Sensitivity of resolved and parameterized surface drag to changes in resolution and parameterization

Annelize van Niekerk

Ted Shepherd

With thanks to: Simon Vosper, Stuart Webster, Andy Elvidge, Irina Sandu and Sylvie Malardel

Large spread in model climatology

University of Reading

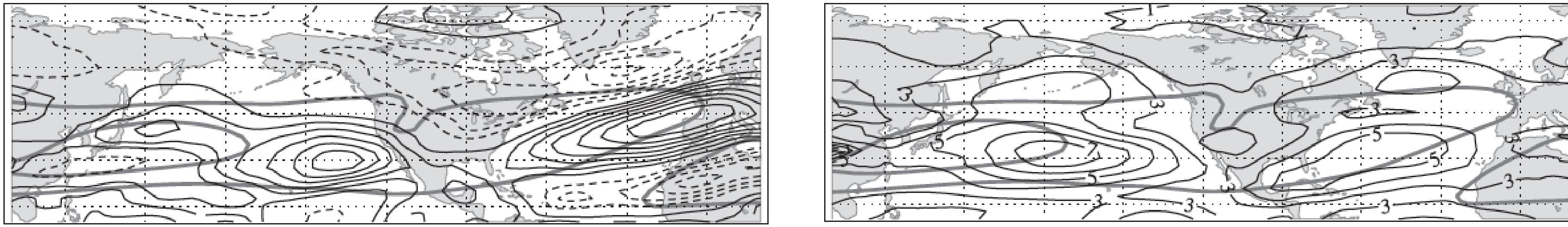
Multi-model mean bias

Inter-model bias spread

300hPa Zonal wind CI = 1 ms^{-1}

a. Ensemble Mean Bias

b. Model Standard Deviation of Bias



Delcambre et al 2013

Large spread in model response

University of Reading

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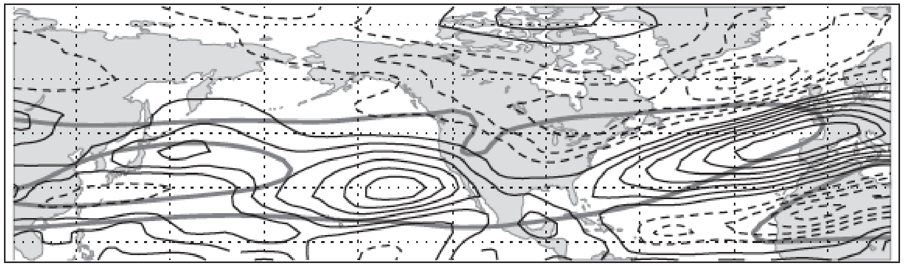
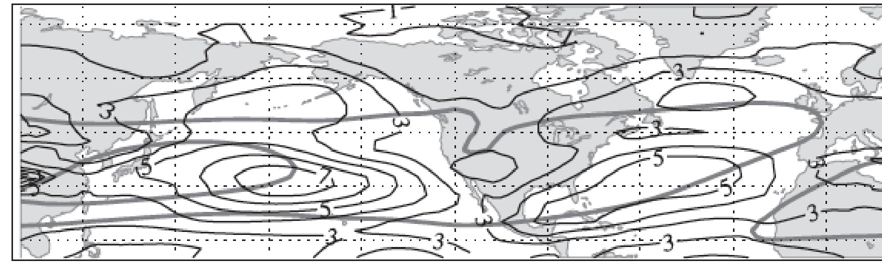
300hPa Zonal wind CI = 1 ms^{-1}

a. Ensemble Mean Bias



b. Model Standard Deviation of Bias

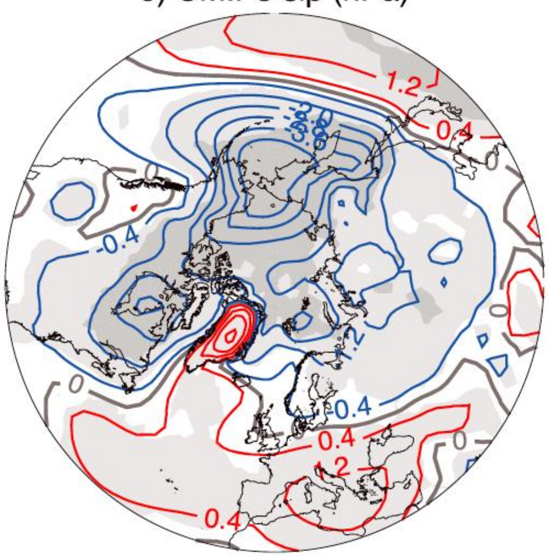


Delcambre et al 2013

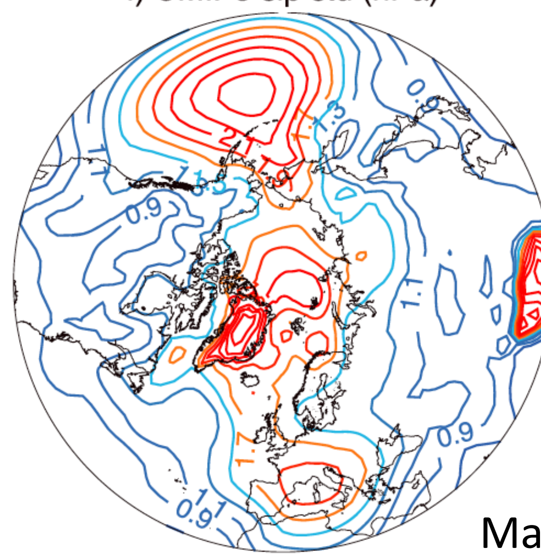
Multi-model mean response

Inter-model response spread

e) CMIP5 slp (hPa)

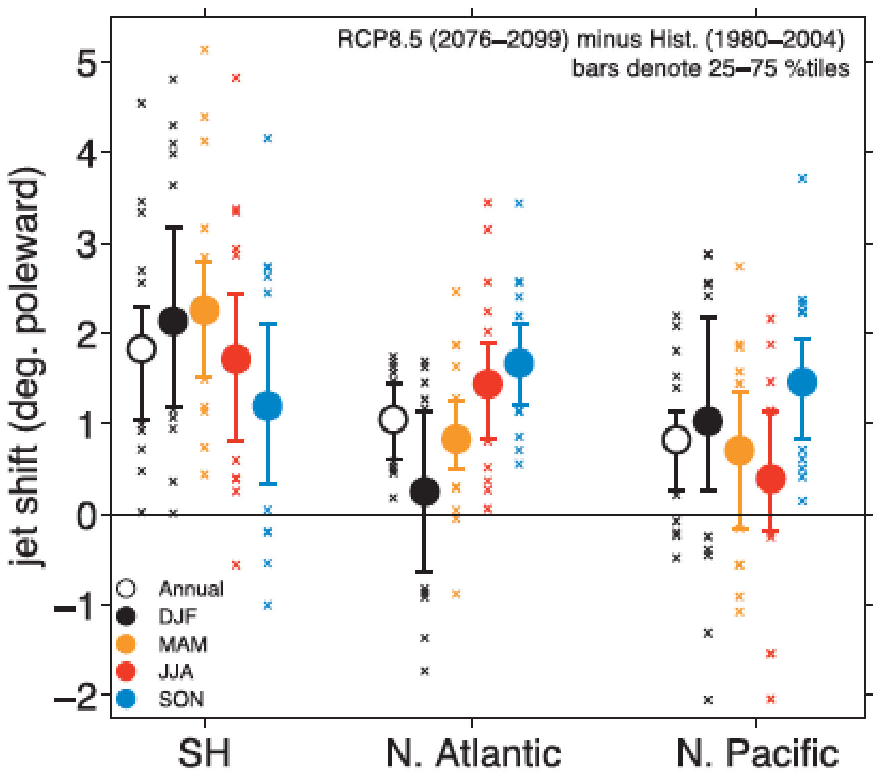


f) CMIP5 slp std (hPa)



Manzini et al 2013

Large spread in model response



Models do not agree on the sign of the shift in the mid-latitude surface jets, let alone the magnitude

Barnes and Polvani (2013)

How can we reduce model uncertainty?

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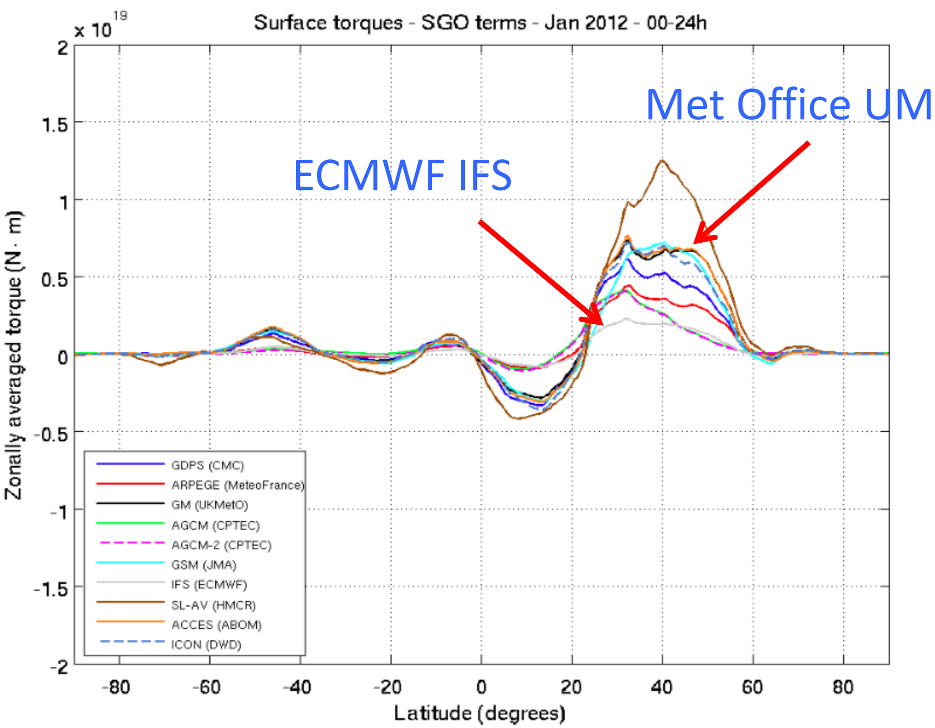
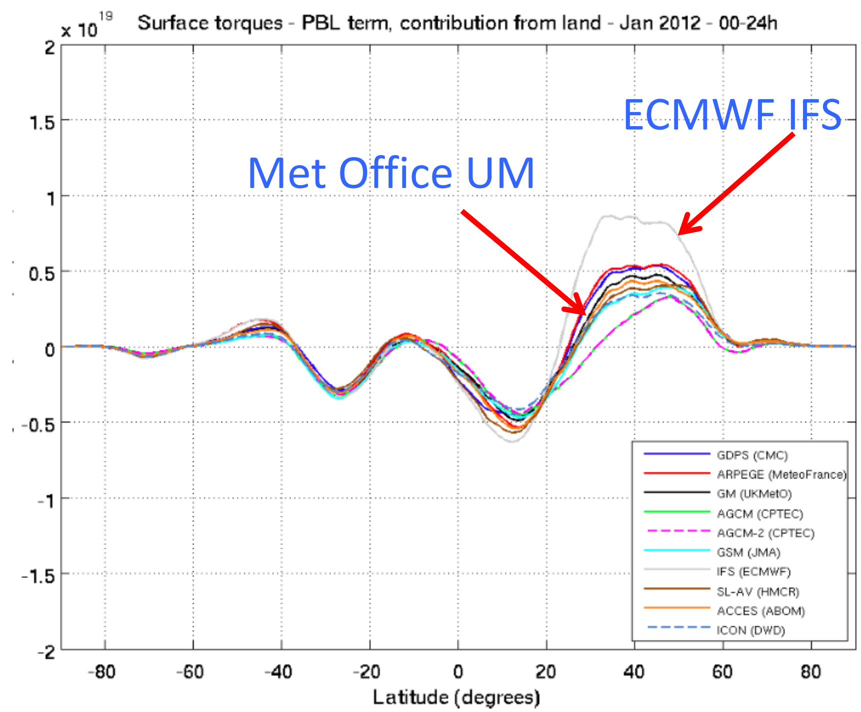
- Better understanding of processes governing the range seen in climatological circulation of models

SSO



BL



WGNE Drag Project, Report No.1, A. Zadra (2013)

Momentum budget as a tool for understanding circulation sensitivity to drag

Vertically integrated zonal mean angular momentum budget:

$$\frac{\partial\left[\int_{z_0}^{\infty} m\rho dz\right]}{\partial t} = -\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho dz\right]\cos\phi\right)}{\partial\phi}$$

$$+\left[\int_{z_0}^{\infty} fvr\cos\phi\rho dz\right] - \left[p_0\frac{\partial z_0}{\partial\lambda}\right] - \left[F_0 r\cos\phi\right]$$

$$\boxed{m = ur\cos\phi}$$

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Coriolis torque

$$\boxed{m = ur\cos\phi}$$

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Vertically integrated zonal mean angular momentum budget:

Angular momentum flux convergence (AMFC)

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Resolved orographic torque

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Coriolis torque

Resolved orographic torque

$$\boxed{m = ur\cos\phi}$$

Boundary layer (BL)

Sub-grid scale orographic (SSO)

$$F_0 = F_{BL} + F_{GWD} + F_{Blocking}$$

Sources of uncertainty in surface drag:

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- Models with different horizontal resolutions will have different resolved surface drag

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Aim: Understand the contributions to model uncertainty from parameterized and resolved orographic drag

Momentum budget as a tool for understanding circulation sensitivity

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$$\cancel{\frac{\partial\left[\int_{z_0}^{\infty} m\rho dz\right]}{\partial t}} = -\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho dz\right]\cos\phi\right)}{\partial\phi}$$

