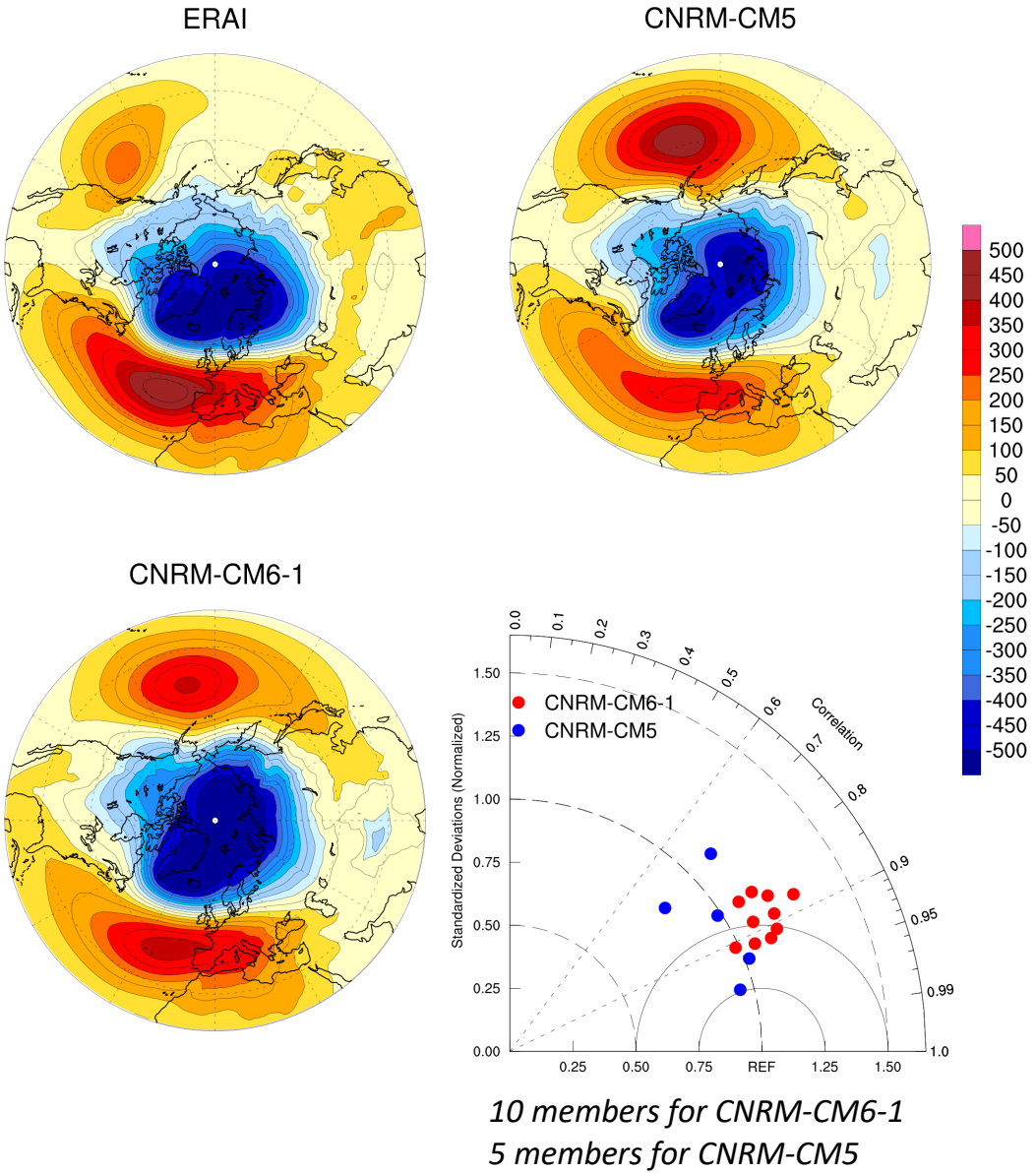
2D blocking index (Scherrer et al. 2007)





Annual climatology of blockings

Northern Annular Mode (NAM)

