

Missing low-level drag causes climate model biases in jet streams, blocking and storm tracks.

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zonally asymmetric

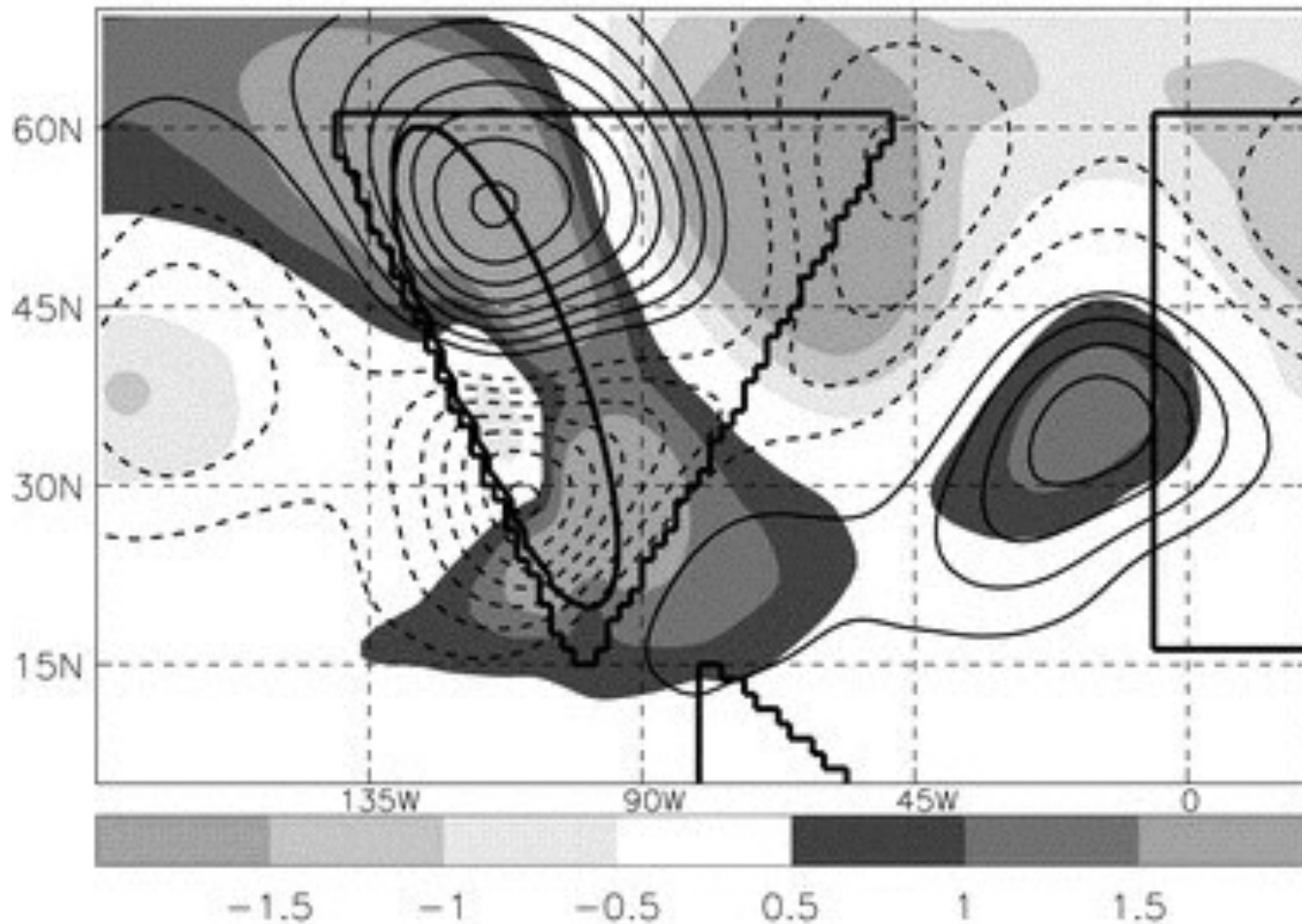
- North Atlantic jet/storm track too zonal
- Lack of European blocking events

zonally symmetric

- Extratropical jet displaced equatorwards
- Southern annular mode timescale too long

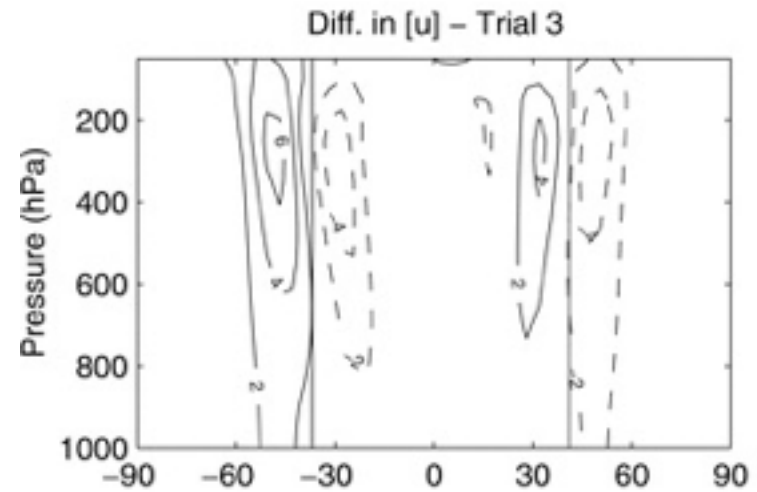
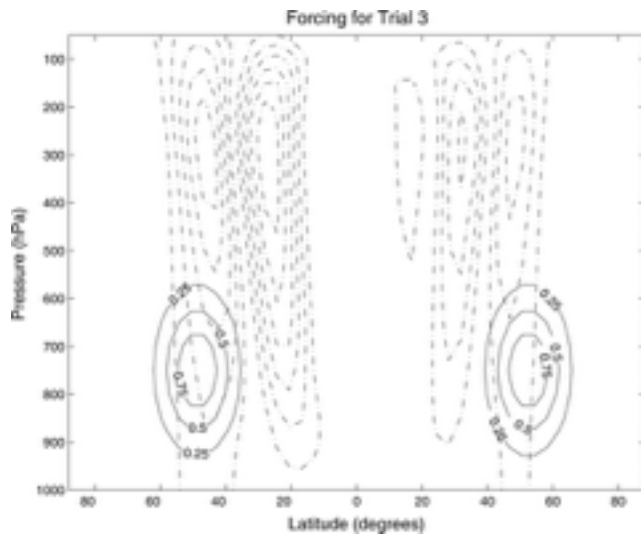
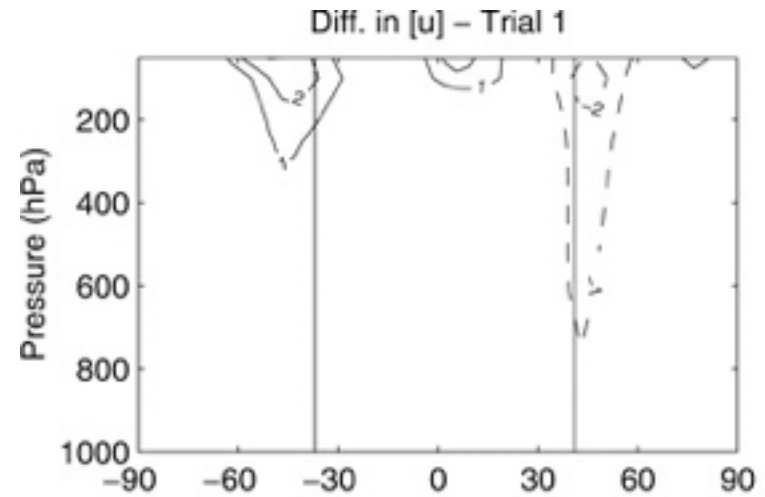
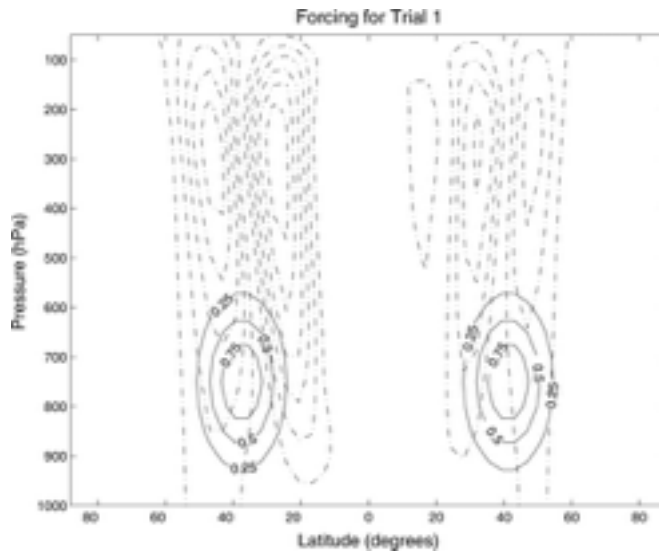
Orography shapes large-scale flow