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Coriolis torque

Resolved orographic torque

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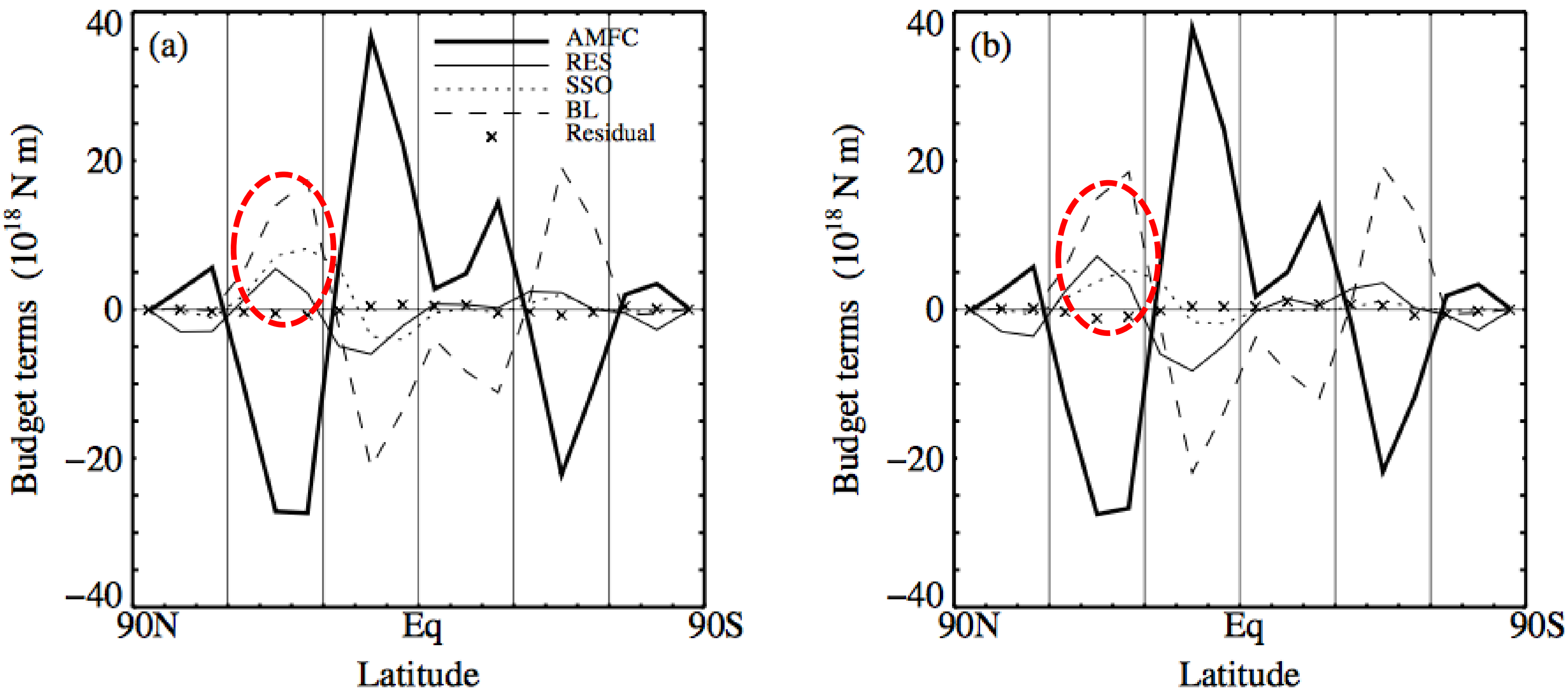
Boundary layer (BL)

Sub-grid scale orographic (SSO)

$$F_0 = F_{BL} + F_{GWD} + F_{Blocking}$$

Earth's angular momentum budget – constrained through initial conditions

T159 T511

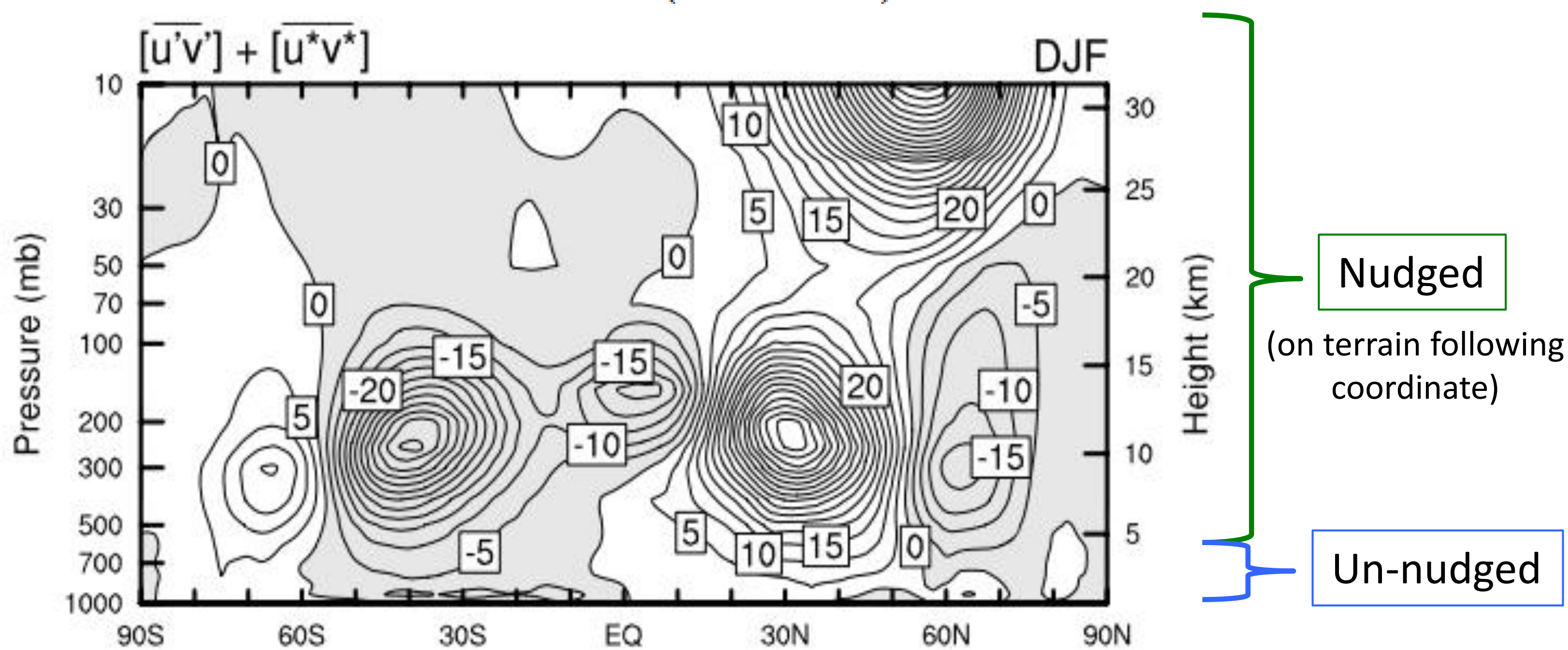


A. Brown (2004), QJRMS

Nudge towards ERA-interim in free atmosphere

$$\frac{\Delta X}{\Delta t} = F(X) + \frac{(X_A - X_M)}{\tau}$$

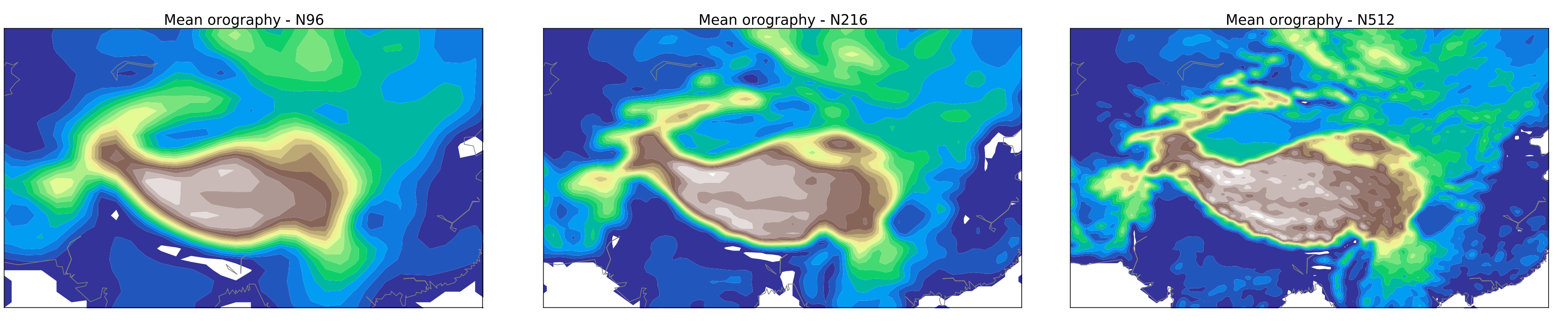
$$X = (u, v, T)$$



Hartmann 2007

Model Setup

- Model: UK Met Office Unified Model (ENDGame)
  Non-hydrostatic, semi-Lagrangian, regular lat/lon grid
  85 hybrid-height vertical levels extending to 85km
- AMIP-style: Prescribed SSTs and sea ice
- Months for analysis: January 1998 and January 2010 (1 month spin up with nudging) & short range forecasts
- 3 resolutions: 130km (climate resolution N96), 60km (‘new’ climate resolution N216), 25km (seasonal forecasting N512)



See: van Niekerk et al (2016), QJRMS

RMetS

Royal Meteorological Society

University of Reading

Sensitivity of resolved and parametrized surface drag to changes in resolution and parametrization

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[a]*Department of Meteorology, University of Reading, UK*

[b]*Met Office, Exeter, UK*

*Correspondence to: A. van Niekerk, Department of Meteorology, University of Reading, Reading, RG6 6BB, UK. E-mail: a.vanniekerk@pgr.reading.ac.uk

The relative contributions of resolved and parametrized surface drag towards balancing the atmospheric angular momentum flux convergence (AMFC) and their sensitivity to horizontal resolution and parametrization are investigated in an atmospheric model. This sensitivity can be difficult to elucidate in free-running climate models, in which the AMFC varies with changing climatologies and, as a result, the relative contributions of surface terms balancing the AMFC also vary. While the sensitivity question has previously been addressed using short-range forecasts, we demonstrate that a nudging framework is an effective method for constraining the AMFC. The Met Office Unified Model is integrated at three horizontal resolutions ranging from 130 ($N96$) to 25 km ($N512$), while relaxing the model's wind and temperature fields towards the ERA-Interim reanalysis within the altitude regions of maximum AMFC. This method is validated against short-range forecasts and good agreement is found. These experiments are then used to assess the fidelity of the exchange between parametrized and resolved orographic torques with changes in horizontal resolution. Although the parametrized orographic torque reduces substantially with increasing horizontal resolution, there is little change in resolved orographic torque over 20–50°N. The tendencies produced by the nudging routine indicate that the additional drag at lower horizontal resolution is excessive. When parametrized orographic blocking is removed at the coarsest of these resolutions, there is a lack of compensation, and even compensation of the opposite sense, by the boundary layer and resolved torques, which is particularly pronounced over 20–50°N. This study demonstrates that there is strong sensitivity in the behaviour of the resolved and parametrized surface drag over this region.

Sources of uncertainty in surface drag:

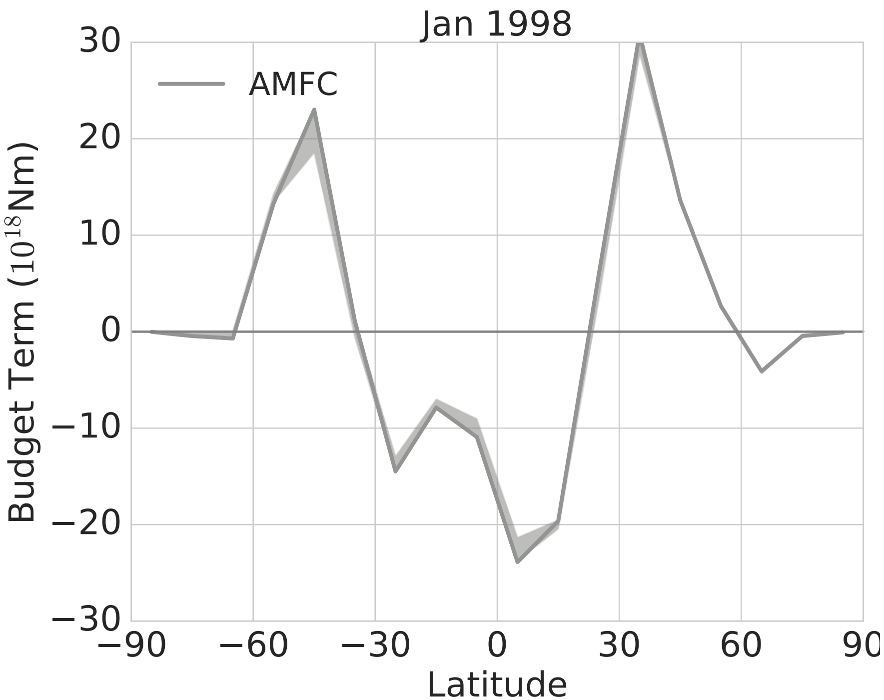
1) Model Resolution:

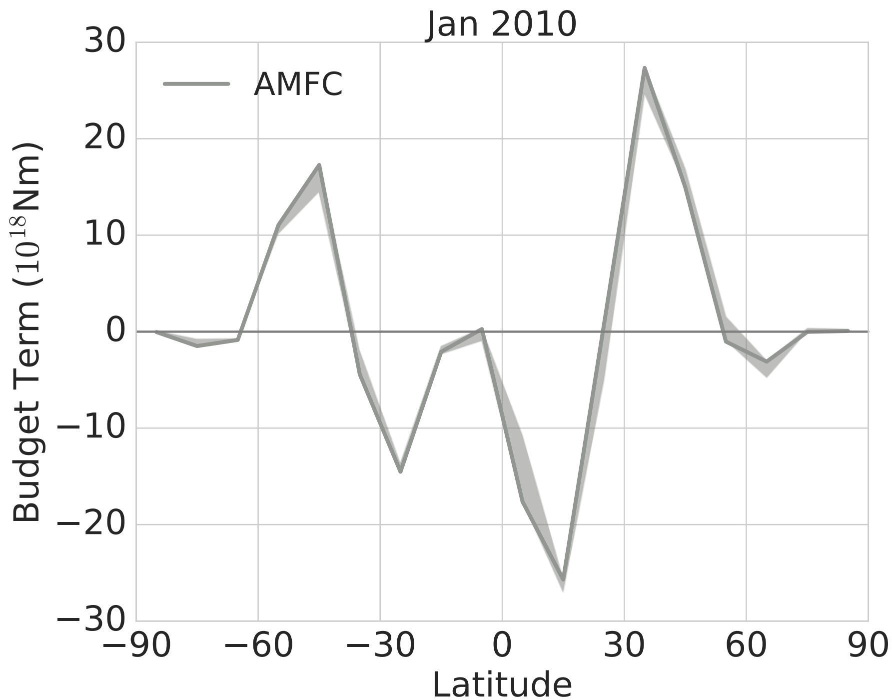
- Models with different horizontal resolutions will have different resolved surface drag

2) Parameterization:

- Orographic drag parameterization formulation varies between models

Shading indicates range over model resolutions

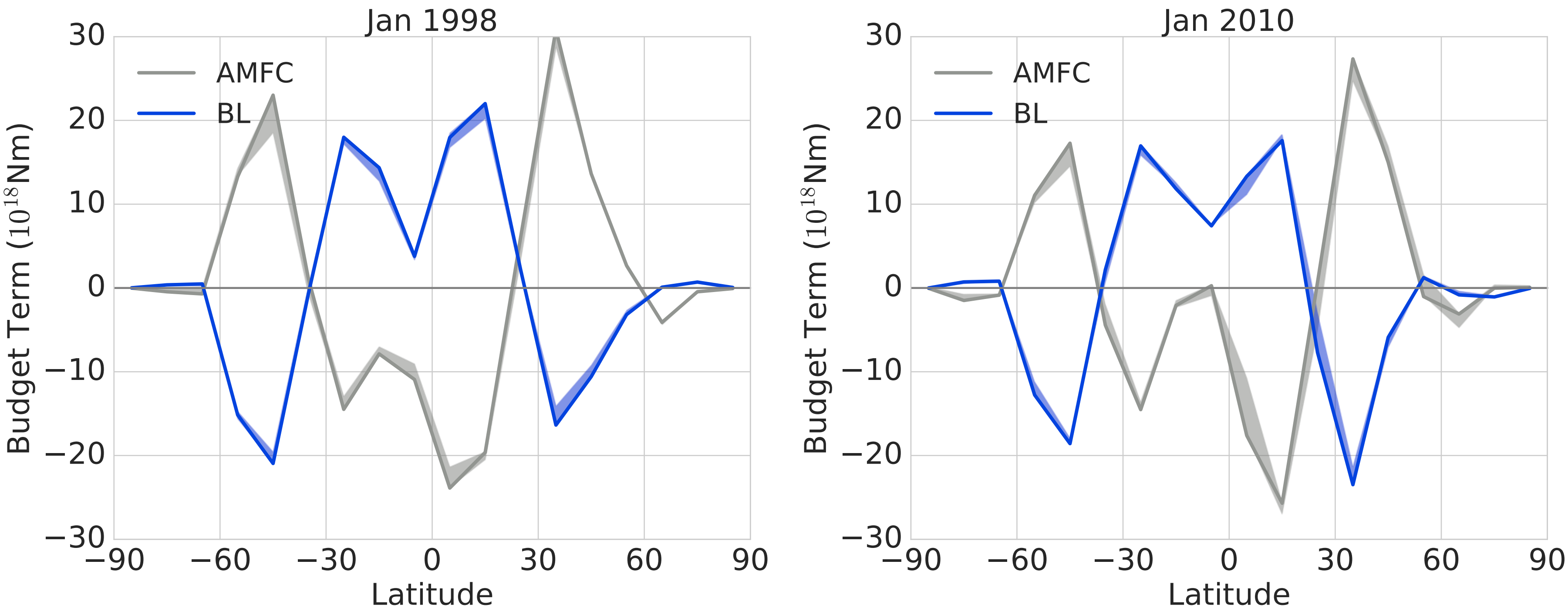




$$- \frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho dz\right]\cos\phi\right)}{\partial\phi}$$

AMFC is well constrained at three resolutions

Shading indicates range over model resolutions

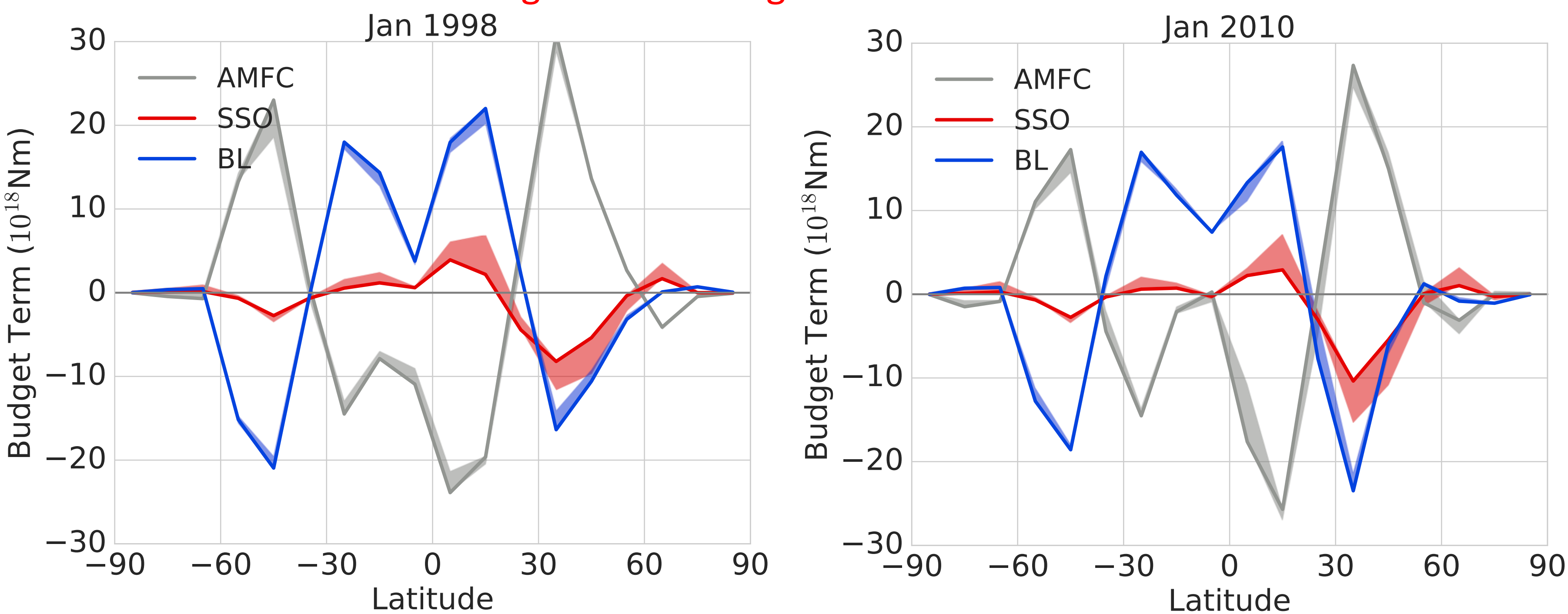


$$-\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho dz\right]\cos\phi\right)}{\partial\phi}$$

$$-F_{BL}$$

BL does not change much with resolution

Shading indicates range over model resolutions



$$- \frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} m v \rho \, dz\right]\cos\phi\right)}{\partial\phi}$$

$$- F_{BL} - F_{GWD} - F_{Blocking}$$

Large change in parameterized orographic torque with resolution

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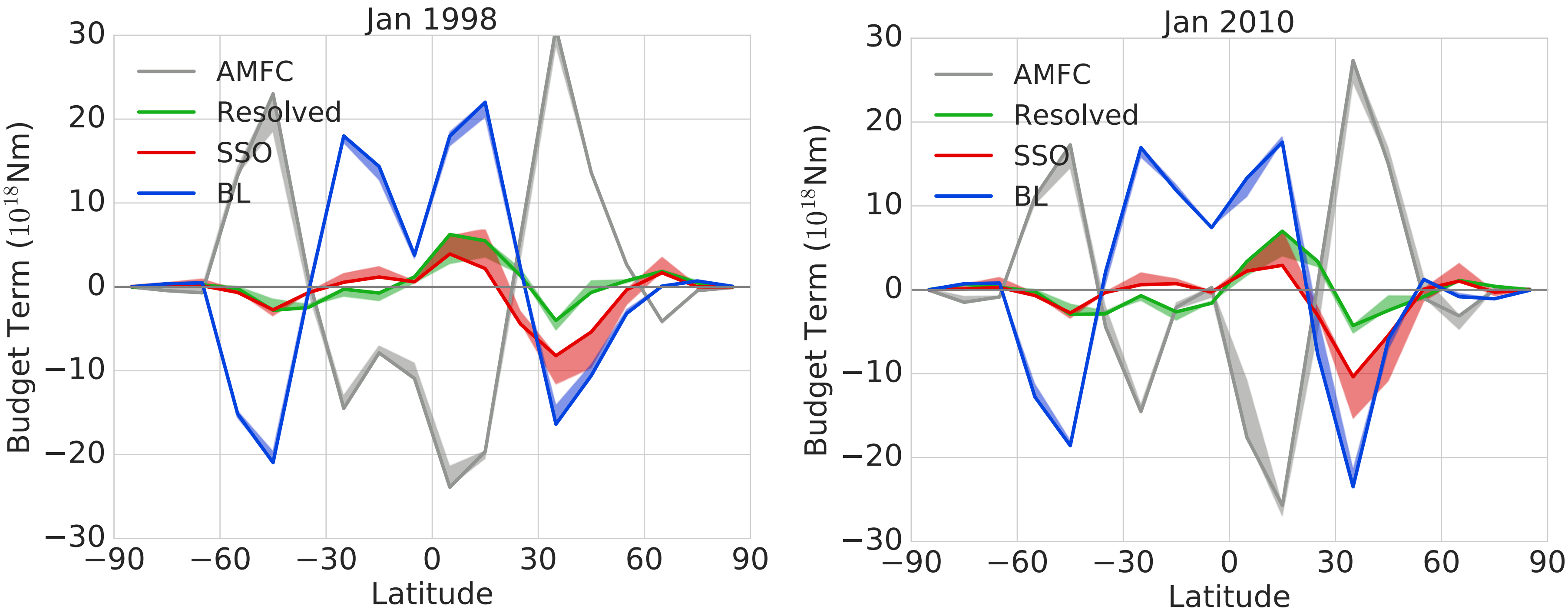
Shading indicates range over model resolutions

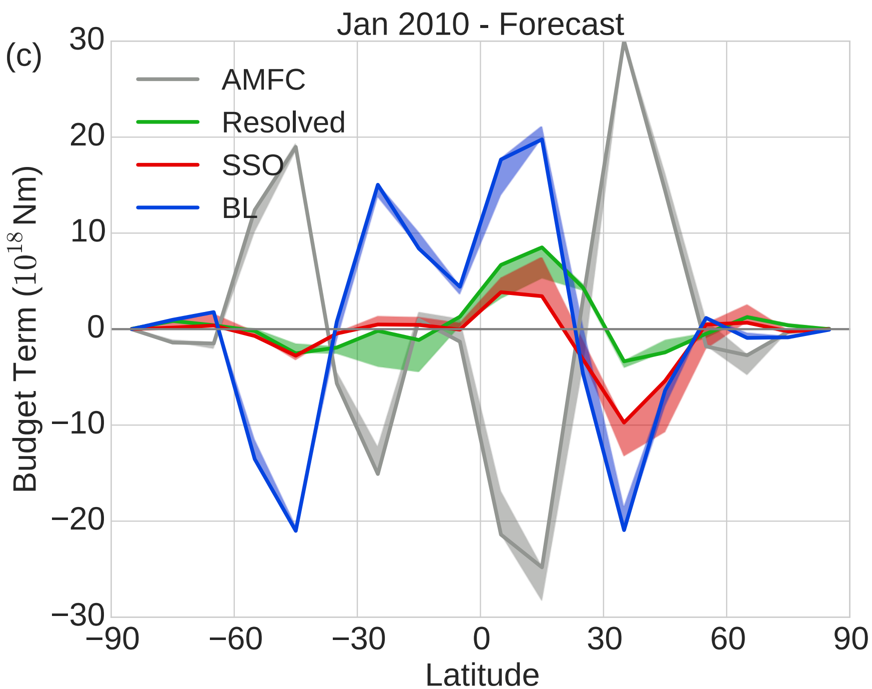


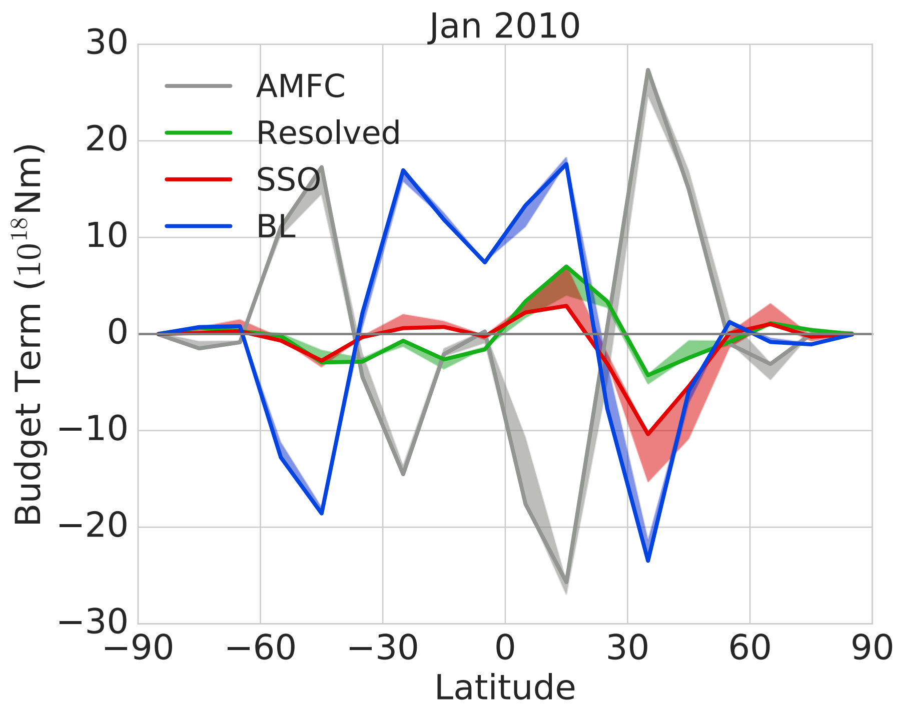
$$-\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho dz\right]\cos\phi\right)}{\partial\phi}$$

Little change in resolved orographic torque with resolution over 30N to 60N

$$-F_{BL} - F_{GWD} - F_{Blocking} - \left[p_0\frac{\partial z_0}{\partial\lambda}\right]$$

