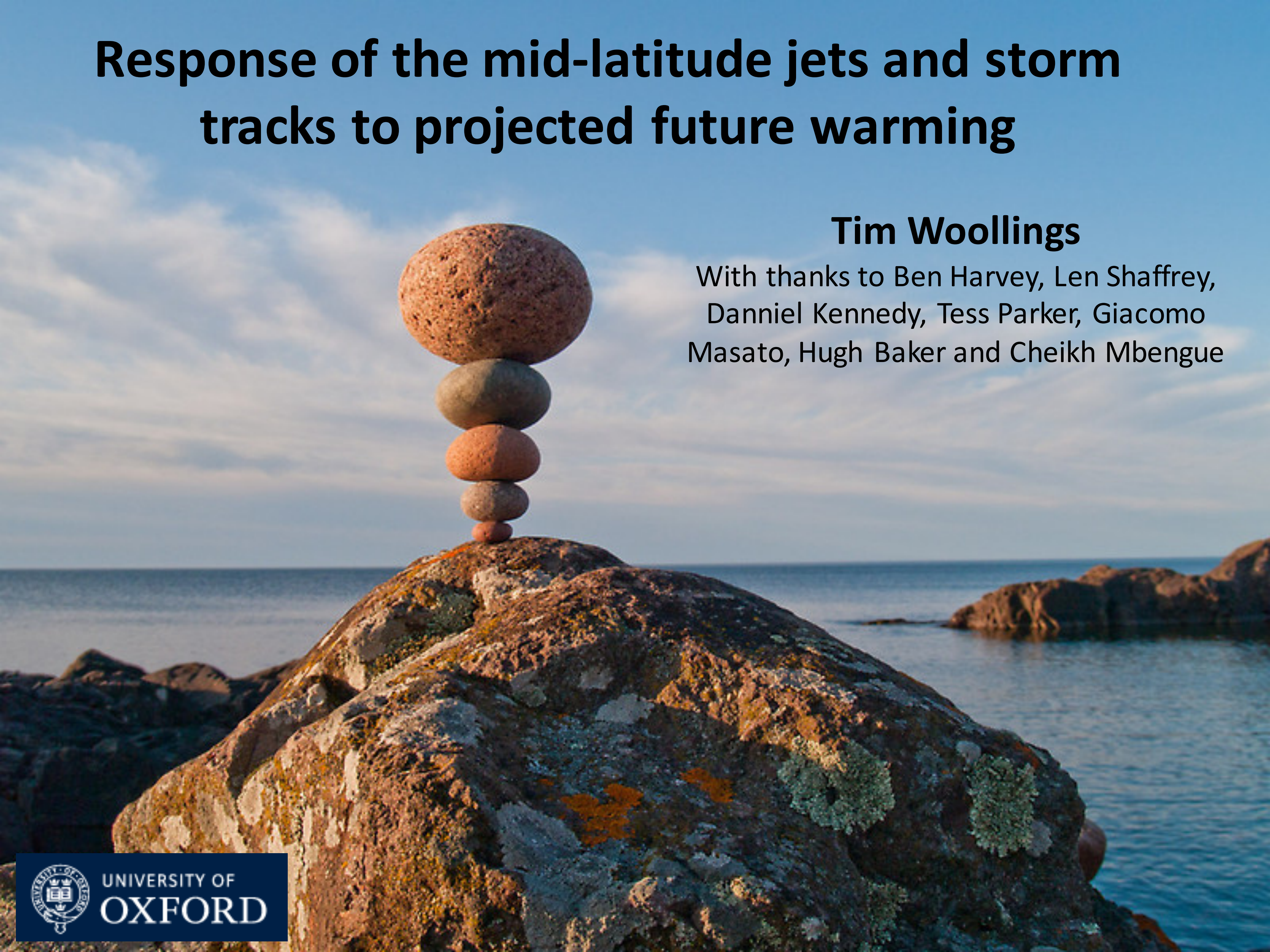
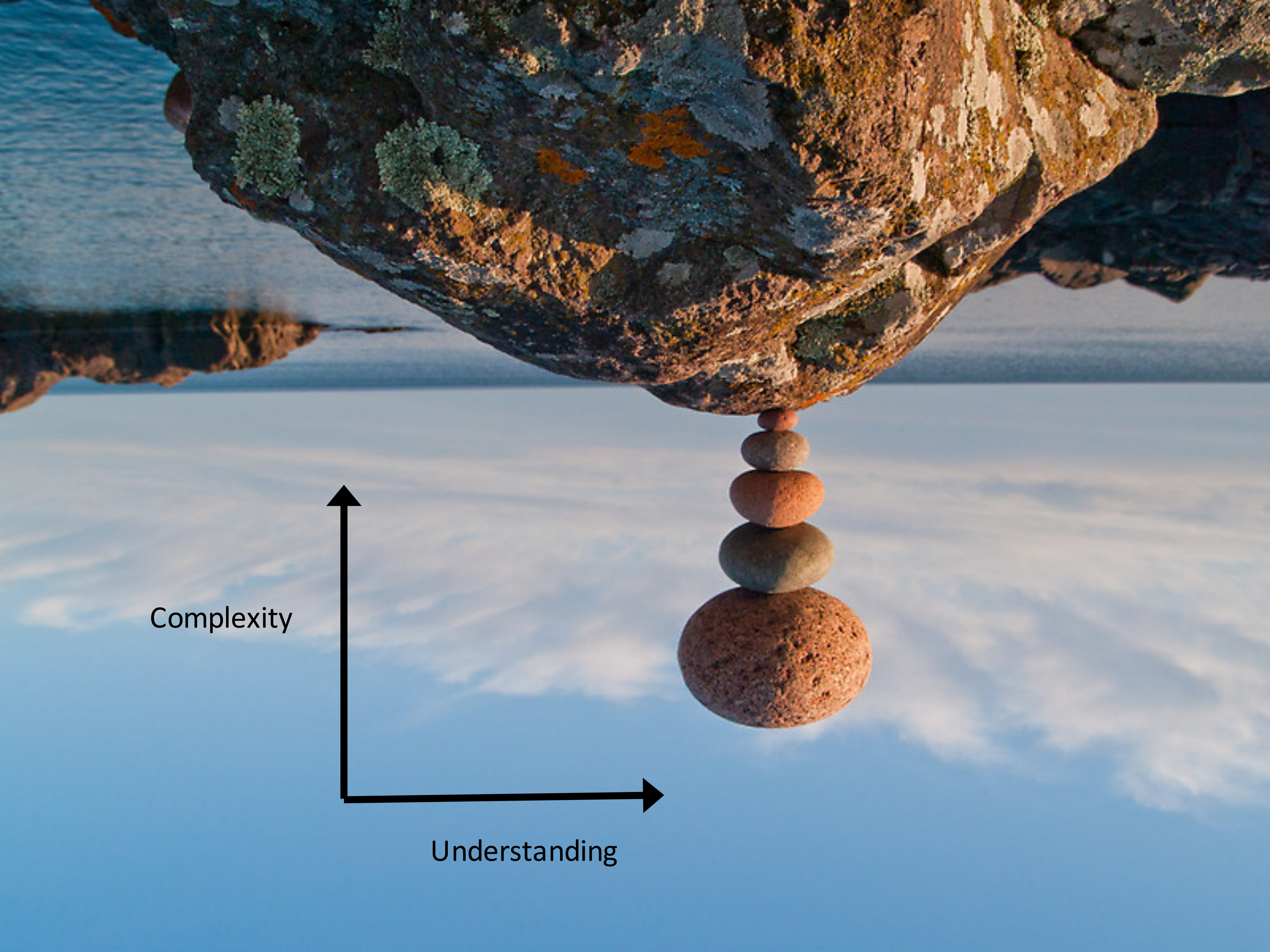
Response of the mid-latitude jets and storm tracks to projected future warming



