Response to Editor's Comments

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Title: Effects of Ozone-Climate Interactions on the Long-Term Temperature Trend in the Arctic Stratosphere

Author(s): Siyi Zhao, Jiankai Zhang, Xufan Xia, Zhe Wang and Chongyang Zhang

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Summary of revision in manuscript

We sincerely thank the editor for the important and constructive comments on our manuscript. In accordance with the suggestions, we have carefully revised the paper. The main revisions are summarized as follows:

1. **We reshaped the core conclusion regarding the interaction between radiation and dynamics.**

2. **We have fully incorporated the valuable suggestion by introducing the perspective from McCormack et al. (2011) into the "Conclusion and discussion" section, and some sentences are toned down.**

3. **We updated the schematic diagram (Figure 11), reviewed and adjusted the language throughout the entire manuscript, including the abstract and main text.**

Response to Comments of Editor

Public justification (visible to the public if the article is accepted and published): Many thanks to the authors for careful consideration and addressing of the further reviewer's concerns! I think the work is in good shape to be accepted for publication.

After careful re-reading of the manuscript, I have some final (overall minor) comments of mine regarding the interpretation of the chain of events behind the early-winter ozone climate feedback (1980-2000). In particular, I remain slightly skeptical about highlighting the role enhanced LW cooling upon higher early-winter Arctic ozone as a driver of the enhanced wave propagation and BDC (although I acknowledge that it is impossible to really identify specific drivers in these fully-coupled simulations).

First, the authors state "Lin and Ming (2021) noted that radiative damping due to longwave cooling could intensify wave dissipation and further enhance subsidence of the BDC". But the work of Lin and Ming focuses on the springtime stratosphere, when ozone absorbs SW radiation and hence any changes in ozone can either enhance or offset radiative damping rates by changing SW heating. Such a mechanism would not be at play in the winter Arctic stratosphere (as no sunlight). In addition, the enhancement of QRL under higher ozone is the result BDC strengthening, and as such it is hard to argue that it is also a driver of the BDC changes.

To me, the enhancement in BDC could just be related to just the presence of interactive ozone to begin with (before any changes in ozone take effect). For example, studies of McCormack et al. (2011, doi:10.1029/2010GL045937) showed that the presence of interactive ozone gives rise to a climatologically weaker, warmer and more disturbed winter Arctic vortex. It is possible that similar processes could also be at play when talking about Arctic trends, especially if the system leans towards stronger BDC and warmer Arctic trend even in the absence of any ozone feedback. And once ozone is allowed to respond, increase in ozone under stronger BDC would amplify the climatological ozone-wave feedbacks, giving rise to even stronger BDC trend.

So I wonder if some sentences need to be toned down in the current manuscript, and a statement added that it is impossible to fully decouple different processes in these coupled simulations (although I agree that this study provides a great step towards that direction!). I also wonder if the left panel of figure 11 should really have "enhanced BDC/wave dissipation" at the very top? (instead of increase in O3 which could be argued is a cause of the BDC change?).

Either way, I would encourage the authors to consider the above points and see if they agree that any changes are warranted. I will then accept the manuscript for publication.

Response: Thank you for your positive feedback and for letting us know that our manuscript is in good shape for publication.

We have carefully considered all the final comments on the interpretation of the early-winter ozone-climate feedback. We agree that there is inherent uncertainty in the causal relationships within a coupled model, and we have revised some statements accordingly.

In the main text, we revised or added some sentences as follows:

"*Specifically, ozone-climate interactions lead to a stratospheric state that enhances upward wave propagation and the downwelling branch of the Brewer-Dobson circulation. This leads to an adiabatic warming that significantly raises the Arctic*

stratospheric temperature. This dynamical heating overwhelmingly offsets the longwave radiative cooling effect associated with the increased ozone during early winter. **" (in Lines 9-12).**

"*McCormack et al. (2011) pointed out that the presence of ozone-climate interactions give rise to a climatologically weaker, warmer and more disturbed polar vortex during Arctic winter*" (in Lines 42-44).

"*It is worth noting that this radiative effect is secondary and is overwhelmingly dominated by dynamical warming. The mechanisms behind these dominant dynamical processes will be discussed in the following analysis (Figures 6 and 8).*" (in Lines 246-248).

