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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Propagation of gravity waves and its effects on pseudomomentum flux in a sudden stratospheric warming event" *by* In-Sun Song et al.

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General comments

Overall this is a nice study that puts together a really unique and well-designed set of experiments. The math is explained very clearly and completely and the paper provides a well-documented citation list. Moreover, just getting the various GWD schemes running in WACCM is a noteworthy achievement. In terms of the application of the new GWD packages to a problem, I am excited to see the topic of the effects of GWD on SSWs see more attention and the inclusion

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Discussion paper

of orographic and nonorographic schemes in a sophisticated model setting like WACCM offers the possibility to explore some noteworthy questions.

That said, I do feel like some of those noteworthy questions were not addressed and I think that this is a real missed opportunity. In the text below, I suggest a few ideas (which would require a few additional figures) that I think would be very worth the effort to include. I suggest these ideas because as it stands, this paper does not really discuss the mechanistic effects of GWD on SSWs, rather it simply provides some momentum budgets. Not that providing momentum budgets is not interesting, I just really think that a few additional figures could turn this paper into a something of very high value to the community. To be clear, my acceptance of this paper is not contingent on the authors adding my suggestions, I am simply trying to help improve the relevance of the paper.

- Authors would like to thank the reviewer for reading and evaluating the original manuscript. We think that the reviewer's questions really help improve discussions on the time evolution of the GW pseudomomentum fluxes in our original manuscript. We have added more figures (Figs. 13–14) and related discussions in our revised manuscript according to reviewer's comments. Please refer to the track-change version of revised manuscript for figure, page and line numbers to be mentioned below.

Major comments

1. There are two overarching concepts that I think would make compelling additions to your paper. One involves the effects of GWD on the pre-warming evolution of the vortex (i.e., preconditioning) and the second involves the possibility that GWD increases or decreases the probability of SSW occurrence. For each of these topics, I suggest two figures from the current literature that would provide a good starting point for figures to provide in the current manuscript.

2. Topic one – preconditioning: Your paper only shows figures for Jan. 20, but one could argue that it is the overall vortex evolution from Jan. 10-20 that is of prime interest in understanding the triggering of this particular SSW. Indeed Figs. 6-10 of Albers and Birner (JAS 2014) show that this period was of notable interest in the development of the SSW and in particular for GWD, it is the zonally asymmetric momentum fluxes that may play an important role in SSW development. Thus can you provide a few additional figures that show the differences in the vortex evolution and zonally asymmetric momentum fluxes for Jan. 10-20? In particular, zonally asymmetric views with GW momentum fluxes and geopotential height contours to indicate vortex shape (as in Figs. 6 and 7 of Albers and Birner) would be very interesting for the various cases that you have run.

    - Following the reviewer's suggestion, two new figures (Figs. 13–14) are added in the revised manuscript. Please find the new figures on the pages 45–46 of the track-change version of the revised manuscript. Thanks to this reviewer's question, we realized we missed opportunity to discuss the importance of the enhanced eastward OGW pseudomomentum fluxes in the middle stratosphere in the early stage of the SSW evolution. Newly added discussions can be found from the bottom of the page 18 to the middle of the page 20. Figures 13 and 14 demonstrate that the zonal-wavenumber-2 structure of the OGW pseudomomentum fluxes is much more enhanced in the middle stratosphere on 11 January 2009 in the 4D than in the 2D. Also, we discuss that this enhanced zonal-wavenumber-2 structure in the 4D interact more actively with the polar vortex in the early period, inducing the formation of the polar vortex of the zonal-wavenumber-2 structure (i.e., Rossby waves with the zonal-wavenumber-2 structure).

3. Topic two – probability of SSW occurrence: I'm not sure that my second suggestion is possible to accomplish with your current ensemble setup, but in case it is possible, I think it would provide a very interesting result. In de la Camara

et al. (JAS 2017), it was shown that perturbations to the vortex prior to a SSW can cause the vortex to evolve in very different ways. In particular, Figs. 2b, 6b, and 7 provide a very interesting way of seeing how perturbations to the vortex can disrupt vortex evolution, and in some cases, even disrupting the SSW from occurring at all. Now, I realize that your ensembles start about two weeks before the SSW central date, which means that most (all?) of your ensembles have a SSW, but even so, are there systematic differences in how the vortex evolves for the different model setups? Are there ensembles where a SSW does not occur or just barely occurs? In a similar fashion to what I suggest above, I would be particularly interested in seeing figures similar to de la Camara et al. Fig.7 (which is itself similar in character to Figs. 6 and 7 of Albers and Birner); that is, how does a stereographic view of the vortex evolution look between the various model setups?

- In the present study, we cannot show how sensitive the evolution of polar vortex is to the perturbations in the stratosphere because the simulations are all offline calculations carried out for fixed time evolution of the large-scale flow. We can understand that there is a possibility of active interaction between GWs and polar vortex (or planetary waves) when the 4D formulations are employed. However, we cannot actually measure how much the different spatial distributions of the GW pseudomomentum fluxes can affects the vortex evolution. But, we added some discussions about the sensitivity to the stratospheric flow in summary and discussion (see texts from the line 34 on the page 21 to the line 12 on the page 22 of the track-change version of the revised manuscript.

Minor comments

1. Figure 9, 10 and S7: These figures are quite difficult to read. Since you are really

only concerned with the NH, why not truncate the figures to include on the NH, or perhaps even just 30-90 N?

- Following the review's suggestion, the southern hemispheric parts of Figs. 9, 10 and S7 are truncated. Please find the modified Figs 9 and 10 on the pages 41 and 42 of the track-change version of the revised manuscript.

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