Equator-to-pole temperature differences and the North Atlantic storm track responses in CMIP5

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There is a **large spread** between the **CMIP5 models** in the responses of the extratropical **storm tracks** to climate change, particularly in the **wintertime North Atlantic** (see Figure 1)

The aim of this study is to understand which **physical processes** are causing this spread and what role changes in the **equator-to-pole temperature difference** play in controlling the storm track responses

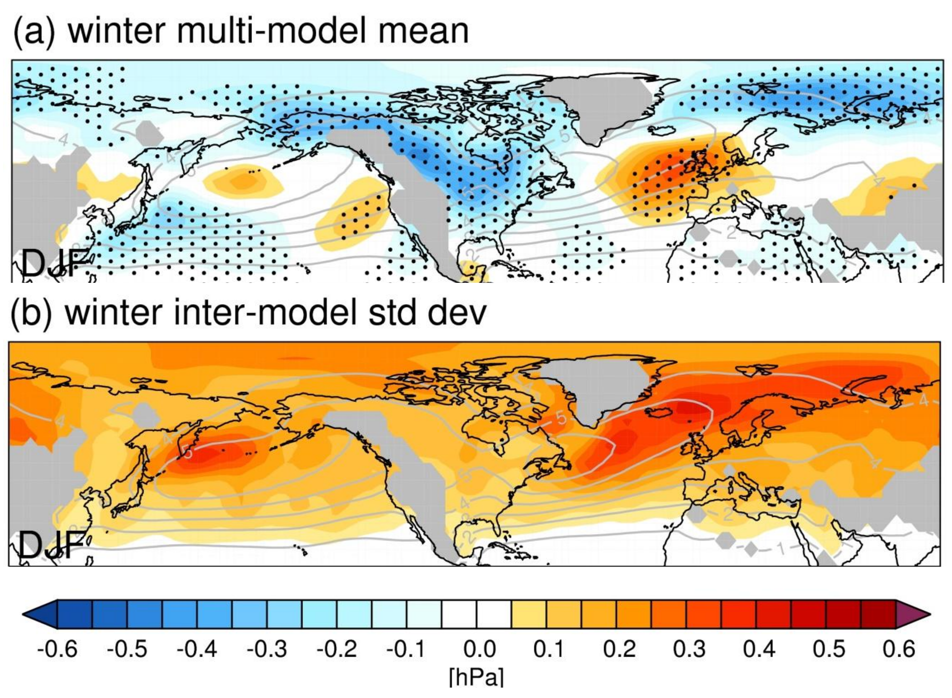

Figure 1: DJF storm track responses from the CMIP5 multi-model dataset. The storm track measure is the standard deviation of the 2-6 day MSLP).
Contours show the multi-model mean HISTORICAL storm track (1975-2005; units: hPa) and the shading shows **(a)** the multi-model mean RCP8.5 response (2070-2099), and **(b)** the inter-model standard deviation of the RCP8.5 responses. One run per model is used.

Equator-to-pole temperature differences

We define the zonal-mean equator-to-pole temperature difference as

$$\Delta T = T_{(30S-30N)} - T_{(60N-90N)}$$

averaged over the North Atlantic basin: 10W-60W. We evaluate this at both a **lower-tropospheric level** (ΔT850) and an **upper-tropospheric level** (ΔT250).

Figure 2 illustrates these definitions and shows the range of their **responses** in the CMIP5 models:

- There is a **wide spread in the magnitudes** of the responses between the models.
- However, they nearly all agree on the signs of the responses, with **ΔT250 increasing** in the future and **ΔT850 decreasing** in the future.

