Impact of stochastic physics on blocking representation in EC-Earth3

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Motivation:

State-of-the-art climate models systematically underestimate winter atmospheric blocking frequency, especially over Europe. This is often attributed to a poor representation of small-scale processes that are fundamental for the onset and maintenance of blocking events. Here, **we explore how the implementation of two stochastic parameterizations, namely the Stochastically Perturbed Parameterization Tendencies (SPPT) scheme and the Stochastic Kinetic Energy Backscatter (SKEB) scheme, influences the representation of Northern Hemisphere winter blocking in EC-Earth3.**

Data:

We use data from the Climate SPHINX experiment. Climate SPHINX data are produced using two versions of the **EC-EARTH** Earth system model: one with the SPPT scheme (**Stochastic** version) and one without (**Baseline** version). Every run was performed with both models at different nominal resolutions: TL159 (10 ensemble members (e.m.)), TL255 (10 e.m.), TL511 (6 e.m.), TL799 (3 e.m.). All members are averaged regardless of resolution, obtaining 29 ensemble members for each model version. As a reference we use **ERA5 reanalysis.**

Methods:

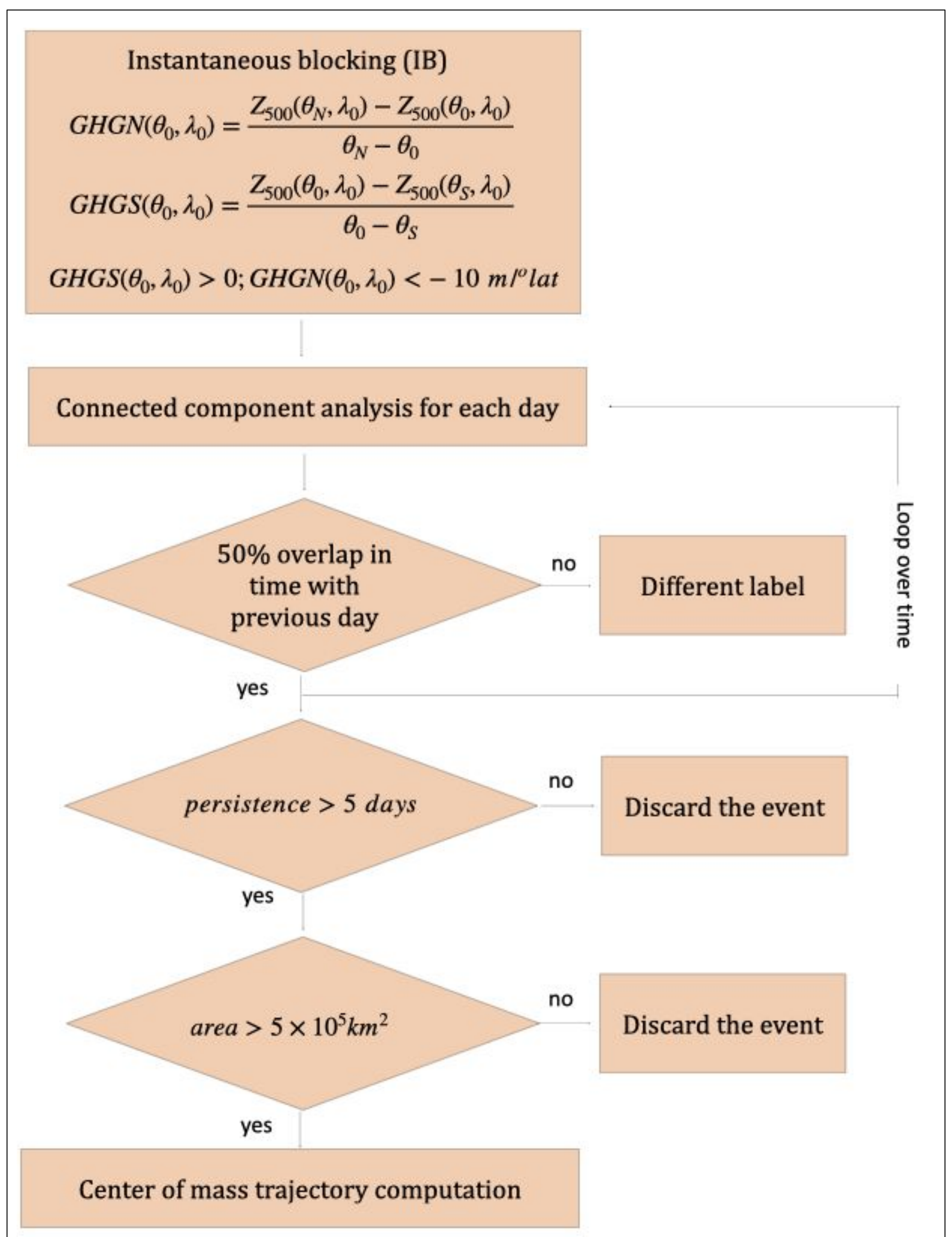
In order to detect atmospheric blocking we apply a **bidimensional index** based on the **geopotential height gradient reversal**.