(b) Temp. and stream function anom. 700 hPa



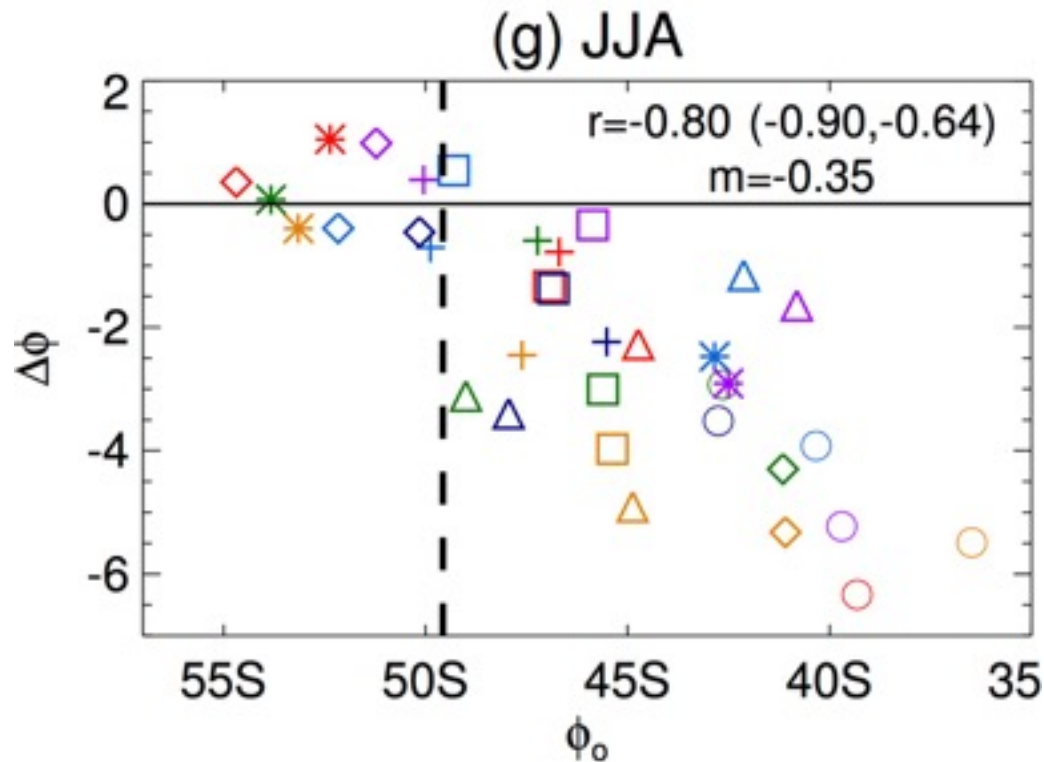
Brayshaw et al. 2010

Jet location in idealised models



Biases affect climate projections

- Larger wintertime jet shift in more biased models (Simpson and Polvani 2016)

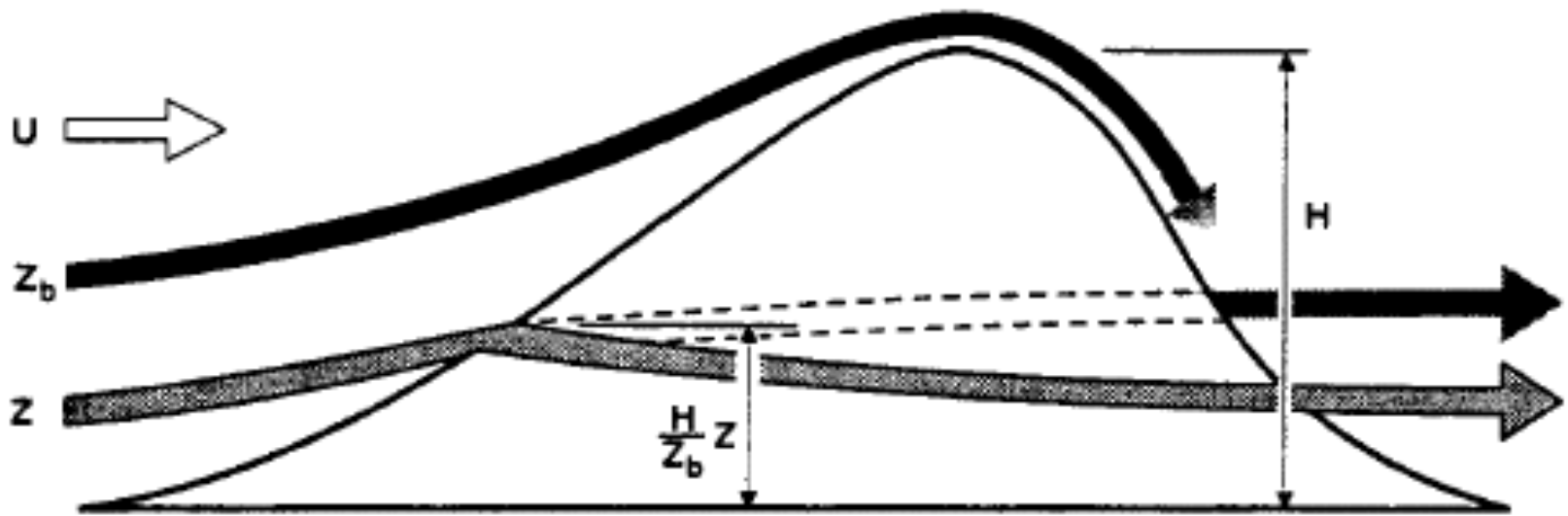


Why does better resolution help?



