Project: **966**

Project title: **DynVar**

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Report period: **2019-01-01 to 2019-12-31**

The DynVar project aims to assess and inter-compare the atmospheric momentum balance and atmospheric circulation variability and change in the climate models participating to the Coupled Model Intercomparison Project Phase 6 (CMIP6) by means of the Transformed Eulerian Mean (TEM) diagnostics and high frequency outputs, respectively, as described in the CMIP6 – endorsed Dynamics and Variability Model Intercomparison Project (DynVarMIP, Gerber and Manzini 2016). Within this last year, DynVarMIP variables have started to become available on the ESFG (Earth System Grid Federation). Here we report preliminary analysis performed on four climate models, contribution to the DynVarMIP workshop just occurred in Madrid (Manzini and Karpechko 2019). This analysis is ongoing, as diagnostics from more and more models are just becoming available. So far, we focused on the boreal winter middle-high latitude stratosphere, a key region of stratosphere-troposphere coupling. To compactly intercompare how the stratospheric momentum transfer responds to global warming, TEM wave activity budgets for the polar stratosphere (10-100 hPa, poleward of 45°N) have been evaluated for the PiControl and abrupt-4xCO_2 experiments, for the four available models, specifically the CESM-WACCM, CanESM5, GFDL-CM4, and MPI-ESM-HR climate models. Figure 1 shows the changes in the December to February (DJF) EP-fluxes integrated over the respective box boundaries (upward fluxes at 100 and 10 hPa, integrated over 45°-90°N; lateral flux at 45°N, integrated over 10-100 hPa) and the resolved wave convergence. Changes are defined as differences between abrupt-4xCO2 and piControl experiments (see caption).

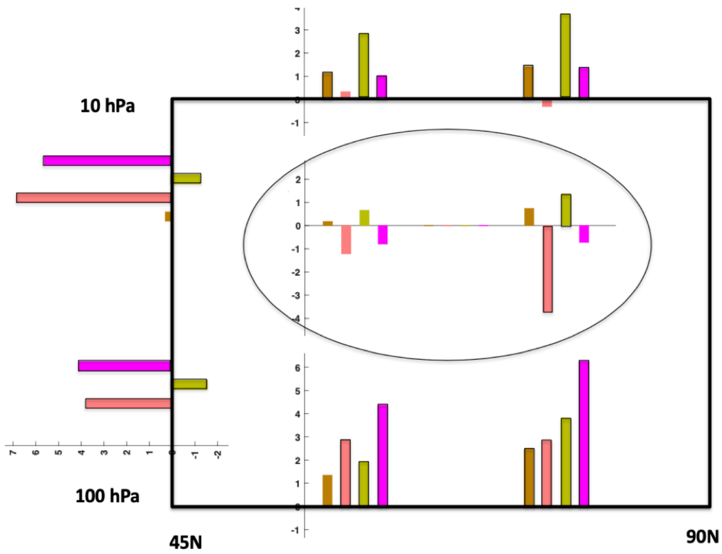

Figure1. Bars depict changes in DJF EP-fluxes integrated over the respective box boundaries, and (middle) the resolved wave convergence, negative of EPFDIV (10^4 kg m s^{-4}). Changes are defined as differences between abrupt-4xCO_2 and piControl experiments, for two time periods of the abrupt-4xCO_2: 1-40 years (left) and 110-150 years (right), representing different stages of equilibration. A reference 40-year mean from the piControl is subtracted from each abrupt-4xCO_2 period. Colours depict models: CESM-WACCM (light brown), CanESM5 (light pink), GFDL-CM4 (light green), and MPI-ESM-HR (magenta). Black contours on bars indicate significance with $p < 0.05$.

Figure 1 shows that there is consensus on the sign of the changes across the models only for the changes in the upward flux emerging from the troposphere (bars at 100 hPa, positive into the box): all models shows an increase in the (bottom) upward flux. This change is indicative of an increased tropospheric wave forcing. Given its generally larger magnitude and clear establishment during the second period (110-150 years of the abrupt-4xCO_2), a role of slow processes (sea surface temperature, sea ice loss) for the cause of the increased flux from the troposphere is suggested. This change alone would lead to an increased convergence. However, that this is not the case can be explained (for two of the four models) by the contrasting changes in the lateral fluxes (bars at 45°N, positive out of the box), which can be large and equatorward. Enhanced equatorward flux is explained by the strengthening of the subtropical jet with global warming (Figure 2). Overall, Figure 1 suggests that a large uncertainty in the stratospheric wave activity budget for the region considered is associated with the lateral flux, although the magnitude of the bottom flux changes and the flux out of the box top (upward flux at 10 hPa, positive outward) can also play a role.

