Atmospheric response to Gulf Stream SST front shifts: impact of horizontal resolution in an ensemble of global climate models

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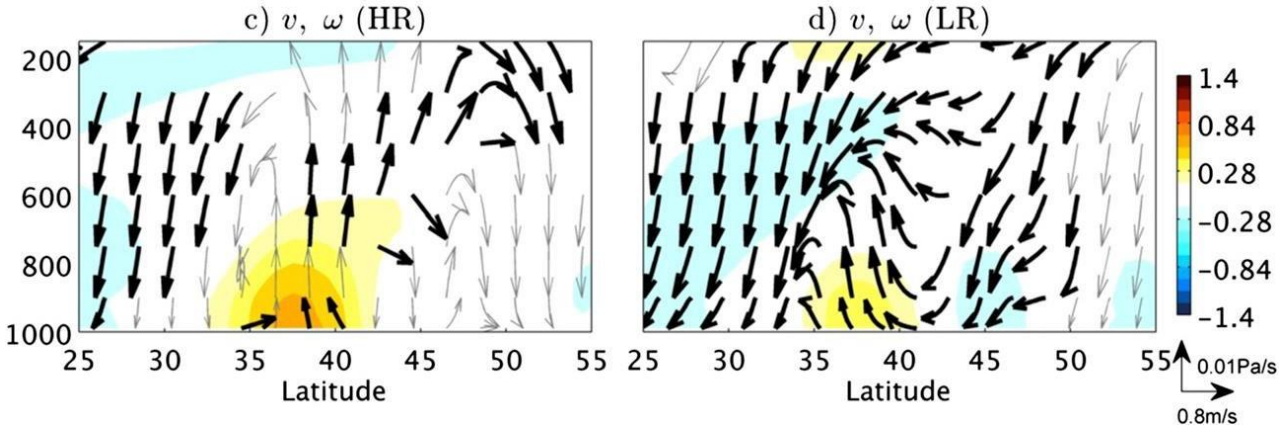
Introduction and objective



Smirnov et al., 2015 *- Winter zonally averaged across-front circulation (vectors) and potential temperature (colors) response to a shift in the Oyashio Extension SST front in an atmospheric general circulation model (AGCM). HR – 0.25°; LR – 1°*

The present work is a **multi-model analysis** to systematically investigate the **role of horizontal resolution in the atmospheric response** to realistic extratropical SST variability. With this purpose, the atmospheric response to extratropical SST anomalies associated with the **inter-annual Gulf Stream SST front (GSF) shifting** during winter has been analyzed.

Data and methods

Table *- High Resolution Model Intercomparison Project (HighResMIP) AGCMs. Each model has been forced with the HadISST2 sea ice concentration and SST dataset*

Institution	Model	Nominal Resolution (km)	Members
EC-Earth-Consortium	EC-Earth3P	100	3
	EC-Earth3P-HR	50	3
MOHC	HadGEM3-GC31-MM	100	3
	HadGEM3-GC31-HM	50	3
ECMWF	ECMWF-IFS-LR	50	8
	ECMWF-IFS-HR	25	6

"North" phase of the GSF → **Upper tercile** of the GSF latitude averaged in [50°–68°W]

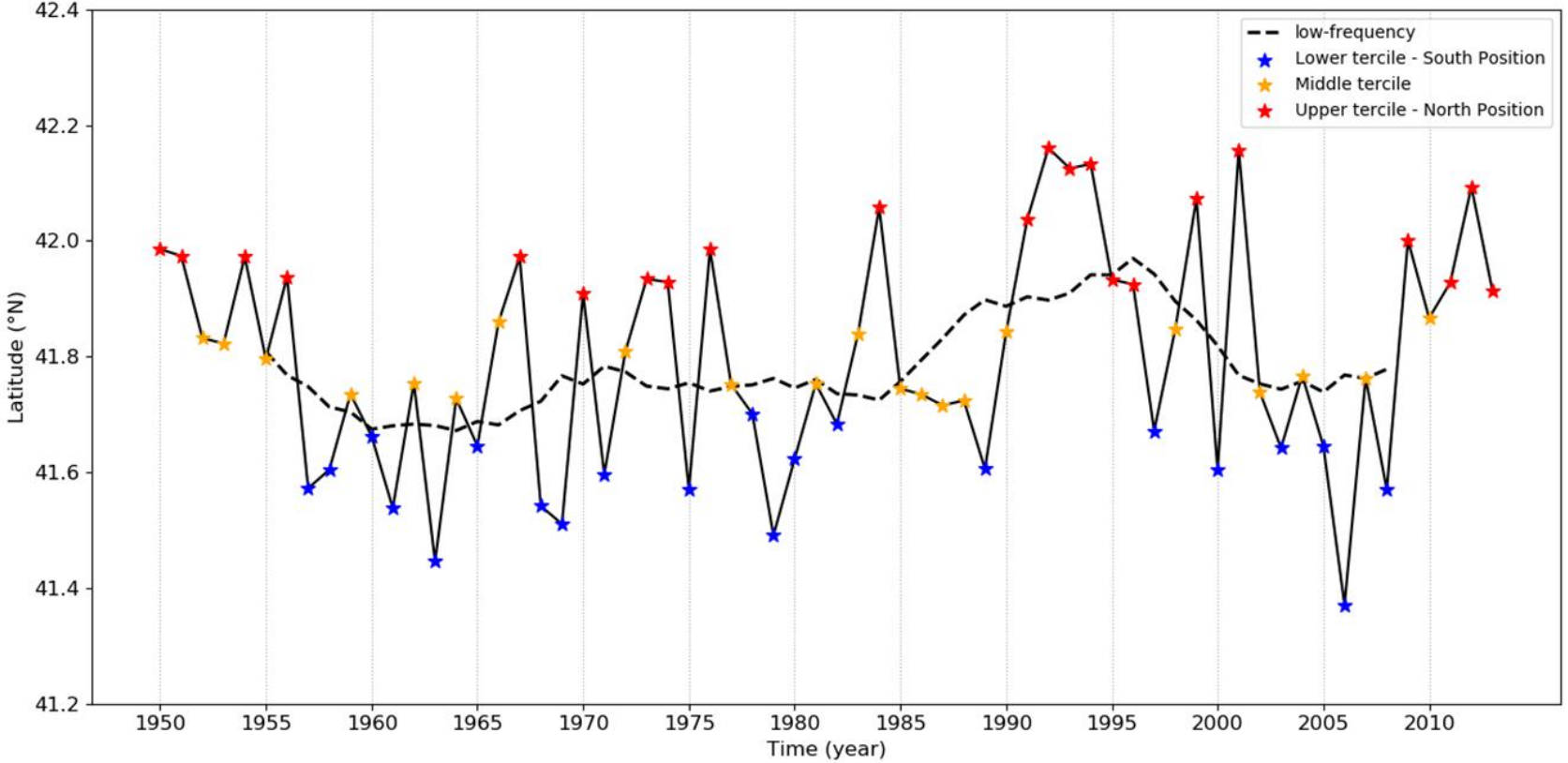
"South" phase of the GSF → **Lower tercile** of the GSF latitude averaged in [50°–68°W]