Tim Woollings

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

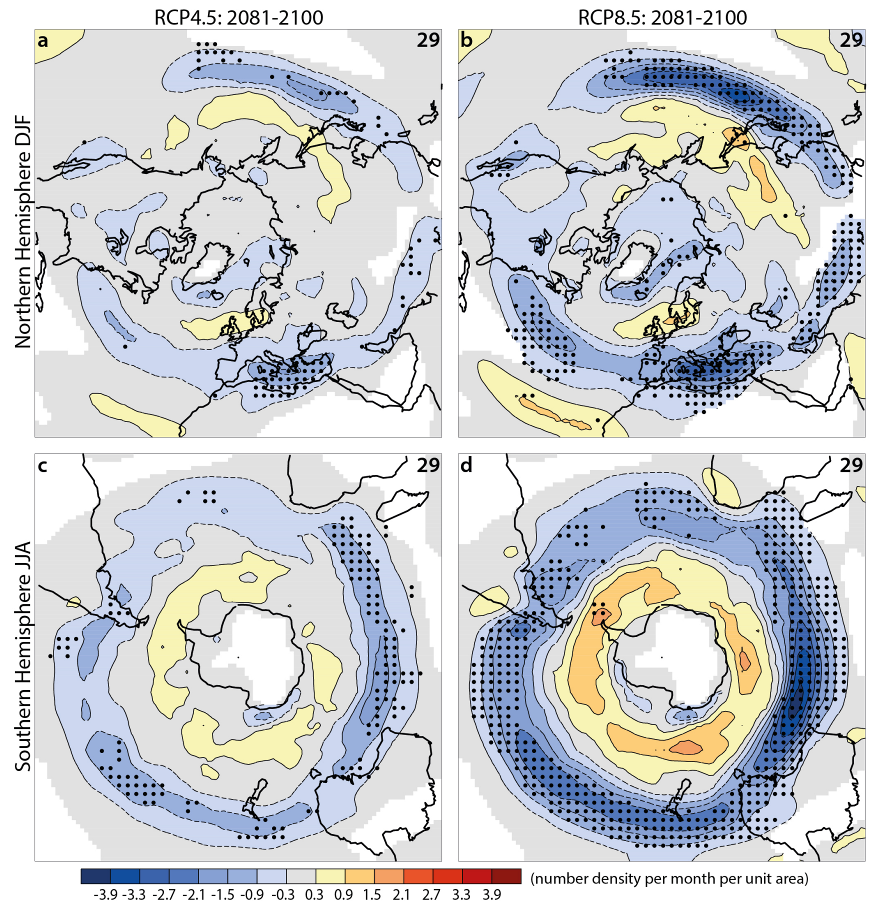
UNIVERSITY OF OXFORD


Complexity
Understanding

Outline

Future climate projections

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



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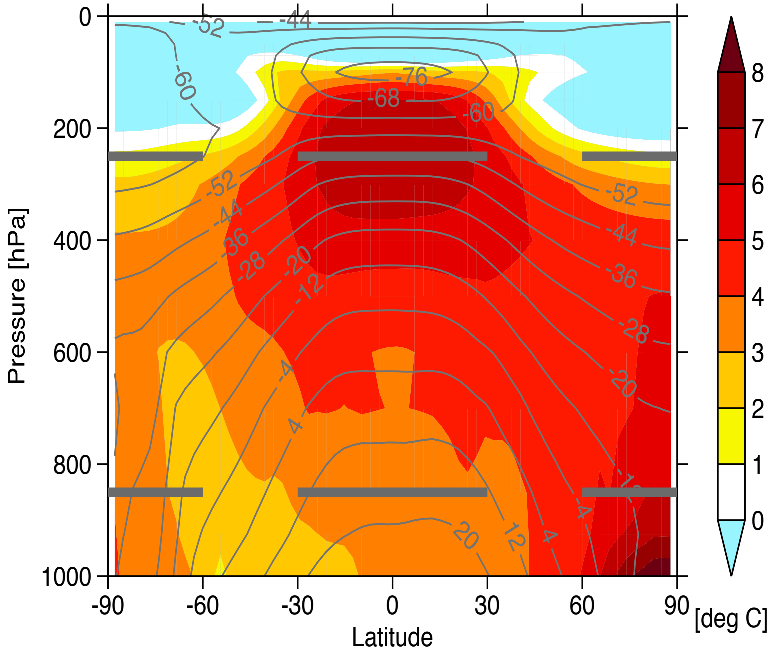


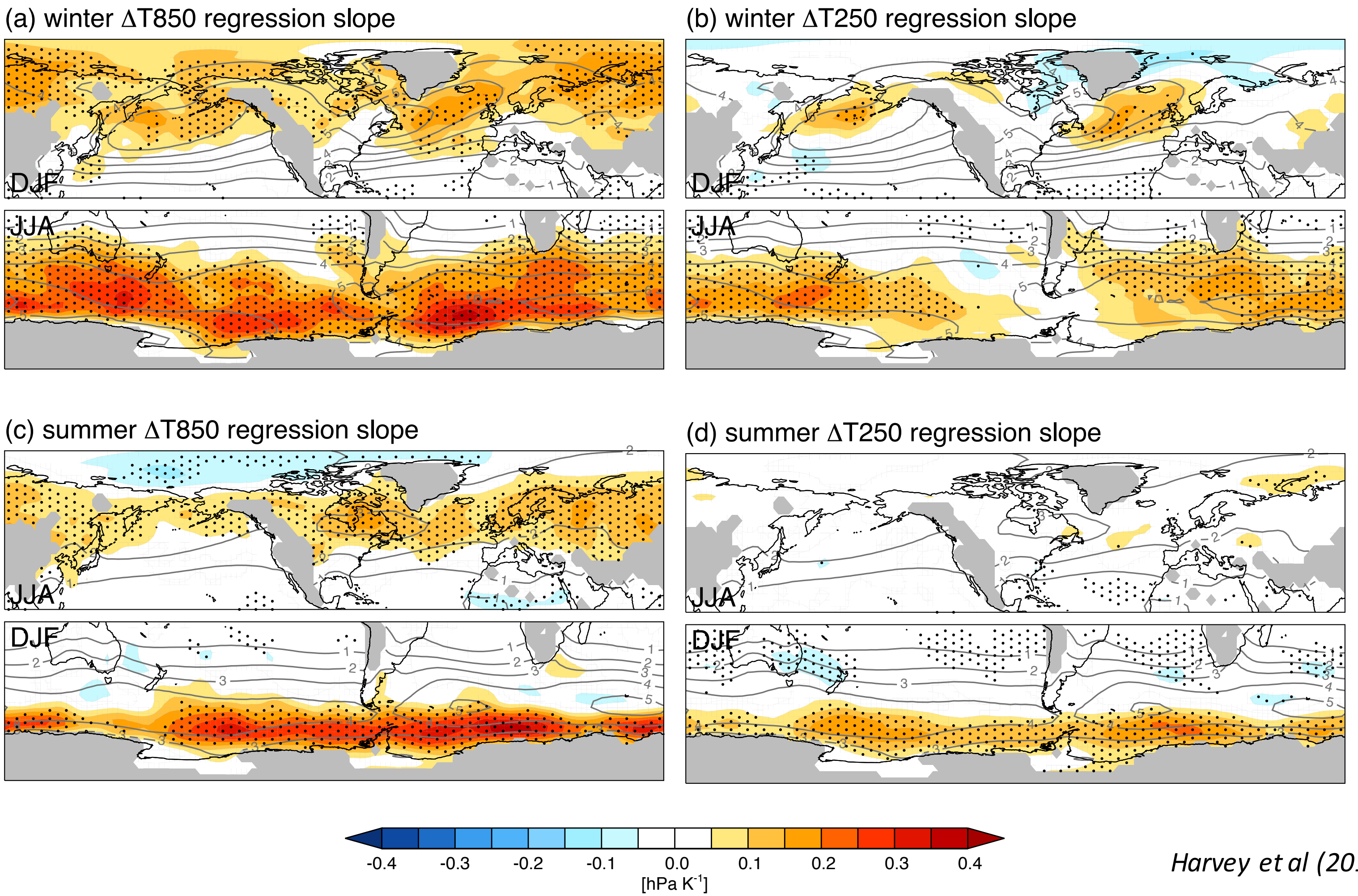
- How Arctic fits in with other forcings
- Use idealised and full models

Harvey et al (2013)

Regression analysis

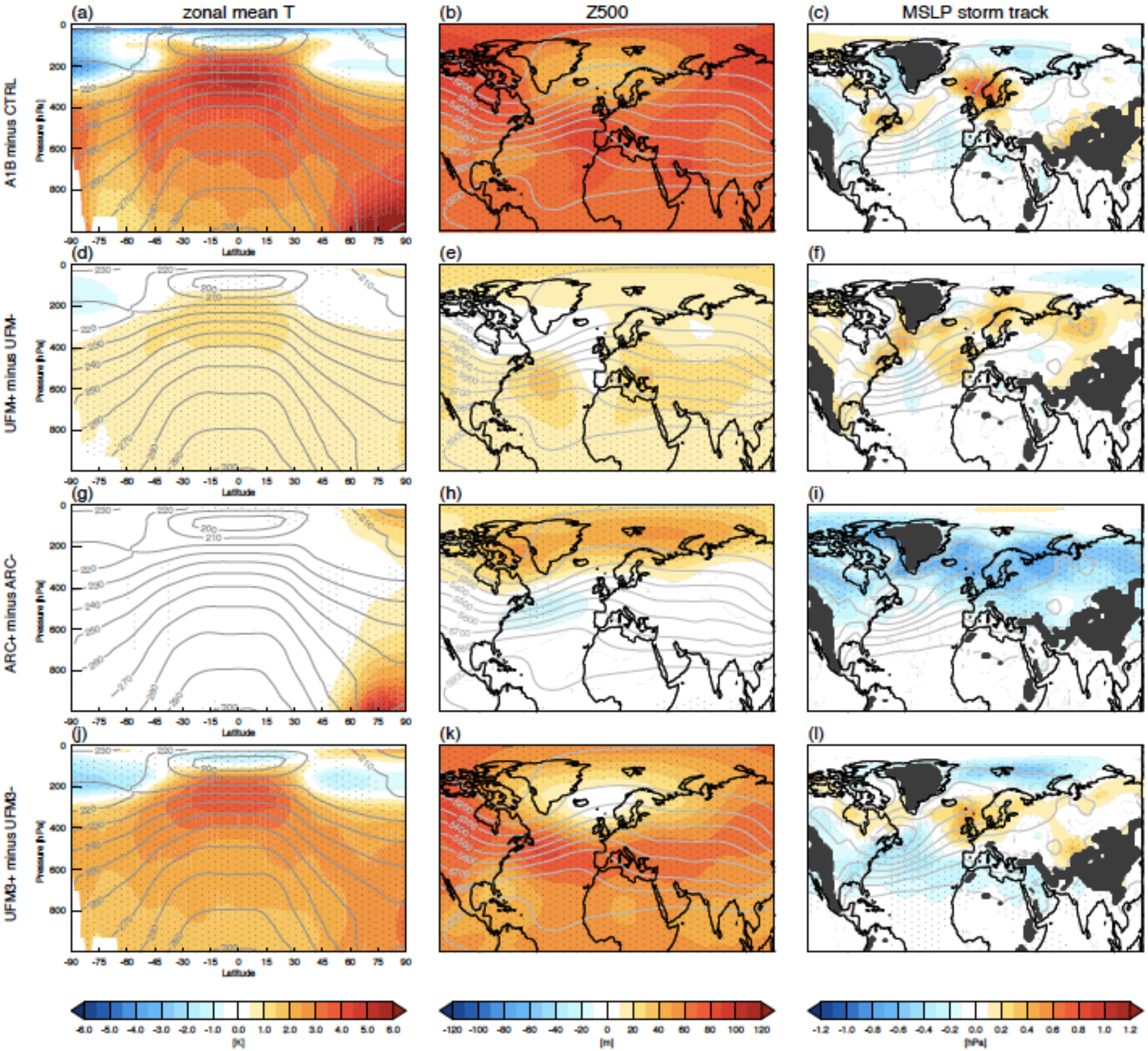
Upper and lower temperature gradients both play a role in explaining uncertainty:

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



Harvey et al (2013)

Full (atmosphere) model experiments



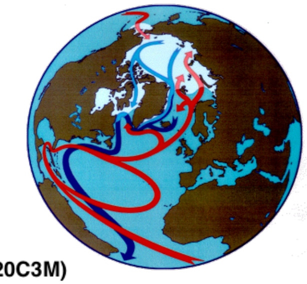
A1B - CTRL

Arctic warming strong source of storm track spread

Upper dT/dy seems to explain the mean response

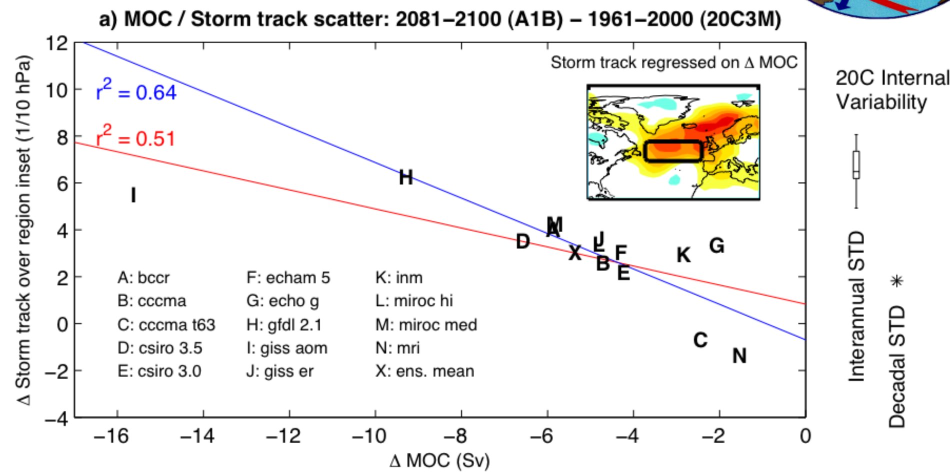
Harvey et al (2015)

Full (atmosphere) model experiments: a role for the AMOC?