$$GHGN(\Phi_0,\lambda_0) = \frac{Z_{500}(\lambda_0,\Phi_N) - Z_{500}(\lambda_0,\Phi_0)}{\Phi_N - \Phi_0}.$$

$$GHGS(\Phi_0,\lambda_0) = \frac{Z_{500}(\lambda_0,\Phi_S) - Z_{500}(\lambda_0,\Phi_0)}{\Phi_0 - \Phi_S}.$$

$$GHGS(\Phi_0,\lambda_0) > 0\ ;\ GHGN(\Phi_0,\lambda_0) < -10\, m/(lat)^{-1}$$

On top of it, we apply a series of filters through a newly developed **Lagrangian tracking algorithm** that is able to detect blocking features, such as area, displacement, duration and center of mass trajectory.



Schematic 1: Simple flow chart of the Lagrangian Tracking Algorithm.

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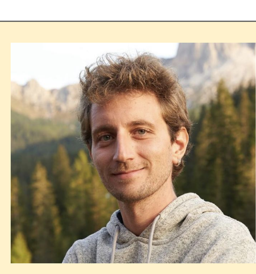
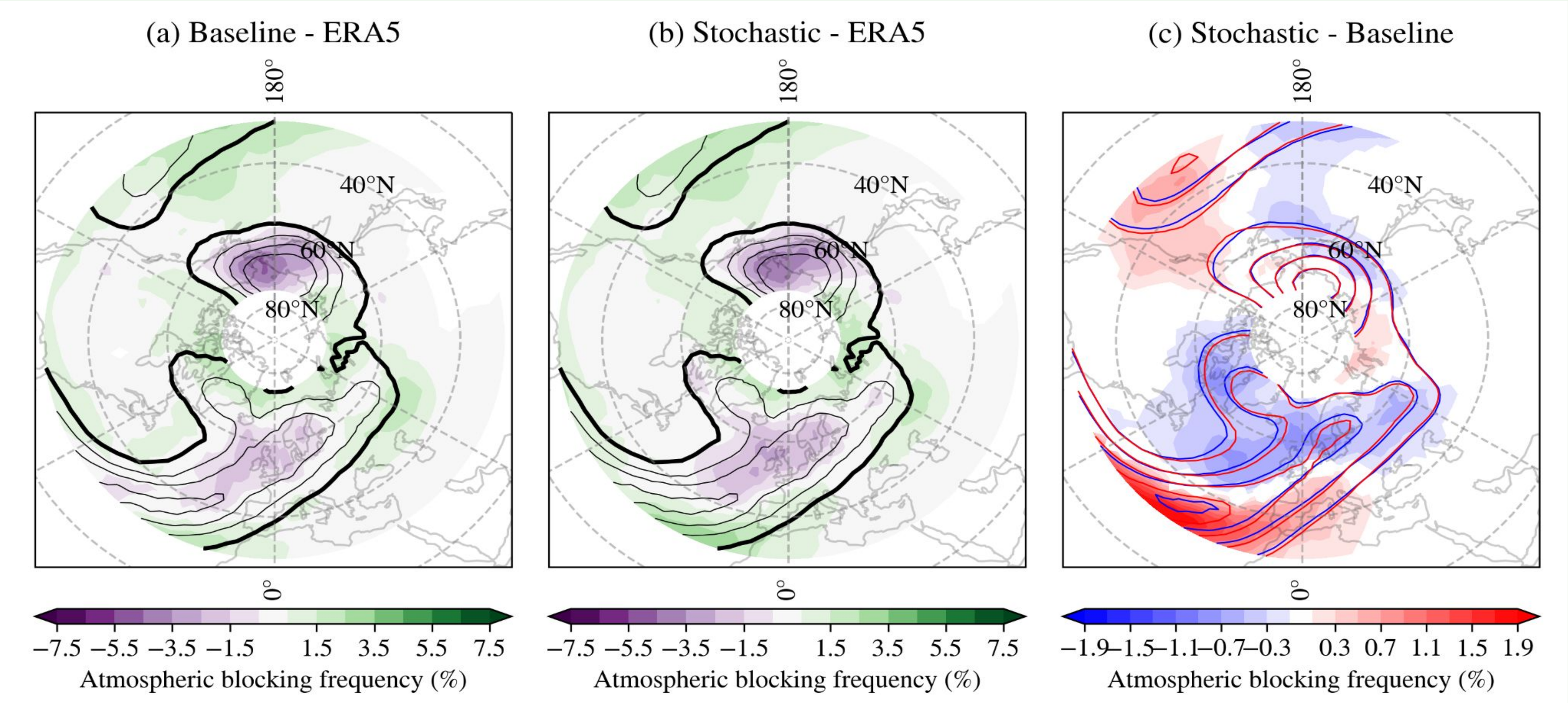


Github profile

Impact of the stochastic parameterisation:



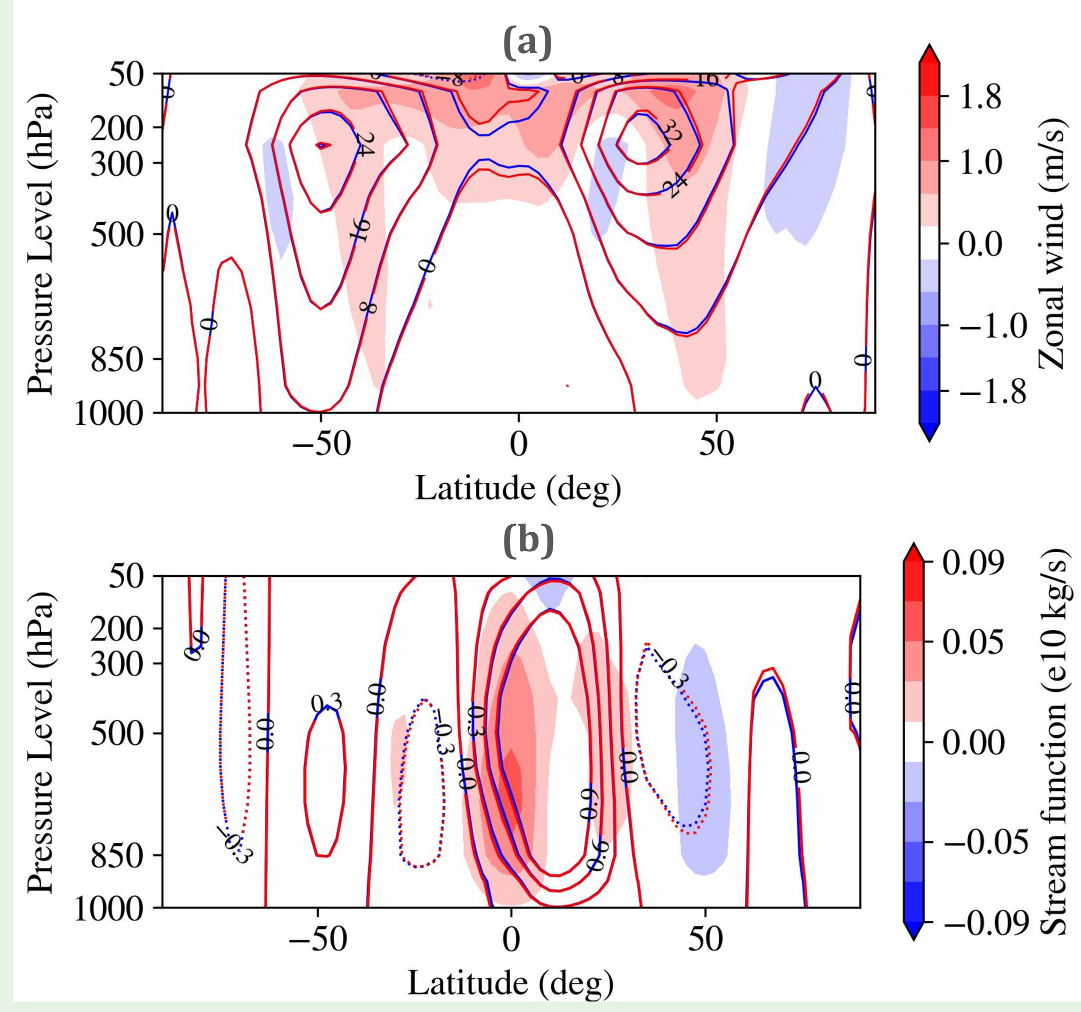
For all Figures:

Contours:
- ERA5
- Baseline
- Stochastic

Shadings:
- EC-Earth - ERA5
- Stochastic - Baseline

Figure 1:
Atmospheric blocking frequency in the Northern Hemisphere extended winter period **December to March (DJFM)**.
a) Difference between the **baseline version** of EC-Earth 3 and **ERA5** reanalysis.
b) Difference between the **stochastic version** of EC-Earth 3 and **ERA5** reanalysis
c) Difference between the **Stochastic** and the **Baseline versions** of EC-Earth3.

Figure 2:
DJFM **mean atmospheric circulation differences**. a) Zonally averaged **zonal winds**; b) Mass overturning **streamfunction** in the meridional plane.