Atmospheric response to GSF shifting

↓

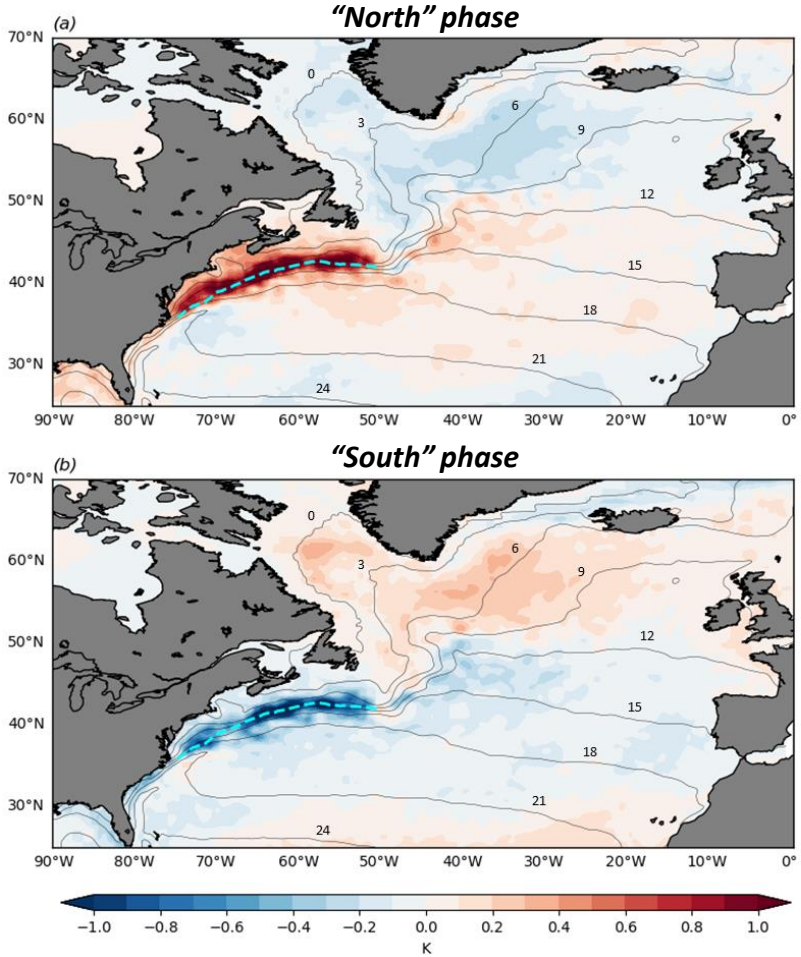
"North" phase minus **"South" phase**

Results – GSF latitude time-series



- Dashed black line is the 10-years running mean

Results – SST anomalies



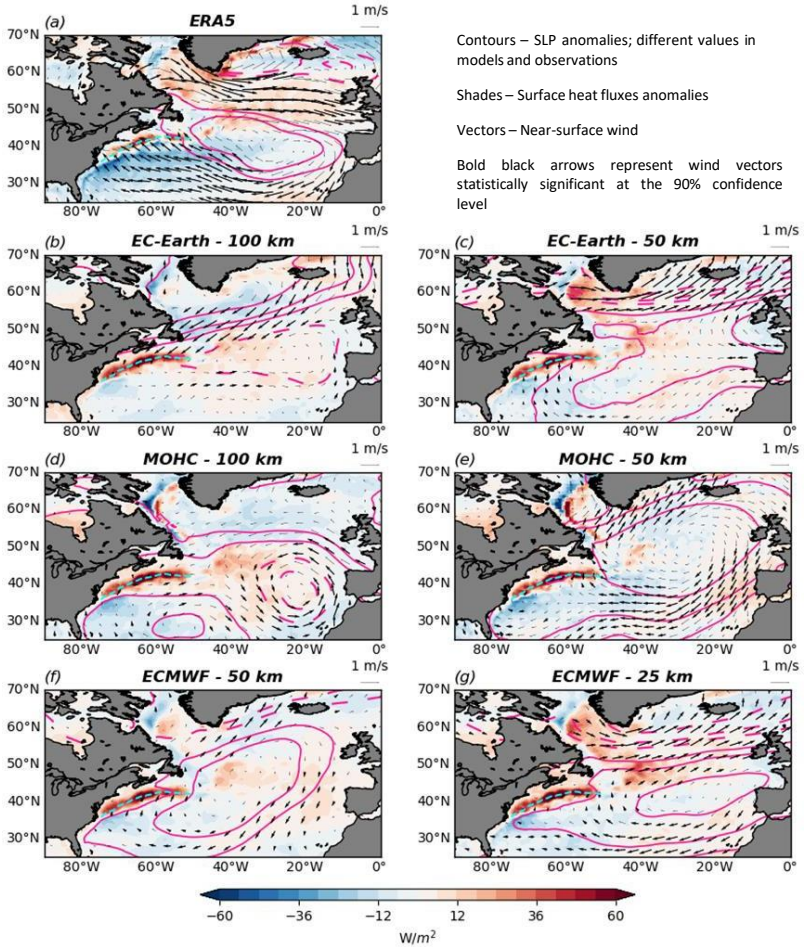
- **Tripolar structure** extending to the entire North Atlantic in both GSF phases but of opposite sign
- SST anomalies particularly strong close to the GSF winter climatological position

NAO forcing

&

Intrinsic oceanic processes

Results – Atmospheric surface response



Contours – SLP anomalies; different values in models and observations

Shades – Surface heat fluxes anomalies

Vectors – Near-surface wind

