General Comments:

This manuscript investigates the cross-seasonal influence of tropical central Pacific SST anomalies (Niño 4 region) on the Antarctic stratospheric circulation and ozone transport. While the topic is of interest and the use of ERA5 reanalysis over a 45-year period is a strength, the study suffers from several major conceptual, methodological, and interpretive flaws that significantly undermine its conclusions. The core argument regarding the delayed influence of boreal winter Niño 4 SSTs on austral winter stratospheric conditions is not convincingly supported by the presented evidence. The analysis relies heavily on correlation and composite methods without sufficient dynamical diagnostics or causal mechanisms. Furthermore, the inclusion of ozone-related content in the introduction and abstract is misleading, as the results pertaining to ozone are minimal and not integral to the main narrative. The manuscript requires substantial revision in both structure and scientific rigor to be considered for publication. Due to the significant issues outlined below, I cannot recommend this manuscript for publication in its current form.

**Reply: Thank the reviewer for the constructive comments which help us to improve our manuscript. We have revised our manuscript following the reviewer's comments. Specifically, we have deleted all the discussions on ozone in abstract and introduction and have conducted additional analyses and discussions on the physical processes, as shown below.**

Specific Comments:

1. Mismatch Between Introduction/Abstract and Actual Content. The introduction and abstract heavily emphasize ozone related processes, yet the results section contains very little substantive analysis on ozone. The sudden mention of "chemical influence" in the abstract (line 44) is unsupported by the rest of the abstract. The authors should refocus the manuscript to align with the actual findings—namely, the dynamical response of the stratosphere to tropical forcing—and remove extraneous discussions on ozone unless they are robustly analyzed and central to the story.

**Reply: In the revised manuscript, we have removed all the discussions on ozone, focusing on dynamical response of the stratosphere to tropical forcing, following the reviewer's comments.**

2. Misinterpretation of Polar Vortex Weakening. The claim that warm Niño4 events lead to a "weakened stratospheric polar vortex" (e.g., abstract, line 32) is not fully supported by Figure 2. The zonal wind anomalies show a dipole structure: weakened winds at mid-latitudes and strengthened winds at high latitudes. Figure 1c also shows the weakened zonal winds locate at mid-latitudes. This suggests a contraction or shift of the vortex rather than a uniform weakening. The authors should supplement their

analysis with horizontal maps of geopotential height, temperature, and wind over the polar region to better characterize the vortex response.

**Reply: We have added horizontal maps of geopotential height, temperature, and zonal wind in Figure 3. We have revised the manuscript by replacing "weakening of the polar vortex" with "contraction of the polar vortex". In addition, we have added the last second paragraph (Lines 322-332) of section 3 to discuss the contraction, as suggested by the reviewer. Specifically, we have added "Moreover, the atmospheric responses exhibit the maximum stratospheric warming appears over the Indian Ocean during June–September, while no significant warming is observed in the South Pacific (Fig. 3a-d). This warming pattern tends to weaken midlatitude baroclinicity, producing a westerly anomaly at high latitudes and a negative anomaly in the midlatitude in stratosphere, indicative of a contraction of the jet stream (Figs. 3e-h). Meanwhile, the stratospheric geopotential heigh show a zonal wavenumber-1 pattern, with a positive center over the Indian Ocean and a negative center over the Pacific and Atlantic, suggesting a role of planetary wave (Figs. 3i-l). The responses intensify from June to September and gradually propagate eastward and poleward (Fig. 3). For example, the maximum westerly anomalies extend into the Pacific polar region by September, while pronounced negative wind anomalies develop over the midlatitude Pacific (Fig. 3h)".**

3. Inadequate Explanation of Stratospheric Warming Mechanism. The proposed mechanism involving planetary wave propagation and E–P flux convergence (Section 4) does not adequately explain the polar stratospheric warming. Figure 6 shows wave activity and residual circulation anomalies primarily confined to mid-latitudes, with limited direct impact on the polar region. The authors need to provide clearer evidence to link mid-latitude wave activity to polar warming.

