

Interactive comment on “HEPPA-II model-measurement intercomparison project: EPP indirect effects during the dynamically perturbed NH winter 2008–2009” by Bernd Funke et al.

Anonymous Referee #2

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Overview:

The paper presents a comprehensive model intercomparison for perturbed and quiescent transport conditions in the mesosphere to evaluate the ability of models to capture EPP induced NO_x transport and the EPP indirect effect. Models with high lids able to capture thermosphere NO_x formation and lower lid models were included in this study. EPP and MLT NO_x were introduced into models with lids lower than the mesopause via a boundary condition derived from MIPAS. The purpose of this study is to evaluate model transport characteristics that are relevant for EPP indirect effects on the

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atmosphere. The 2008/2009 winter was chosen as the study period due in part to the availability of an extensive set of satellite observations. This winter also had a major SSW in January which was associated with the descent of a substantial amount of NO_x in spite of relatively quiet geomagnetic conditions. This is the only study to focus on EPP and NO_x transport effects. Other model intercomparison projects have focused on dynamical characteristics during perturbed winters (e.g. Pedatella et al., 2014).

Aside from EMAC and FinROSE models were nudged with assimilated data (MERRA, ERA-Interim, ECMWF operational) below 1 hPa in order to approximate circulation during the observation period. This approach does not replace nudging by assimilated data in the mesosphere and is dictated by the lack of such data. It is hoped that having the model levels below the stratopause be in a circulation regime following observations imposes a dynamical boundary condition that propagates into the mesosphere and dominates the circulation response there as well. Although a non-local constraint on the dynamics will be imposed this way (e.g. via Rossby wave propagation), it will be partial since there are multiple solutions to a given set of boundary conditions. This "degeneracy" is apparent from non-orographic wave drag scheme tuning. It is possible to get reasonable temperatures and winds while not capturing tracer transport well.

Models are found to capture EPP NO_x transport in the mesosphere during quiet periods reasonably well. However, the transport pattern in the wake of the major SSW in January 2009 is not captured well by models. Descent in models is too rapid and is associated with a warm bias in the lower mesosphere. At the same time high lid models underestimate downward transport in the upper mesosphere. Models with lids in the mesosphere that require an EPP NO_x boundary condition show a large spread indicating substantial differences in vertical structure and transport in the mesosphere.

Aside from model weaknesses such as the tuning of the non-orographic gravity wave drag schemes, the assimilated wind and temperature data had inadequacies that likely contributed to the excessively early descent of NO_x in the wake of the SSW (p 35–38).

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Major Comments:

1) The authors raise the issue of assimilated data biases as a factor in the poor model performance at capturing transport in the wake of the major SSW in January. But another important issue is the use of nudging restricted below 1 hPa. The mesospheric circulation is not a linear problem and is not fully determined by the dynamical boundary condition at 1 hPa. In fact, multiple solutions are possible for the mesospheric state given the same set of stratopause conditions. In other words, it is not really possible to approximate nudging of the mesospheric circulation by restricting the circulation below 1 hPa. In the case of a CTM like FinROSE, the circulation needs to be specified in the mesosphere and the quality of the ECMWF data used is not clear and likely to be deficient (for example, gravity waves become increasingly important with altitude but are treated as noise in standard data assimilation systems.)

I would think that nudging restricted to below 1 hPa is a bigger problem than the biases in the assimilated data in the stratopause region. In particular, the non-orographic gravity wave drag schemes are essentially running in free mode in the mesosphere and impose biases since there is no local nudging to offset them. Non-orographic gravity wave drag cannot be constrained to the observed regime by imposing the right winds in the stratosphere (e.g., Scinocca and McLandress, 2005). Various built-in assumptions such as a constant source spectrum will still impact the response.

The basically free mode simulation of the mesosphere also affects the radiative transfer calculations. Radiatively active trace gas distributions are not likely to be ideally distributed to conform to observations. So the radiative damping impact on the evolution of the state in the wake of the major SSW will deviate from observations.

In addition the evolution of the highly nonlinear SSW in the mesosphere is not guaranteed to follow observations even if the wave amplitudes at the stratopause conform to observations. The progression of SSW events is rather complex (Matthewman et al., 2009) and the mesospheric component of a major SSW cannot be trivially constrained

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by the stratospheric part. The SSW exhibits a high degree of top-down evolution with the mesosphere being an important layer of the atmosphere for this phenomenon.

It appears that relatively good performance of EMAC (Fig. 13, 14, 15, 16) and its application of assimilated data up to 0.2 hPa may not be a coincidence since every scrap of nudging in the mesosphere counts. FinROSE appears to do a better job as well (Fig., 13, 14) but performs worse than EMAC apparently due to issues with the vertical upwelling. CTMs use geostrophic balance to infer the upwelling from the temperature and horizontal winds, but this fails to capture the ageostrophic part which is not negligible in the mesosphere due to the amplification of gravity waves and general deviation from geostrophic balance. In addition, several models linearly ramp nudging above 40 km so that they are not imposing as much of a constraint on the upper stratosphere and lower mesosphere dynamical state as models that fully nudge up to 1 hPa.

The authors mention the study of Siskind et al. (2015) which highlighted the need for nudging to much higher altitudes (92 km) to improve simulations of NO descent compared to observations. But there is no focused discussion of the limitations of the nudging approach adopted by most models in this intercomparison. Such a discussion has to be included either in the introduction or in the conclusions sections to put the results from these models in a better context.

References:

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J. Scinocca, and C. McLandress: The GCM Response to Current Parameterizations of Nonorographic Gravity Wave Drag, *J. Atmos. Sci.*, 62(7), 2394-2412, 10.1175/JAS3483.1, 2005.

[Interactive comment on Atmos. Chem. Phys. Discuss.](#), doi:10.5194/acp-2016-971, 2016.

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