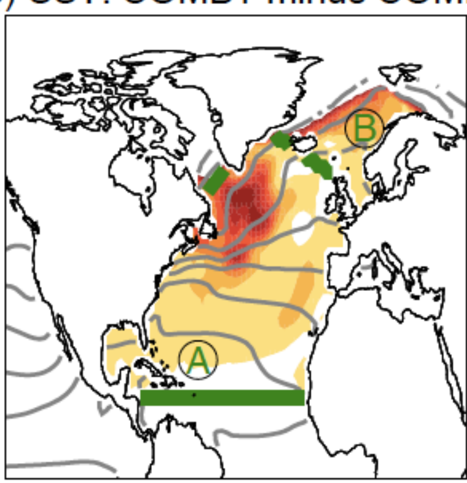
- Stronger AMOC reduction
- ➔ (relatively) cooler northern North Atlantic
- ➔ increased meridional SST gradient and stronger storm track

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



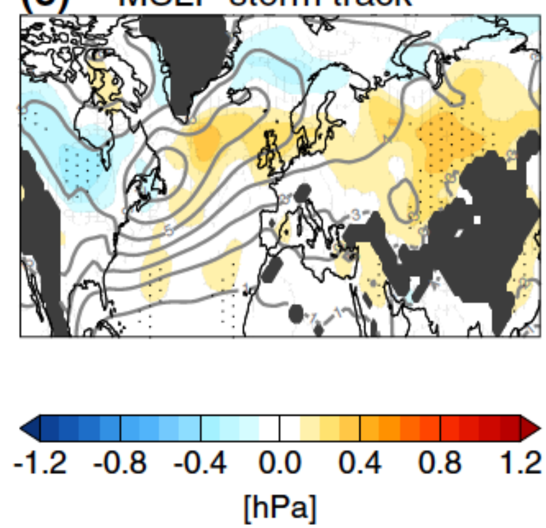
Woollings et al (2012) Nat. Geosci.

(b) SST: COMB+ minus COMB-



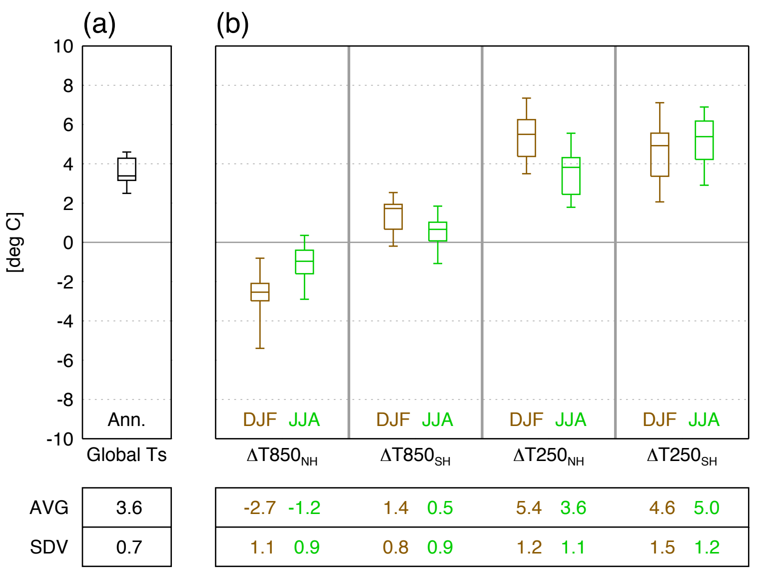
However, little response to this SST pattern in this model…

(c) MSLP storm track

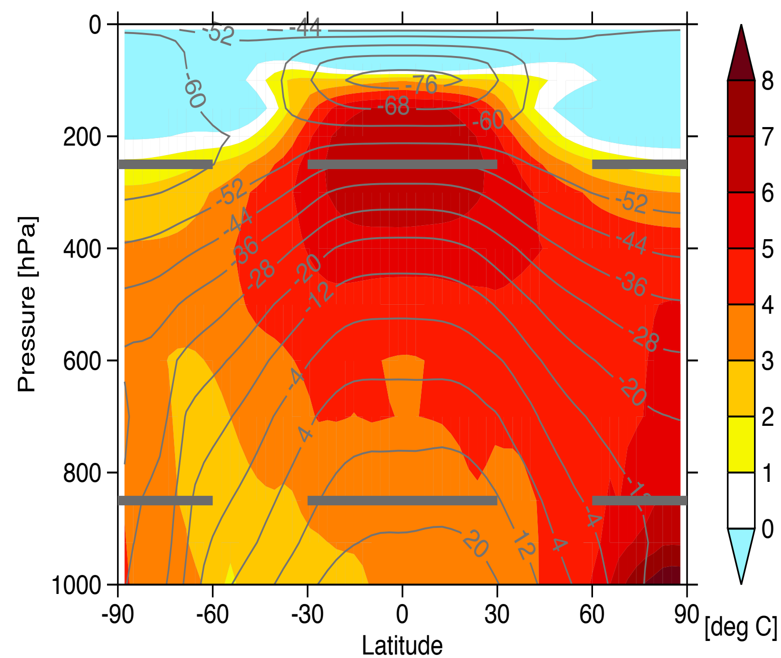


Full (atmosphere) model experiments: Summary

- 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…

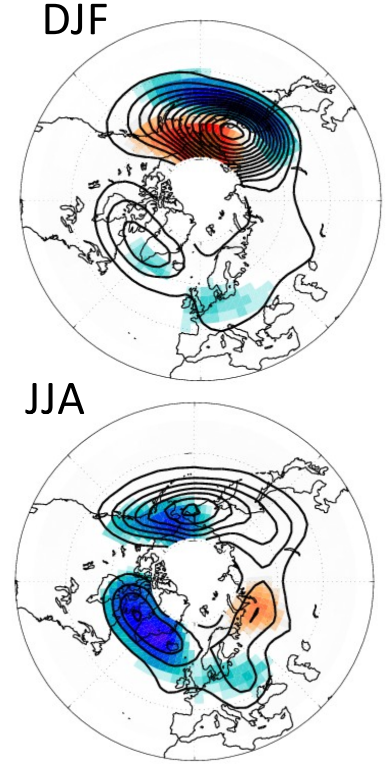


Harvey et al (2013)

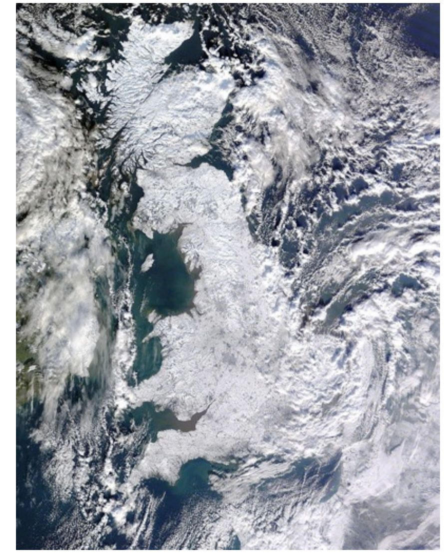


What about blocking?

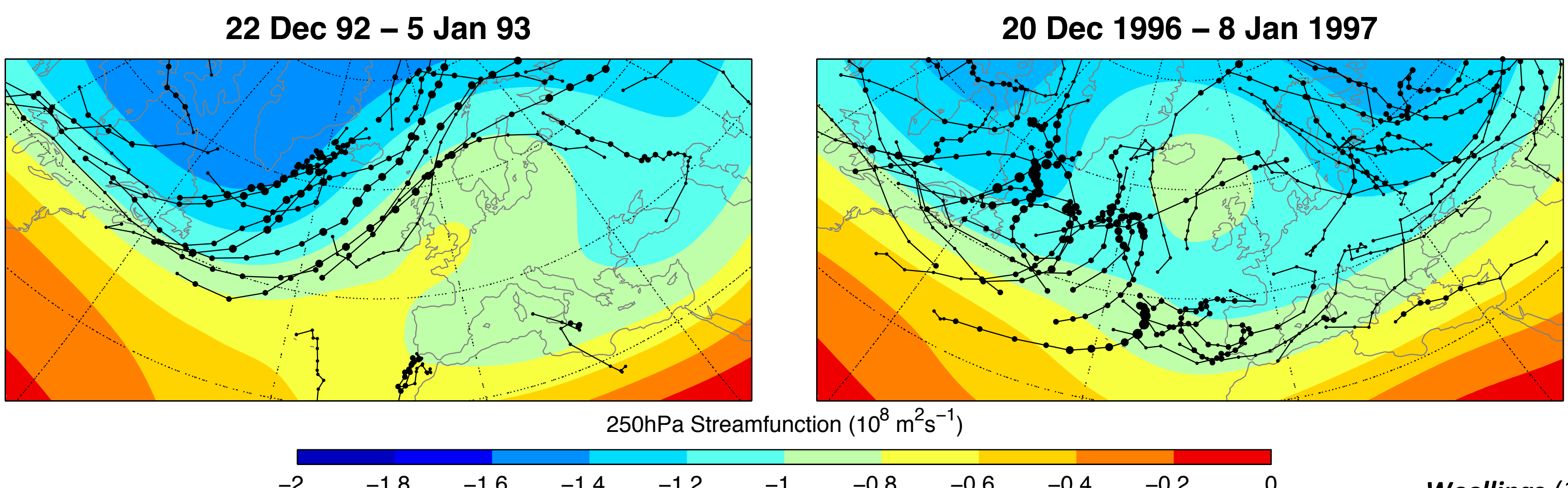
- *Persistent* flow pattern
- Blocks storms and westerlies
- Brings heatwaves in summer and cold in winter
- Projected to decline in future