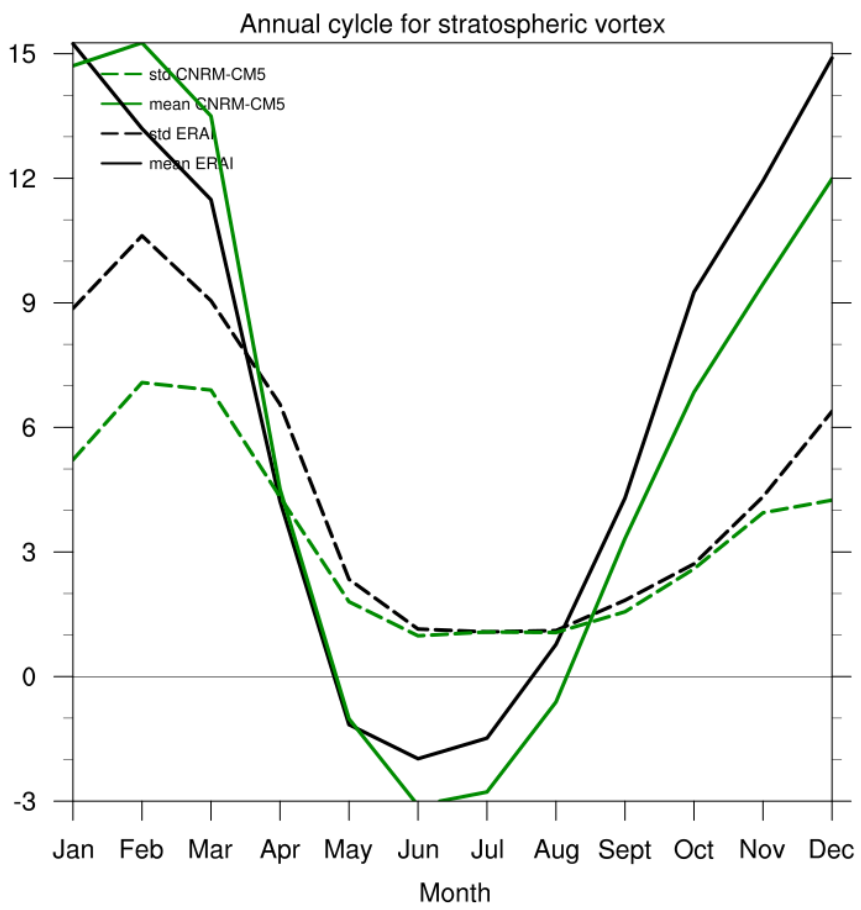


10 members for CNRM-CM6-1
5 members for CNRM-CM5

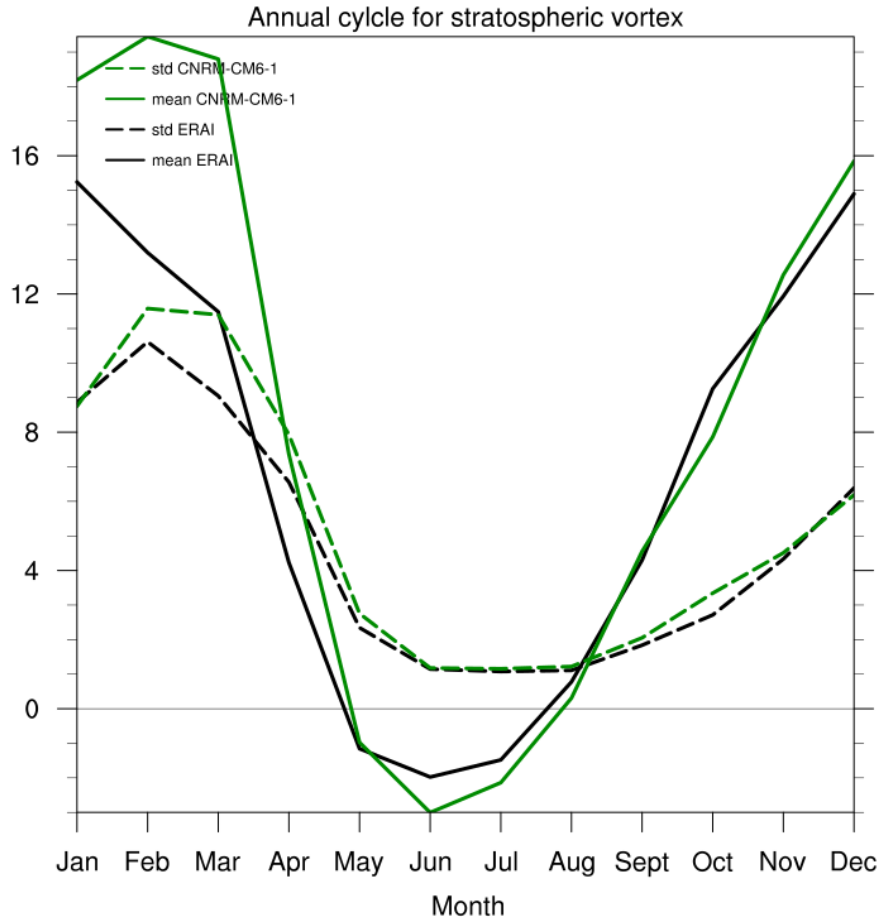
- The NAM is the first mode of variability in the Northern Hemisphere.
- NAM computed as the first EOF of Sea level Pressure in DJFM