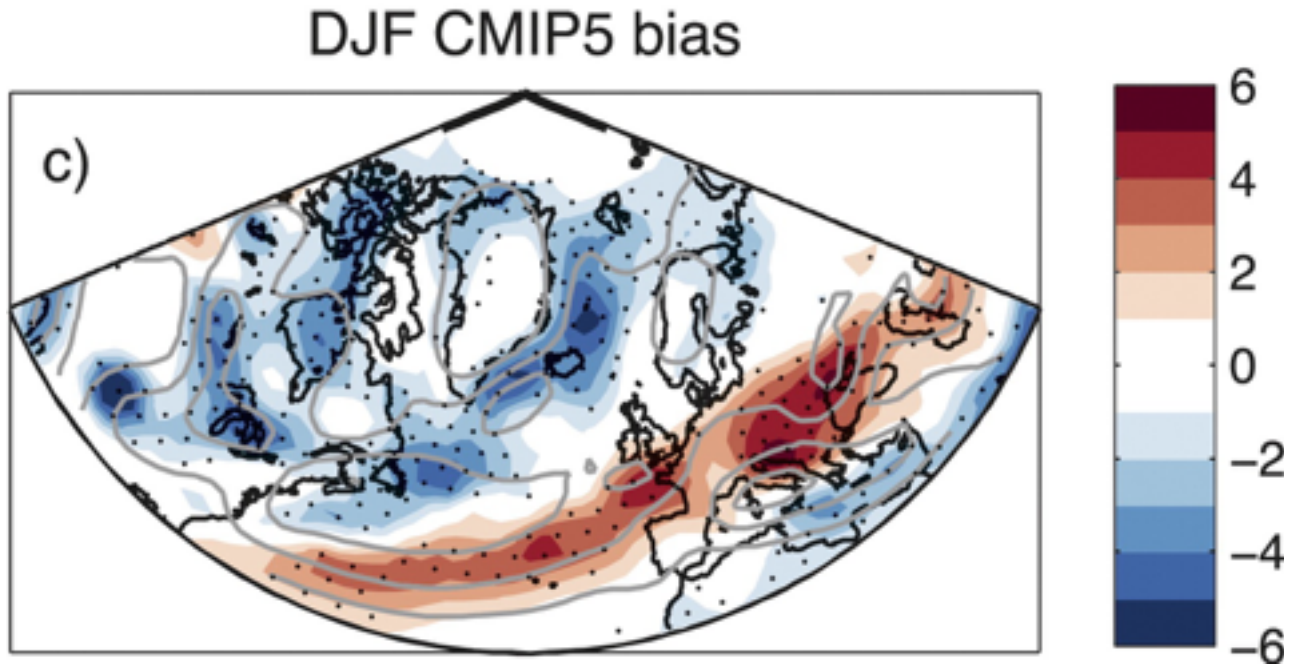
- Higher horizontal resolution leads to improved large-scale flow (e.g. Manabe (1970))
- better representation of Rossby wave-breaking (in past decades of modelling)
- better representation of orography (for current model resolutions, see Berckmanns et al. 2013)

Resolved and parameterized drag



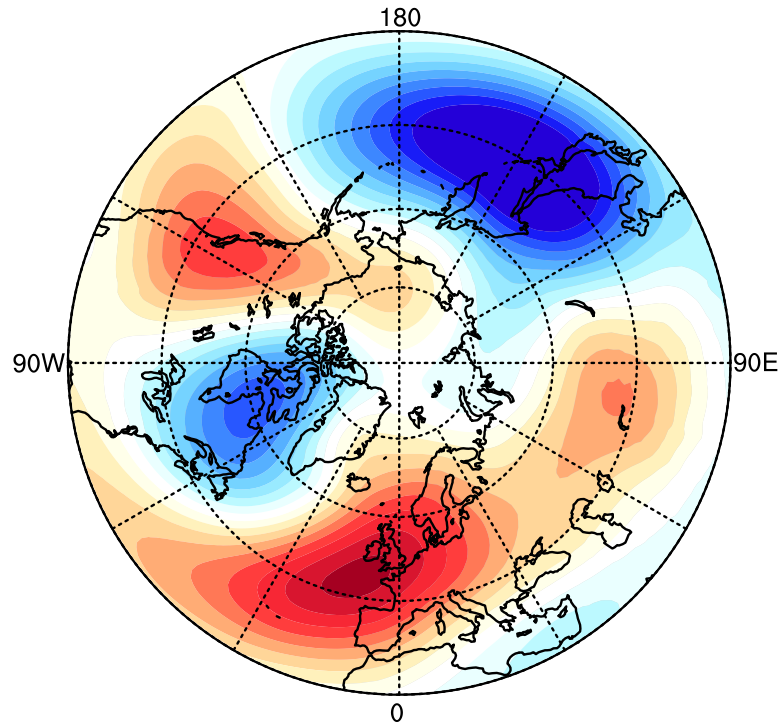
drag scheme: Lott and Miller (1997)