"*This dynamical heating dominates the longwave radiative cooling effect due to the ozone-climate interaction, resulting in a warming of the middle and lower Arctic stratosphere during early winter.*" (in Lines 282-283).

"*The ozone transport associated with circulation changes could give feedback effect on polar ozone redistribution. Thus, it is plausible that the trends in stratospheric temperature and ozone are an amplification of by ozone-climate interactions. These ozone-climate interactions resemble previous findings on the climatic effects induced by zonally asymmetric ozone variations (McCormack et al. 2011; Rae et al., 2019; Zhang et al., 2020). Their experiments that account for the phase overlap between zonally asymmetric ozone heating and planetary wave centers tend to produce a climatologically warmer, weaker, and more disturbed winter Arctic vortex compared to simulations driven solely by zonal-mean ozone forcing.*" (in Lines 431-436).

Regarding the comment on Figure 11, we fully agree that depicting the mechanism as a simple linear chain starting with an "increase in O3" could be misleading. To better represent ozone-climate interaction processes, cyclical of the process, we have completely revised the "Early Winter" panel of Figure 11.

The new schematic now illustrates the process as a feedback loop showed in Figure R1, placing the dynamical processes (enhanced BDC and upward wave propagation) at the core. This makes it clear that the system is a dynamically-driven positive feedback loop: Enhanced BDC leads to dynamic warming and increased ozone transport. Dynamic warming is the dominant factor leading to the temperature increase. Radiative cooling is a secondary response that partially offset the dynamic warming, rather than being a driver of the dynamics.

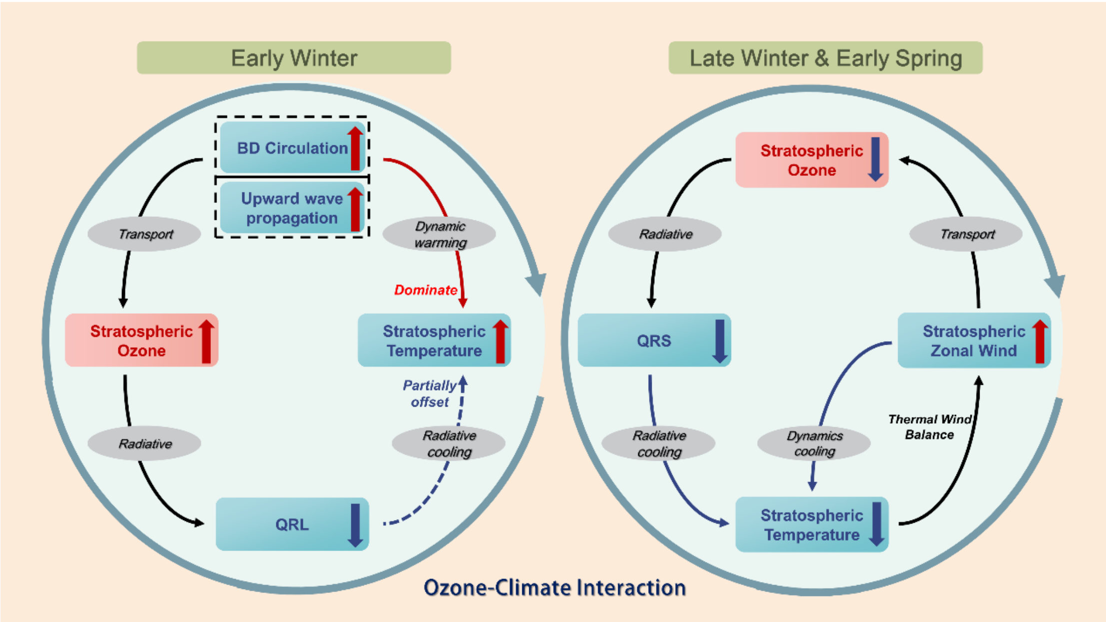

Figure R1. Schematic diagram of the ozone-climate interactions in the Arctic stratosphere during winter and spring. The red upward arrow indicates an increase, while the blue downward arrow denotes a decrease.