Masato et al (2013)



MODIS 7 JAN 2010

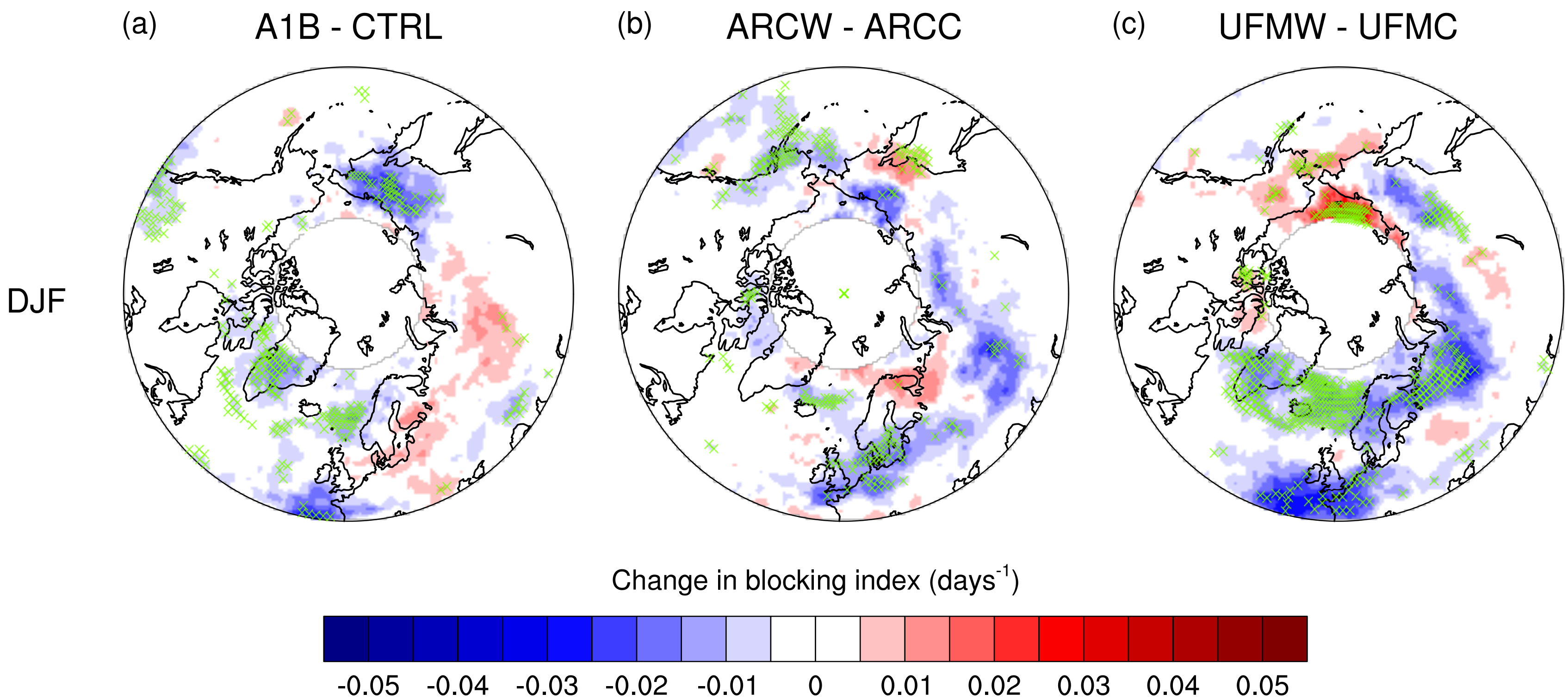


***Woollings** (2010).*

What about blocking? It's most sensitive to upper levels.

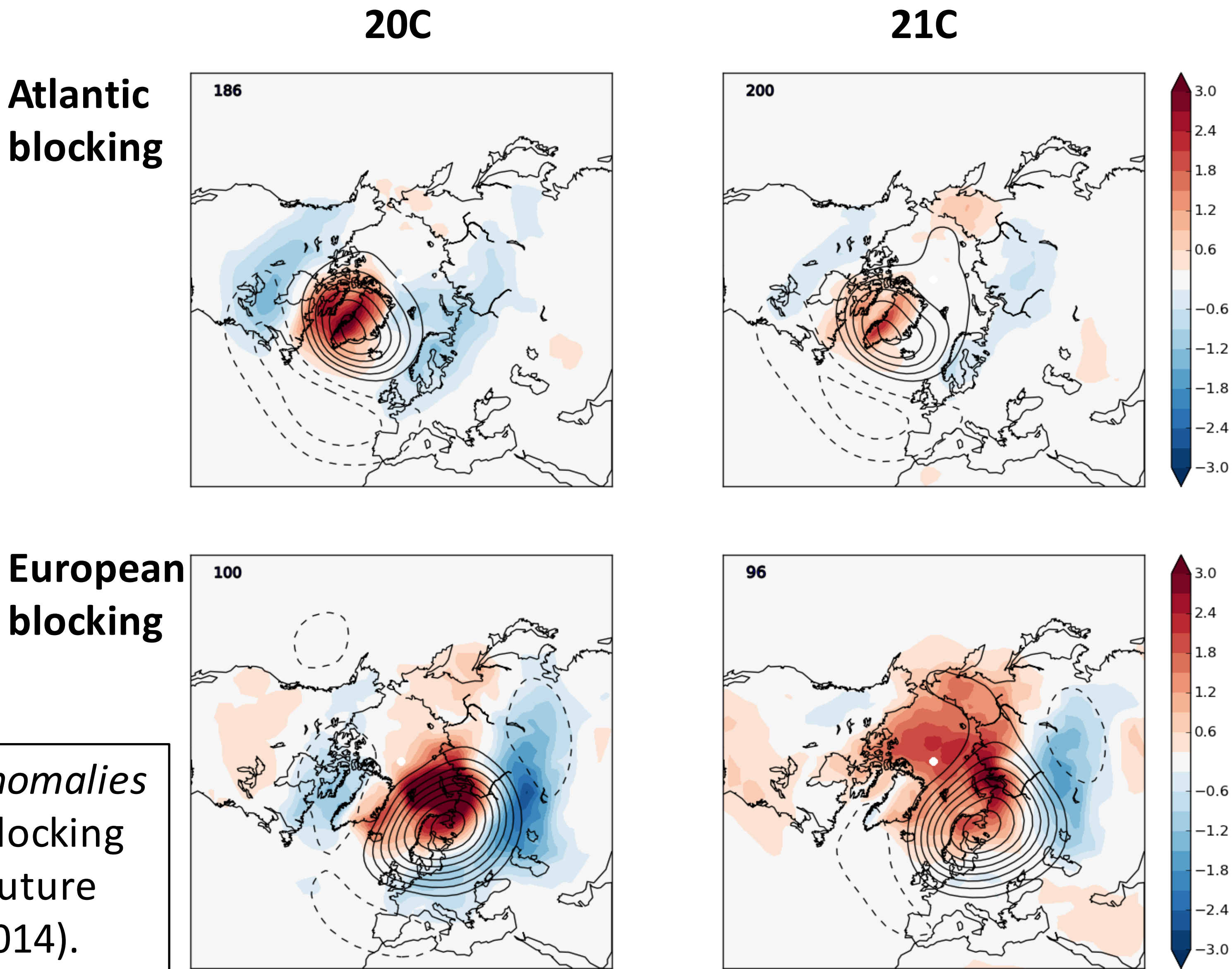
Warm Arctic - cold Arctic

Warm uniform - cold uniform



Kennedy et al (2016)

What about blocking?



Temperature *anomalies* due to winter blocking weaken in the future (Masato et al 2014).

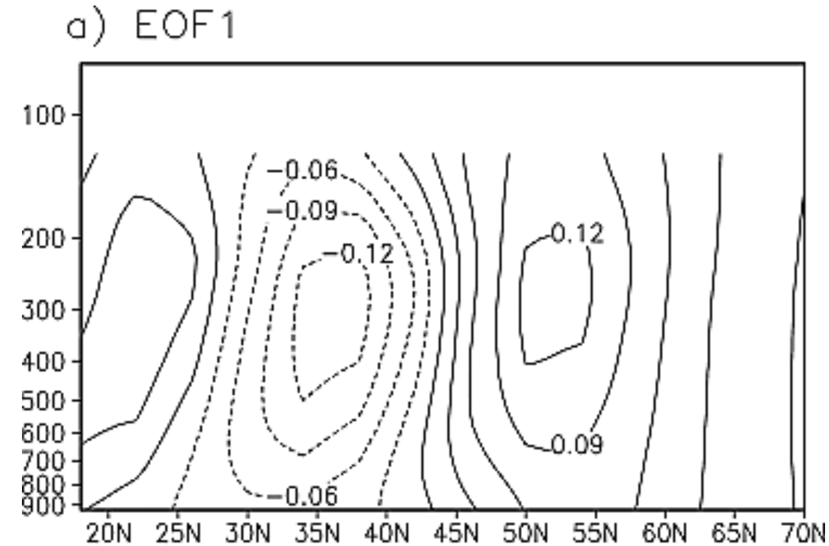
(Also Screen, Holmes, Schneider…)

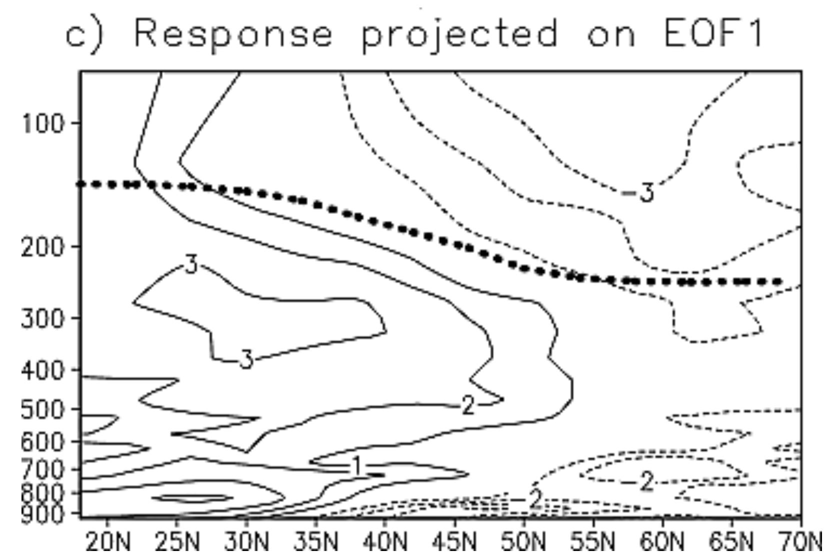
Idealised modelling: Sensitivity patterns for the jet

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.

