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Stratosphere-troposphere coupling: The impact of model configuration on extratropical wave coupling

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Introduction

Planetary-scale waves play an important role in determining the climate of the winter hemisphere. They are well known to be one of the dominant modes of coupling between the stratosphere and troposphere during winter because of their significant vertical propagation. A proper representation of the structure and propagation characteristics of planetary waves is required for the accurate modeling of the stratosphere-troposphere coupled system as well as for the climate system as a whole. Here we examine the impact of model configuration on planetary waves in Northern Hemisphere high winter (January, February and March). We focus on the impact of model lid height using a series of Canadian Middle Atmosphere Model (CMAM) simulations (high-lid model labeled HIGHC and two low-lid models with and without conservation of parameterized gravity wave momentum flux labeled LOWC and LOWN, respectively) that were previously analyzed by Shaw et al. (2009) and Shaw and Perlwitz (2010) along with the available IPCC CMIP5 AMIP simulations, which include low and high lid models. All of the models are compared to the ERA-Interim data set (Dee et al. 2011).

Stratospheric polar vortex

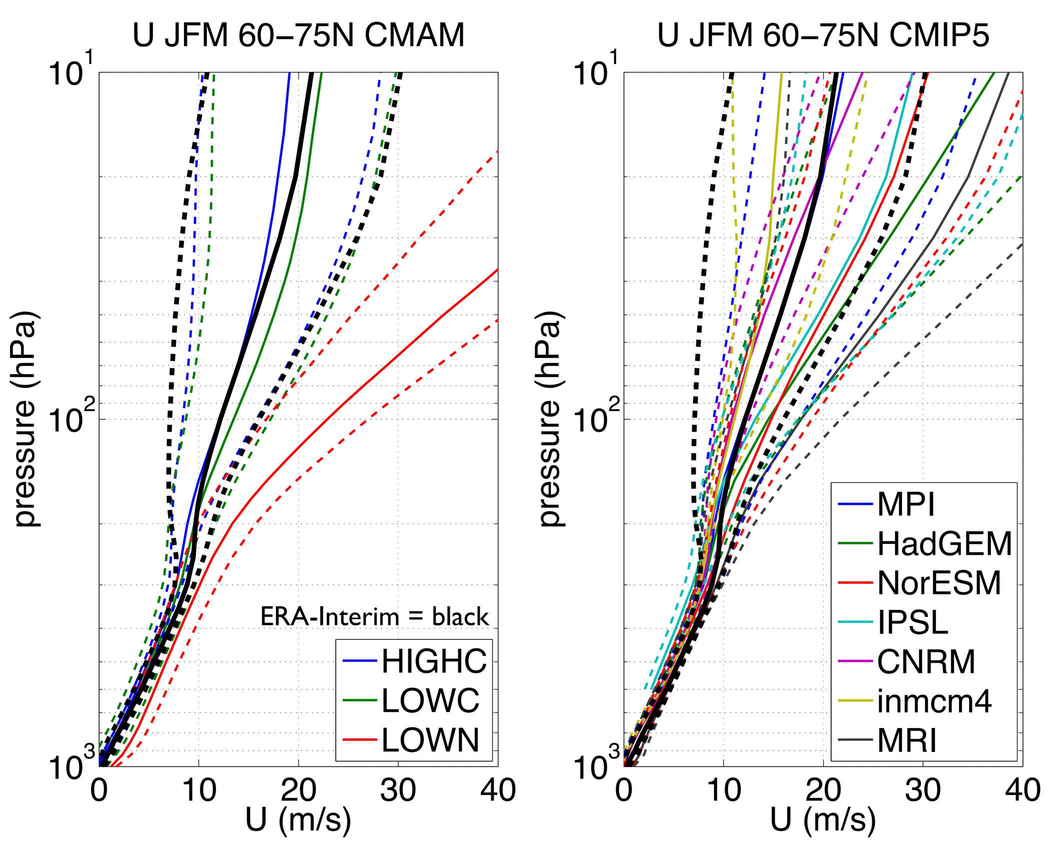

Figure 1: Zonal-mean zonal wind in JFM averaged from 60-75N (solid) and composites of years that exceed +/- 0.5 standard deviation at 30 hPa (dashed)