Polar stratospheric vortex

CNRM-CM5

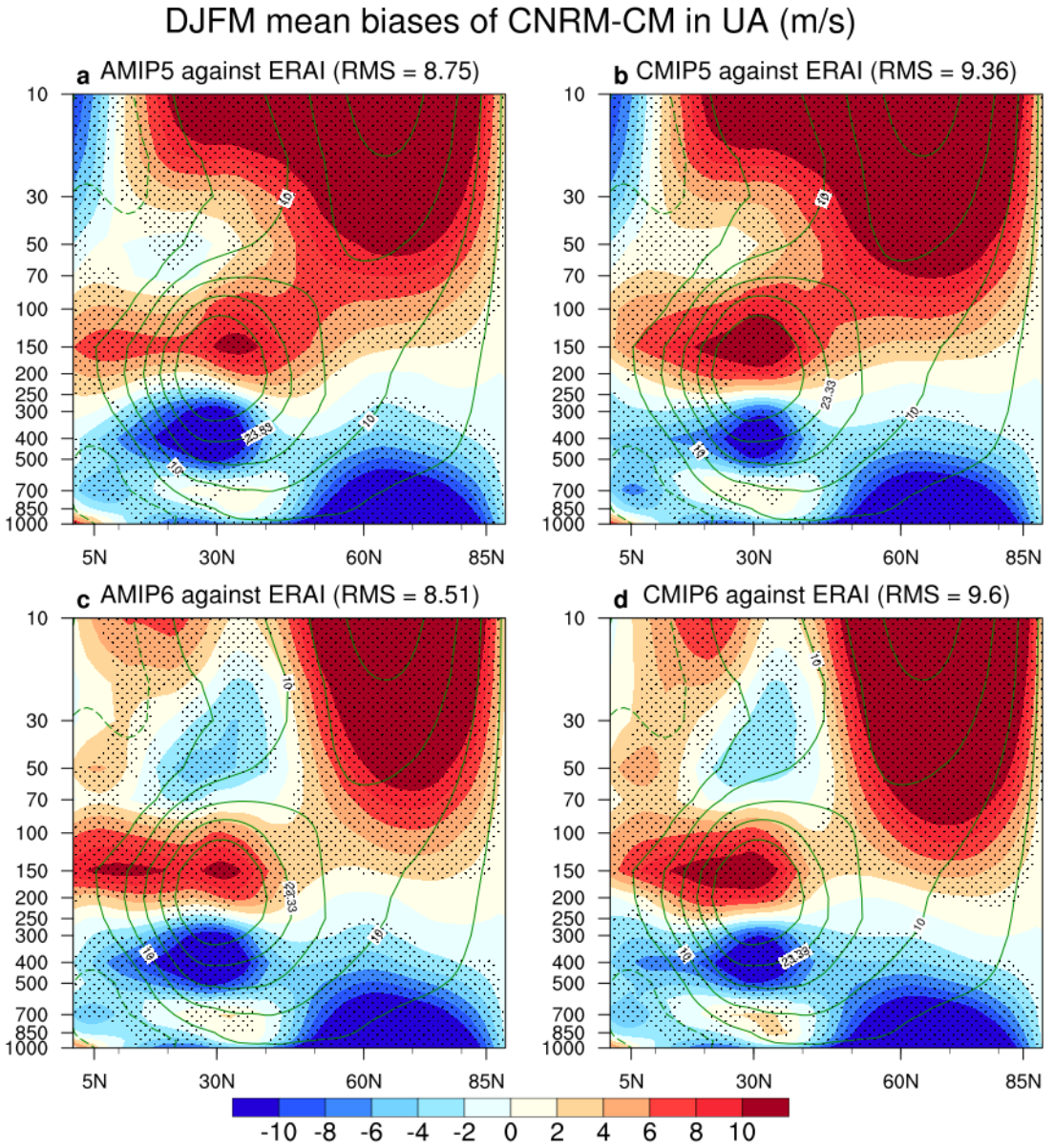


CNRM-CM6-1

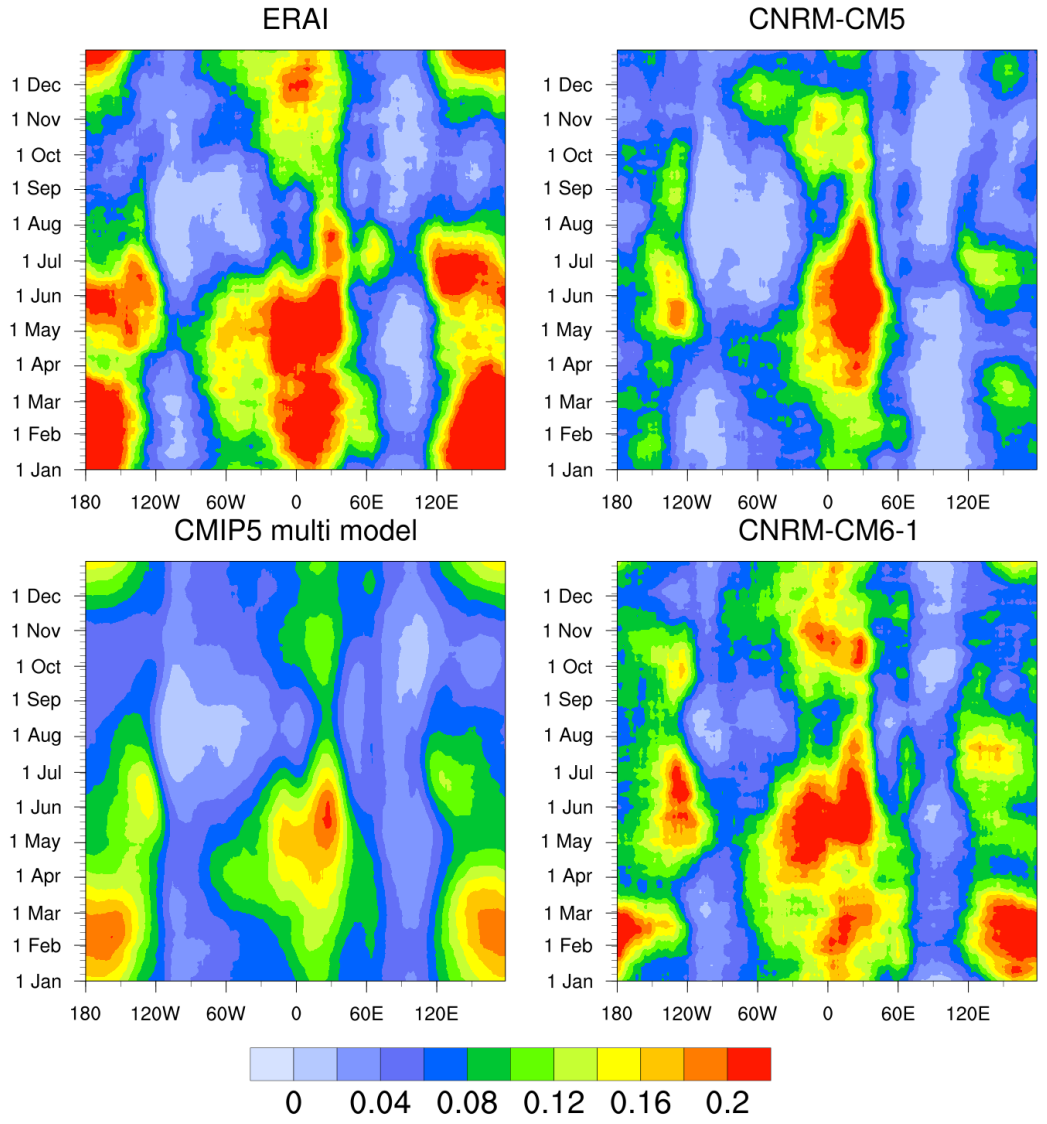


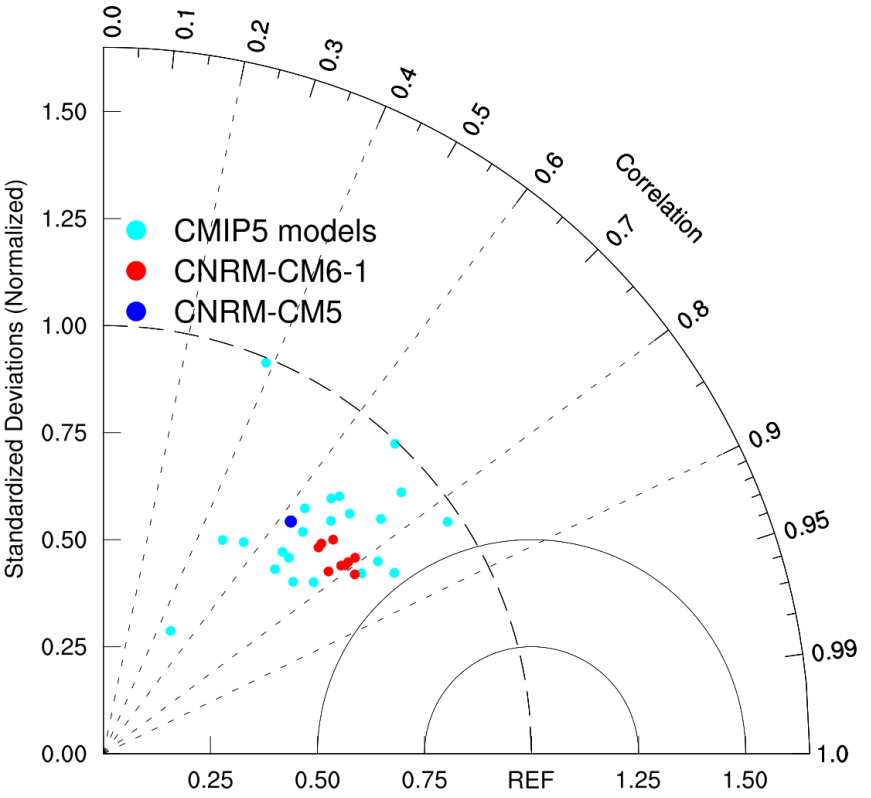
Seasonal cycle of the zonal wind at 50 hPa (between 70°N and 80°N)

Biases of U


DJFM mean biases of CNRM-CM in UA (m/s)
a AMIP5 against ERAI (RMS = 8.75)
b CMIP5 against ERAI (RMS = 9.36)
c AMIP6 against ERAI (RMS = 8.51)
d CMIP6 against ERAI (RMS = 9.6)
10
30
50
70
100
150
200
250
300
400
500
700
850
1000
5N
30N
60N
85N
-10 -8 -6 -4 -2 0 2 4 6 8 10