Too zonal, too far south

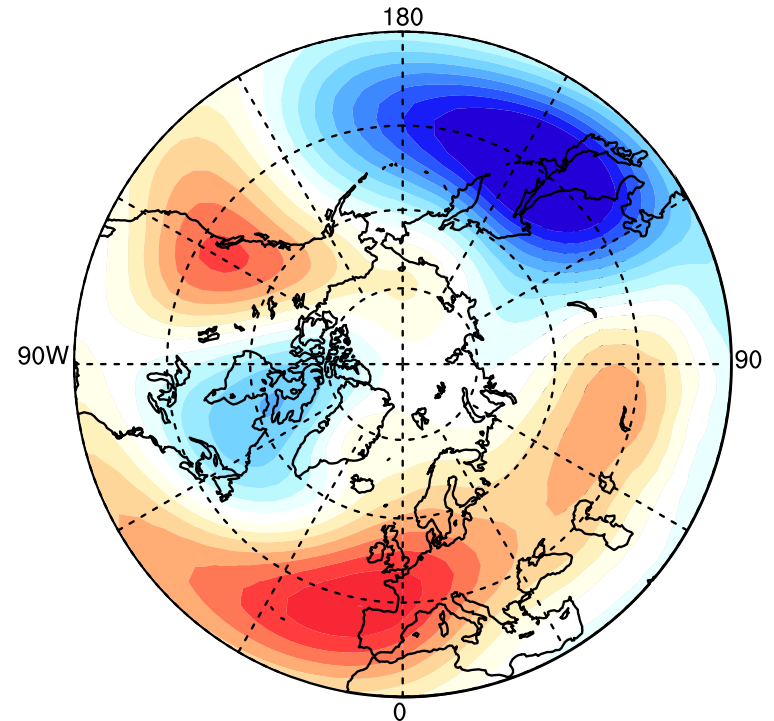


Zappa et al. 2013, Track density bias against ERA-Interim

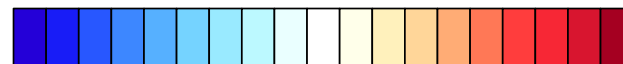
North Atlantic jet stream biases



ERA - Interim



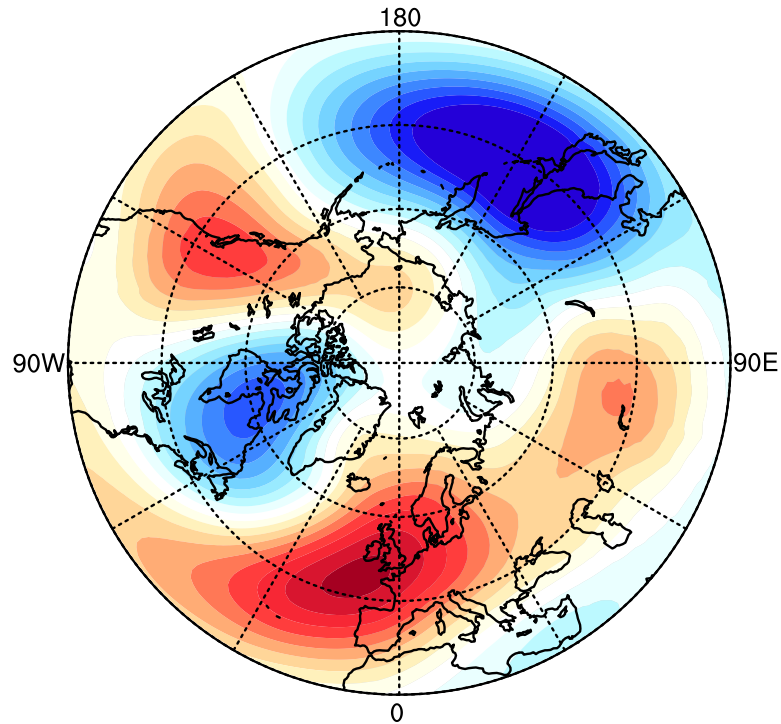
CMIP5



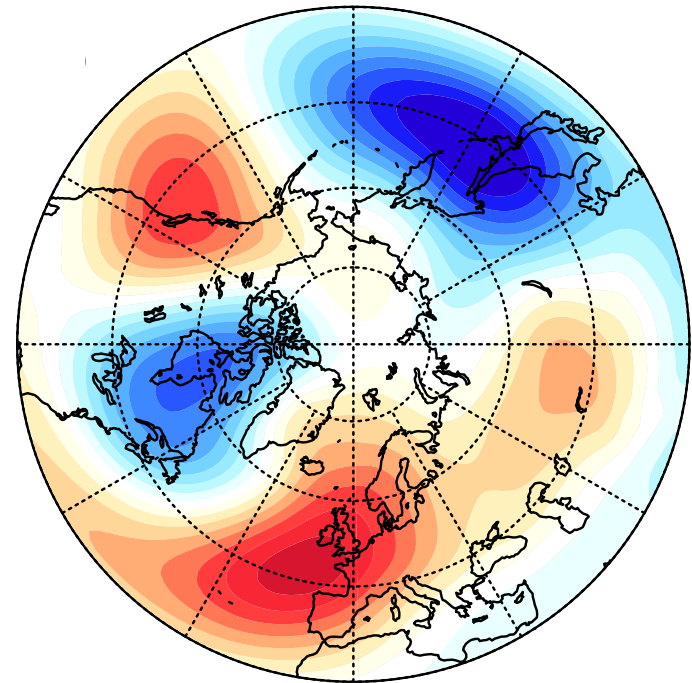
-150 -110 -70 -30 30 70 110 150

500 hPa geopotential height (m)

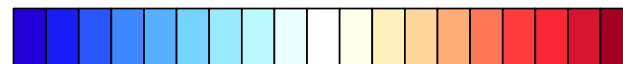
North Atlantic jet stream biases



ERA - Interim



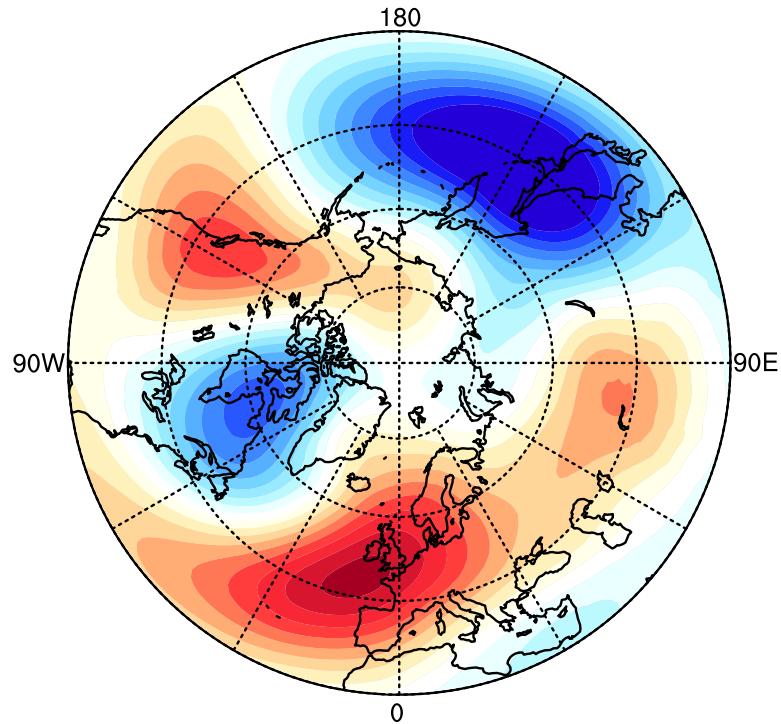
UM standard



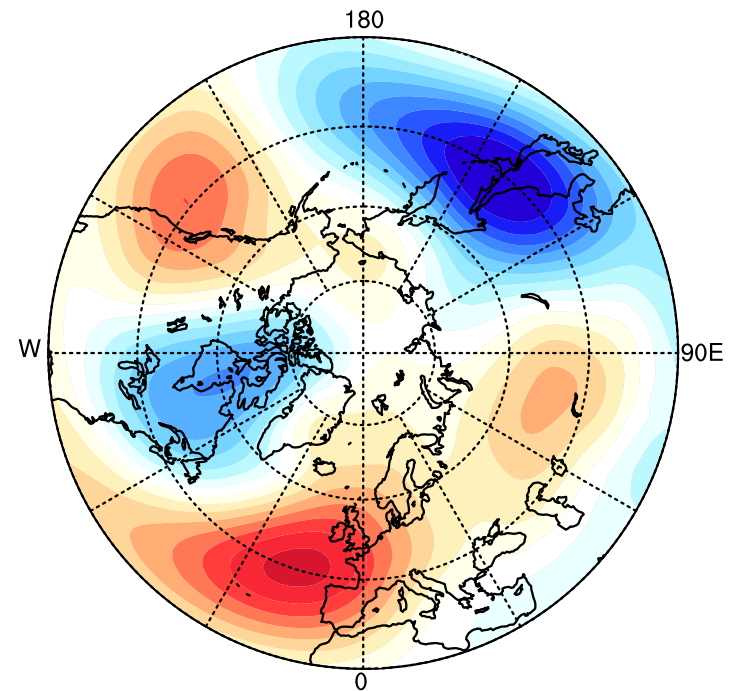
-150 -110 -70 -30 30 70 110 150

500 hPa geopotential height (m)