Bold black arrows represent wind vectors statistically significant at the 90% confidence level

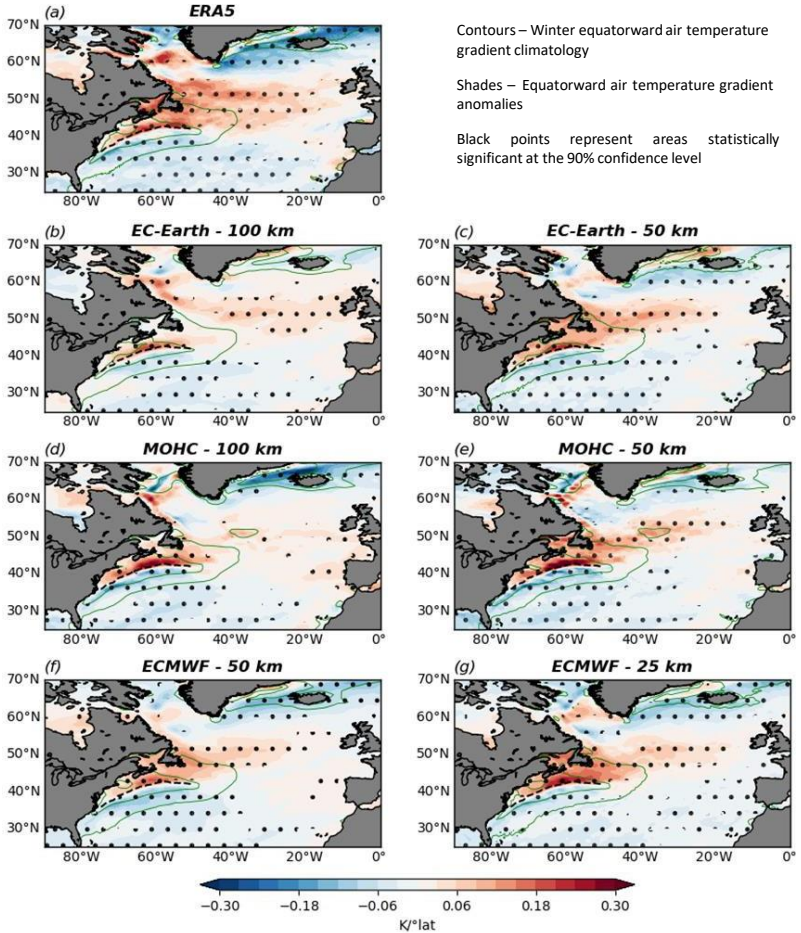
AGCMs with horizontal resolution = 100 km

- **Negative SLP anomalies** downstream the diabatic heating source, recalling cold air from higher latitude → as expected in «theoretical linear models»
- **Strong surface heat fluxes (SHF)** anomalies close to the GSF winter climatological position

AGCMs with horizontal resolution ≥ 50 km

- **Positive SLP anomalies** downstream the diabatic heating source, recalling warm air from lower latitude
- **Strong SHF anomalies** close to the GSF winter climatological position
- Response comparable to **observations**

