Response of the mid-latitude jets and storm tracks to projected future warming

Tim Woollings

With thanks to Ben Harvey, Len Shaffrey, Danniell Kennedy, Tess Parker, Giacomo Masato, Hugh Baker and Cheikh Mbengue
Complexity

Understanding
Outline

Future climate projections
- Several competing effects
- Storm tracks and jets contract poleward
- Fewer cyclones (as more moisture?)
- Blocking declines

Figure 1: Multi-model, zonal and annual mean HIST temperature (gray contours; units: deg C) and its RCP8.5 response (shading). The horizontal lines indicate the tropical and polar regions used to define the equator-to-pole temperature difference in Section 2.2.

The inter-model spread of the temperature difference responses using simple linear regressions. That is, the numbers $\alpha$ and $\beta$ are calculated at each grid point so as to minimise the RMS of the residuals $\epsilon_i$ in the equation

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

where $ST_{\text{resp},i}$ is the storm track response from model $i$ and $\Delta T_{\text{resp},i}$ is the response of one of the temperature differences from model $i$. The association between the responses of the temperature variables and the storm track variables is assessed by considering maps of the following: the regression slopes $\beta$, the significance of the inter-model correlations between $ST_{\text{resp}}$ and $\Delta T_{\text{resp}}$, and the fraction of variance explained (FVE) by the regression model (2), which is defined as

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

Upper and lower temperature gradients both play a role in explaining uncertainty:

- Lower level has more leverage.
- But upper level forcing is larger...

Harvey et al (2013)
Arctic warming seems to be a strong source of storm track spread in the Arctic region. Upper $dT/dy$ seems to explain the mean response to climate change.

Harvey et al. (2015)
Stronger AMOC reduction
⇒ (relatively) cooler northern North Atlantic
⇒ increased meridional SST gradient and stronger storm track

Evidence for causality by comparison with slab model and freshwater hosing simulations.


However, little response to this SST pattern in this model...
Full (atmosphere) model experiments: Summary

- Both upper and lower temperature gradients affect the storm track
- There are regional and seasonal differences, but broadly:
  - The upper level changes set the mean response
  - The lower level changes are responsible for more of the uncertainty
- Seemingly no role for the ocean...

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<th>ΔT850_{SH}</th>
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<td>SDV</td>
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</table>

Harvey et al (2013)
What about blocking?

- **Persistent** flow pattern
- Blocks storms and westerlies
- Brings heatwaves in summer and cold in winter
- Projected to decline in future

**Fig. 3.** Top row. 2-D daily frequency of blocking (expressed in percentages, see section 2.b for more details) during winter for the multi-model mean (20th and 21st century) and the inter-model standard deviation of their difference (21st minus 20th century). The colour shading represents the difference between the multi-model means (21st-20th century).

**Bottom rows.** 2-D daily blocking frequency by the end of the 21st century for all the models considered (see table 1 for details). Contours are every 0.05. The colour shading represents the difference between the 21st and the 20th century frequencies for each of the models.

**Fig. 7.** Top row. 2-D daily frequency of blocking (expressed in percentages, see section 2.b for more details) during summer for the multi-model mean (20th and 21st century) and the inter-model standard deviation of their difference (21st minus 20th century). The colour shading represents the difference between the multi-model means (21st-20th century).

**Bottom rows.** 2-D daily blocking frequency by the end of the 21st century for all the models considered (see table 1 for details). Contours are every 0.05. The colour shading represents the difference between the 21st and the 20th century frequencies for each of the models.

_Masato et al (2013)_

22 Dec 92 – 5 Jan 93

20 Dec 1996 – 8 Jan 1997

_Woollings (2010)._
What about blocking? It’s most sensitive to upper levels.
What about blocking?

Temperature anomalies due to winter blocking weaken in the future (Masato et al 2014).
(Also Screen, Holmes, Schneider...)
Idealised modelling: Sensitivity patterns for the jet

Lorenz and DeWeaver performed sensitivity analysis in idealised model. (Also Son&Lee, Butler, Hassanzadeh, McGraw...)

Lorenz and DeWeaver focused on the annular mode response.

Here we diagnose effects on jet latitude and speed separately.
**Idealised Model**

- Dry dynamical core (Schneider/Walker)
- GFDL model, T42, 37 levels
- Relaxed towards radiative equilibrium temperatures
- Convection scheme relaxes towards dry adiabatic lapse rate
- State broadly mimics the north Atlantic
- But zonally symmetric
- Both summer and winter hemispheres

Forcing:
- Diabatic heating term
- Gaussian patch
- 2K per day max
- Area: 0.1 rads, 0.05 sigma

*Baker et al (2017, JClim)*
Example run

Heating applied in summer hemisphere

Summer jet shifts poleward and weakens in this case...
Sensitivity results

Jet latitude and speed are sensitive to different forcings.

Basic support for the responses in complex model.
Responses to polar / tropical / subtropical regions not that sensitive to location of forcing
Sensitivity results

Figure 3. Sensitivity of the jet indices to heating experiments (colours) in the latitude-sigma plane. Contours indicate the control. The black dots mark where the difference between the control and perturbed simulations is statistically significantly different from the control, while the grey dots show where the difference is not statistically significant. Positive values correspond to poleward shift or strengthening of the jet in the target hemisphere (top: winter; bottom: summer).

Sensitivities shift poleward in summer
Sensitivity results

Figure 4. Same as Fig. 3 but for $v_0 T_0$. Positive values correspond to poleward shift or an increasing of the amplitude of $v_0 T_0$ in the target hemisphere.

General mechanism: Changes in position and strength of $v'T'$ maximum
Spin up example

Day 0.25

Change in zonal wind [m/s] (Contours show potential temperature)
Sensitivity results: linearity

(It’s not actually a linear model, I promise...)
So what about the AMOC?

Maybe we forced in the wrong place for this model...

Jet sensitivity
So what about the AMOC?

- Nordic seas: An important region?
- Forces on poleward side of storm track
- Linked to both Arctic warming and AMOC change
So what about the AMOC?

And what about small-scale features such as polar lows...?

The impact of polar mesoscale storms on northeast Atlantic Ocean circulation

Alan Condron¹ and Ian A. Renfrew²*
Conclusions

- Upper level temperature gradients seem to dominate the mean response (including blocking) but lower level gradients are an important source of spread.
- Jet latitude and speed are sensitive to different regions.
- Responses seen in full model are quite robust in idealised model, eg to exact location of heating within polar / tropical regions.
- But the response is very sensitive to the exact location of mid-latitude forcing.
- Sensitivities shift poleward in summer.
- Maybe there is still a role for the AMOC, and even polar lows...?
- Nordic seas likely a key region in terms of coupled change.