**Reply: Based on the E-P flux theorem, E-P flux can be used to diagnose the poleward transport of heat associated with upward planetary waves in the troposphere. For example, when E-P flux convergence occurs in the midlatitudes, the jet stream tends to weaken and poleward heat transport increases. During July–September, the strong Antarctic polar vortex inhibits the poleward propagation of planetary waves, resulting in relatively weak polar warming and stronger warming in the subpolar and midlatitude regions. As a result, significant high-latitude warming and contraction of the polar vortex are observed during April-September (Fig 3). This has been added at the end of Section 4.1 (Lines 450-458).**

4. Overreliance on Correlation and Composite Analysis. The study relies heavily on statistical correlations and composite differences without sufficient dynamical or causal diagnostics. The discussion of sea-air and ice-air interactions is largely descriptive and lacks quantitative support. For instance, the claim that sea-ice loss

enhances shortwave radiation absorption (lines 428–430) is not plausible during austral winter (JAS) when solar insolation is minimal.

**Reply: We agree with the reviewer that the results from correlation and composite analysis need to be supported with dynamical or causal diagnostics. To address the reviewer's concern, we have expanded our analyses on physical processes associated with impacts of Nino4 SST anomalies on stratospheric warming.**

**(1)We have expanded our discussions on E-P fluxes. It shows that anomalous upward planetary waves triggered by positive SST anomalies tend to enhance upward and poleward heat transport and weaken the jet stream in the stratosphere (See Lines 450-458 of Section 4.1 and Comment 3 above).**

**(2)We have added Fig. 3 to show horizontal patterns of temperature, wind, and geopotential height. The stratospheric responses to positive Nino4 anomalies features a contracted polar vortex (See Lines 322-332 of Section 3 and Comment 2 above).**

**(3)We have added CMIP6 results in Section 6 (Lines 626-644). The results show significant lagged correlation between tropical central Pacific SST and sea ice over the Amundsen and Ross Seas, consistent with ERA5 reanalysis in Section 4.2.**

**(4)Moreover, recent model studies suggest that decrease in early-winter sea ice in the Amundsen Sea region can significantly impact Antarctic stratospheric vortex. At the end of Section 4.2, we have added "Recent modeling studies also suggest that sea ice loss in the Amundsen Sea and the broader Antarctic region can have pronounced impacts on stratospheric temperatures (Song et al., 2025). The loss of sea ice tends to sustain the influence of Niño 4 SST on stratospheric temperatures during JAS by enhancing surface heat fluxes (Fig.8)"**

**(5)We agree with the reviewer that solar shortwave radiation reaches its minimum during the polar winter, and thus its contribution is small. The primary contribution comes from the turbulent heat flux (the latent and sensible heat fluxes) and temperature advection, as shown in Fig 8 . In the second paragraph of Section 4.2.2 (Lines 502-509), we have added "Comparison between surface heat flux (Fig.8o) and ice concentration (Fig.8l) shows ice loss has a pronounced impacts on surface heat flux. During JAS, solar short-wave radiation reaches its minimum, and its contribution to the net heat flux is relatively small. (Figs. 8r). The primary contributions come from turbulence heat fluxes (Fig.8x) and temperature advection (Figs 8i) while the contribution from longwave radiation is relatively weak (Fig. 8u)."**

5. Flawed Multivariate Regression Model. The multivariate regression model uses predictors that are highly correlated with each other, violating the assumption of independence in linear regression. The low explained variance (35%) further undermines the model's utility. The authors should either use orthogonal predictors or apply methods more suitable for correlated predictors. A physical justification for including each predictor is also needed.

**Reply: We have removed the regression analyses involving the sea ice concentration (SIC) index and the South Pacific SST index, and only the June PSA teleconnection index is retained in the regression model, following the reviewer's comments. Although the Niño4 index during winter is strongly correlated with the concurrent PSA index ($r = 0.40$, $p < 0.01$), indicating that tropical central Pacific SST anomalies can trigger PSA pattern, its lagged correlation with the June PSA index is not significant ($r = 0.28$, $p > 0.05$). In contrast, the June PSA index is significantly correlated with Antarctic sea ice loss ($r = 0.49$, $p < 0.01$), suggesting that the June PSA pattern may be maintained by sea ice anomalies and another factors. In the third paragraph of Section 5 (Lines 560-563), we have added "However, the correlation between the June PSA index and the Niño 4 index is not significant ($r = 0.28$, $p > 0.05$). In addition , the June PSA index is significantly correlated with Antarctic sea ice ($r = 0.49$, $p < 0.01$), suggesting that the June PSA pattern may be maintained by sea ice anomalies and another factors".**