Shading indicates range over model resolutions

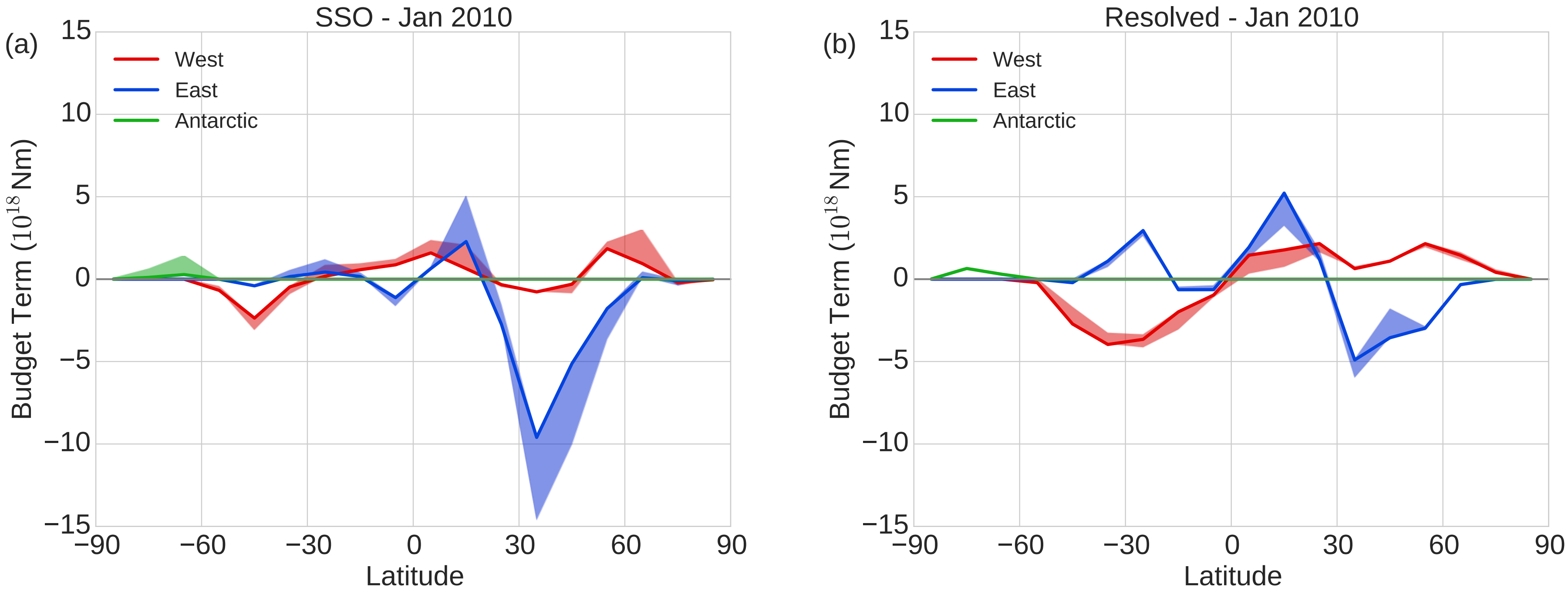




Good agreement with short-range forecasts

Hemispheric Contributions

Resolution sensitivity predominantly over Eastern Hemisphere



Shading indicates range over model resolutions

Nudging Tendencies

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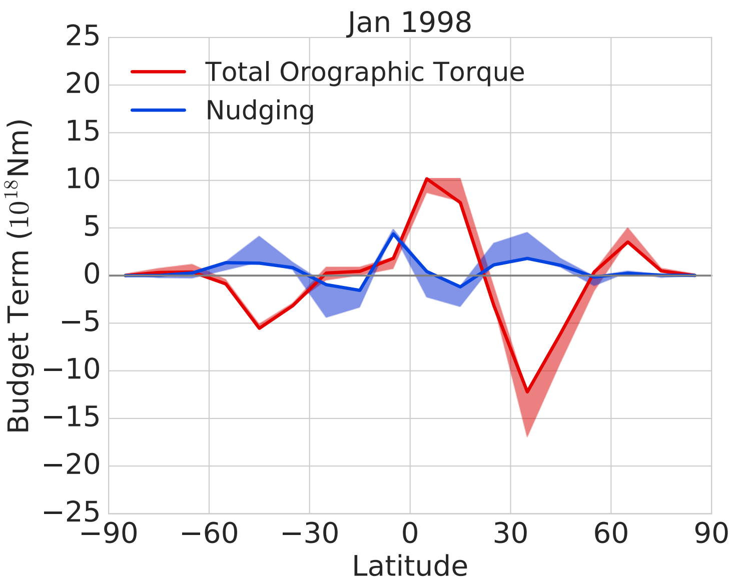

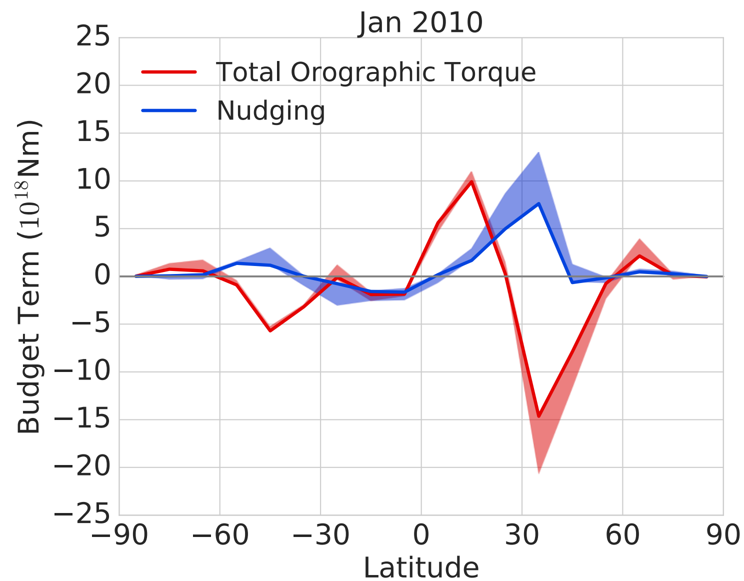

$$-\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} m v \rho \, dz\right]\cos\phi\right)}{\partial\phi}$$

Nudging tendencies indicate too much drag at lower resolutions

$$- F_{BL} - F_{GWD} - F_{Blocking} - \left[p_0 \frac{\partial z_0}{\partial \lambda}\right]$$

+ nudging tendencies (reflects model error)

Nudging Tendencies

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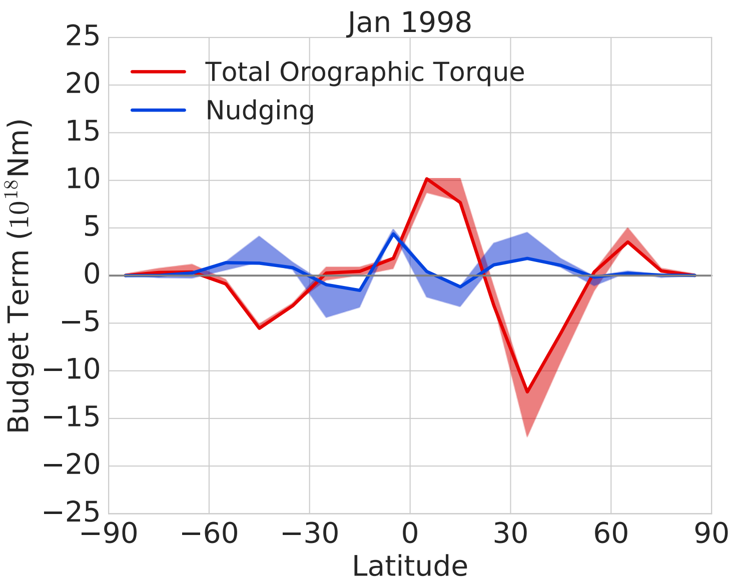

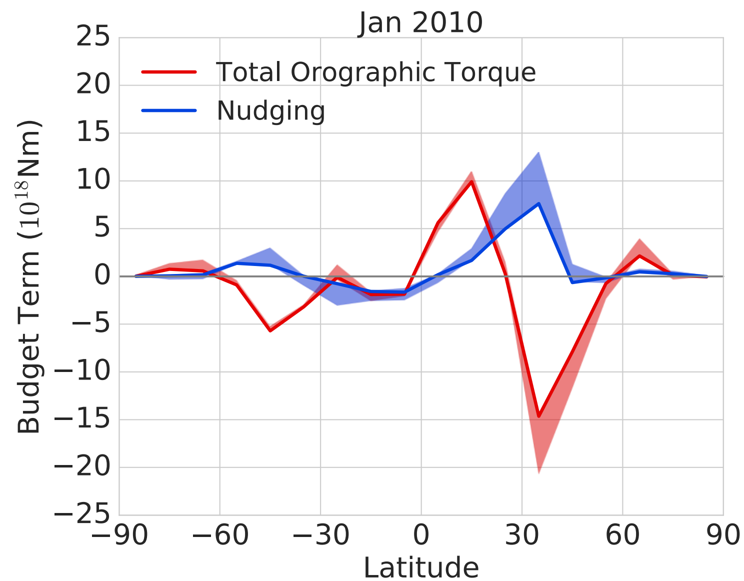

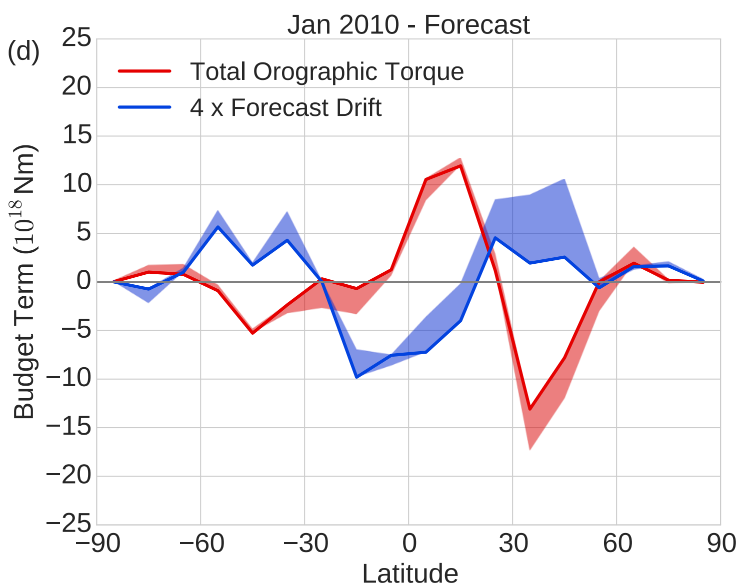

Drift in short range forecasts also indicate too much drag at lower resolutions

Nudging Tendencies

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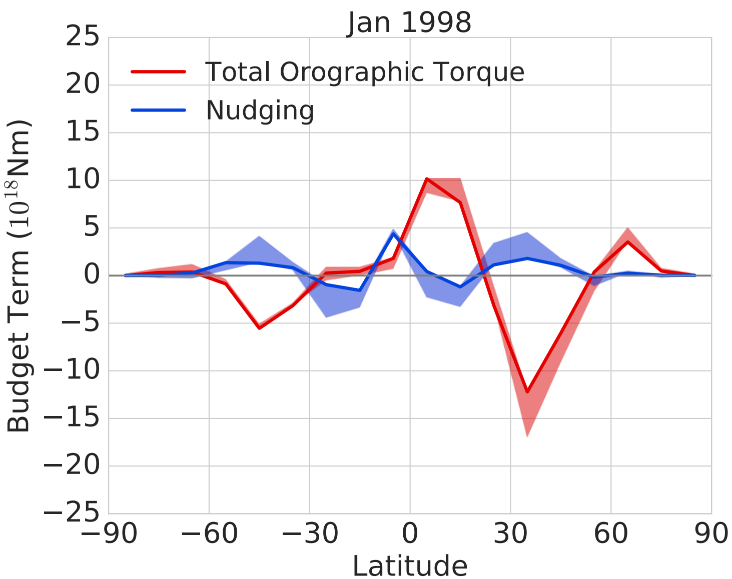

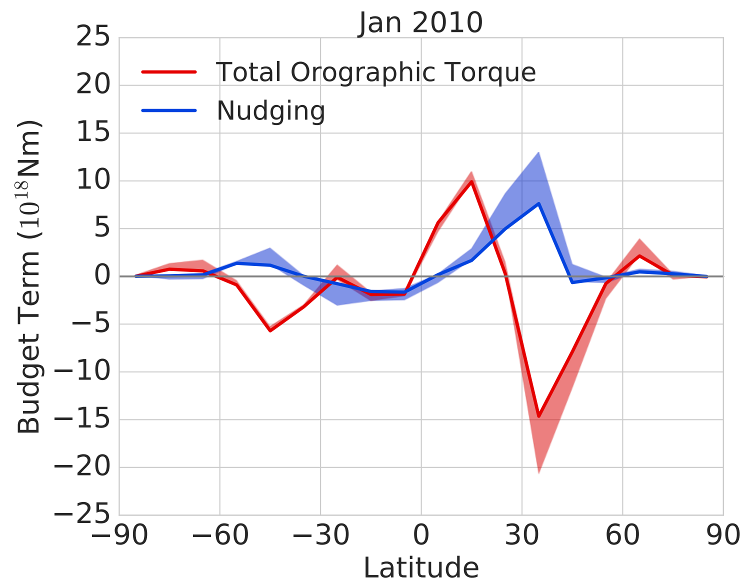

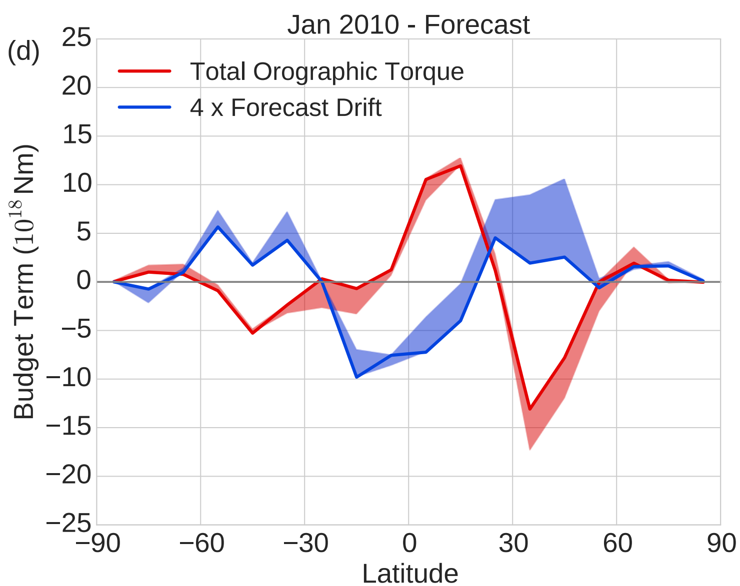

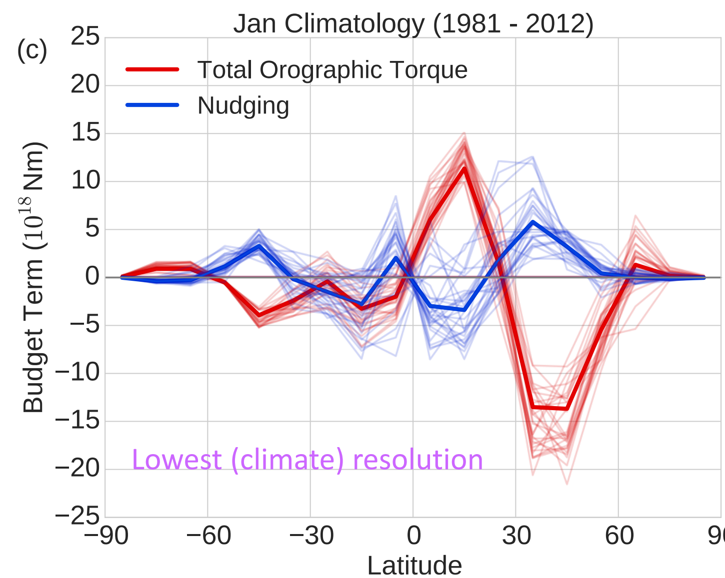

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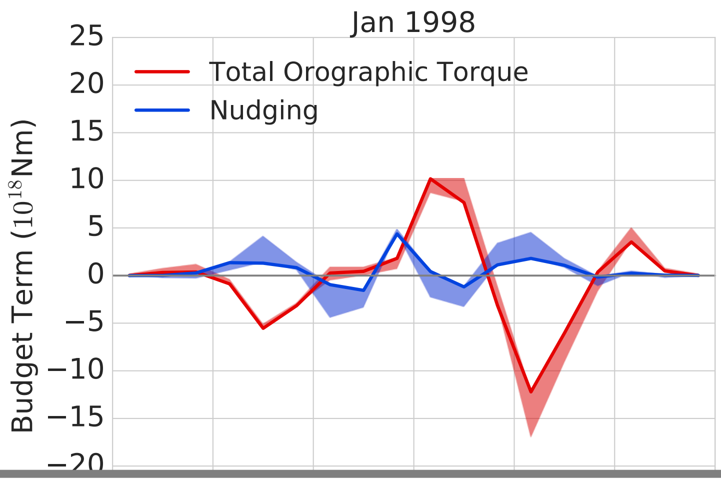