Vortex strength and variability depends sensitively on the model lid height and conservation of momentum (HIGHC vs LOWC vs LOWN)

The mean vortex in 4 out of 7 CMIP5 models is too strong

CMIP5 models display a large range of vortex variability

Note the vortex strength is often tuned to avoid excessive wind speeds near the model lid (see LOWN) using artificial dissipation, e.g. Rayleigh drag, which does not conserve momentum

Planetary wave amplitude

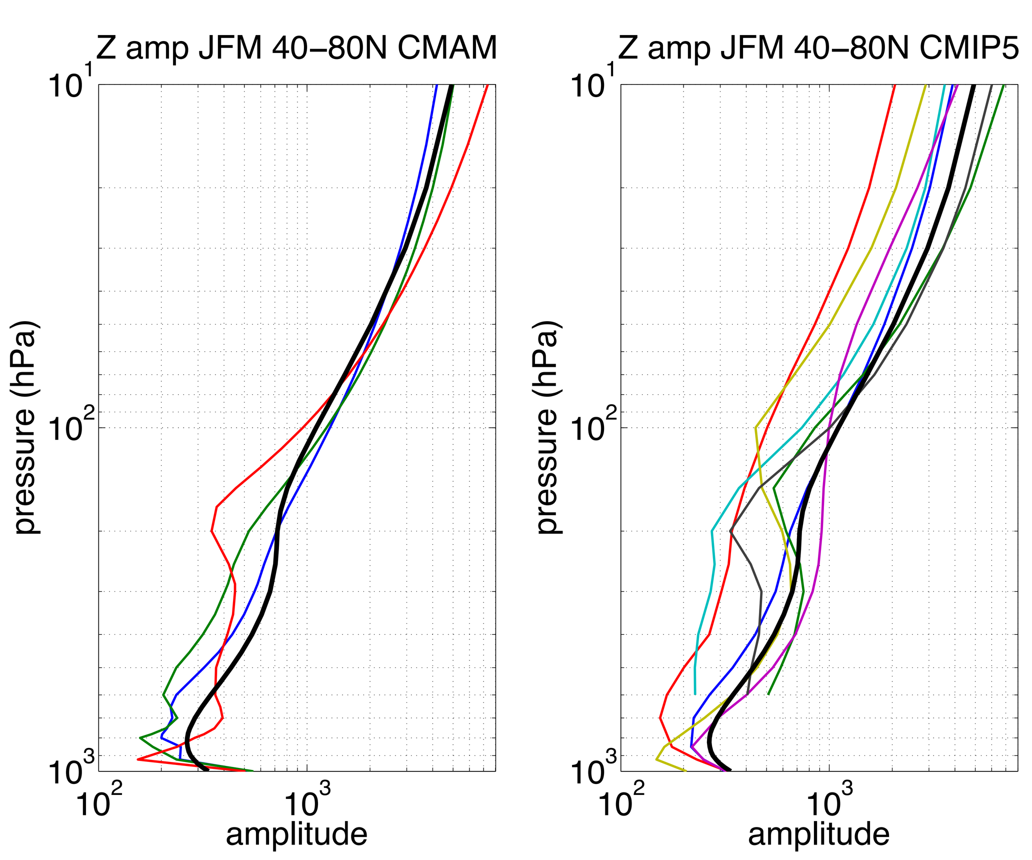

Figure 2: Wave-1 amplitude during JFM averaged from 40-80N

Wave-1 amplitude increases significantly from the troposphere to the stratosphere

Wave-1 amplitude is very sensitive to the treatment of the upper boundary (LOWC vs LOWN)