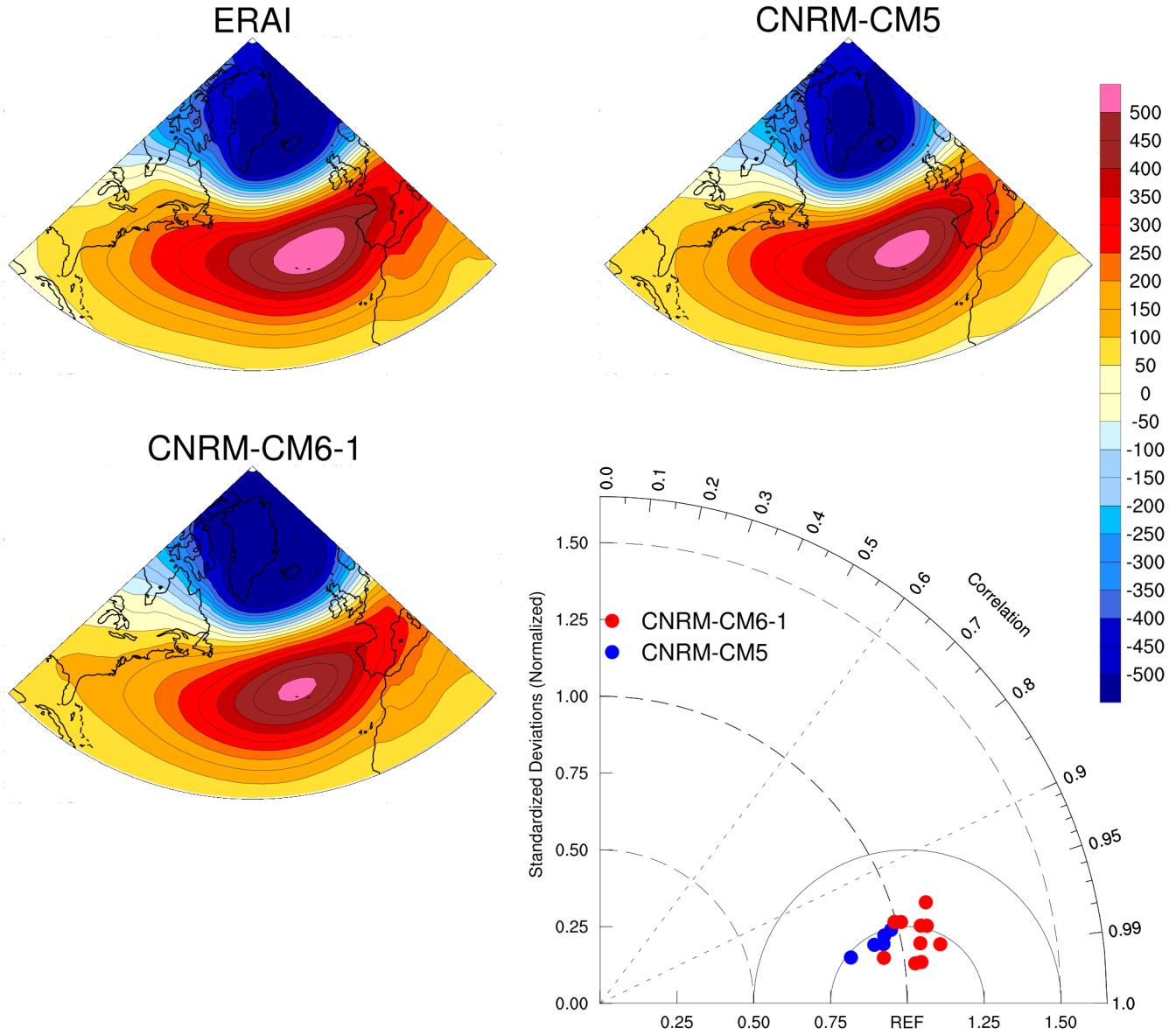
1D blocking index (Tibaldi-Molteni)