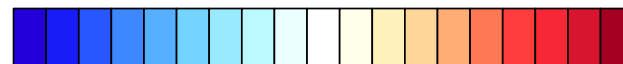
North Atlantic jet stream biases



ERA - Interim



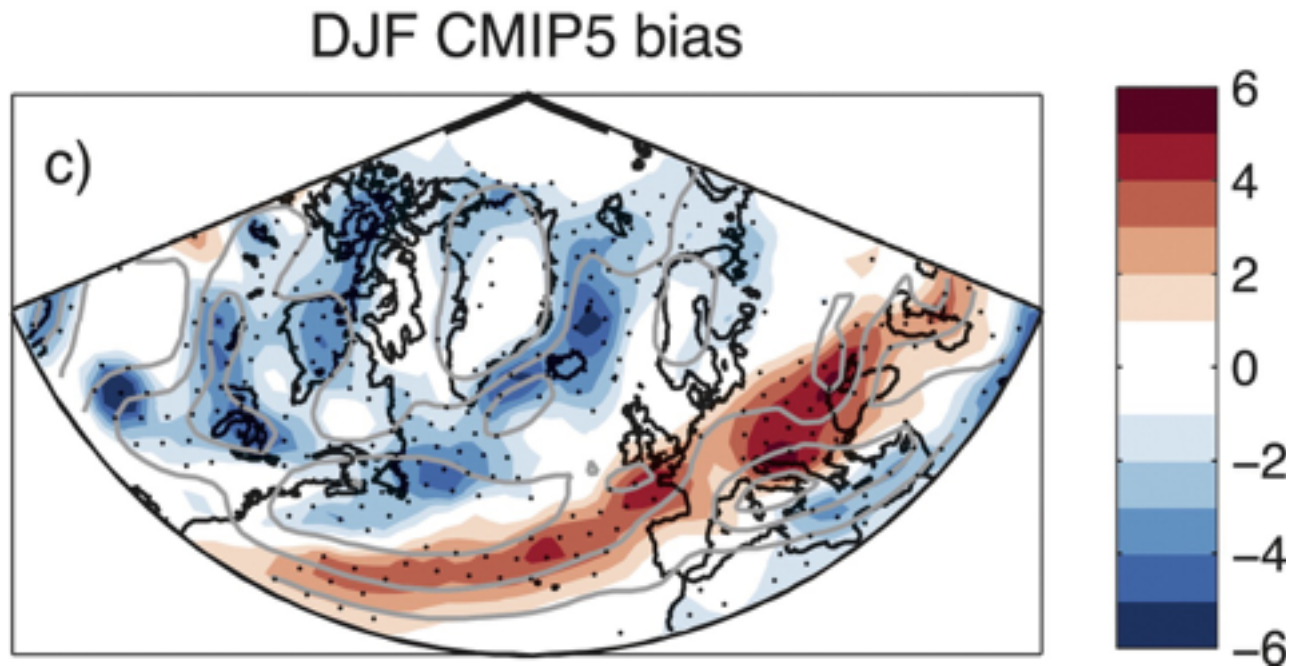
UM noblock



-150 -110 -70 -30 30 70 110 150

500 hPa geopotential height (m)

Too zonal, too far south



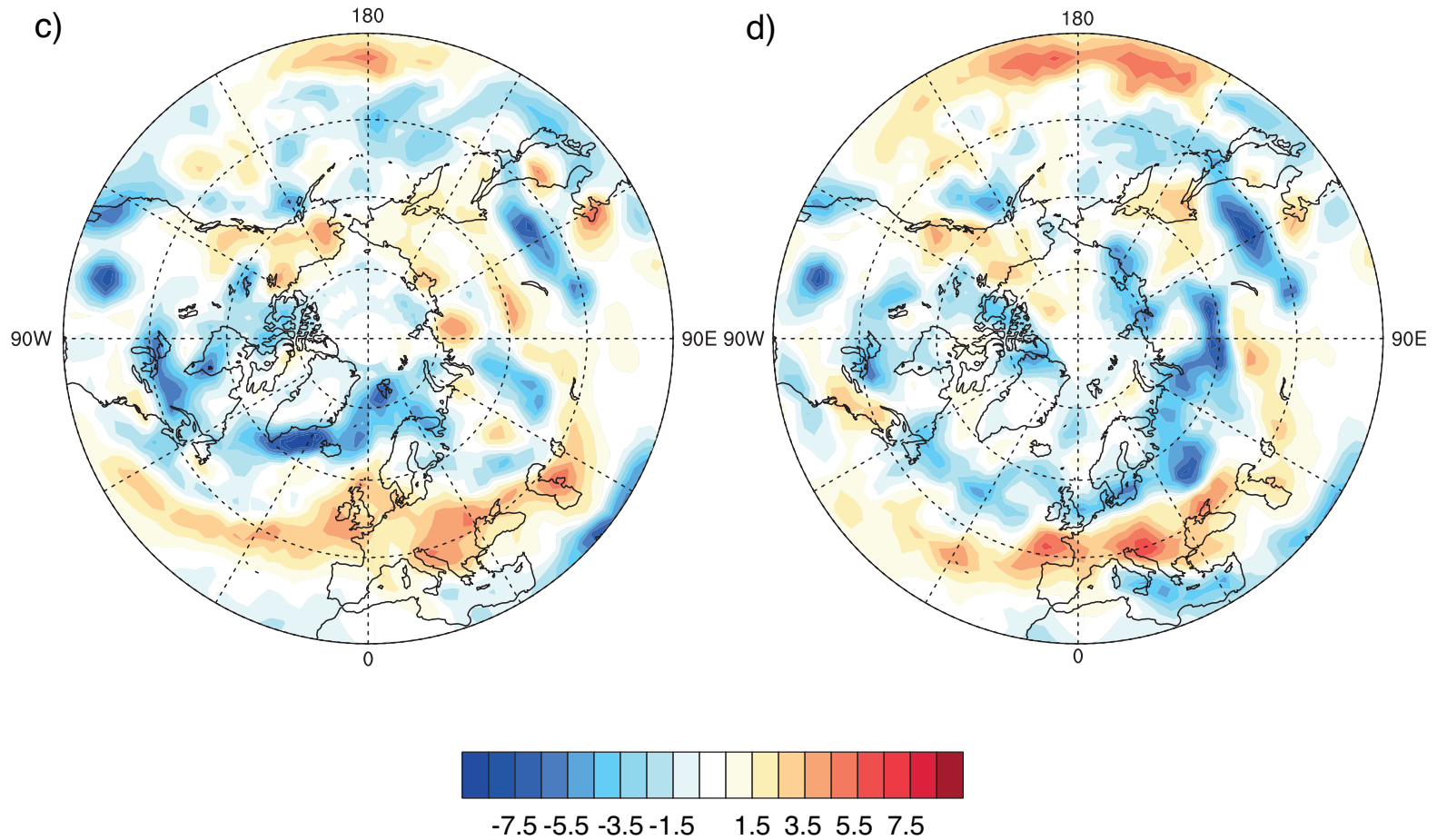
Zappa et al. 2013, Track density bias against ERA-Interim