In general, a strong polar vortex is associated with increased wave amplitude

CMIP5 models display a large range of wave-1 amplitudes in the troposphere and stratosphere

Planetary wave phase

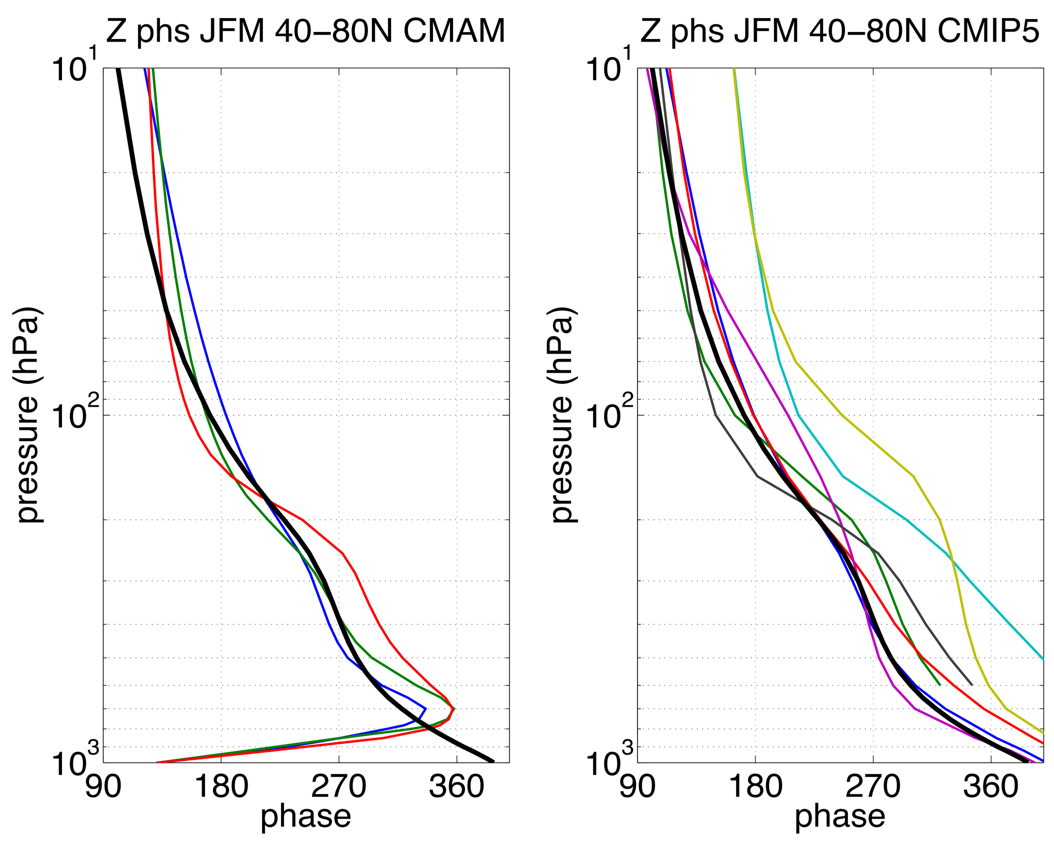

Figure 3: Wave-1 phase during JFM averaged from 40-80N

Wave-1 displays a westward phase tilt with height indicating upward wave propagation from the troposphere to stratosphere

Decreased westward phase tilt with height between 100 to 10 hPa in LOWN associated with both increased wave amplitude and increased vortex strength, which in combination are signatures of wave reflection

Several of the low-lid CMIP5 models also have a decreased phase tilt with height in the stratosphere