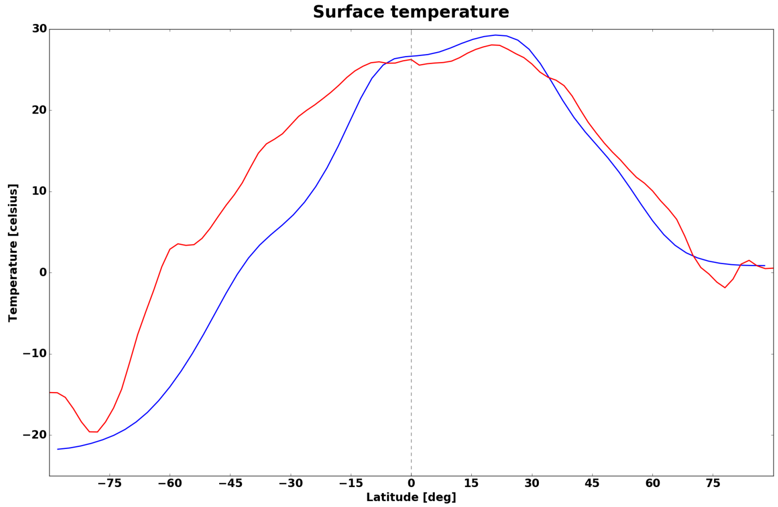




Lorenz and DeWeaver 2007

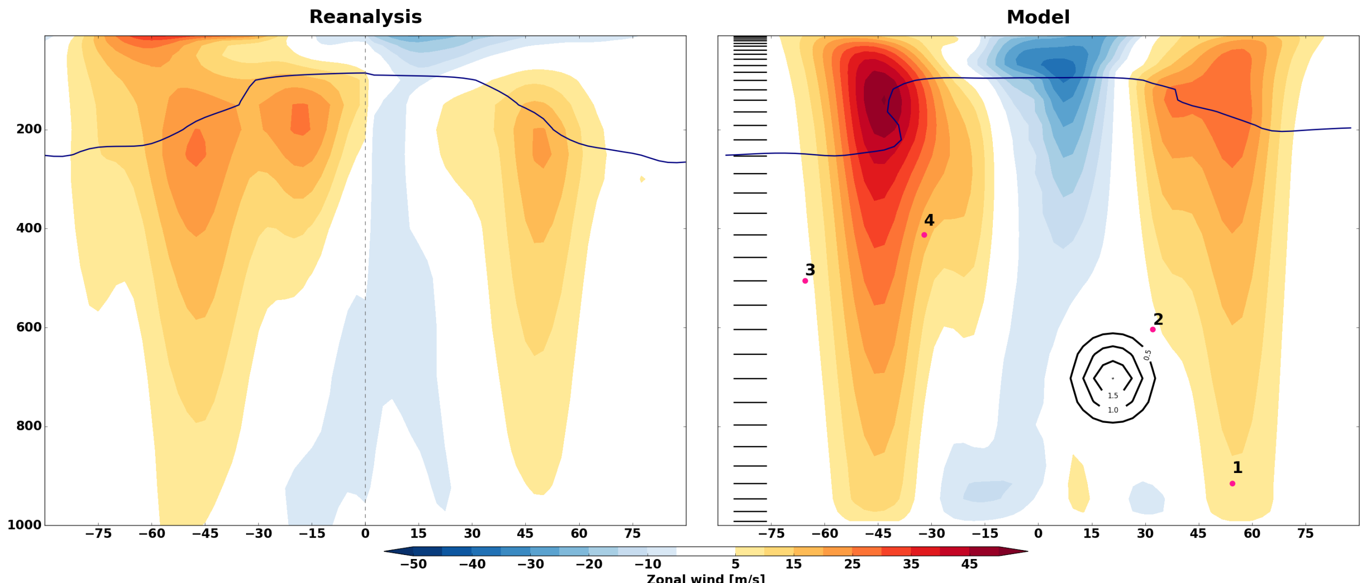
Idealised Model

- 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:

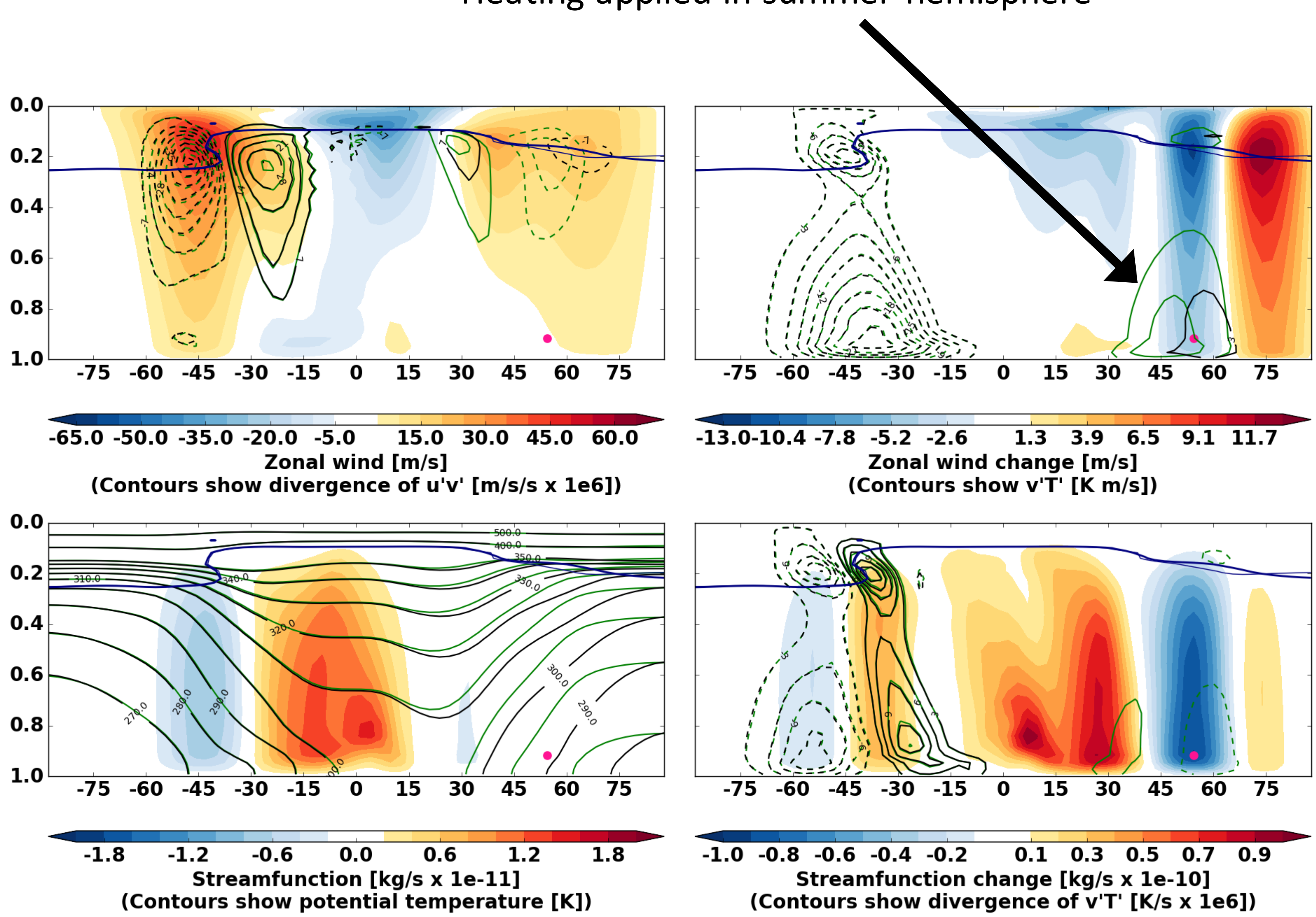
- Diabatic heating term
- Gaussian patch
- 2K per day max
- Area: 0.1 rads, 0.05 sigma



Baker et al (2017, JClim)