Results – Meridional air temperature gradient at 925hPa



Contours – Winter equatorward air temperature gradient climatology

Shades – Equatorward air temperature gradient anomalies

Black points represent areas statistically significant at the 90% confidence level

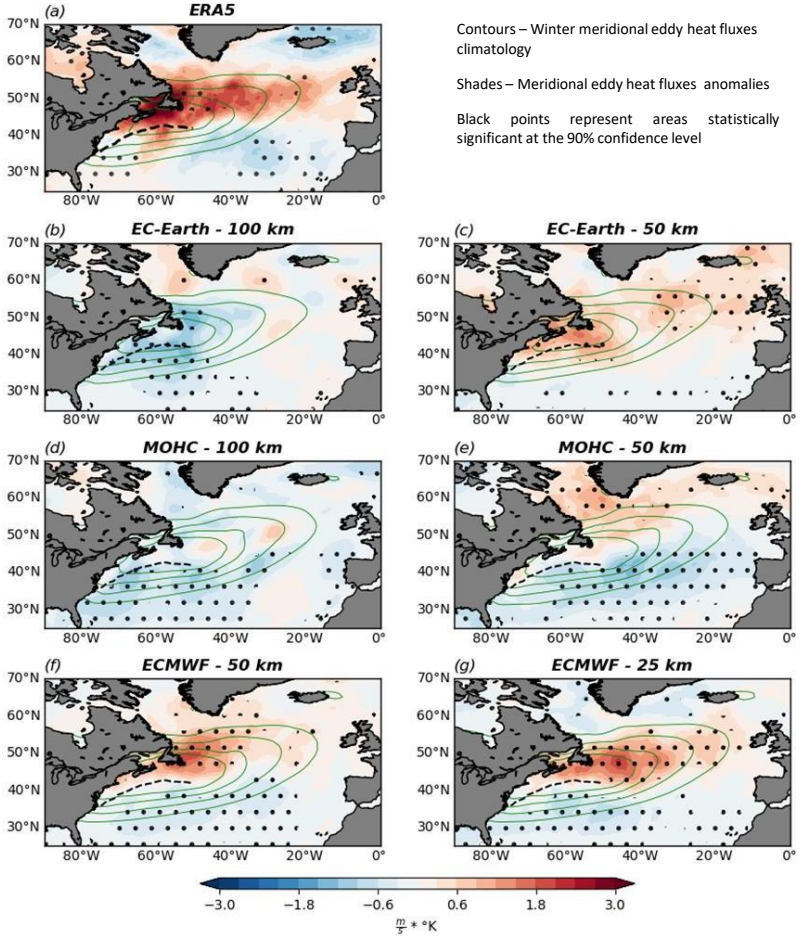
AGCMs with horizontal resolution = 100 km

- **Enhancement of meridional air temperature gradient (baroclinicity)** close to the GSF, consistent with SHF anomalies

AGCMs with horizontal resolution ≥ 50 km

- **Enhancement of baroclinicity** close to the GSF, consistent with SHF anomalies
- **Large-scale baroclinicity anomalies** extending downstream and north the GSF (*see next slide*)
- Response comparable to **observations**

Results – Meridional eddy heat fluxes (v'T') at 850hPa



Contours – Winter meridional eddy heat fluxes climatology

Shades – Meridional eddy heat fluxes anomalies

Black points represent areas statistically significant at the 90% confidence level

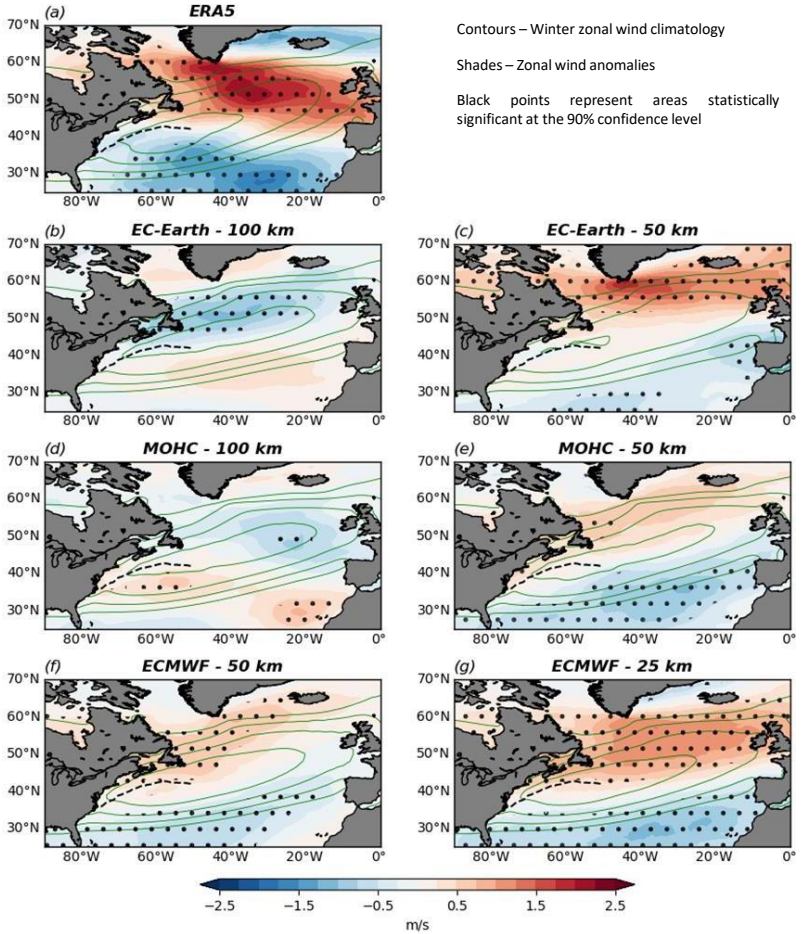
AGCMs with horizontal resolution = 100 km