Planetary wave fluxes -- 100 hPa

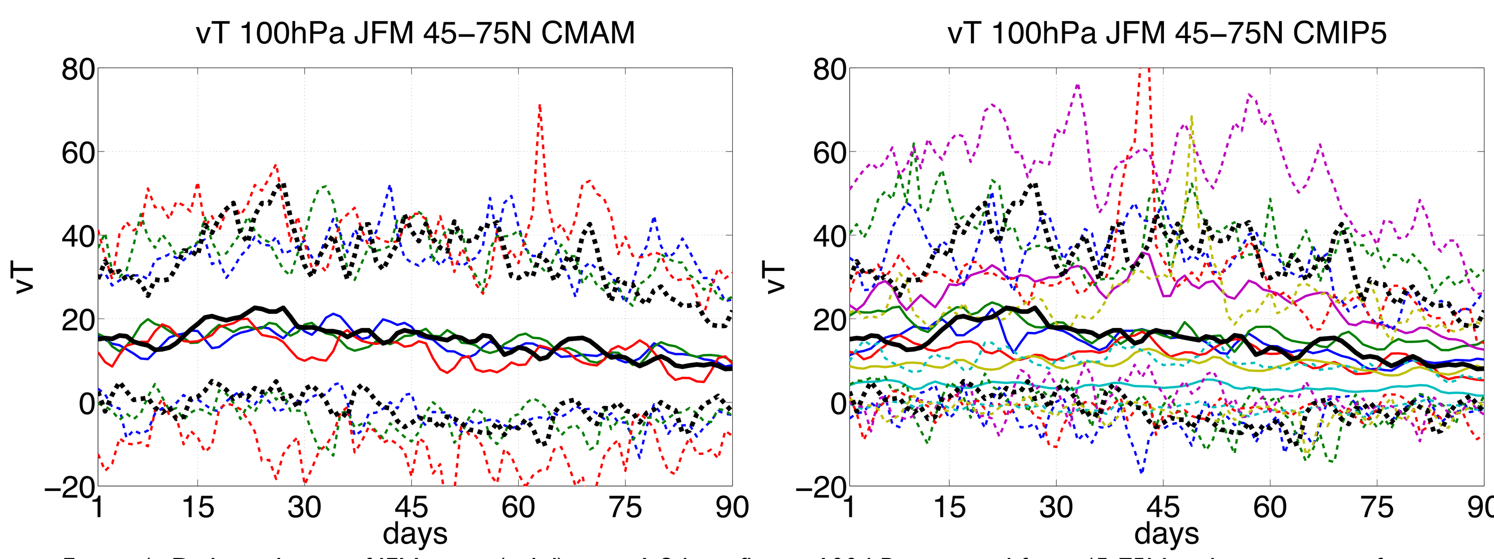

Figure 4: Daily evolution of JFM mean (solid) wave 1-3 heat flux at 100 hPa averaged from 45-75N and composites of years that exceed +/- 1 standard deviation (dashed)

- Most models capture the seasonal decrease in heat flux from January to March
- High-lid models are in good agreement with ERA-Interim, low-lid models are not robust in terms of their agreement with reanalysis