Storm track biases in AO phases

positive AO

negative AO

CMIP5 ensemble - ERA



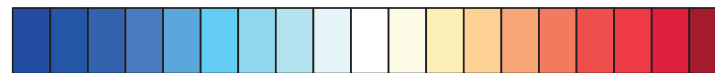
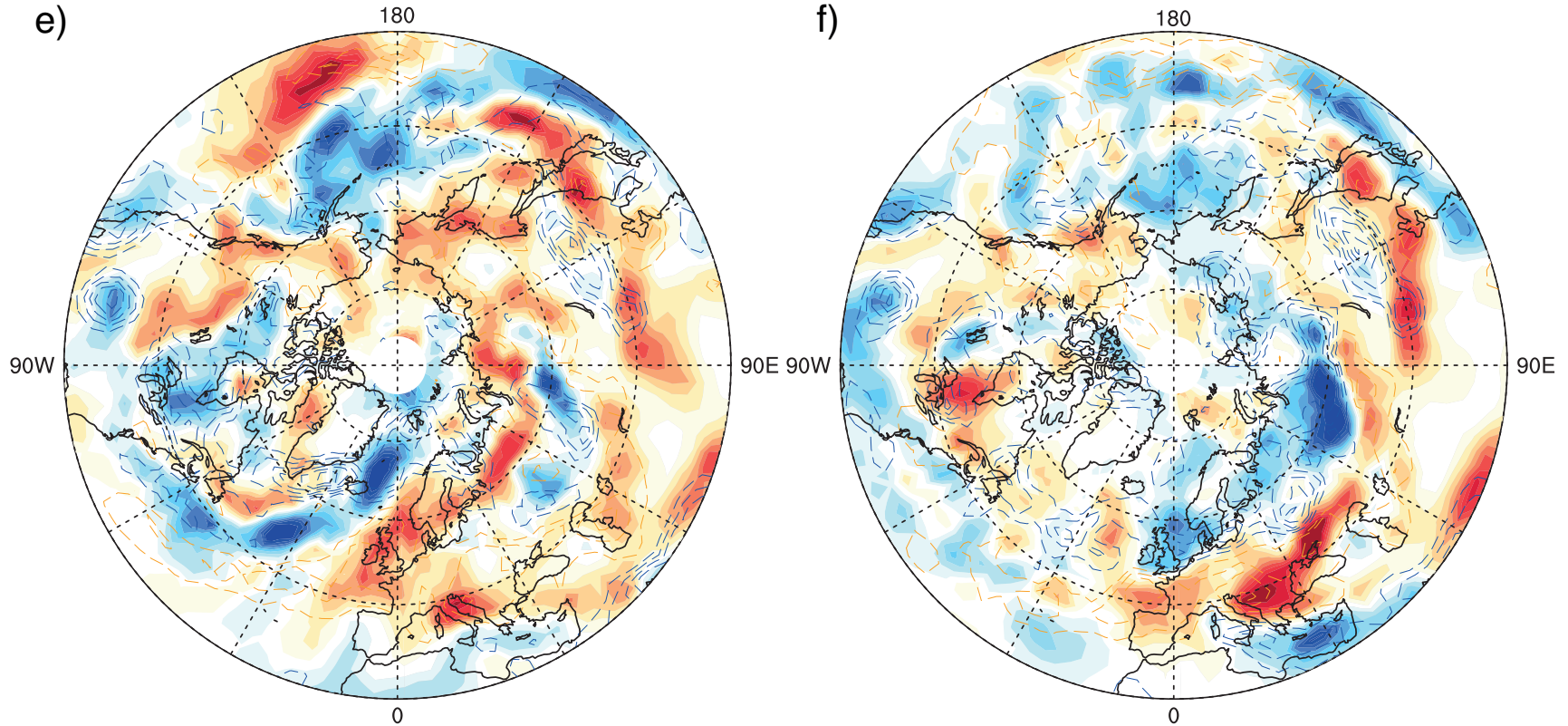
Storm track biases in AO phases

positive AO

negative AO

e)

f)



