Project: 966

Project title: DynVar

Principal investigator: Elisa Manzini

Report period: 2018-01-01 to 2018-12-31

Text: maximum of two pages incuding figures.

The DynVar project aims to assess and inter-compare the atmospheric momentum balance in climate models by means of the Transformed Eulerian Mean (TEM) diagnostics, as described in Gerber and Manzini (2016). Resources have been used so far to store the model outputs for a prototype TEM diagnostics model inter-comparison, carried out with a set of idealized climate change experiments performed with the ICON-DRY model (Haufschild and Manzini, in preparation). The goal of the idealized climate change experiments is to identify drivers of the stratospheric circulation response to global warming. The ICON-DRY model is a dry (no moisture effects included) configuration of the ICON-A icosahedral non-hydrostatic atmosphere model. The ICON-A model is described in Giorgetta et al (2018). ICON-DRY excludes explicit representation of moist processes by setting to zero the fields of atmospheric water vapour and cloud water as well as their sources, and by turning off the parameterizations of cloud processes. Radiation and vertical diffusion parameterizations are as in Giorgetta et al (2018), while gravity wave parameterizations are off. The large-scale circulation of ICON-DRY is forced by an imposed (time and zonal) mean tropospheric thermal forcing, sensible heat form the underling imposed (time and zonal) mean sea surface temperatures, solar irradiance in the stratosphere, and rotation. The ICON-DRY model is constructed at a horizontal resolution of ~40 km (R2B06) and for 95 vertical levels (top at 83 km). We have used the ICON-DRY model with either a flat or an undulating topography.

For each model configuration (either a flat or undulating topography, or other options), a pair of climate change experiments (the control, with unperturbed tropospheric thermal forcing, and the idealized climate scenario experiments) has been carried out. The idealized climate scenario experiment is obtained by adding a thermal forcing anomaly in the equatorial troposphere. Thereafter, TEM budgets for the mid-lower polar stratosphere (10-100 hPa, polar cap poleward of 60N) have been evaluated for each experiment, and for each pair the change in the TEM budgets is given by the difference between the scenario and control budgets. The mid-lower polar stratosphere has been chosen because a key region for wave-mean interaction, with increased wave dissipation in this region leading to a weakening of the winter stratospheric vortex.

Figure 1 shows the change in the stratospheric TEM budget for a total of 13 pairs of idealized climate change experiments. For each pair, Figure 1 shows the change in upward wave activity flux entering (at 100 hPa, upward arrows at bottom of the box) and exiting (at 10 hPa, upward arrows at top of the box) the budget region; the change in the lateral wave activity flux (horizontal arrows) exiting the budget region at 45N, and the change in the wave activity convergence (bars, with a positive change meaning increased wave dissipation, hence deceleration of the mean flow). Figure 1 is a compact visualization of the change in the atmospheric momentum budget due to momentum and heat transfer by the atmospheric waves, which are resolved in the models. Figure 1 therefore allows for a direct model inter-comparison. Figure 1 has required substantial resources, given that the TEM diagnostics involve the calculation of fluxes using 3-dimentional daily outputs and that each experiments is ~5000-day long.

Figure 1 demonstrates that for only a few configurations of the ICON-DRY model, the budget change is indicative of increased wave activity dissipation (positive bars) and consequently stratospheric polar vortex weakening. The atmospheres of the configurations shown in red, yellow and light blue colours are those that sustain a field of stationary planetary (Rossby) dry waves, generated by the flow blowing on the prescribed undulating topography. The prescribed undulating topography consists of sinusoidal perturbations of the surface geopotential height, either a wave 1 or a wave 2 or a combined wave 1 and 2 anomalies, with amplitudes ranging from 200 to 800 m. According to Figure 1, a prescribed anomaly of 600 m is sufficient for leading to increased wave activity dissipation. The stationary waves are therefore a key driver, because they can lead to almost a doubling of the change in the vertical wave activity flux entering the mid-lower polar stratosphere, with respect to the change obtained from ICON-DRY model

configurations with flat surfaces (shown in black, light green and pink), which atmospheres support only (dry) transient waves. In turn, this increase in the vertical wave activity flux is essential to the potential for increased wave dissipation, because of the changes in the horizontal wave activity flux, which for all experiments indicate increased wave propagation out of the box. Indeed, although for all configurations the vertical wave activity flux entering the box is increased, also all the fluxes exiting the boxes are increased, most notably the horizontal wave activity flux.

Figure 1 shows also another model configuration with increased wave activity dissipation (dark blue bar). This is an AQUA PLANET ICON model. Idealized climate change in the AQUA PLANET is realized imposing a constant 4 K sea surface temperature anomaly. This result shows that in a moist atmosphere, the change in transient waves alone is capable of increasing wave dissipation, indicating that more than one driver can lead to a weakening of the stratospheric vortex with global warming. It remains to be seen, how the presence of idealized stationary waves may further affect the TEM momentum budget in the AQUA PLANET model.



Figure 1: TEM budget (see text for explanation of arrows and bars). The units are in 10^4 kg m s⁻⁴. The arrows of the individual changes are scaled with respect to the leftmost change arrow at 100hPa. The bars of the individual changes are scaled with respect to the leftmost bar change. The red/yellow colours are for model configurations with wave 1 / wave 2 surface geopotential anomaly with increasing amplitude, from left to right the anomaly amplitude is: 200, 400, 600 and 800 m. The light blue colour is for a combined wave1 and wave 2 anomaly of 600 m amplitude. For the other colours, see text.

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

Giorgetta, M. A. et al. (2018) ICON-A, the atmosphere component of the ICON Earth system model: I. Model description. Journal of Advances in Modeling Earth Systems, 10, 1613–1637. https://doi.org/10.1029/2017MS001242

Haufschild T. and E. Manzini (2019) Controls of the stratosphere troposphere coupled response to global warming in idealized models (in preparation for J. Climate)