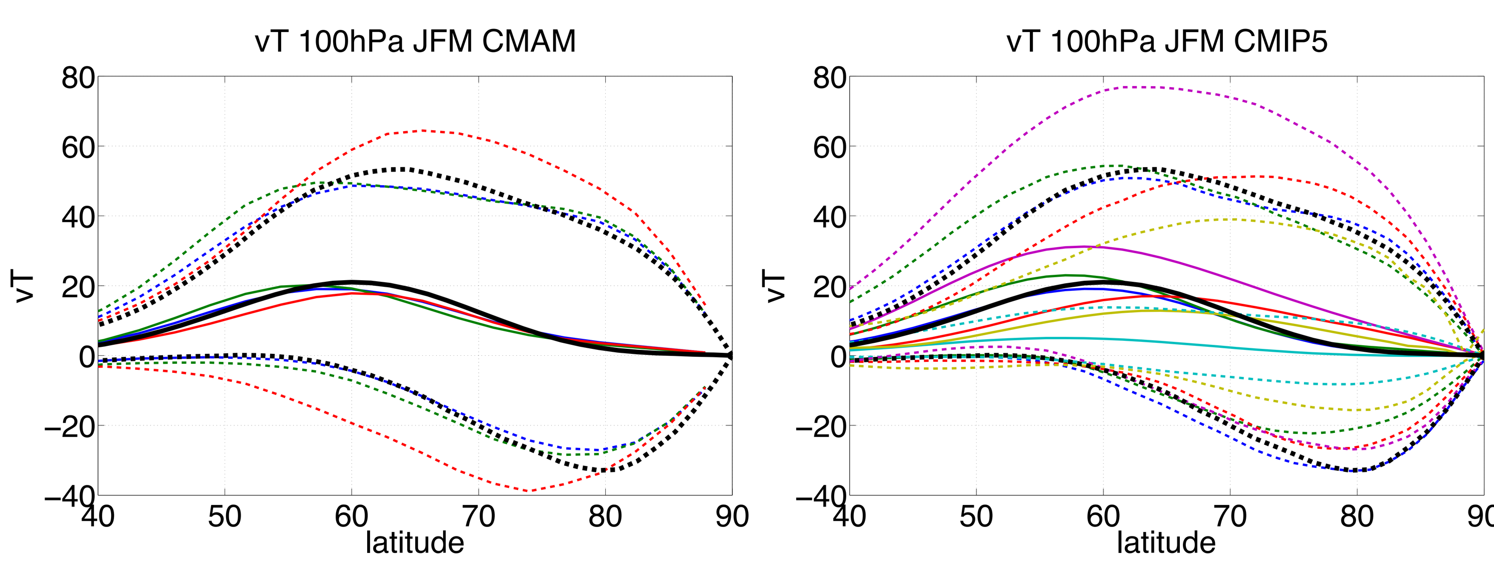

Figure 5: JFM mean (solid) wave 1-3 heat flux at 100 hPa and composites of years that exceed +/- 1 standard deviation (dashed)

- CMAM models capture mean heat flux maximum at 60N, however the position of the maximum in the CMIP5 models varies considerably
- High-lid models capture significant variability of positive and negative heat flux values