- **Reduction of meridional eddy heat fluxes (MEHF)** in the western North Atlantic
- Reduction of transient eddy activity also in eastern North Atlantic (*see the supplementary material – Meridional momentum flux at 250hPa*)

AGCMs with horizontal resolution ≥ 50 km

- **Intensification of MEHF** that relaxes the local enhancement of baroclinicity → «Atmospheric baroclinic adjstument»
- **MEHF convergence** and **poleward warm temperature advection** by anomalous mean flow extend the baroclinicity anomalies north and downstream
- Response comparable to **observations**

Results – Zonal wind at 850hPa



Contours – Winter zonal wind climatology

Shades – Zonal wind anomalies

Black points represent areas statistically significant at the 90% confidence level

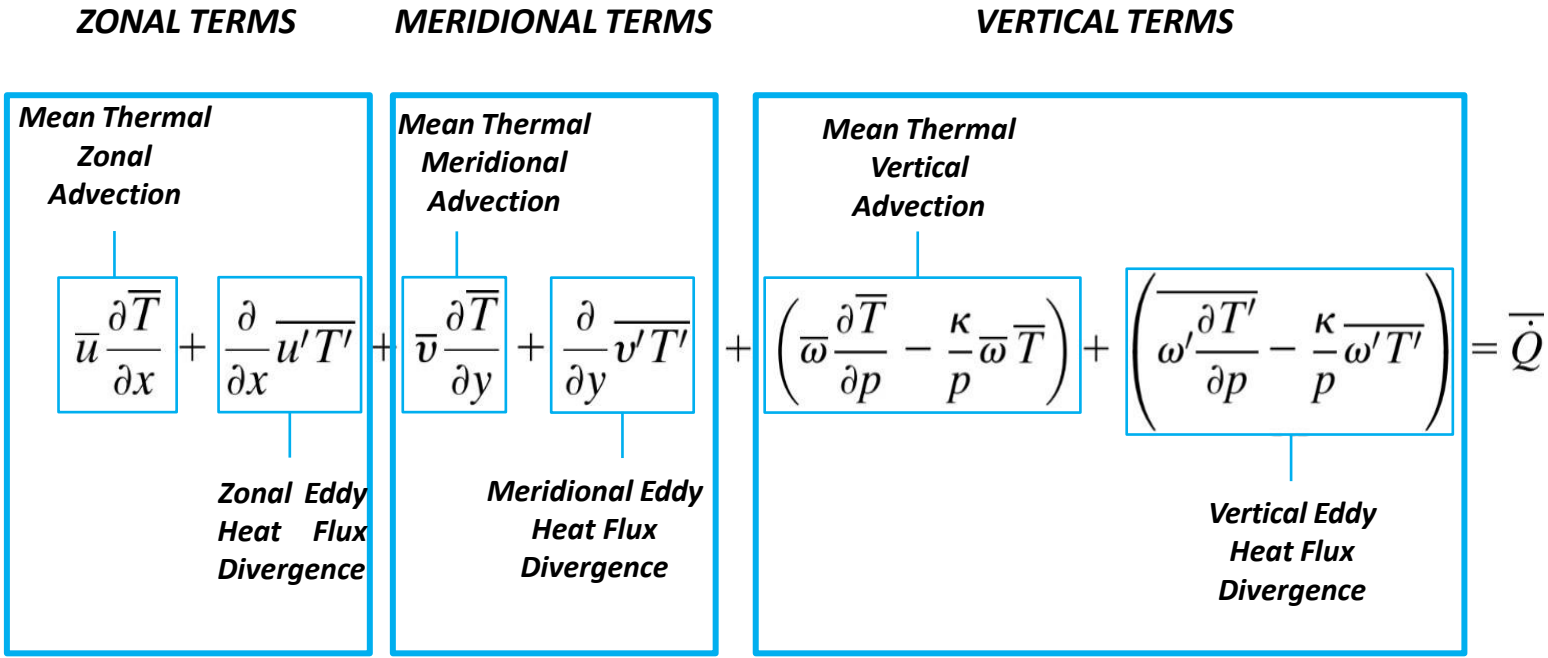
AGCMs with horizontal resolution = 100 km

- **Equatorward shifts** of the jet stream
- Increasing in frequency of southern jet position (*see the supplementary material – PDFs of jet stream latitude)*