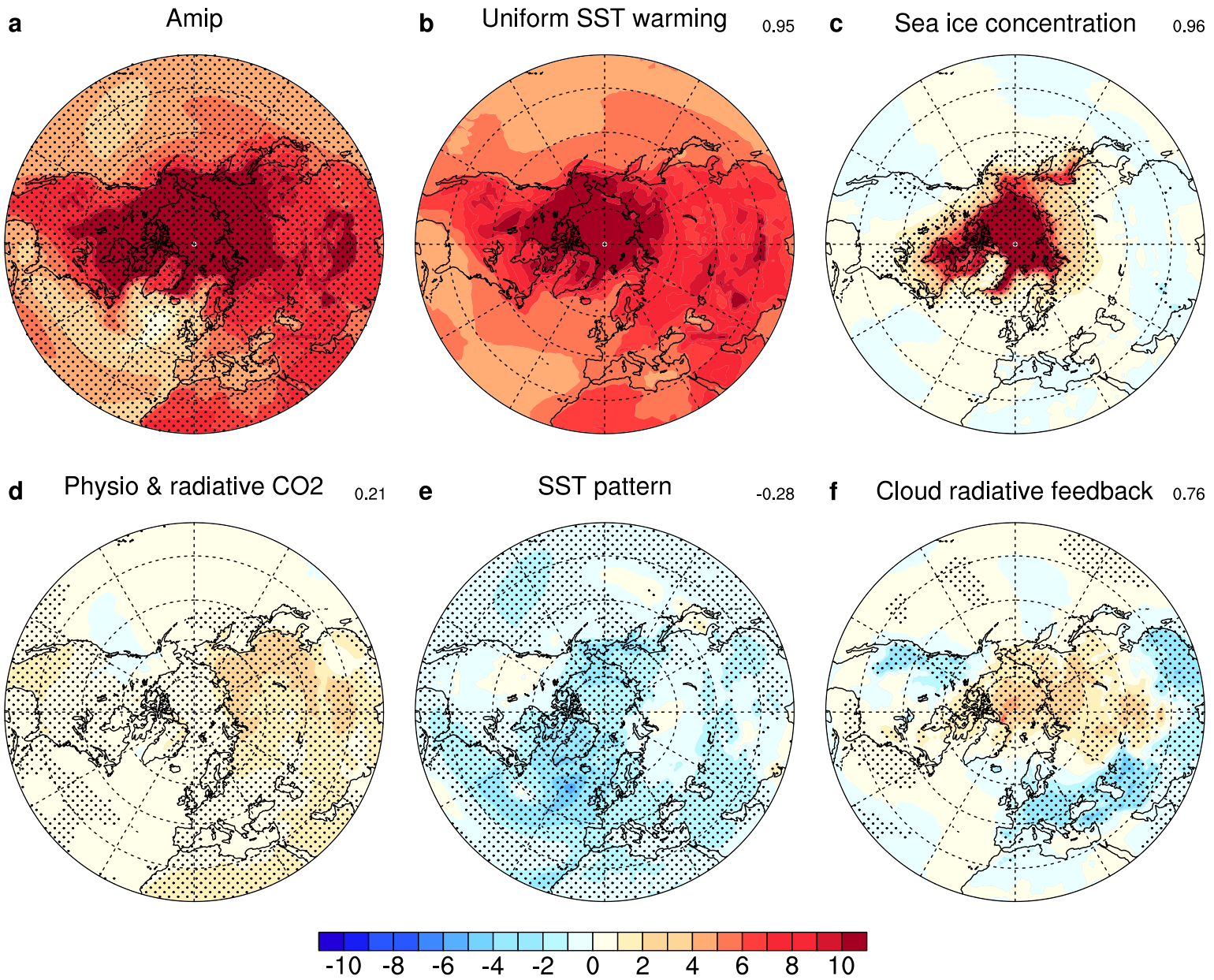


Improvement of the representation of blockings in CNRM-CM6-1

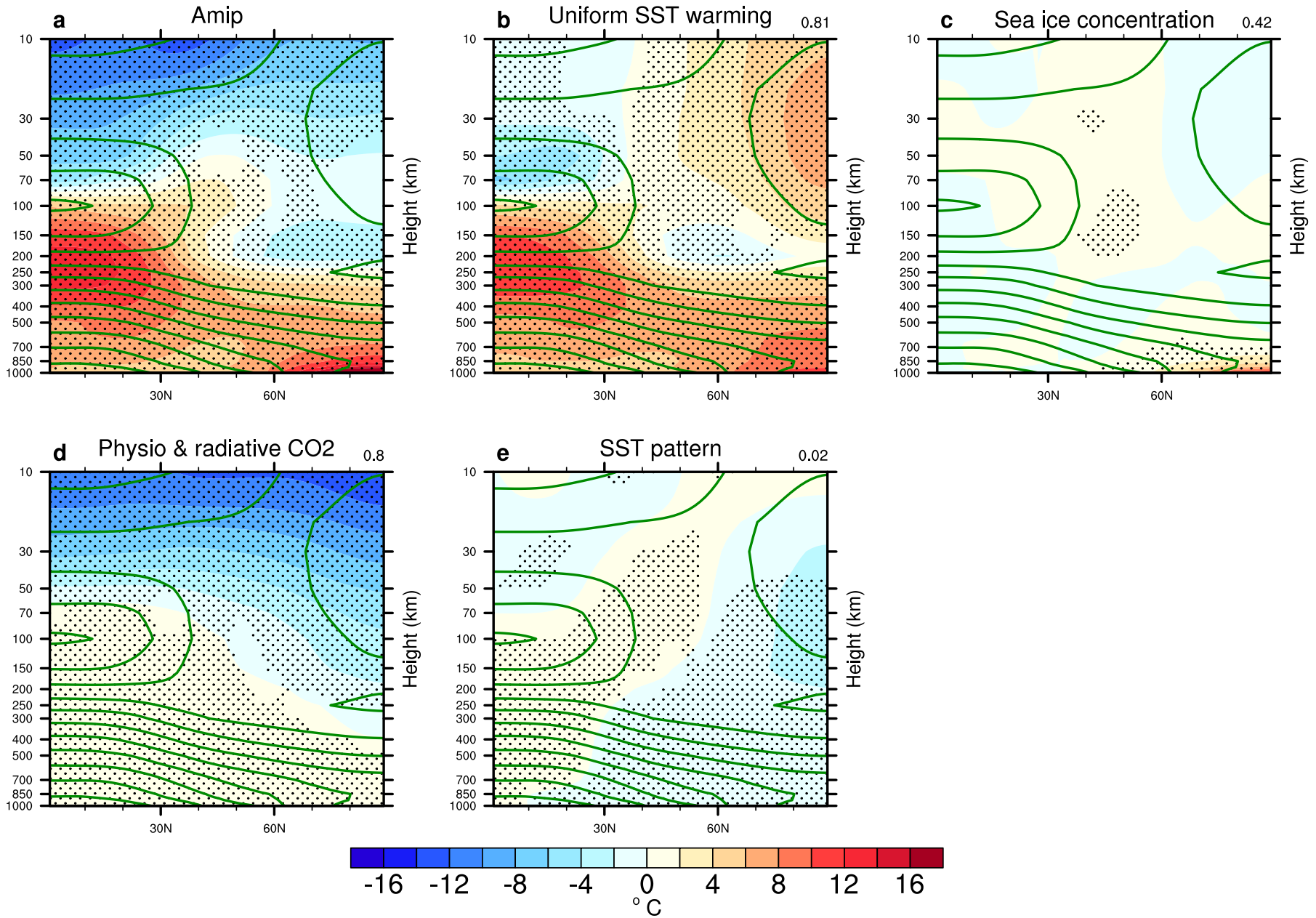