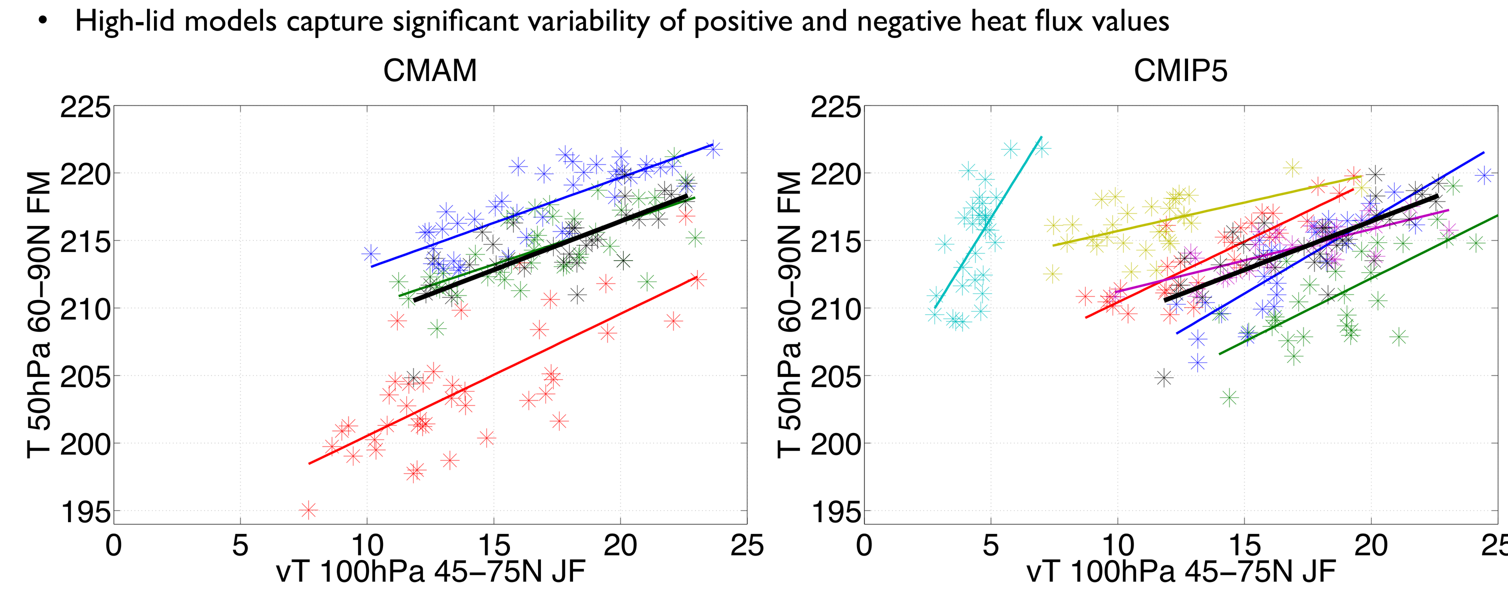

Figure 6: Polar cap averaged temperature at 50 hPa during February-March versus wave 1-7 heat flux at 100 hPa during January-February averaged from 45-75N

- HIGHC and LOWC CMAM models capture the relationship between heat flux and polar-cap temperature
- CMIP5 models are either too cold or too warm in the absence of planetary wave heat flux (y-intercept)
- Efficiency of heat flux at driving polar temperatures (slope) varies across the models