AGCMs with horizontal resolution ≥ 50 km

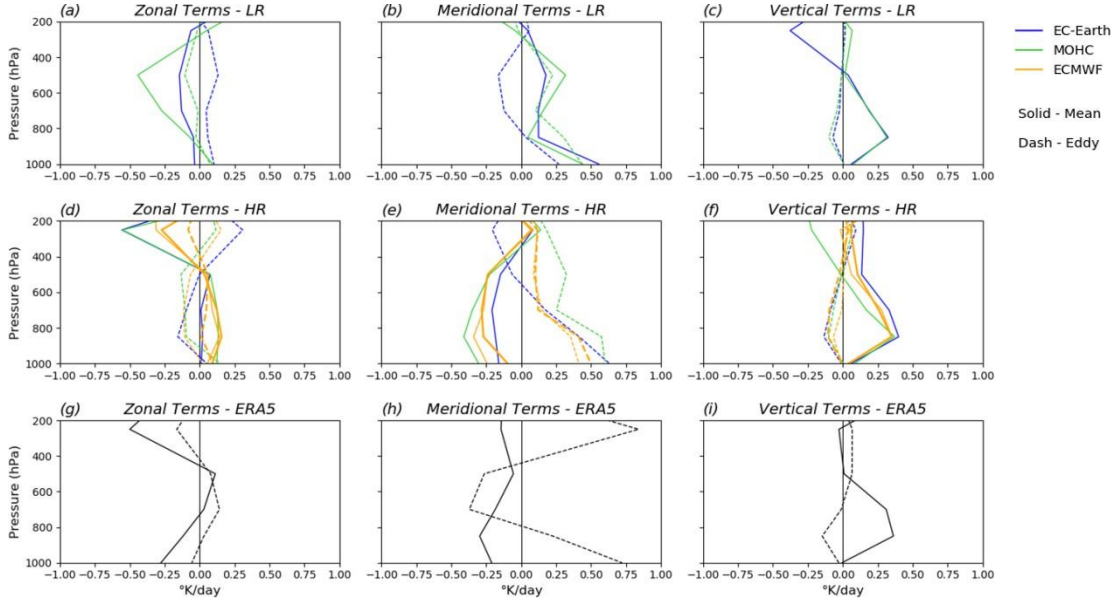
- **Poleward shifts** of the jet stream
- Increasing in frequency of northern jet position (*see the supplementary material – PDFs of jet stream latitude)*
- Response comparable to **observations**

Results – Thermodynamic budget



- Equation applied to each GSF phase
- Averaged within ±1°N band (band of positive SST anomalies) respect the GSF

Results – Thermodynamic budget



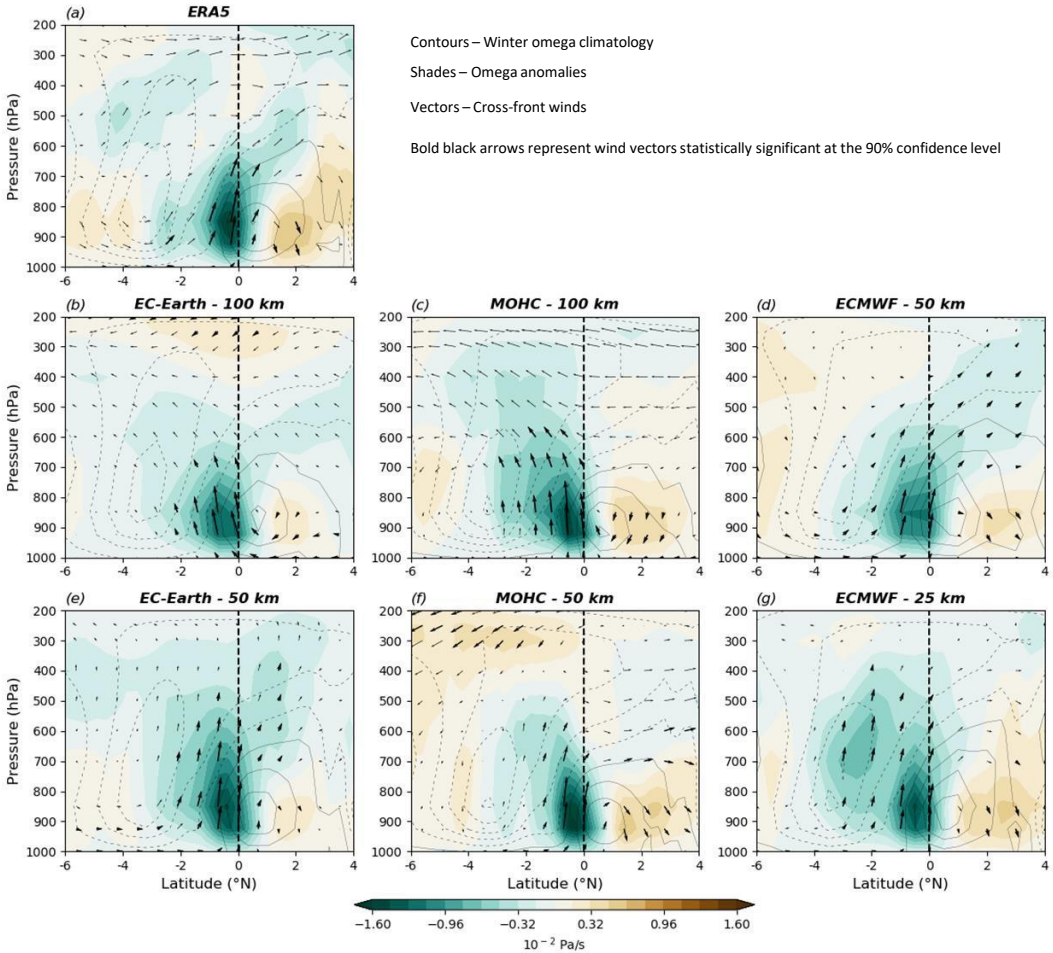
AGCMs with horizontal resolution = 100 km (LR)