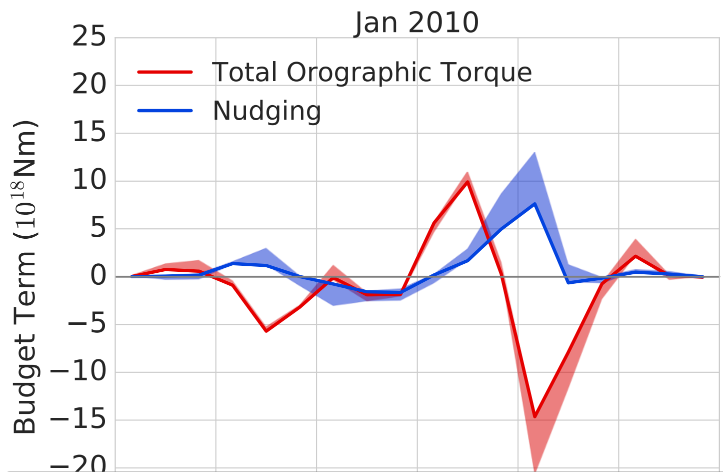

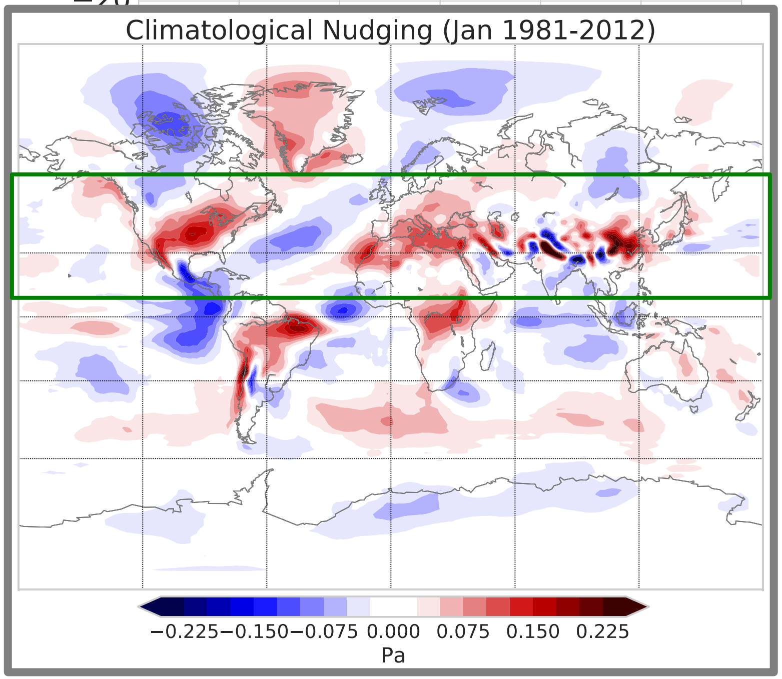

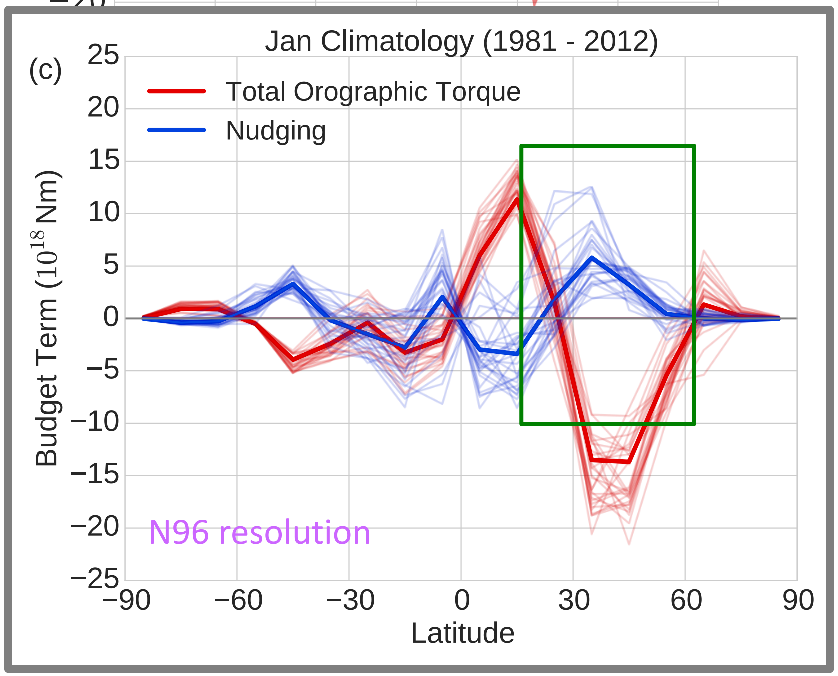

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Model Comparison

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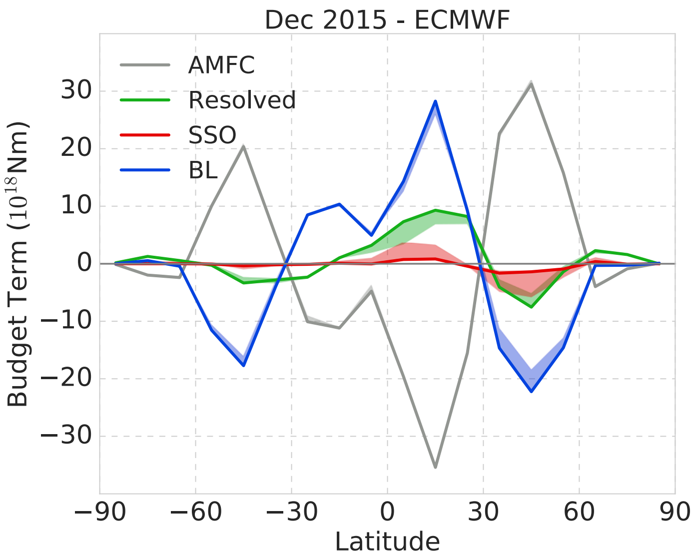
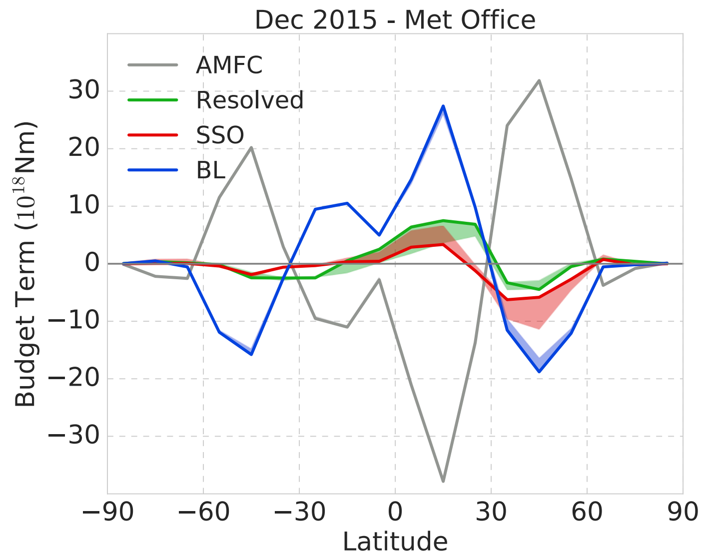
TL1279 vs TL159



N768 vs N96



(Thanks to Andy Elvidge, Irina Sandu and Sylvie Malardel)

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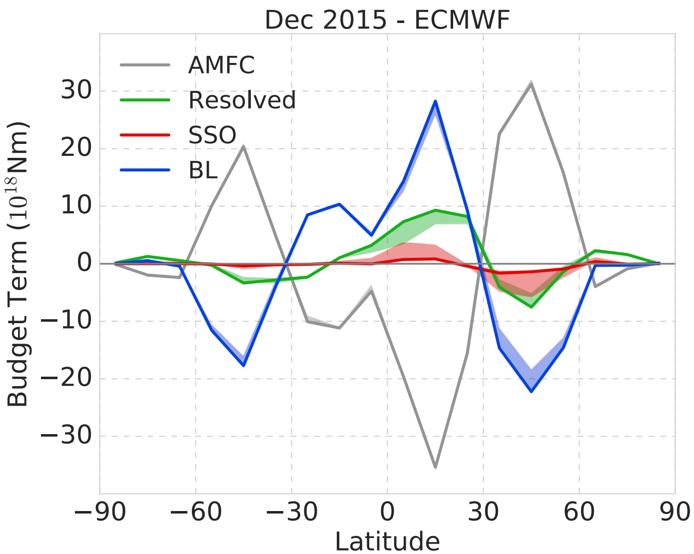
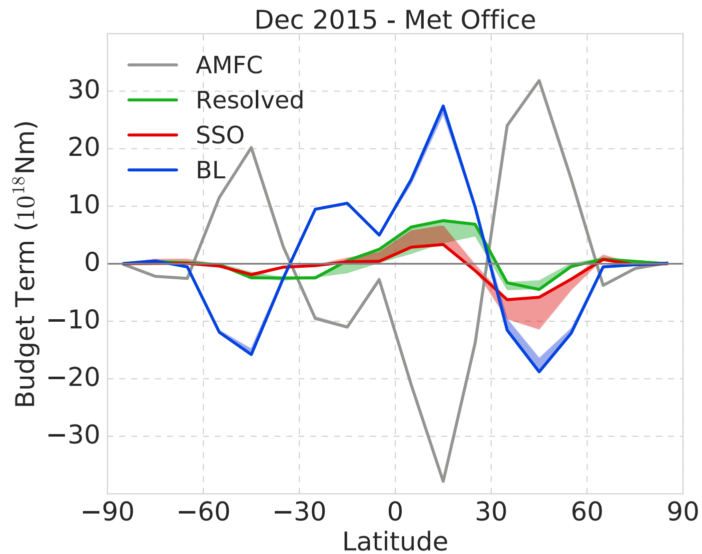
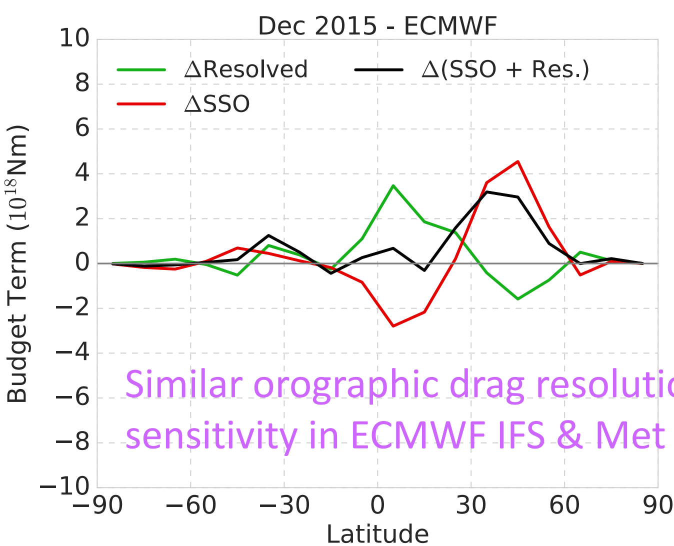
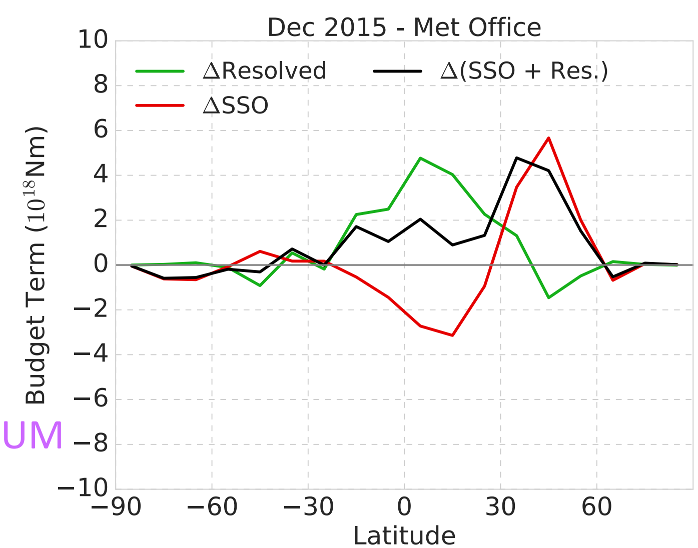