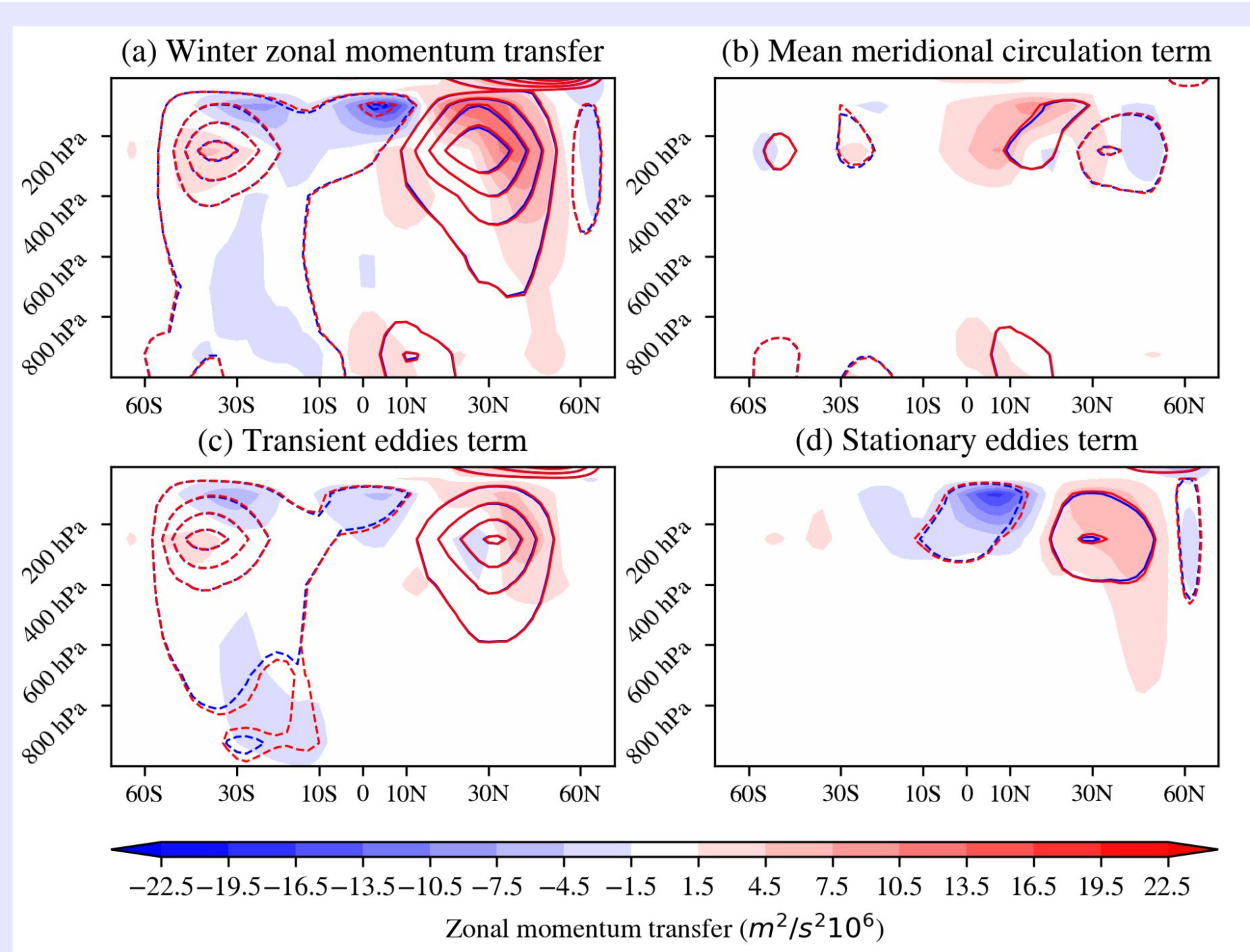


Figure 4: Meridional momentum transport (a) is decomposed in three terms::

$$\underbrace{[\overline{vM}]}_{a} = [\overline{v(\Omega a\cos\theta + u)ua\cos\theta}] = \underbrace{[\bar{v}](\Omega a\cos\theta + [\bar{u}])a\cos\theta}_{b} + \underbrace{[\overline{v'u'}]a\cos\theta}_{c} + \underbrace{[\bar{v}^*\bar{u}^*]a\cos\theta}_{d}$$

where b) is the transport due to the mean meridional circulation, c) is the transport due to transient eddies and d) is the transport due to stationary eddies.