- Near-surface diabatic heating anomalies mainly balanced by **mean thermal meridional advection** (cold air from higher latitudes)
- **Mean thermal vertical advection** quite relevant in the interior of the atmosphere (*see next slide)*

AGCMs with horizontal resolution ≥ 50 km (HR)

- Near-surface diabatic heating anomalies balanced by **meridional eddy heat flux divergence**
- **Mean thermal vertical advection** quite relevant in the interior of the atmosphere (*see next slide)*

Results – Omega



Contours – Winter omega climatology

Shades – Omega anomalies

Vectors – Cross-front winds

Bold black arrows represent wind vectors statistically significant at the 90% confidence level

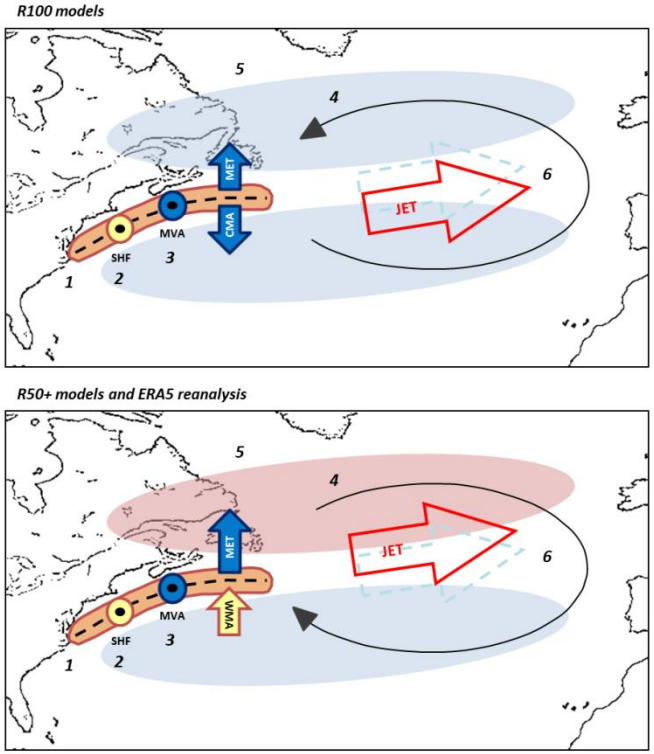
AGCMs with horizontal resolution = 100 km

- **Intense upward motion anomalies** in the vicinity of the GSF
- **Equatorward motion** extending throughout the troposphere

AGCMs with horizontal resolution ≥ 50 km

- **Intense upward motion** anomalies in the vicinity of the GSF
- **Weak circulation cell** south of the GSF
- Response comparable to **observations**

Schematic of the atmospheric response to the GSF shifts



SHF: Surface heat fluxes; MVA: Mean vertical advection; WMA: Warm meridional advection; CMA: cold meridional advection; MET: meridional sub-monthly eddy transport; JET: Eddy-driven jet ; large-scale shades: positive (red) and negative (blue) anomalies in transient eddy activity

- The SST anomalies induce **intense SHF anomalies** close to GSF
- The **local atmospheric response** to this anomalous diabatic heating is **fundamentally different** between R100 and R50+ models
- Differences in local response are reflected in **discrepancies in large-scale atmospheric response**
- Only models with a resolution greater than **50 km** reproduce an atmospheric response similar to observations

Conclusions

- The role of **horizontal resolution** on the atmospheric response to the **interannual GSF shifts** has been investigated in a multi-model multi-member ensemble of atmosphere-only historical simulations

- The atmospheric response to the GSF shifts is **strongly-resolution dependent**

- AGCMs with horizontal resolution = 100 km:
  local SHF anomalies → **southward cold air advection** → southward shifts of jet stream

- AGCMs with horizontal resolution ≥ 50 km:
  local SHF anomalies → **northward transient eddy heat transport** → large-scale baroclinicity anomalies → northward shifts of jet stream

- AGCMs with horizontal resolution ≥ **50 km** are in agreement with observations

- Possible existence of a **positive feedback** between the GSF and NAO:
  Positive NAO → poleward GSF shift → positive NAO