Δ = High Resolution – Low Resolution

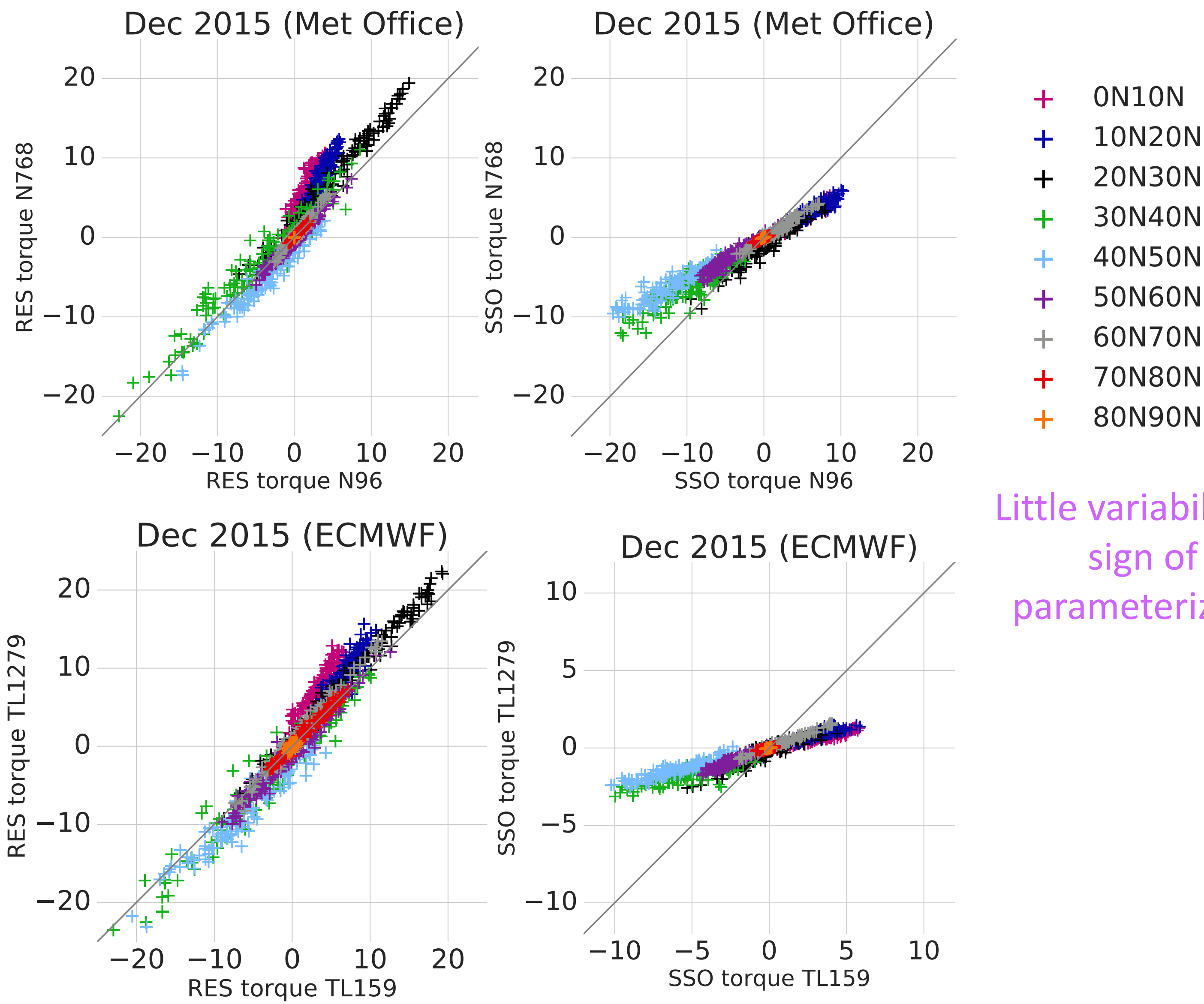




Similar orographic drag resolution sensitivity in ECMWF IFS & Met Office UM

Variability

Short range forecasts



Little variability in the sign of the parameterized drag

Sensitivity to parameterization

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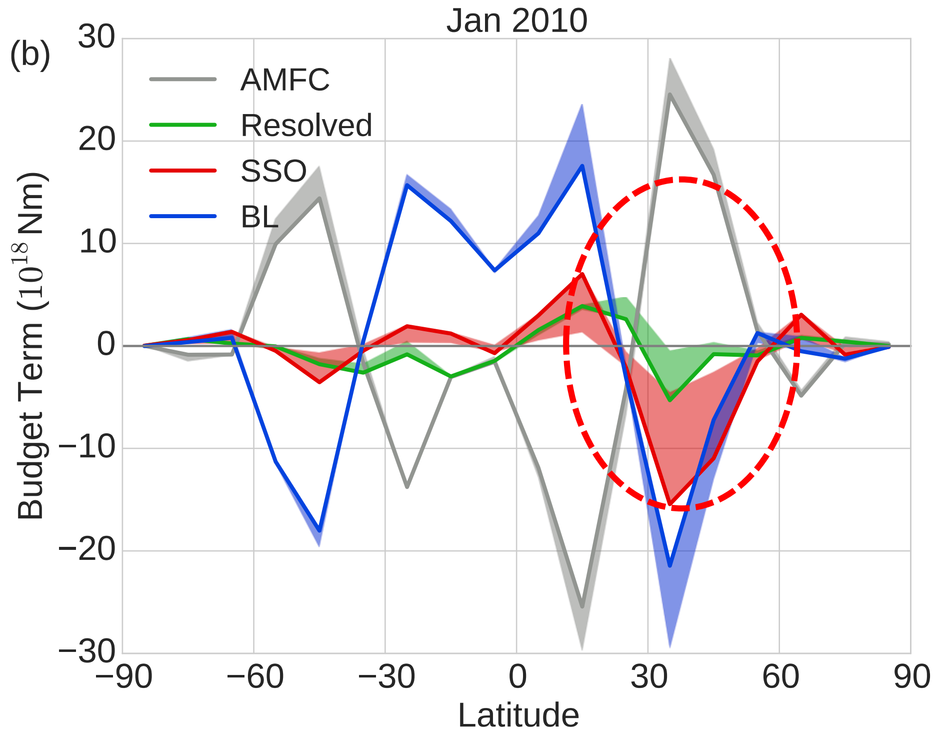

Unexpected decrease in resolved orographic torque when blocking is switched off

$$-\frac{1}{r\cos\phi}\frac{\partial\left(\left[\int_{z_0}^{\infty} mv\rho\, dz\right]\cos\phi\right)}{\partial\phi}$$

Solid line is CNTRL and shading indicates range over CNTRL and no blocking experiment

$$-F_{BL} - F_{GWD} - \cancel{F_{Blocking}} - \left[p_0\frac{\partial z_0}{\partial\lambda}\right]$$

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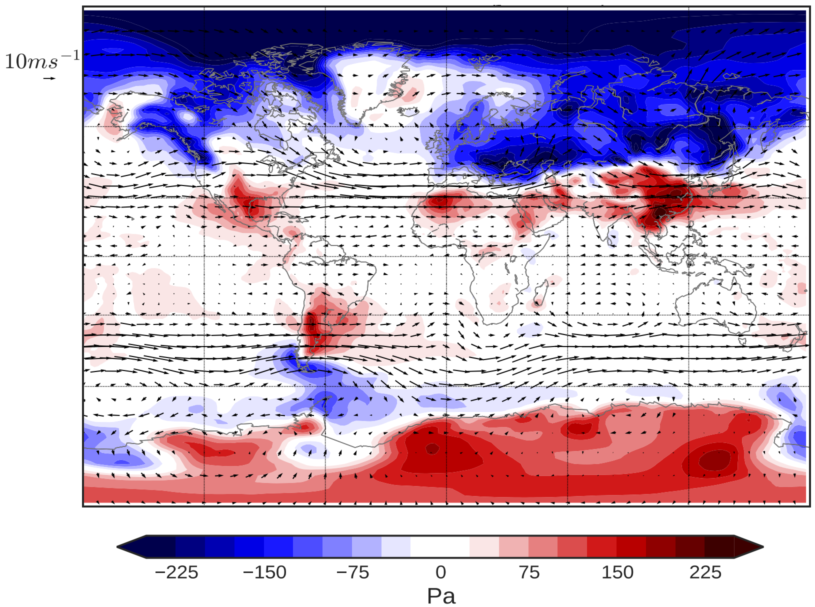
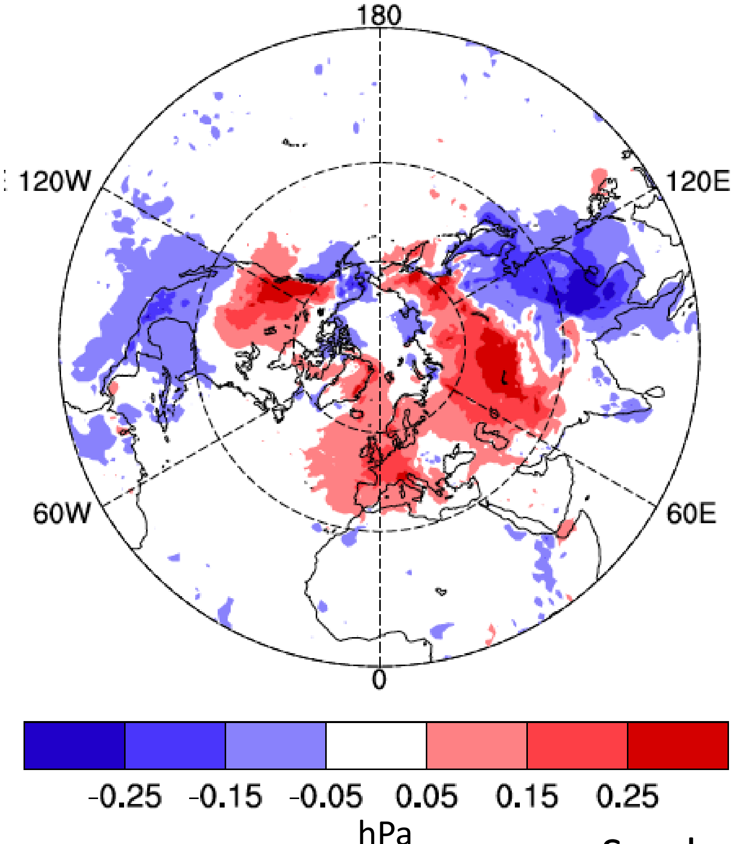
No blocking minus control (Nudged runs)

Δ Surface pressure (& 850hPa wind vectors)



Increased surface pressure on lee-ward side of Himalayas when blocking is switched off – consistent with reduction in resolved drag

High blocking minus control (24 hour lead time)



Sandu et al. 2016

Sensitivity to parameterization

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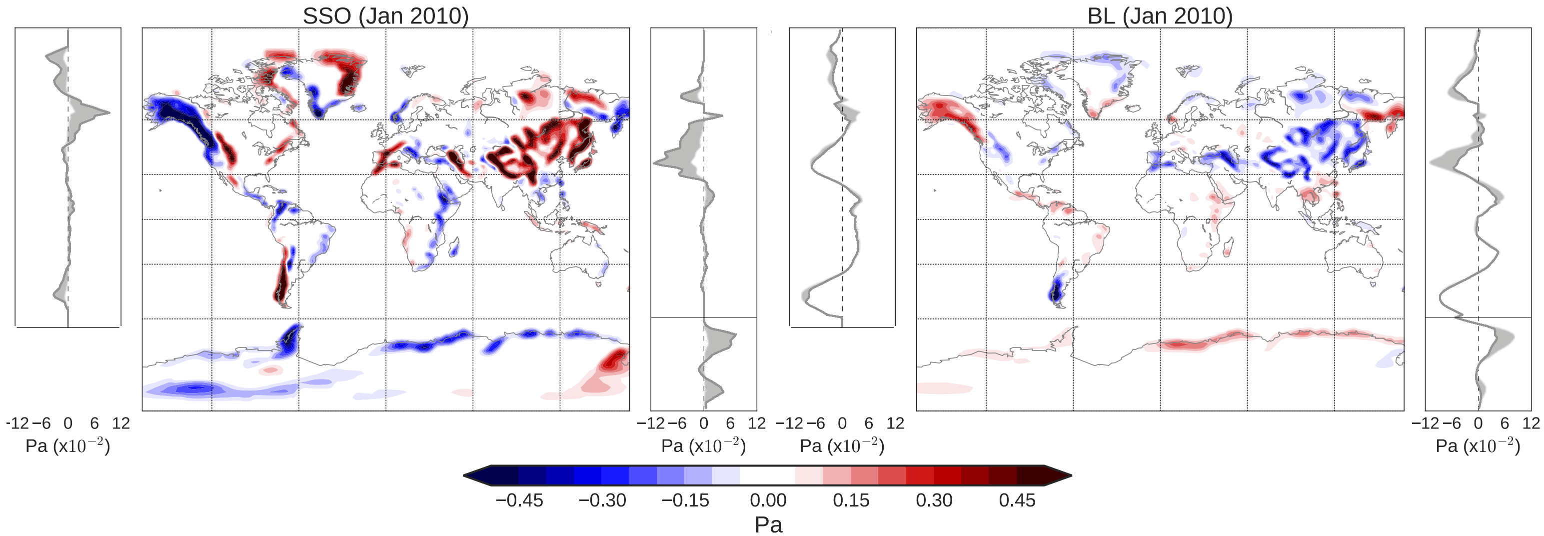
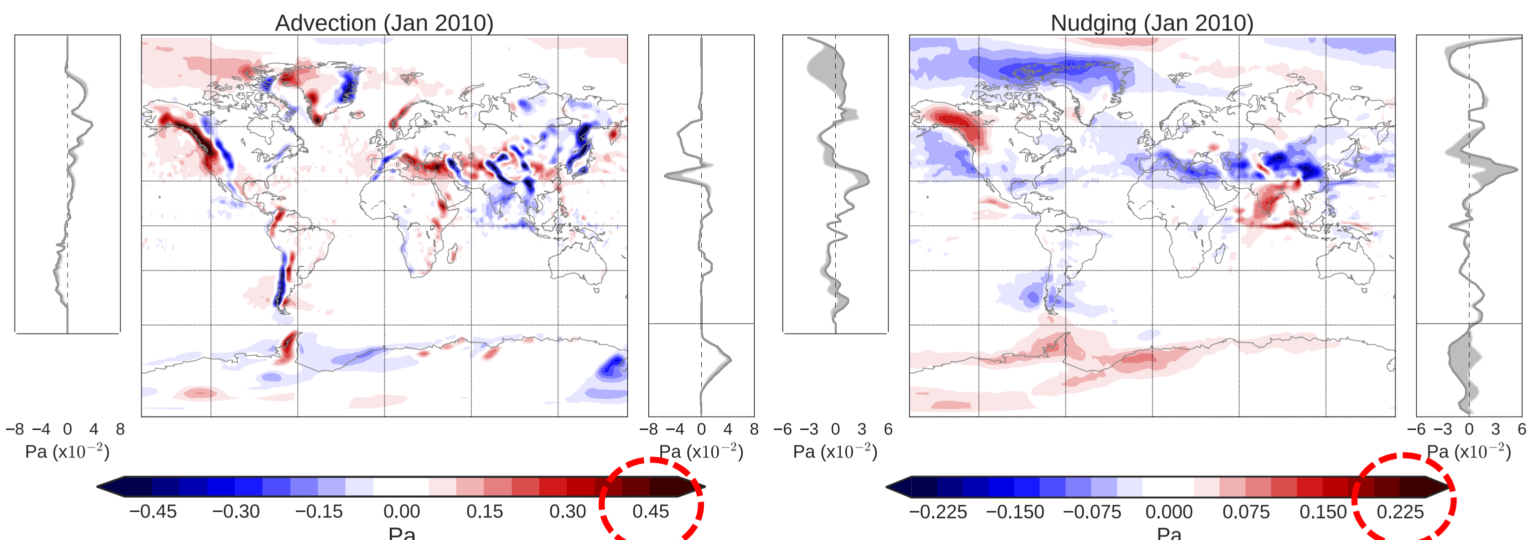
No blocking minus control