Planetary wave fluxes -- 10 hPa

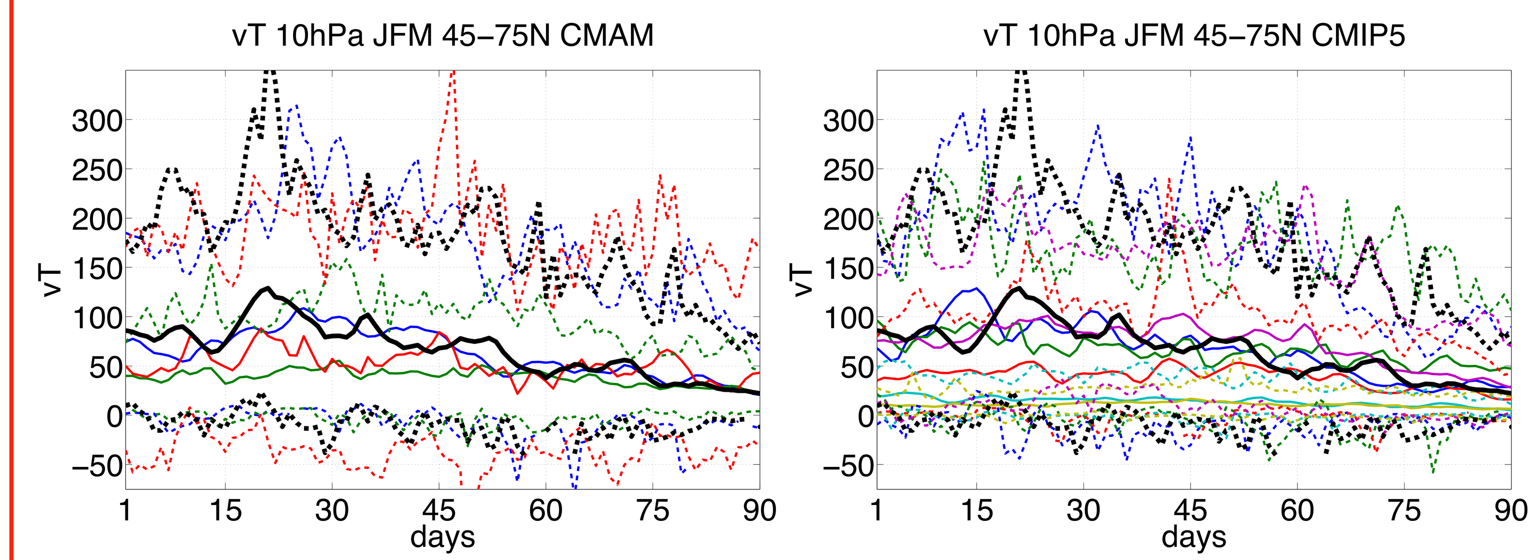

Figure 7: Daily evolution of JFM mean (solid) wave 1-3 heat flux at 10 hPa averaged from 45-75N and composites of years that exceed +/- 1 standard deviation (dashed)

- Most models capture the seasonal decrease in heat flux from January to March
- High-lid models are in good agreement with ERA-Interim, low-lid models generally underestimate the heat flux at 10 hPa

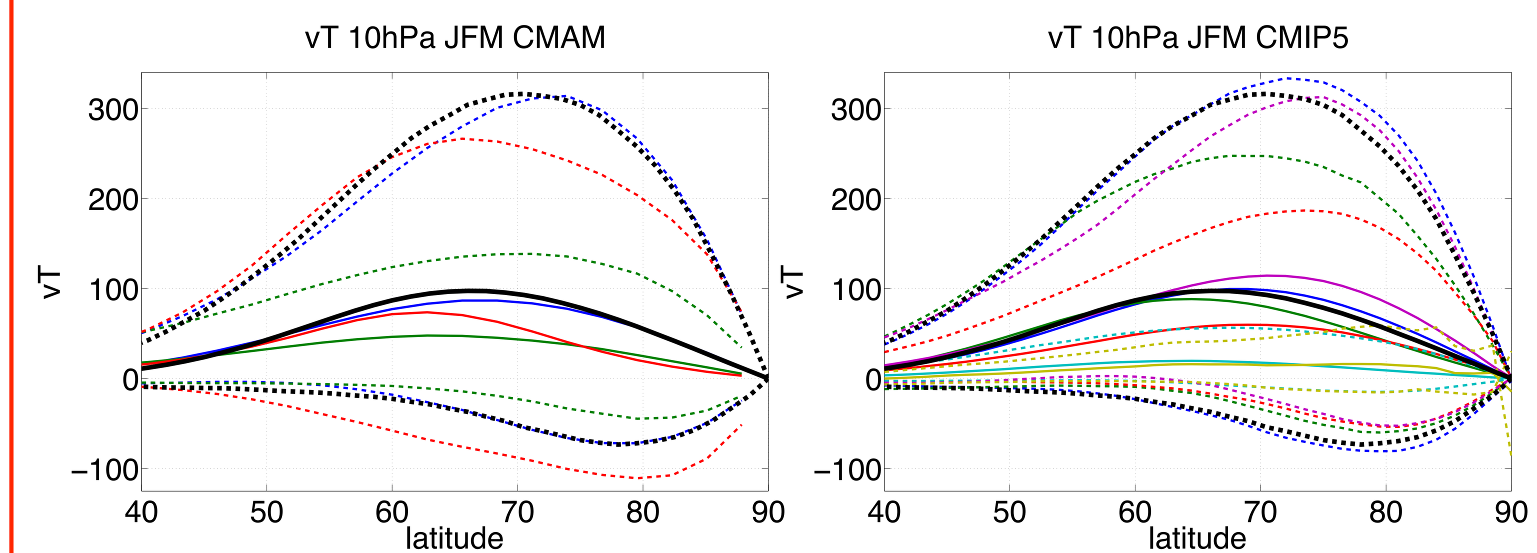

Figure 8: JFM mean (solid) wave 1-3 heat flux at 10 hPa and composites of years that exceed +/- 1 standard deviation (dashed)

- Significant decrease in the number of low-lid models that capture mean and variability of heat flux at 10 hPa as compared to 100 hPa