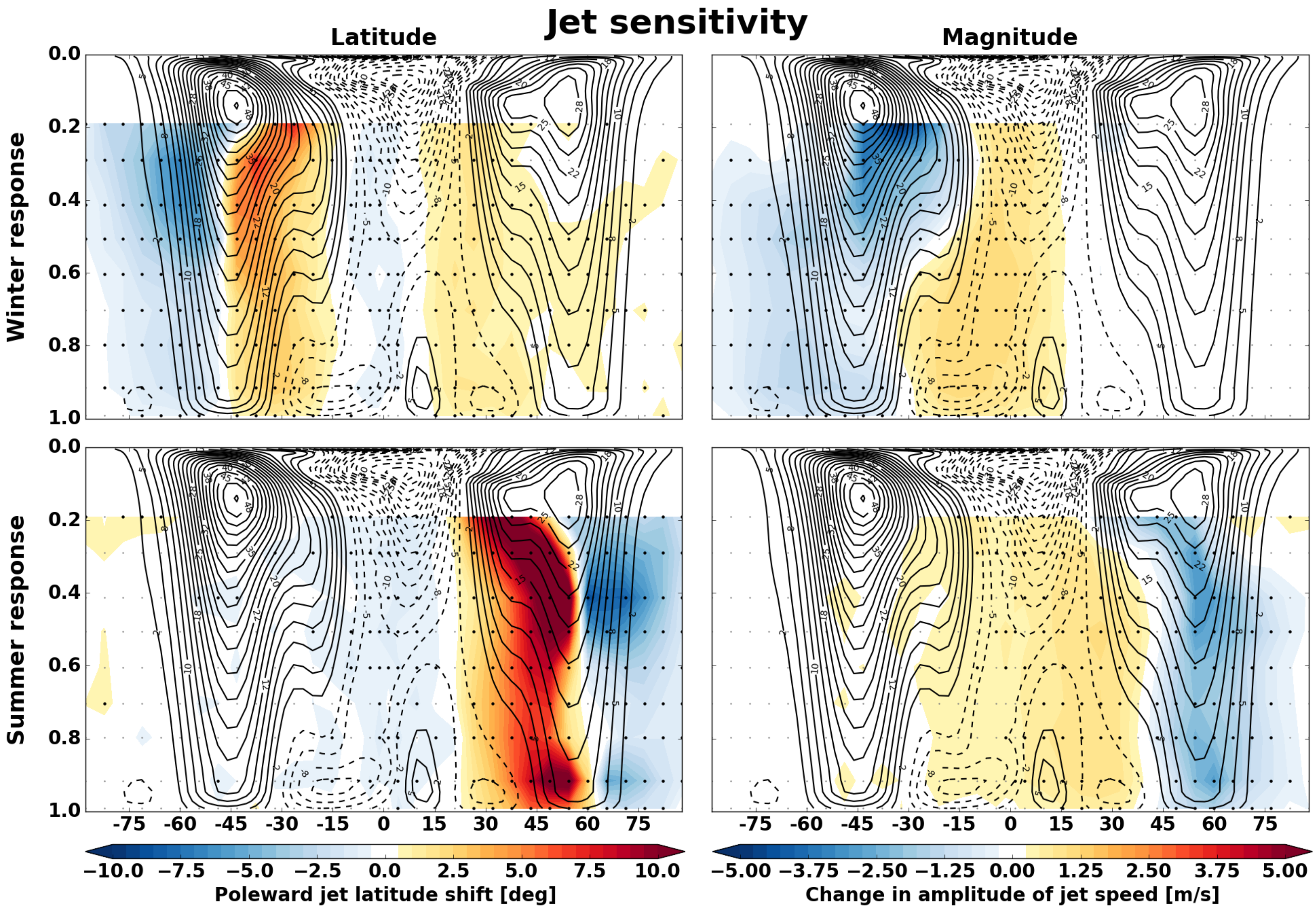
Example run

Heating applied in summer hemisphere



Summer jet shifts poleward and weakens in this case…

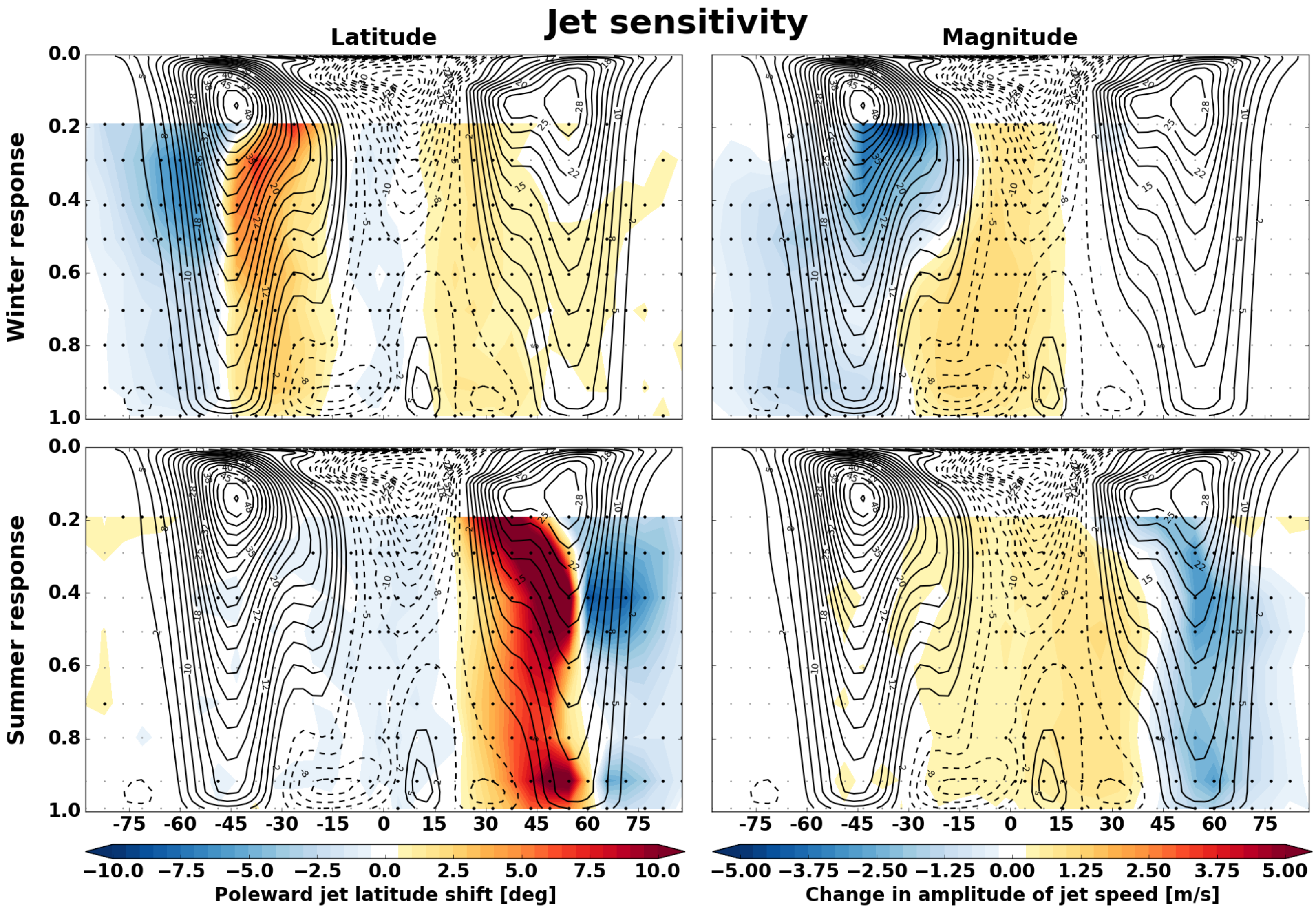
Sensitivity results



Jet latitude and speed are sensitive to different forcings

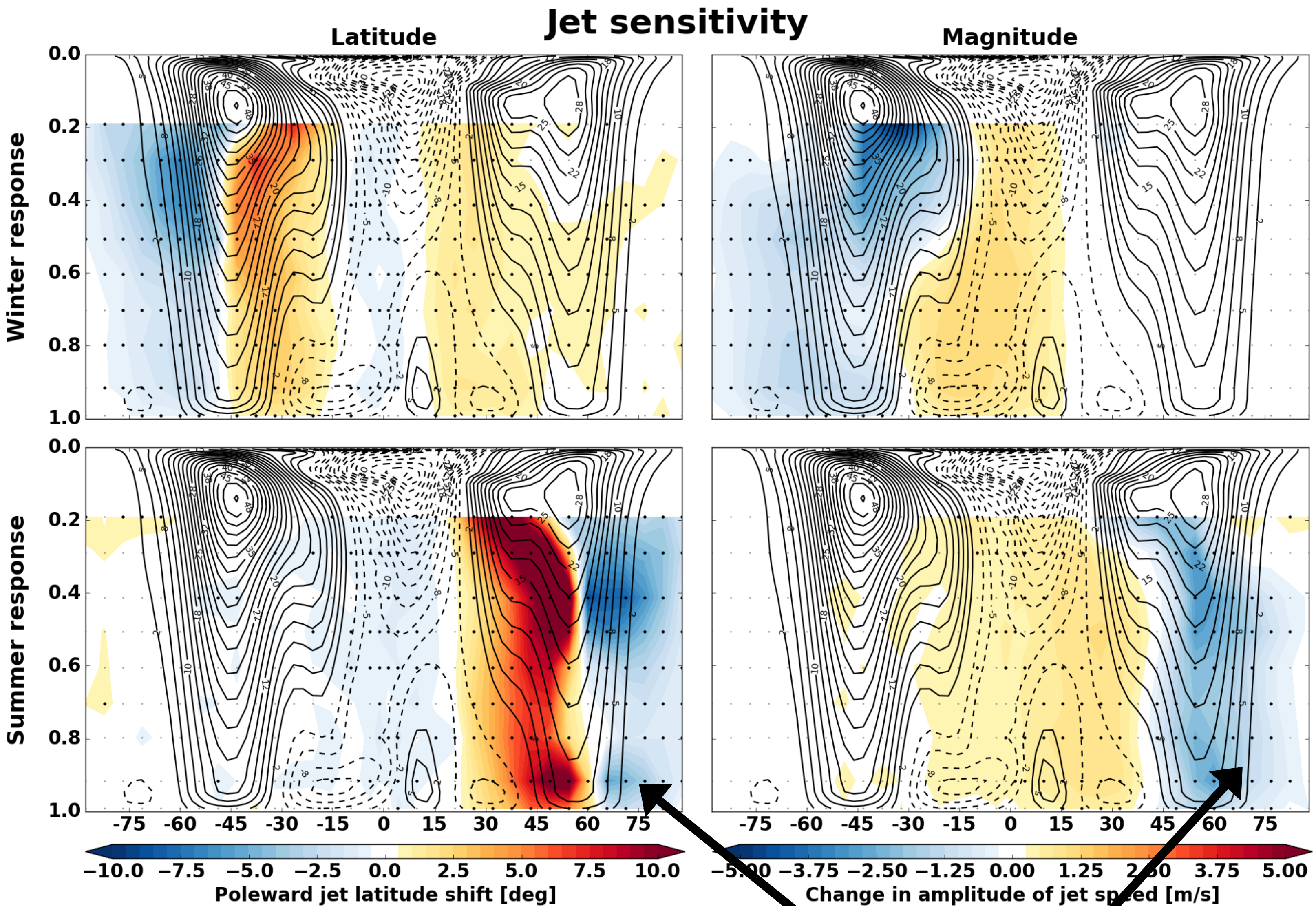
Basic support for the responses in complex model