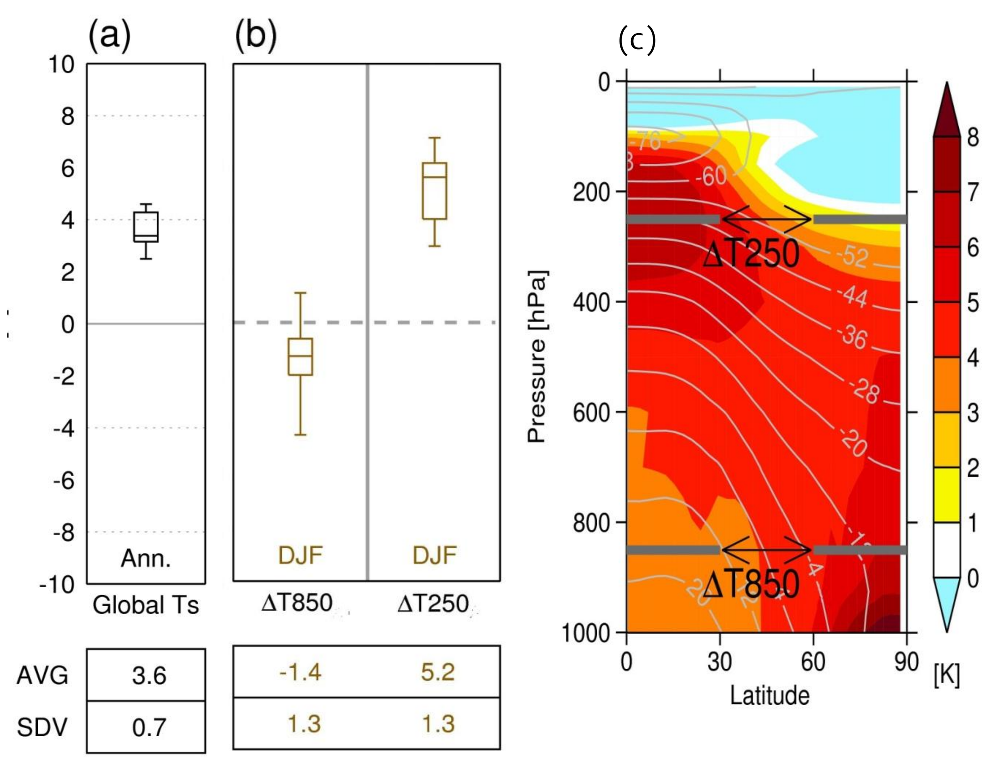

Figure 2: DJF responses of **(a)** the global mean surface temperature and **(b)** the two equator-to-pole temperature differences defined above (units: K).

Panel **(c)** shows the multi-model zonal mean NH temperature response and illustrates the definitions of the two temperature differences.

Simple linear regression

To assess the association between the ensemble of storm track responses and the responses of the equator-to-pole temperature differences, we fit a **simple linear regression model**

$$ST_{resp,i} = \alpha + \beta \Delta T_{resp,i} + \epsilon_i$$

where α and β are calculated at each grid point to **minimise the RMS of the residuals** ε_i and i labels the models.

The **fraction of inter-model variance explained** (FVE) by this regression is defined as

$$FVE = 1 - \frac{\sum \epsilon_i^2}{\sum ST_{resp,i}^2}$$

Results

Figure 3 shows **regression slopes** (β) and the regions of **significant correlation** for the two temperature differences, and Figure 4 shows the FVE by each regression.

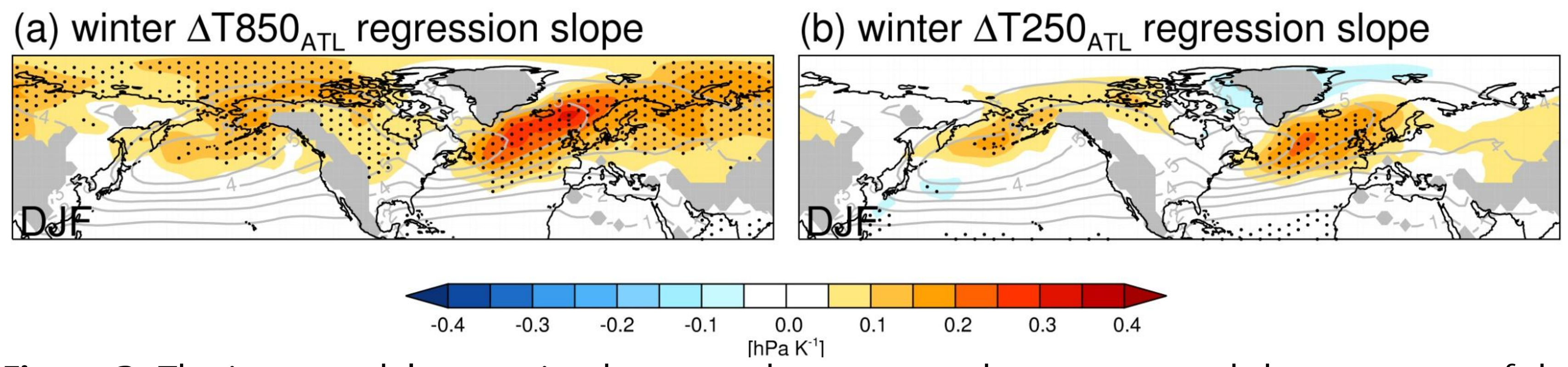

Figure 3: The inter-model regression between the storm track responses and the responses of the **(a)** ΔT850 and **(b)** ΔT250 zonal-mean equator-to-pole temperature differences. Stippling indicates a significant correlation at the 95% level.