Change in nudging indicates change in total surface drag



Sensitivity to parameterization

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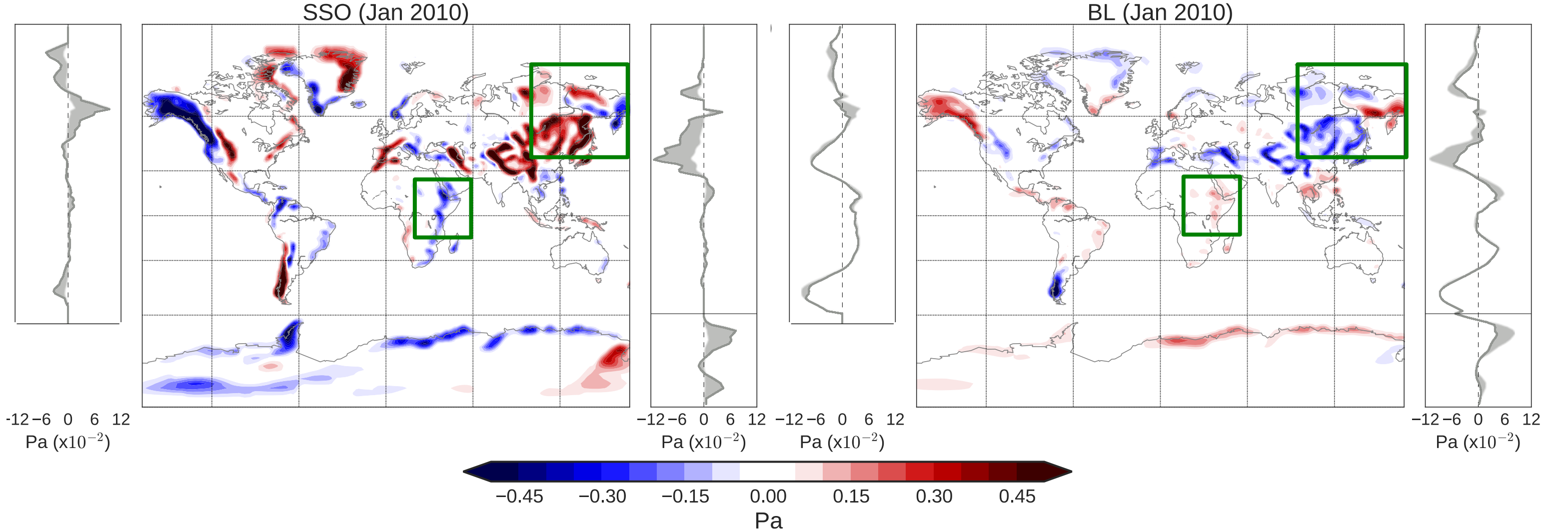
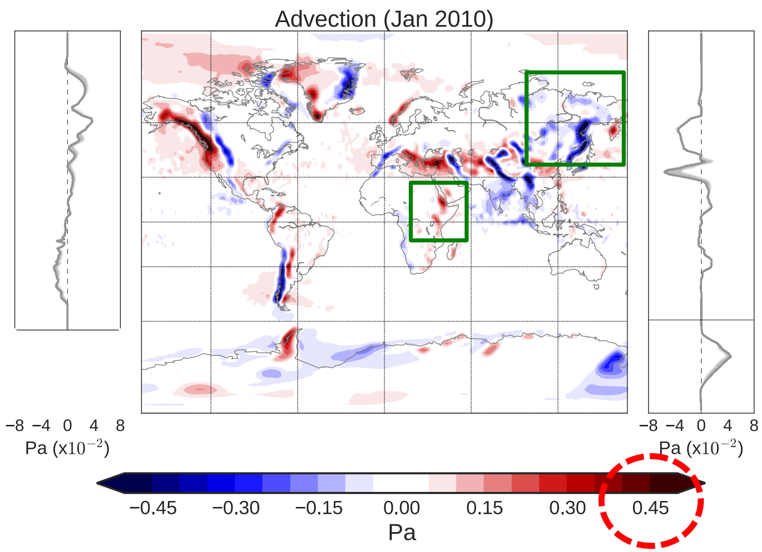
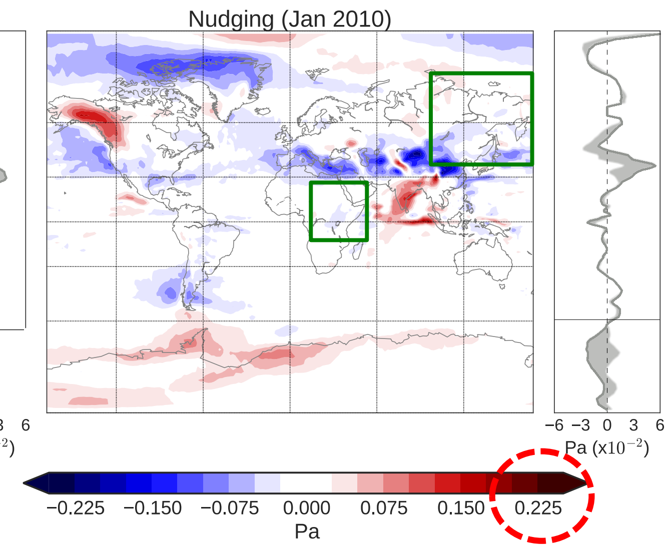
Partial compensation from BL