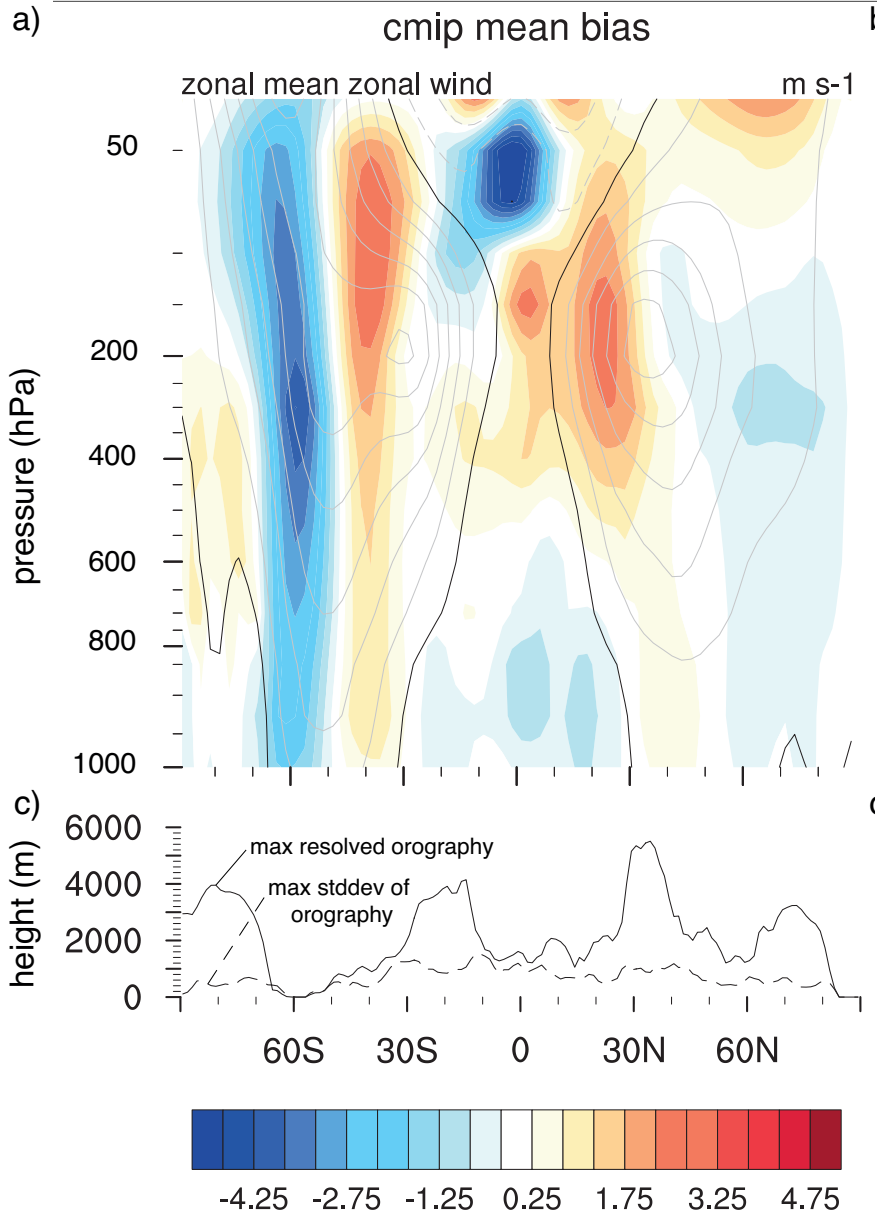
-7.5 -5.5 -3.5 -1.5 1.5 3.5 5.5 7.5

Understanding the impact

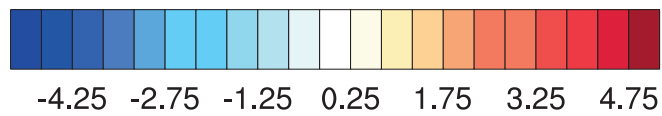
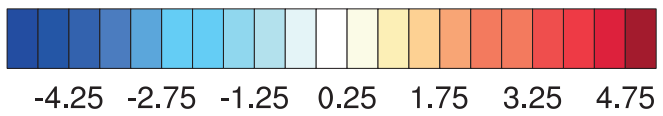
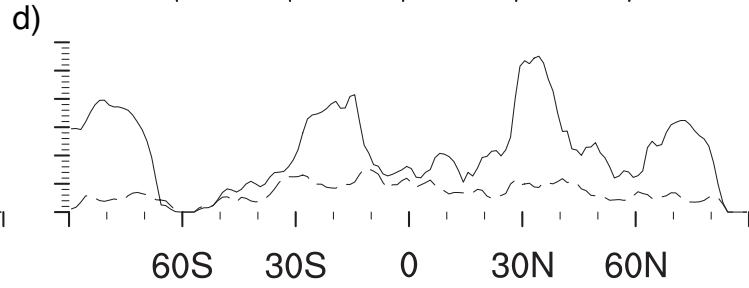
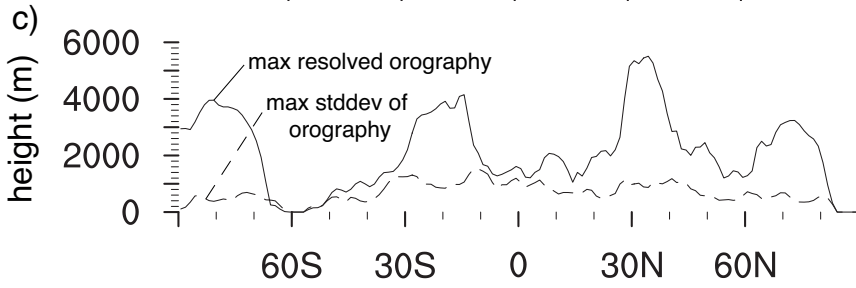
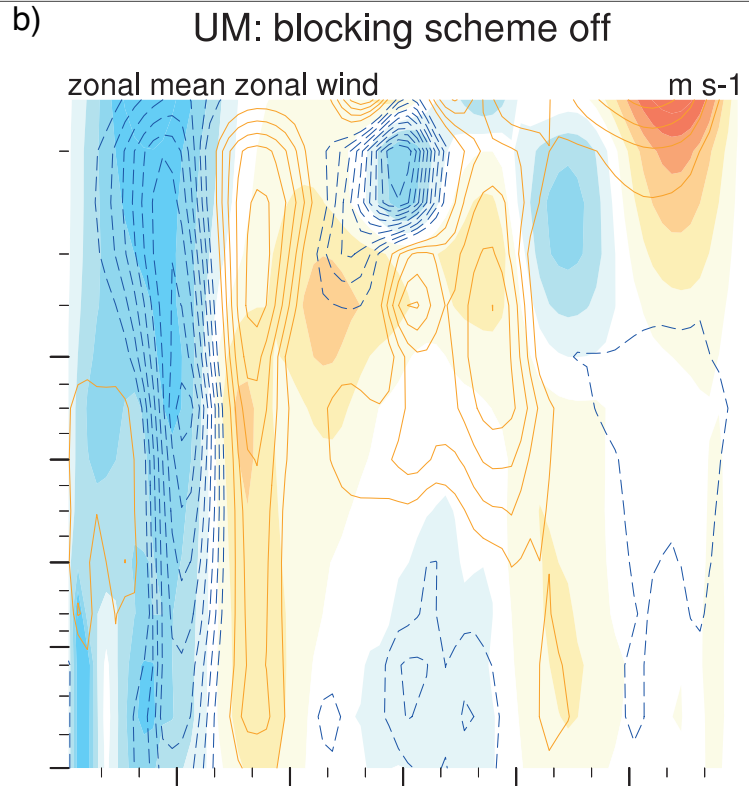
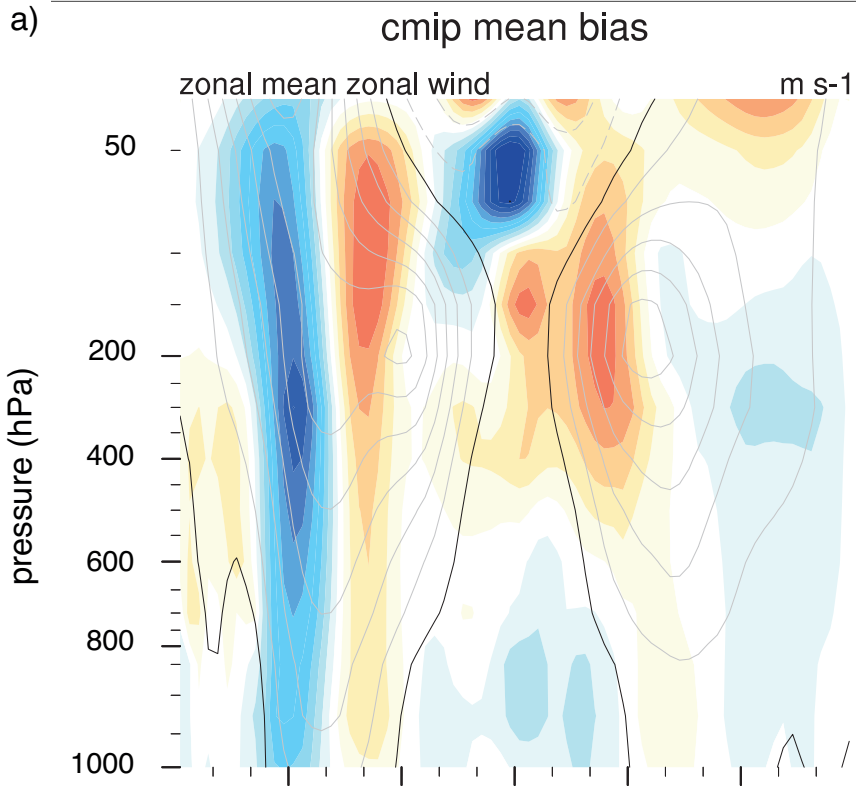


- bias: standing wave too long and propagation too zonal
- theory: both of these are to first order consistent with too high zonal winds (Held, 1983)
- impact: switching off drag leads to stronger zonal winds in mid-high troposphere over American continent