North Atlantic Oscillation



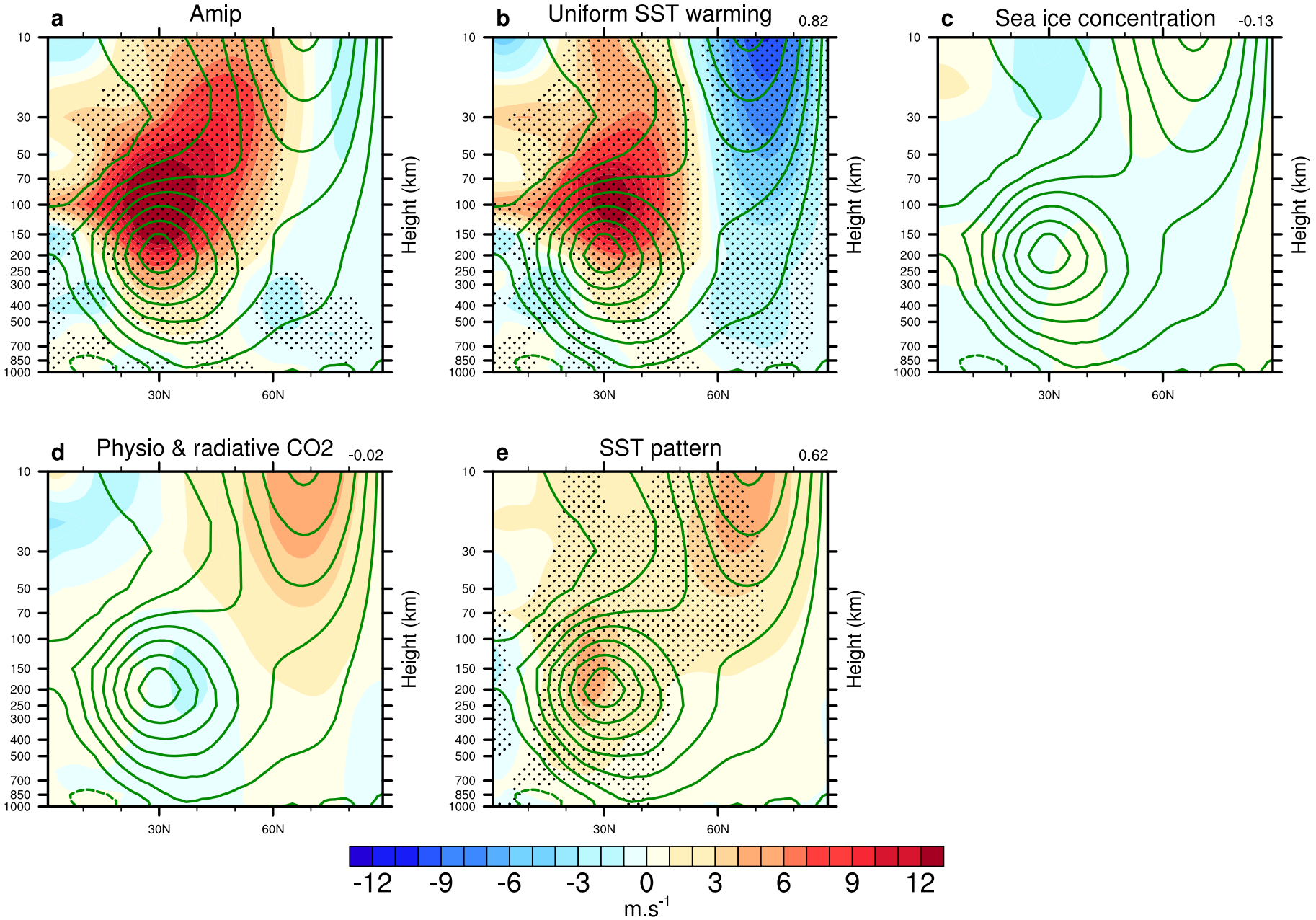
Near-surface temperature



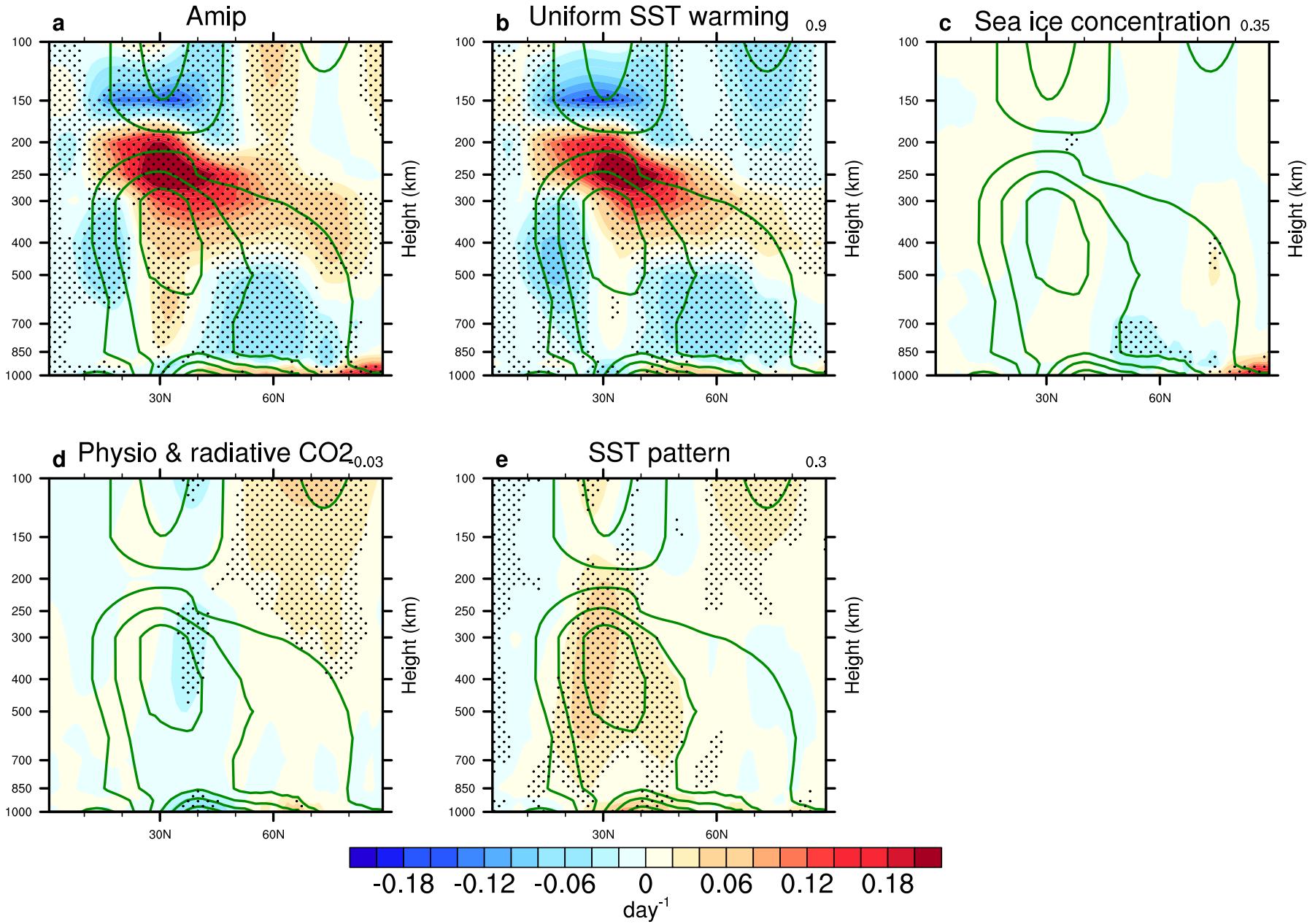