Partial compensation from resolved torque

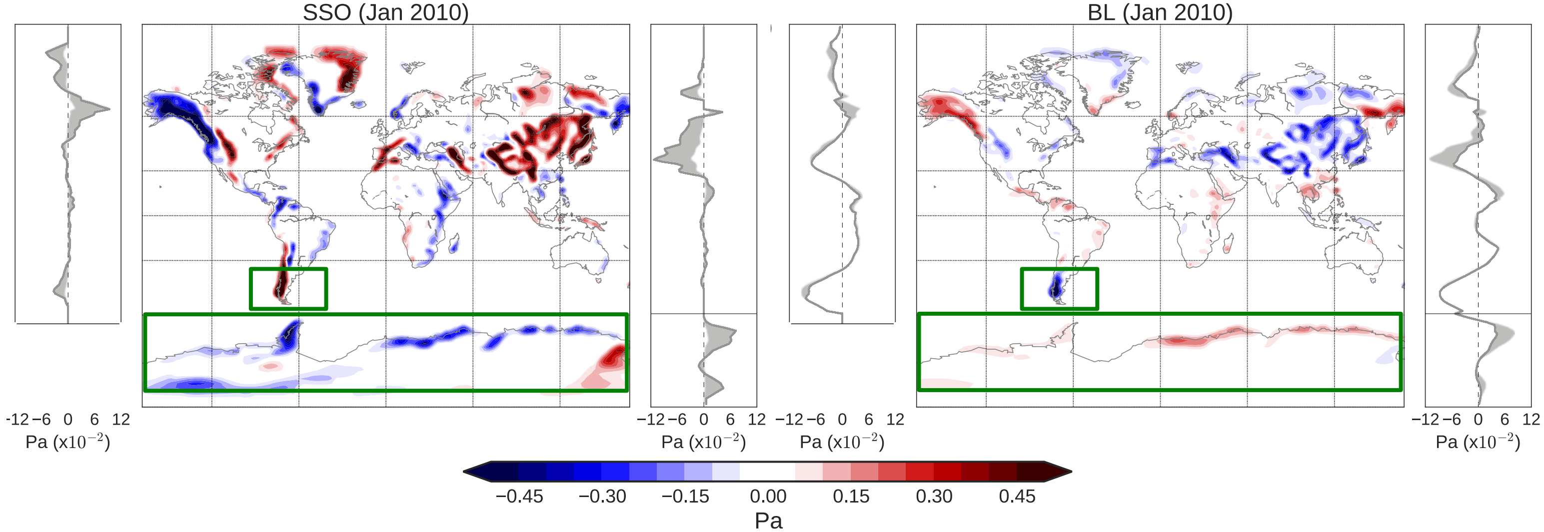


Little change in nudging

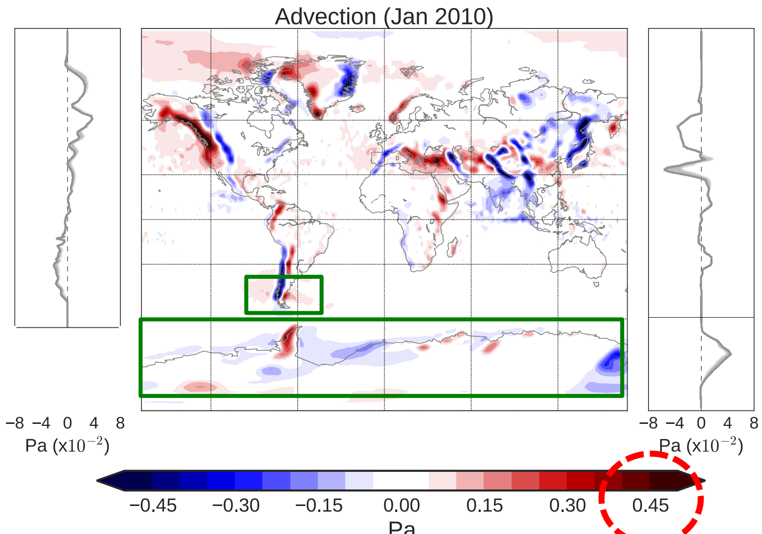


Sensitivity to parameterization

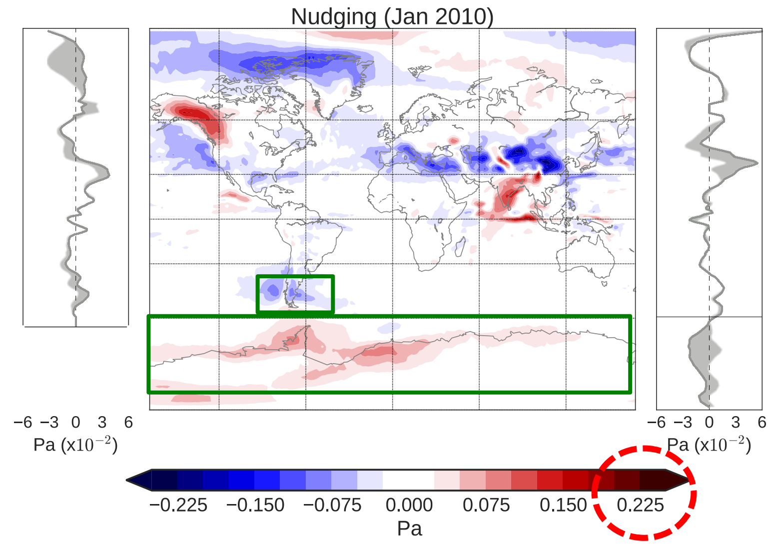
Weak compensation from BL



Weak compensation from resolved torque

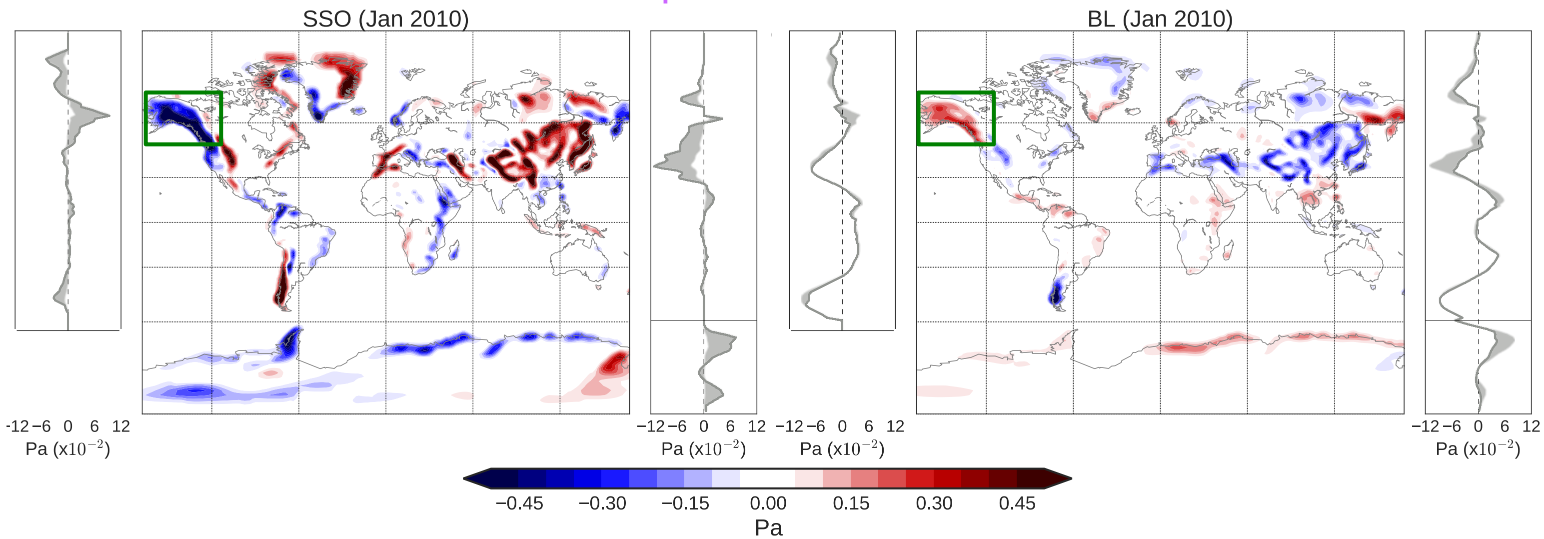


Decrease in nudging



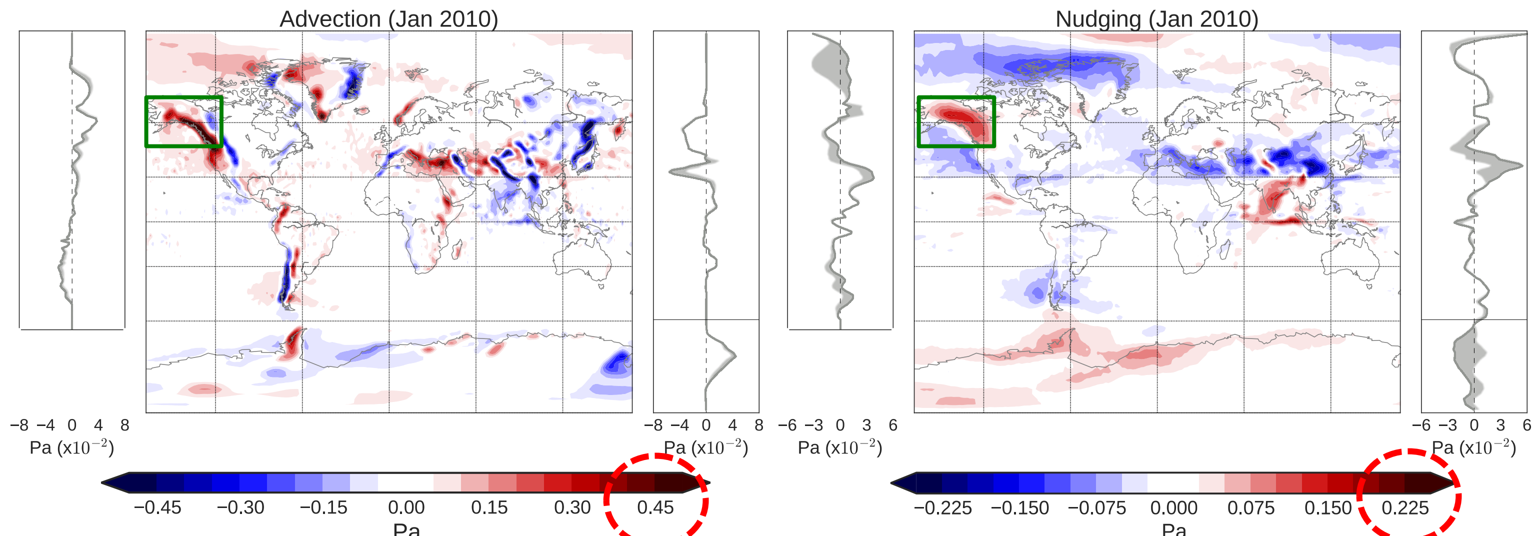
Sensitivity to parameterization

Weak compensation from BL



Weak compensation from resolved torque

Increase in nudging



Sensitivity to parameterization

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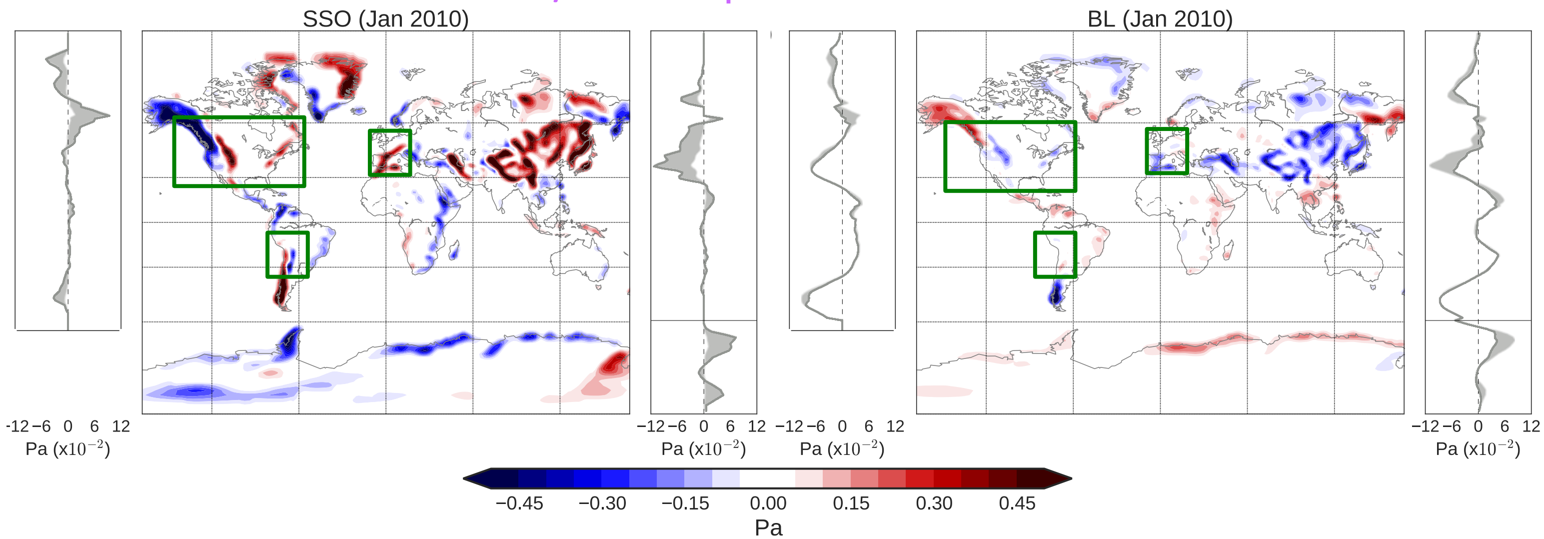
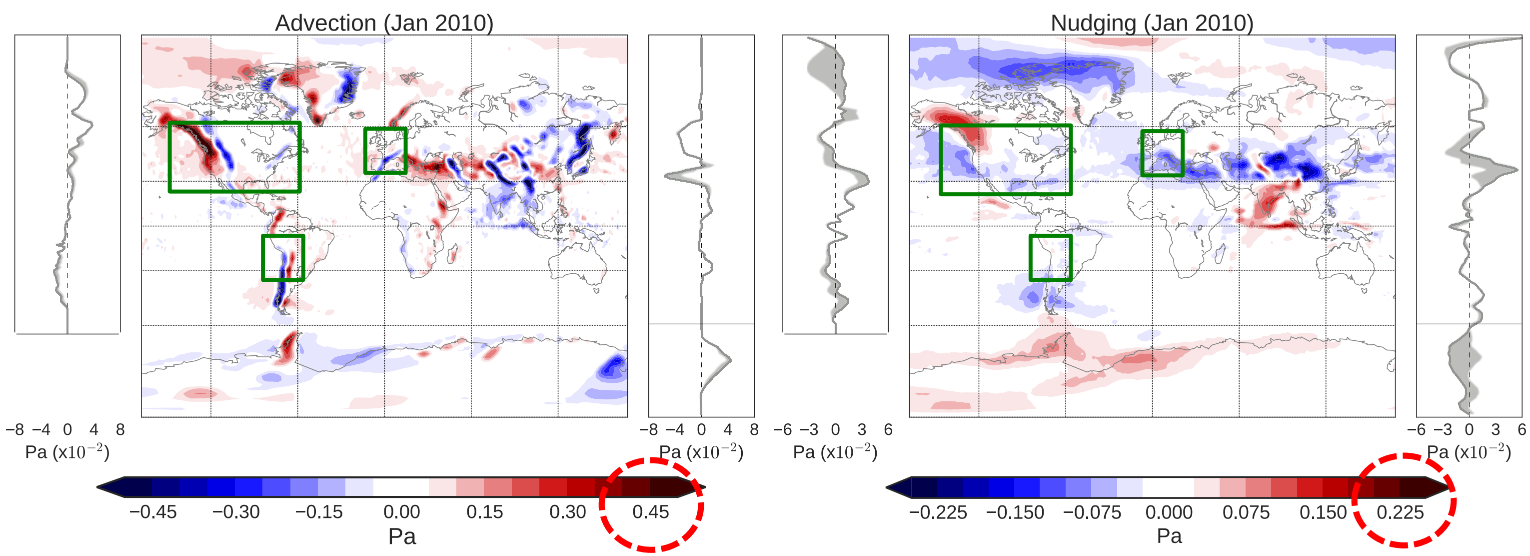
Little/No compensation from BL



Compensation from resolved torque

Little change in nudging



Sensitivity to parameterization

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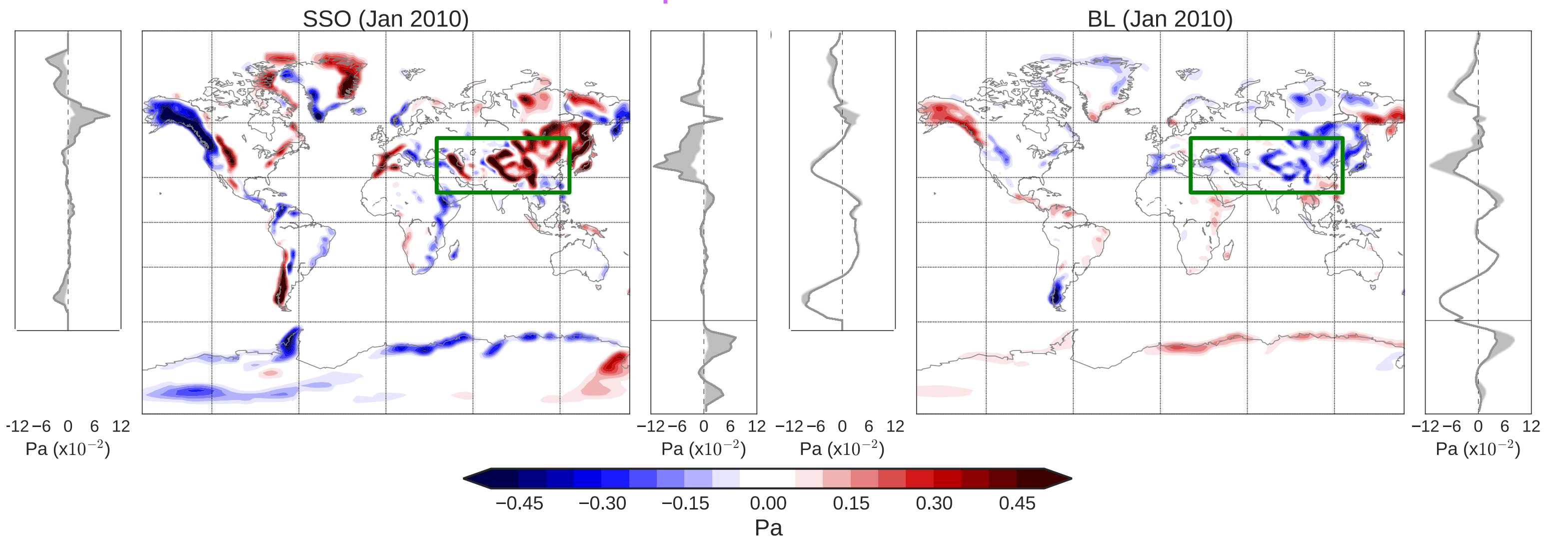
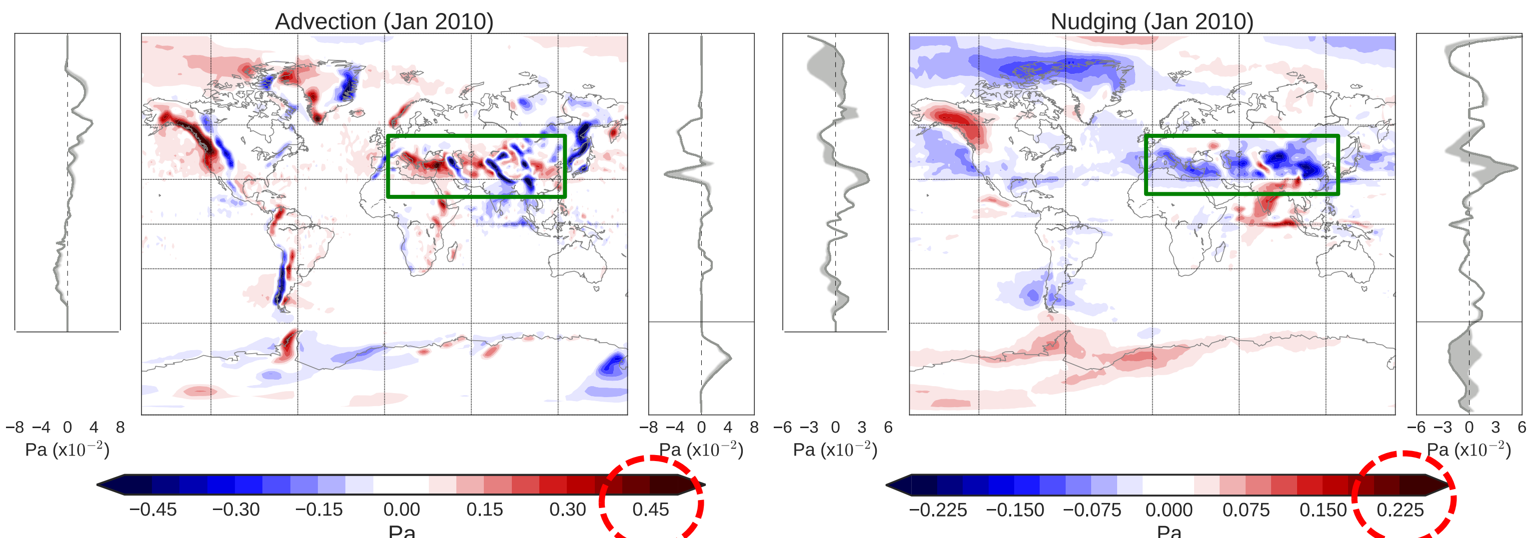
Weak compensation from BL



Reduction in resolved torque

Decrease/change of sign in nudging



Summary

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- Total orographic drag is dependent on resolution: circulation is non-robust to changes in resolution – particularly over NH mid-latitudes
- Regional dependence of parameterization formulation: retuning of schemes for subjectively desirable features of circulation is not globally consistent – can lead to model discrepancies