Zonal mean circulation



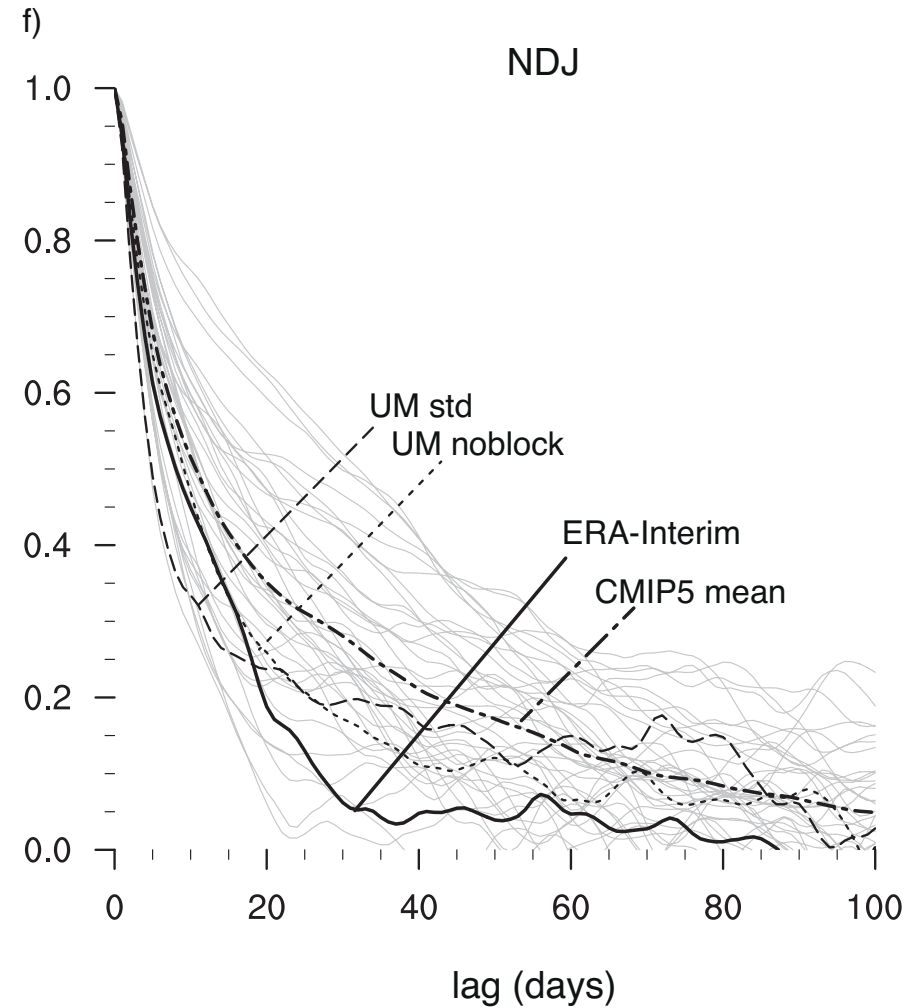
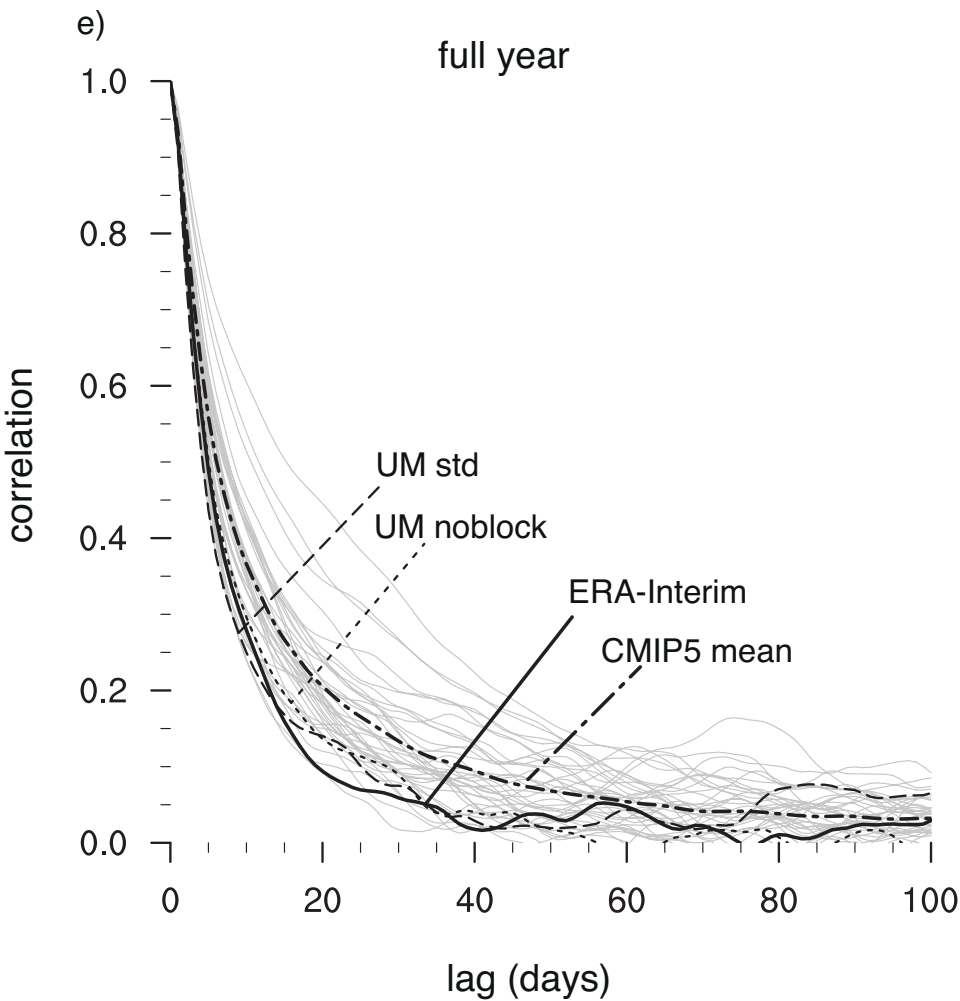
Zonal mean circulation



Annular mode timescale



Southern annular mode index autocorrelation



Understanding the impact

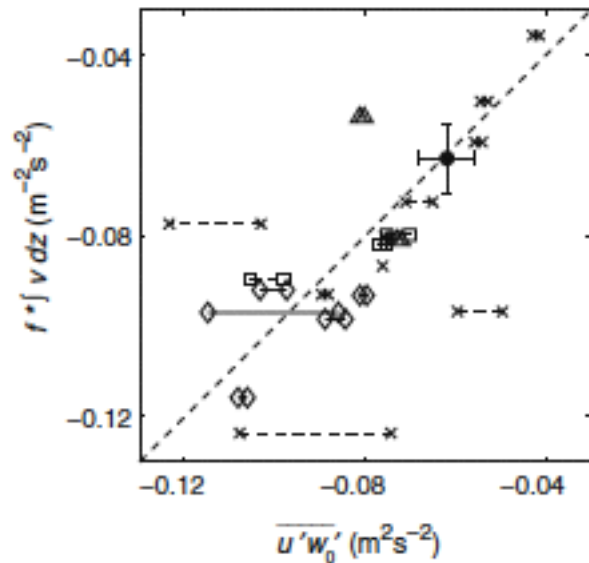


- Additional drag projects on annular mode and leads to AM-like response (jet shift)
- drag is a negative feedback on jet shifts and thus shortens timescale
- improved jet position does not lead to improved timescales (Simpson et al. 2013)

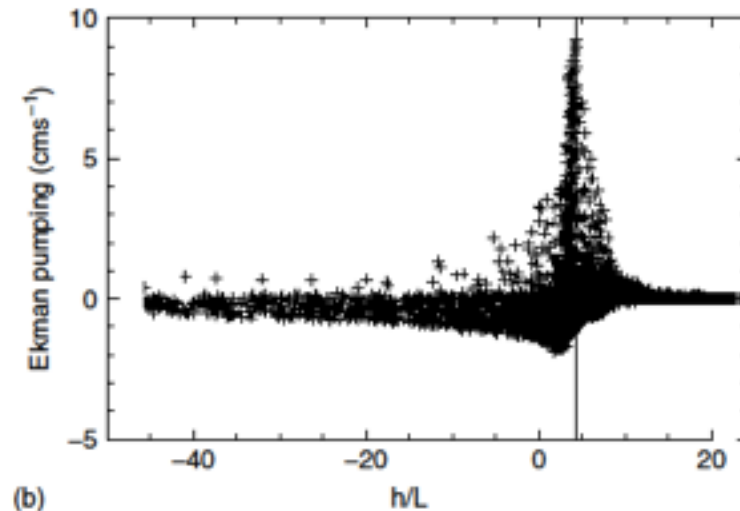
- To what extent does low-level drag affect the climate change signal?
- What is the right amount of SGO drag? most CMIP5 models have too little, UM probably too much (van Niekerk et al. 2016)

How does drag affect cyclones?

- cross-isobaric flow in (stable) boundary layers?



Svensson and Holtslag 2009



Beare 2007

- The effect of switching off low-level drag in a single GCM resembles typical circulation biases of the CMIP5 ensemble
- This suggests that the extratropical circulation could be represented much better in coarse-resolution models if parameterisations are improved or tuned accordingly