Sensitivity results



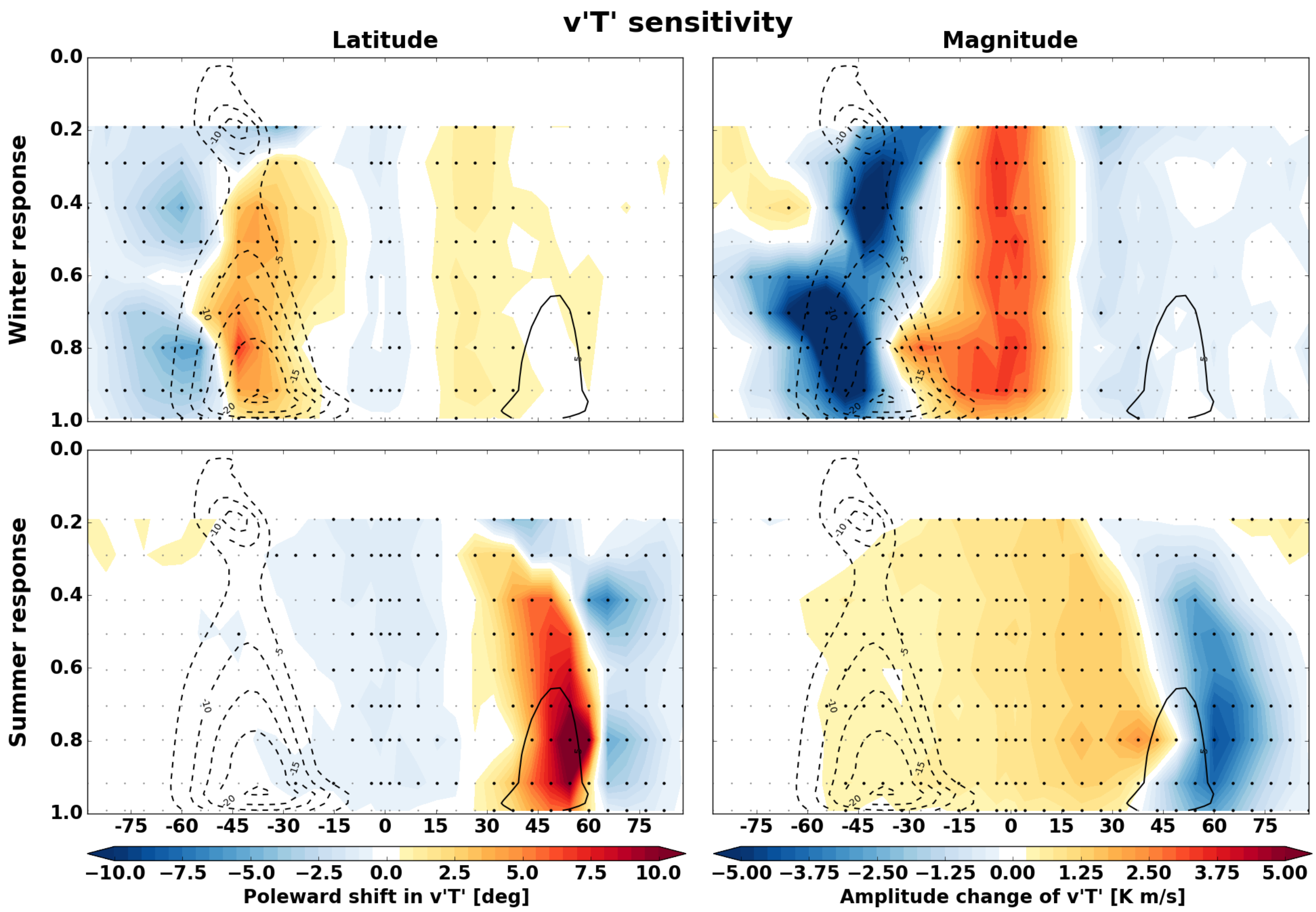
Responses to polar / tropical / subtropical regions not that sensitive to location of forcing

Sensitivity results



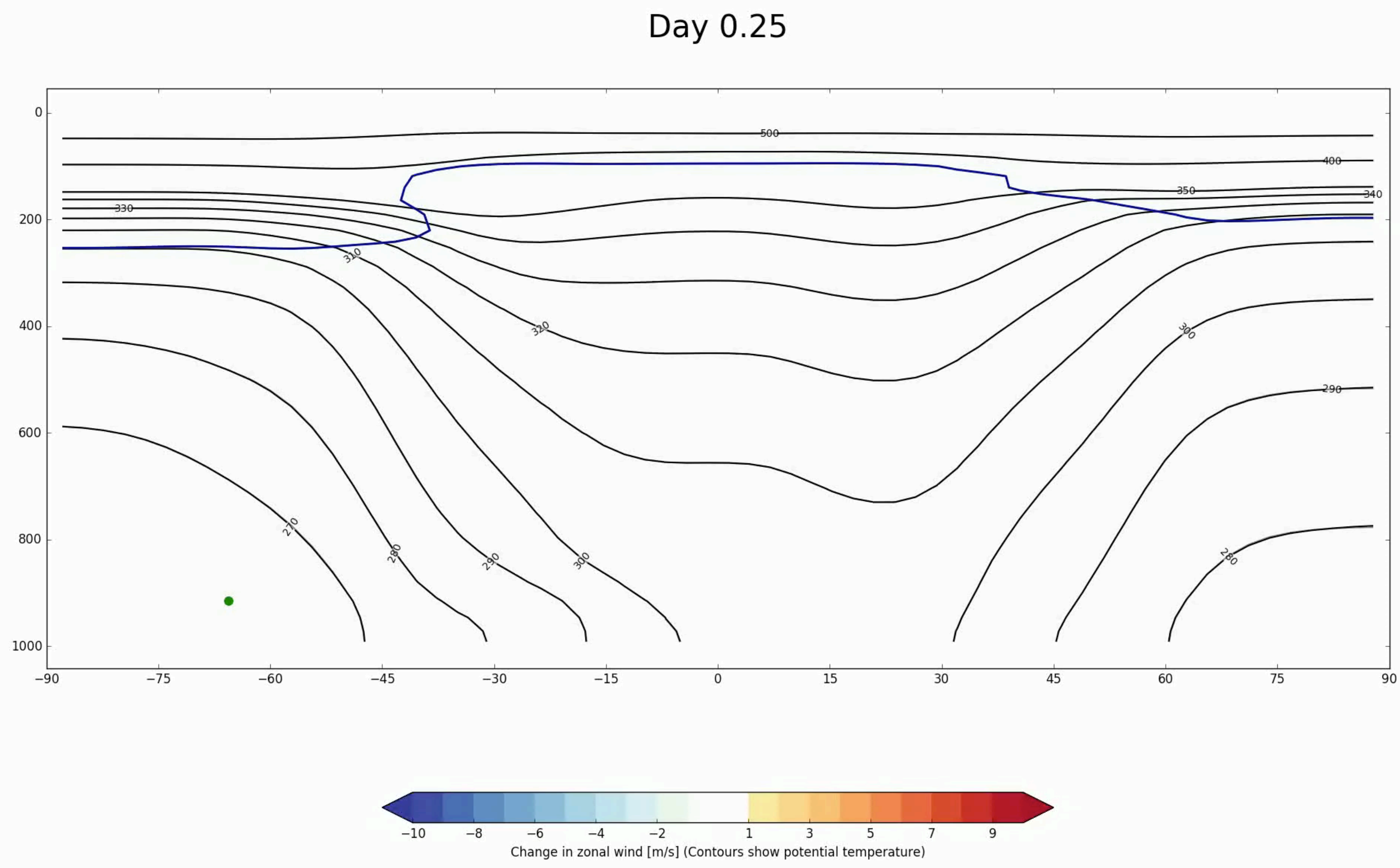
Sensitivities shift poleward in summer

Sensitivity results



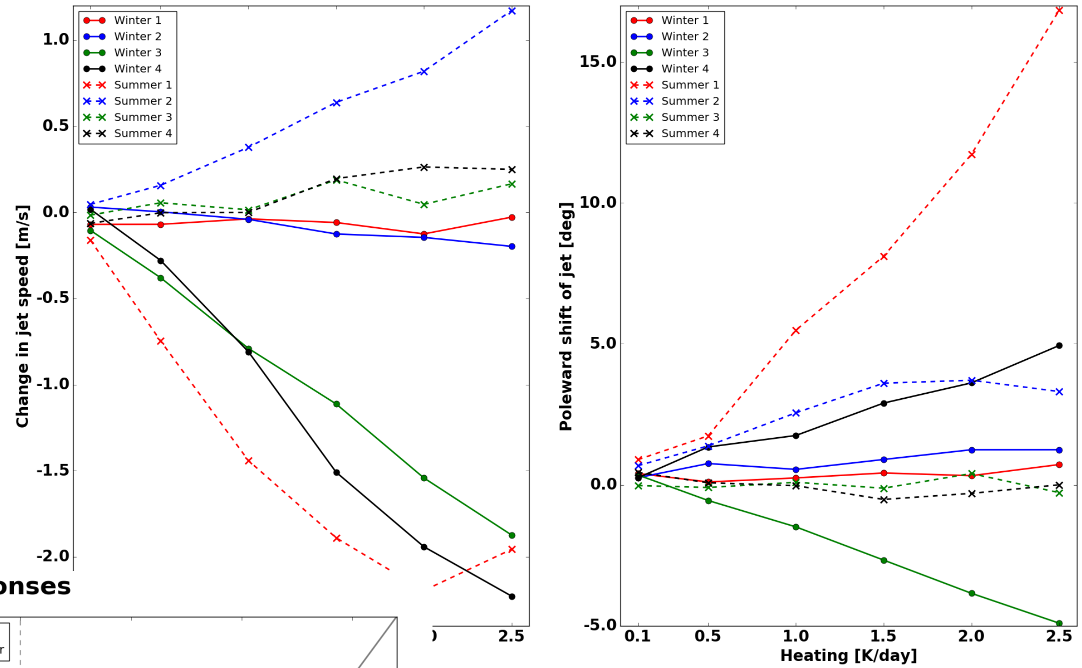
General mechanism: Changes in position and strength of v’T’ maximum