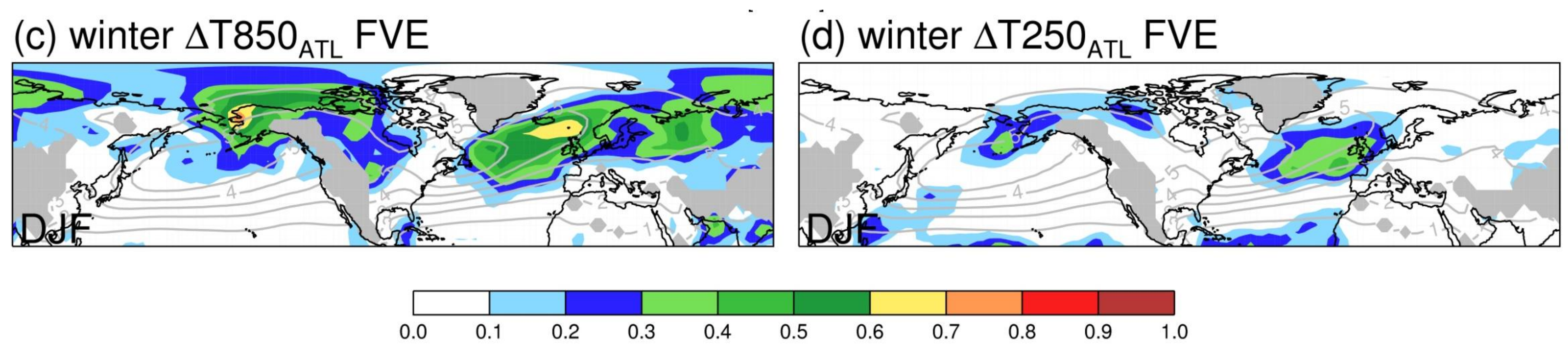

Figure 4: The fraction of inter-model storm track variance explained by the temperature difference regressions of Figure 3.

- There are **large regions with significant correlation** for both the ΔT850 and ΔT250 temperature differences.
- The **regression slopes** in these regions are mostly **positive**, consistent with the storm track responses being **driven by the responses of the baroclinicity** rather than the other way around.
- The **impact of ΔT850** on the multi-model mean storm track response (Figure 1a) is **negative** across most of the hemisphere, whereas the **impact of ΔT250** is **positive** but confined to the ocean basins.
- Together, the two linear regression maps qualitatively **capture the spatial pattern of the multi-model mean response**.
- The FVE by ΔT850 is over **50%** in the North Atlantic and Norwegian Sea and by ΔT250 is over **30%** in the North Atlantic but small elsewhere.

Discussion

These results suggest that there is potential to **reduce the spread** in the storm track responses by **constraining the relative strengths** of the warming in the tropics and polar regions.

A similar analysis has been performed for the summer and also for the North Pacific and SH storm tracks (see [1]). There is a **strong association** between the storm track and temperature difference responses **in the SH** but **very little association in the North Pacific**.

The **North Atlantic winter is unique** in that **both the ΔT850 and ΔT250 regressions are needed to capture the pattern of the mean response**. This more complex behaviour may go some way towards explaining the particularly large inter-model spread in the North Atlantic region (Figure 1b).

One limitation of this study is that the **causality of the correlations cannot be determined**. It is not clear whether the storm tracks respond directly to the **equator-to-pole temperature difference**, or instead to more **local baroclinicity changes** (e.g. SST, sea-ice or land-sea contrast changes) which may themselves be correlated with the equator-to-pole temperature difference. AGCM experiments are planned to try and isolate the mechanisms involved.

[1] Harvey, B. J., Shaffrey, L. C. and Woollings T. J., Equator-to-pole temperature differences and the extra-tropical strm track responses of the CMIP5 climate models, *submitted to Climate Dynamics.*

We thank Giuseppe Zappa for help in obtaining the CMIP5 data used in this study.