Ultimately, our interest resides in the relationship between the resolved convergence changes and the changes in the stratospheric polar vortex. This part is ongoing, as outputs from more models are needed to search for relationships. Form the diversity of the responses of the current four models (Figure 2), it appears that the CMIP6 models will still show a spread in the stratospheric polar vortex response to global warming, as previously found for the CMIP5 models. Figure 2 shows that for two models (upper left and bottom right) out of the four available models the stratospheric polar vortex weakens (easterly, or negative, change at 10 hPa, 70°-80°N), in agreement with the change reported for the majority of the CMIP5 models (Manzini et al 2014; Simpson et al 2018). Figure 2 also shows that the high latitude easterly change for these two models is deep and connect to the surface, indicative of stratospheric circulation changes linked to sea ice loss (Manzini et al 2018). However, consensus still has to be reached, given that the remining two models show instead a strengthening (albeit with very different structures) of the stratospheric polar vortex. The very large (up to 16 ms^{-1}) zonal wind changes along 45°N for the model at upper right explain the substantial equatorward flux change (Figure 1, light pink), and may be related to the high level of global warming of that model (not shown). The dipole changes occurring within the considered box for the other three models explain the relatively overall minor changes in the integrated convergence.

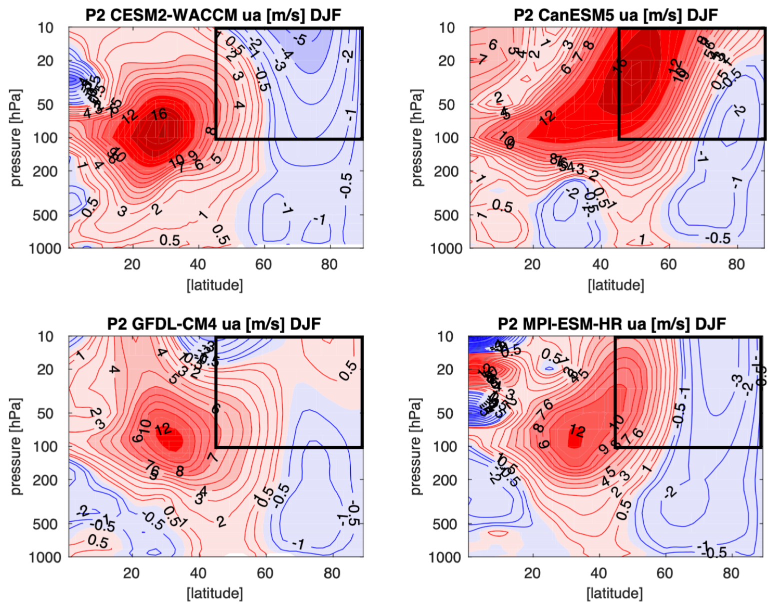

Figure 2. DJF zonal mean zonal wind change for the second period (110-150 years of the abrupt-4xCO_2 minus the reference 40-year average of the control). Contours are ±0.5, ±1 and then each 1 ms^{-1}. Red / blue colours denote positive / negative changes. Black rectangle denotes the boundary of the box used to calculate the wave activity budget of Figure 1.

References

- Gerber, E. and E. Manzini (2016) The Dynamics and Variability Model Intercomparison Project (DynVarMIP) for CMIP6: assessing the stratosphere–troposphere system. Geosci. Model Dev. 9, 3413-342. DOI 10.5194/gmd-9-3413-2016
- Manzini et al (2014) Northern winter climate change: Assessment of uncertainty in CMIP5 projections related to stratosphere-troposphere coupling. J. Geophys. Res. Atmos. 119, 7979–7998. DOI 10.1002/2013JD021403
- Manzini et al (2018) Nonlinear response of the stratosphere and the North Atlantic-European climate to global warming. Geophysical Research Letters, 45, 4255-4263. https://doi.org/10.1029/ 2018GL077826
- Manzini, E. and A. Yu. Karpechko (2019) Stratosphere – Troposphere Circulation Changes. Presentation at the Atmospheric Circulation in a Changing Climate, a joint DynVarMIP – DynVar – SNAP Workshop, Madrid, Spain, 22-25 October 2019.
- Simpson et al (2018) The Downward Influence of Uncertainty in the Northern Hemisphere Stratospheric Polar Vortex Response to Climate Change. J. Climate, 31, 6371-6391. DOI: 10.1175/JCLI-D-18-0041.1