THANK YOU FOR THE ATTENTION

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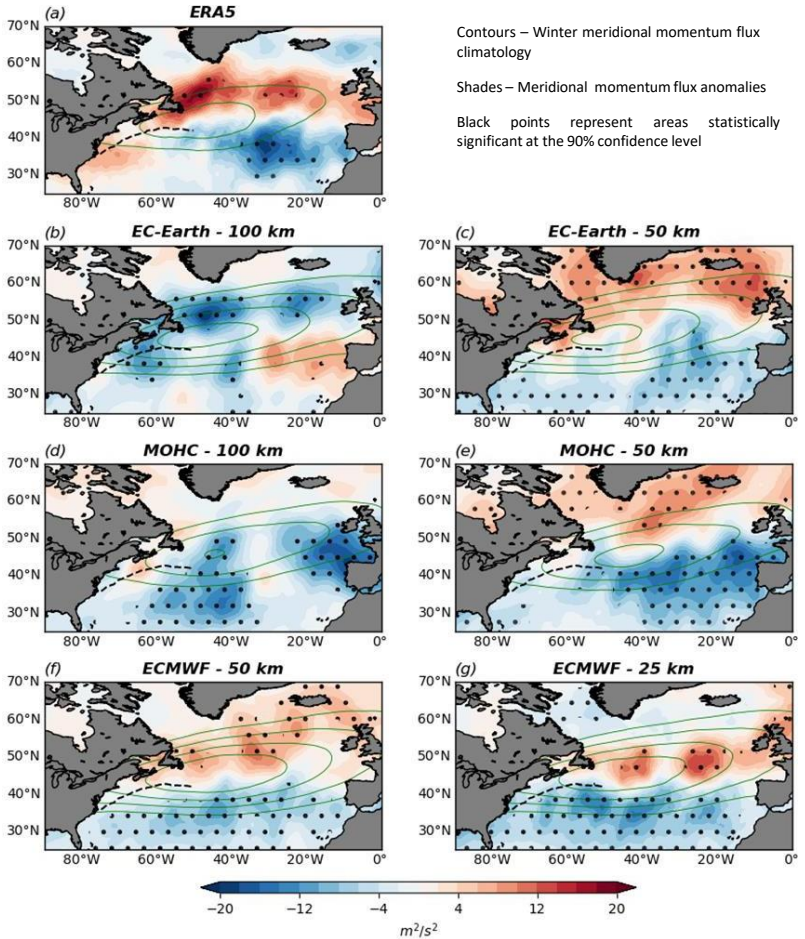
Supplementary material – Meridional momentum flux (v'v') at 250hPa



Contours – Winter meridional momentum flux climatology

Shades – Meridional momentum flux anomalies

Black points represent areas statistically significant at the 90% confidence level

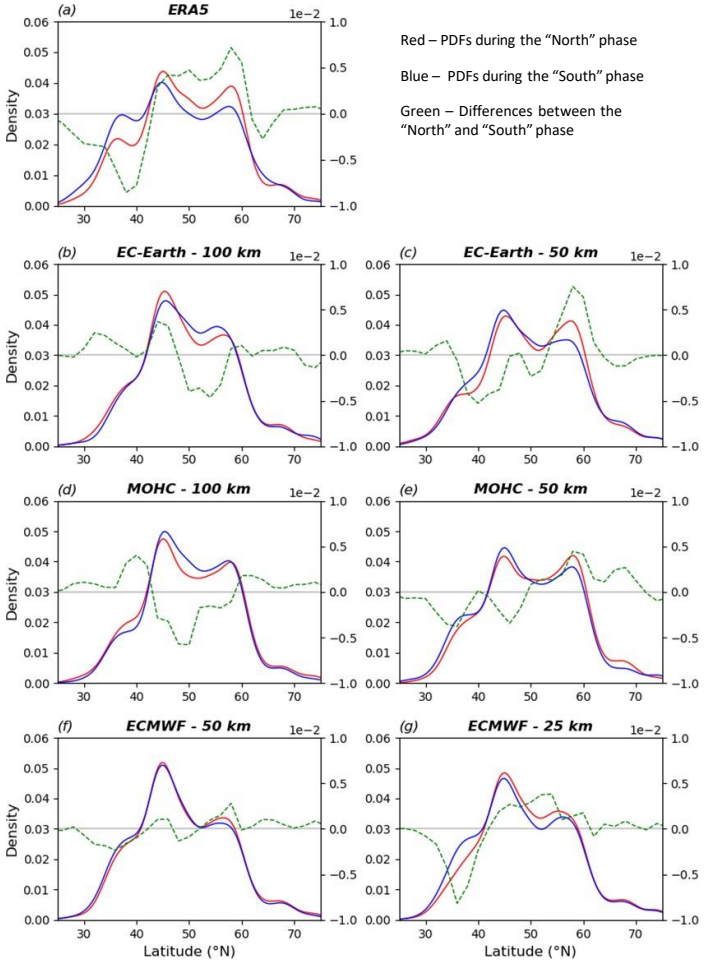
AGCMs with horizontal resolution = 100 km

- **Reduction of storm track activity** in the North Atlantic

AGCMs with horizontal resolution ≥ 50 km

- **Poleward shifts of storm track**
- Response comparable to **observations**

Supplementary material – PDFs of jet stream latitude



Red – PDFs during the "North" phase

Blue – PDFs during the "South" phase

Green – Differences between the "North" and "South" phase

AGCMs with horizontal resolution = 100 km

- PDFs more (less) pronounced towards **southern** (northern) jet position
- Changes in variability of jet position consistent with equatorward jet stream shifts

AGCMs with horizontal resolution ≥ 50 km

- PDFs more (less) pronounced towards **northern** (southern) jet position
- Changes in variability of jet position consistent with equatorward jet stream shifts
- Response comparable to **observations**