Mechanisms of the observed changes:

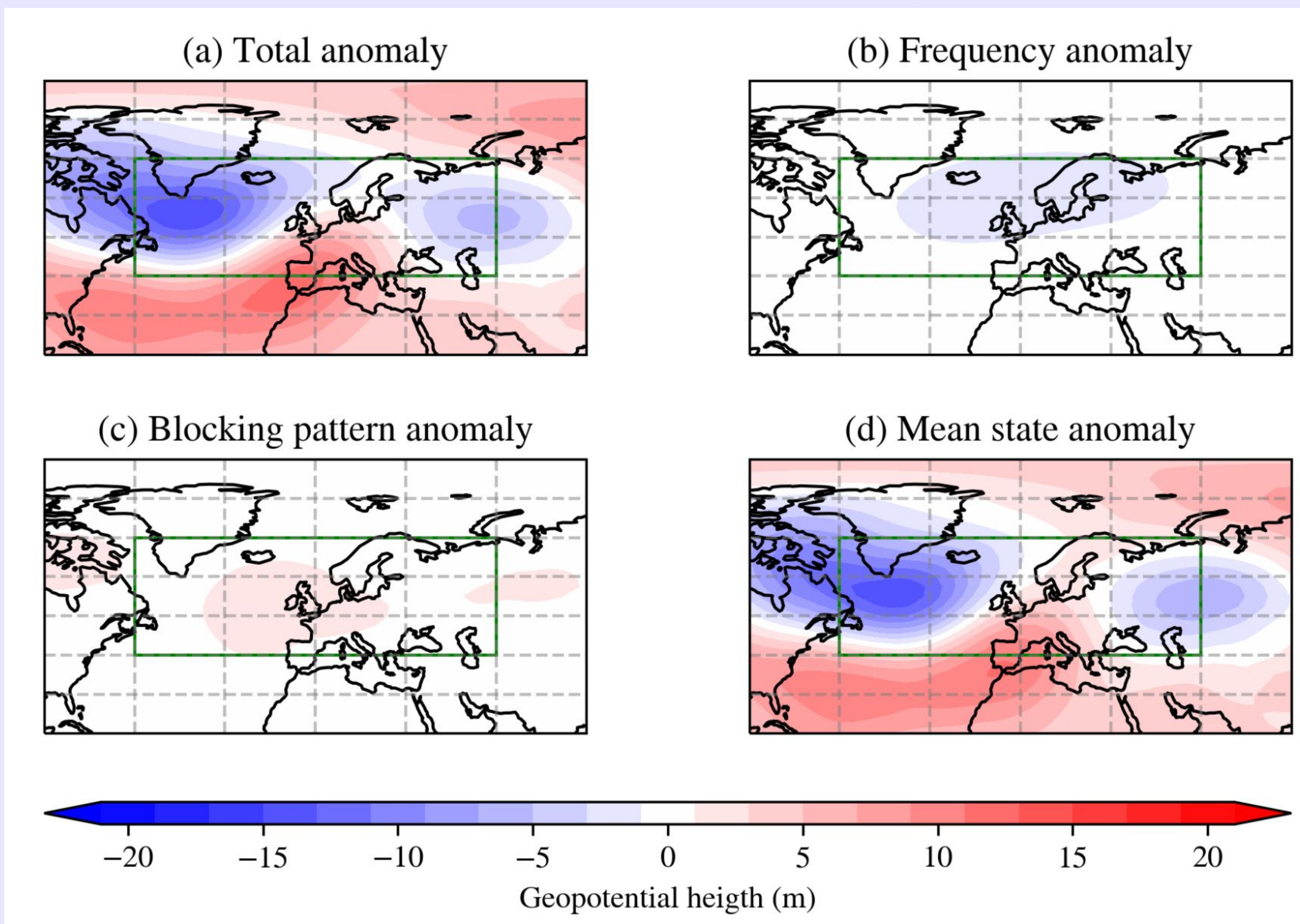
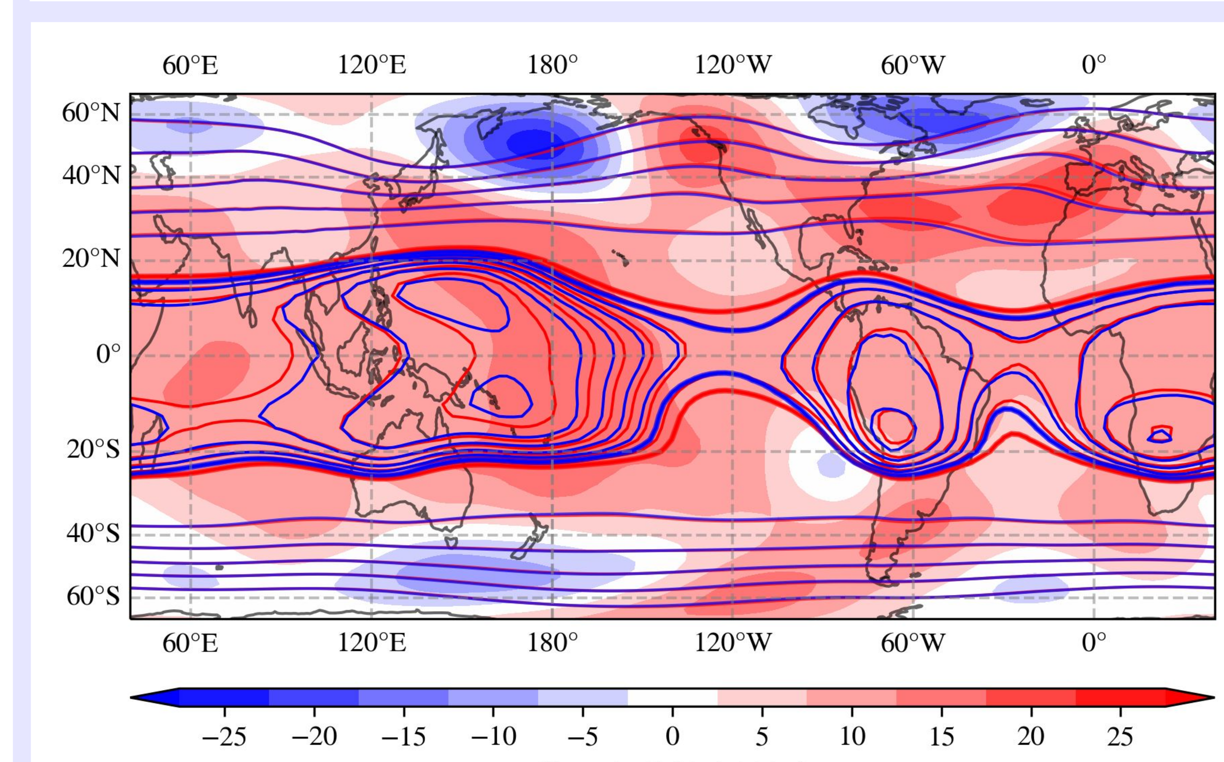


Figure 3: **Blocked-zonal flow linear decomposition**. The geopotential height difference (a) between the stochastic and baseline version of the model is decomposed in three terms.

$$\underbrace{z-\hat{z}}_{a} = \underbrace{(f-\hat{f})(z_b - z_z)}_{b} + \underbrace{\hat{f}[(z_b-\hat{z}_b)-(z_z-\hat{z}_z)]}_{c} + \underbrace{z_z-\hat{z}_z}_{d}$$

b) the anomaly due to blocking frequency changes, c) changes due to blocking pattern and d) anomaly during non-blocked days.

Figure 5: DJFM geopotential field at 250 hPa



Conclusions:

- The activation of the two stochastic schemes has **detrimental effects on blocking representation**.
- Such deterioration is attributed to **changes in the mean winter atmospheric circulation**, primarily manifested in a strengthening of the mid-latitude jet stream and an intensification of the Hadley Cell.
- These circulation differences **arise from** a modified condensation process in tropical clouds that impacts the **tropical stationary eddy activity**, which in turn modifies the zonal momentum balance.
- Our findings reconnect with earlier literature on similar experiments and suggest that the activation of stochastic parameterizations **may require a retuning of the model to correct for significant biases in the mean atmospheric circulation**.