Upward and Downward wave coupling

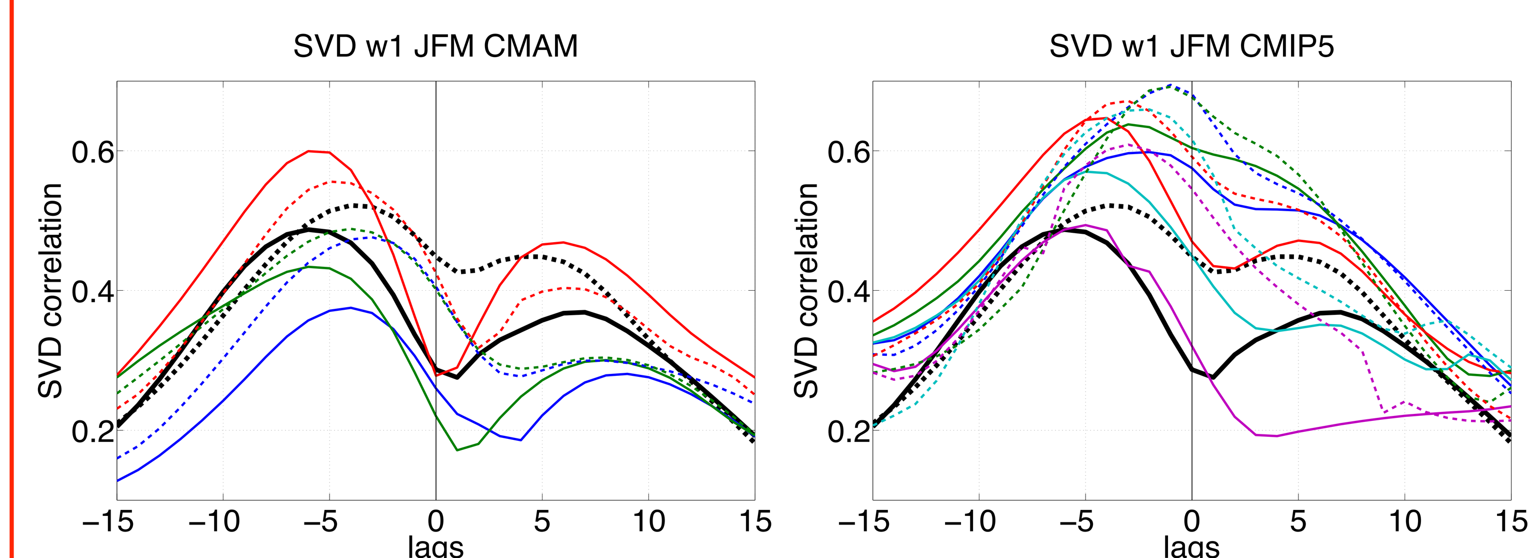

Figure 9: Correlation of the temporal expansion coefficients between the leading wave-1 singular value decomposition mode at 500 hPa and two stratospheric levels; 10 hPa (solid) and 50 hPa (dashed).

- All models capture upward wave coupling, however they have different propagation timescales
- Overall, the models do not accurately capture downward wave coupling

Conclusions

We have examined the impact of model configuration on the simulation of the stratospheric polar vortex, planetary wave structure, and propagation in CMAM and CMIP5 AMIP simulations. The CMAM simulations show that model lid height and conservation of momentum flux have a significant impact on the polar vortex, planetary wave structure and extratropical wave coupling. The CMIP5 models display a large range of polar vortex strengths, planetary wave structure and wave coupling. While the high-lid models were in closest agreement with the ERA-Interim data set overall, further analysis with is required to thoroughly assess the impact of a high model lid.

References

Dee, D. P., et al., 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quart. J. R. Meteor. Soc., 137, 553-597.
Shaw, T.A., M. Sigmond, T. G. Shepherd and J. F. Scinocca, 2009: Sensitivity of simulated climate to conservation of momentum in gravity wave drag parameterization. J. Climate, 22, 2726-2742.
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