Zonal-mean temperature



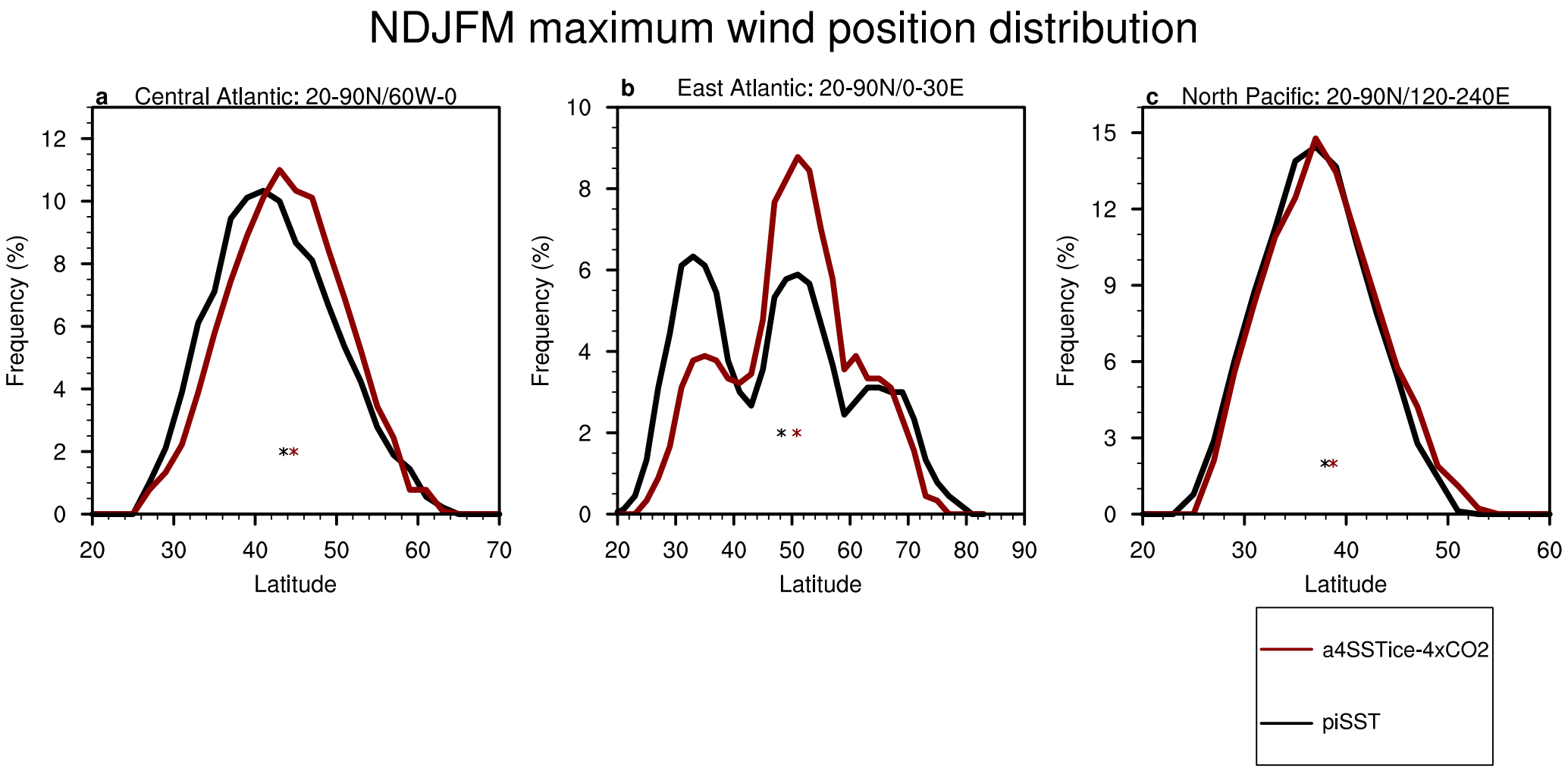
Zonal-mean zonal wind



Eady growth rate



Jet position response in AGCM



Other seasons