Spin up example

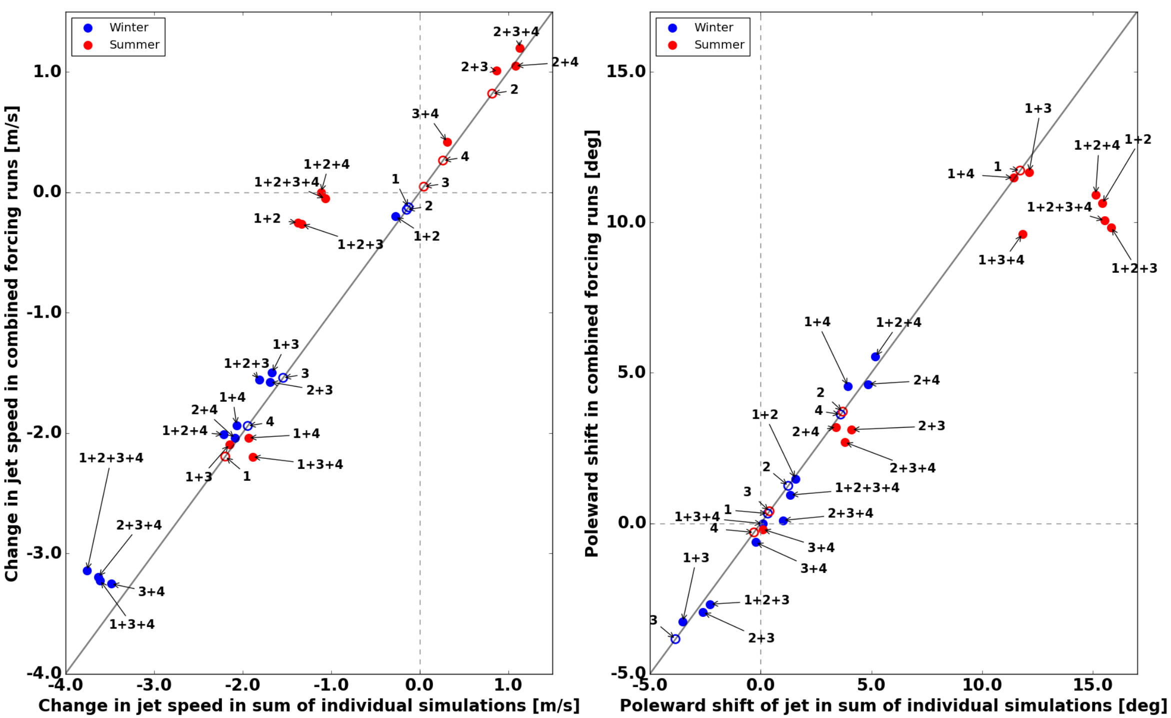


Sensitivity results: linearity

Linearity of response with respect to magnitude of heating

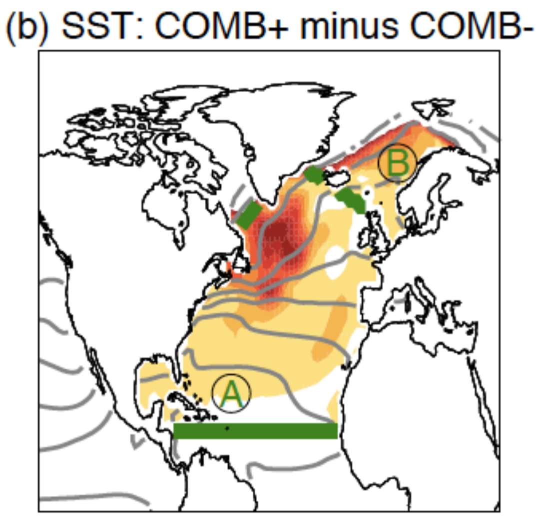


Linearity of combined responses

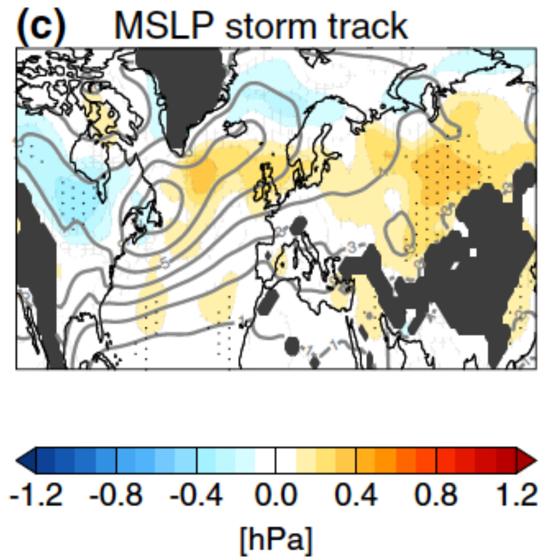


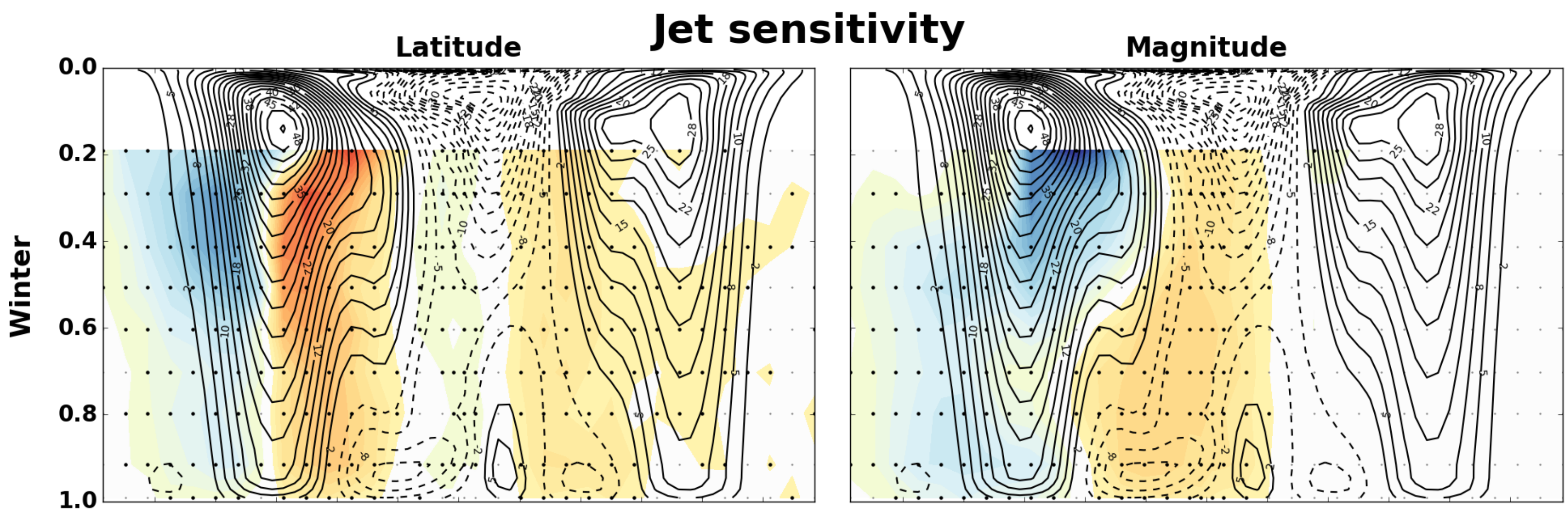
(It's not actually a linear model, I promise…)

So what about the AMOC?



Maybe we forced in the wrong place for this model…





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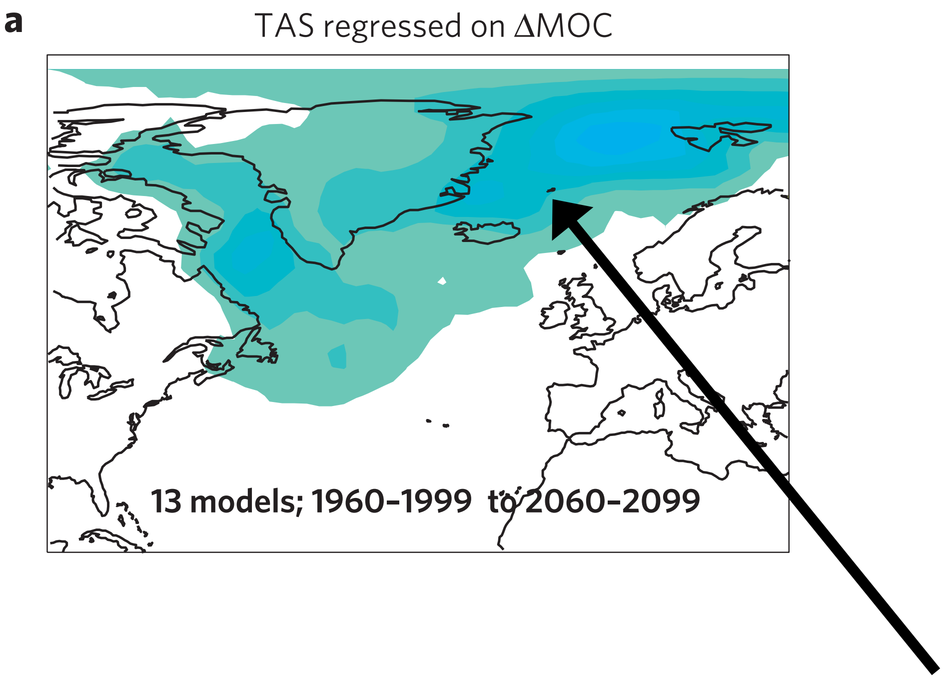


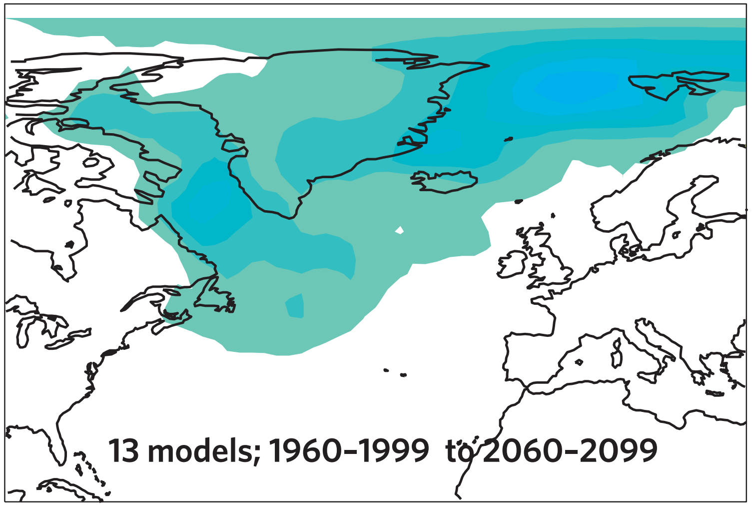
- Nordic seas: An important region?
- Forces on poleward side of storm track
- Linked to both Arctic warming and AMOC change

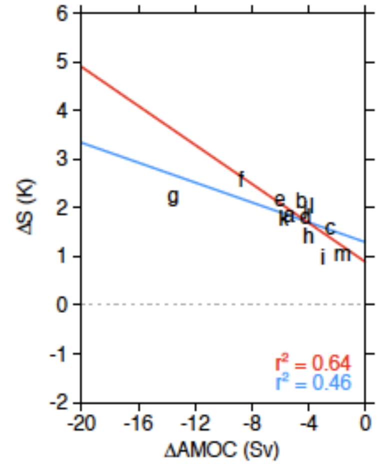
So what about the AMOC?

S = T500 - SST

a

TAS regressed on ΔMOC





Area-averages over ice-free points poleward of 45N; Woollings et al (2012) GRL

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

LETTERS
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nature geoscience

The impact of polar mesoscale storms on northeast Atlantic Ocean circulation

Alan Condron[1] and Ian A. Renfrew[2]*

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.