Response to Reviewer 2

General Comments

This letter investigates the recurrent post-SSW warming episodes occurred in the Antarctic stratosphere during austral winter 2024. These warming episodes and the stratospheric background state in 2024 are unusual during past decades. The authors propose the stratospheric wave-mean flow feedback as the driver of post-SSW oscillations under favorable stratospheric background state. The paper is well written and the results are interesting and convincing. I have only a few minor comments that could help improve the manuscript. I recommend minor revisions before publication.

Response: We thank the reviewer for the careful reading of the manuscript, the positive assessment, and the helpful suggestions.

Specific Comment 1

This stratospheric oscillation phenomenon and its interpretation in this study bring to mind the Holton-Mass vacillation. Holton and Mass (1976) studied the stratospheric vacillation cycles in a dynamics model. The authors could add a brief discussion of their relationship.

Holton, J. R., and C. Mass, 1976: Stratospheric vacillation cycles. J. Atmos. Sci., 33, 2218–2225.

Response: Thank you for this suggestion. The 2024 oscillation is reminiscent of the Holton–Mass vacillation because both involve feedback between planetary-wave forcing and the mean flow. In the classical Holton–Mass vacillation, planetary-wave forcing reverses the westerly mean flow, producing easterlies and a descending critical level that suppresses further upward propagation. Radiative relaxation then restores the westerlies and allows the next cycle to begin.

The 2024 event did not undergo this classical transition. The minor warmings did not produce a comparable deep wind reversal or descending critical level. Instead, upward propagation was regulated mainly by meridional displacements of the vortex edge, which modified the alignment between the waveguide and the main wave-activity region. We have added this comparison to the Discussion and Conclusions.

Changes in manuscript:

To clarify the relationship between the 2024 sequence and the Holton–Mass vacillation, we have added the following paragraph to the Discussion and Conclusions:

"This alternating control of wave propagation by the evolving mean flow is reminiscent of the stratospheric vacillations described by Holton and Mass (1976) and Christiansen (1999). In these model vacillations, wave forcing decelerates and eventually reverses the westerly mean flow, producing easterlies and a descending critical level that suppresses further upward propagation. Radiative relaxation then restores the westerlies and permits the next cycle. Such a deep reversal is less readily achieved in the Southern Hemisphere, where the climatological polar vortex is stronger and planetary-wave forcing is weaker. The 2024 minor warmings did not involve this wind-reversal transition; instead, upward wave propagation was modulated by changes in the meridional alignment between the waveguide and the main wave-activity region."

Specific Comment 2

Line 34: Recent studies have highlighted the role of vortex preconditioning in triggering the Antarctic weak polar vortex events.
Lim, E.-P., et al., 2021: The 2019 Southern Hemisphere stratospheric polar vortex weakening and its impacts. Bull. Amer. Meteor. Soc., 102, E1150–E1171.
Yang, P. et al., 2025: The role of vortex preconditioning in the occurrence of Antarctic weak polar vortex events. J. Climate, 38, 1319-1332.

Response: We agree that these studies are directly relevant. We have added Lim et al. (2021) and Yang et al. (2025) to the Introduction where vortex preconditioning is discussed.

Changes in manuscript:
The corresponding sentence in the Introduction has been revised as follows:
"Previous work has identified several pathways to anomalous upward wave forcing, including enhanced tropospheric planetary-wave activity (Polvani and Waugh, 2004; Garfinkel et al., 2010), favorable vortex preconditioning (Albers and Birner, 2014; Lim et al., 2021; Yang et al., 2025), and internal stratospheric amplification (Matthewman and Esler, 2011; de la Cámara et al., 2017)."

Specific Comment 3

It would be beneficial to include a discussion on the possible causes for the unusual stratospheric background state during 2024. Readers may be interested in learning about this.

Response: Thank you for this helpful suggestion. In this study, the "unusual stratospheric background state" refers primarily to the anomalous post-SSW vortex structure and associated waveguide during July–September 2024. Our diagnostics suggest

that this state was largely established by the initial SSWs, particularly the first event. The wave forcing associated with these events markedly weakened and contracted the polar vortex, shifting the strongest QGPV-gradient anomalies and the stratospheric waveguide poleward. Because the vortex subsequently recovered only partially, an anomalous high-latitude waveguide characterized the post-SSW background state and provided generally favorable propagation conditions for the later warming episodes. We have clarified this interpretation in the revised Discussion and Conclusions.

Regarding the conditions preceding the first SSW, previous studies provide useful context. Yang et al. (2025) showed that Antarctic weak-vortex events are commonly preceded by a two- to three-month preconditioning period, during which the polar-night jet shifts poleward, creating more favorable conditions for planetary waves to propagate into the vortex. For 2024 specifically, Lim et al. (2026) documented persistent upward planetary-wave activity from May to July, which may have contributed to the development of the first SSW. These studies have been cited in the Introduction to provide broader context. However, the pre-SSW processes are beyond the scope of the present study and have therefore not been discussed in detail in the revised manuscript.

Yang, P., et al., 2025: The role of vortex preconditioning in the occurrence of Antarctic weak polar vortex events. J. Climate, 38, 1319–1332.

Lim, E.-P., et al., 2026: Characteristics of Antarctic stratospheric variability during winter: A case study of the 2024 sudden stratospheric warming and its surface impacts. J. Geophys. Res. Atmos., 131, e2025JD045089.

Changes in manuscript:

To clarify how the anomalous post-SSW background state developed, we have added the following explanation to the Discussion and Conclusions:

"The first SSW markedly contracted the polar vortex, which subsequently recovered only partially. The resulting post-SSW background state was characterized by anomalously strong QGPV gradients poleward of 60°S, favoring a high-latitude waveguide and helping to sustain the prolonged dynamical activity."