**In addition, In the first paragraph of Section 5 (Lines 544-547), we have added "Nino 4 SST anomalies can influence stratospheric temperatures through the PSA pattern, which affects surface conditions at high latitudes during boreal winter. During JAS, the atmospheric circulation associated with the PSA pattern can enhance surface heat transport (Fig. 8i) and help sustain the stratospheric response (Figs. 8c, f)."**

6. Arbitrary Definition of Warm/Cold Years. The use of ±0.5 standard deviations to define warm/cold years is arbitrary. The authors should provide a justification or conduct a sensitivity test (e.g., using $\pm 1\sigma$) to ensure the robustness of the composite results.

**Reply: As shown in Figures R1 and R2, we tested two additional standard deviation thresholds ($\pm 0.75\sigma$ and $\pm 1\sigma$), and the results remain consistent with those obtained using the $\pm 0.5\sigma$ threshold. Therefore, our conclusions are not sensitive to the choice of threshold, indicating that the findings are robust and reliable. In the seventh paragraph of Section 3 (Lines 298-300), we have added "The ±0.5 standard deviation is chosen to include relative strong warm and cold events, but the results are not sensitive to the choice of the threshold value."**

7. Inaccurate Figure Captions. Several figure captions (e.g., Figures 4, 7) use the phrase "same as" despite the panels showing different variables or time periods. This

is confusing and unprofessional. The captions should be rewritten to accurately describe each panel.

**Reply: Done.**

Others:

1. Use consistent formatting for ENSO indices: e.g. "Niño4" → "Niño 4" (with space).

**Reply: Done.**

2. Subscript the "3" in "TCO3" (line 131).

**Reply: Done.**

3. Avoid using asterisks in line 171 when they are also used in line 185.

**Reply: The asterisk is replaced with the symbol '×'.**

4. L149-149: It is recommended to specify the timescale by filtering interannual component.

**Reply: Since results obtained after filtering the interannual component are similar, no filtering has been applied. This statement has been added to the end of this first paragraph of Section 2.1.**

General comments:

This study investigates the cross–seasonal effects of boreal winter sea surface temperature anomalies over the central tropical Pacific on Antarctic stratospheric circulation and ozone transport during the subsequent austral winter. By exciting the PSA wave train, SST anomalies in the Nino4 region led to warmer SSTs in the southeastern Pacific, accelerating sea ice melt. The subsequent release of ocean heat maintained atmospheric high-pressure anomalies during July–September, which in turn strengthened planetary wave anomalies. Furthermore, multivariate regression statistical model was used to verify the combined importance of both tropical forcing and mid–latitude atmospheric responses in stratospheric temperature predictability. These results further help to improve modeling and forecasting of future changes in the polar vortex. Some additional analyses are needed to verify these results.

**Reply: We thank the reviewer for the encouragement, and we have revised the manuscript, following the reviewer's comments.**

Major comments:

1. All conclusions are obtained from the reanalysis dataset. Can these results also be identified in CMIP6 simulations? Furthermore, I suggest that the author perform sensitivity experiments using numerical models to further support their conclusions.

**Reply: Following the reviewer's comments , we have examined 20 CMIP6 historical fully-coupled model simulations from the period 1951-2014 to further assess the cross-seasonal effects of tropical central Pacific SST anomalies on Antarctic stratospheric temperatures. Model simulations show that the July–September mean polar-cap (60°–90°S) mean stratospheric temperature at 10 hPa ($T_{10}$) exhibits a robust positive correlation with tropical central Pacific SSTs during previous boreal winter (January-March) in most CMIP6 simulations. In addition, the simultaneous correlations between July-September $T_{10}$ and SSTs show a statistically significant positive correlation over the southeastern Pacific (Fig. 12). Similarly, correlations with sea-ice concentration in the Amundsen Sea and Ross Sea exhibit strong negative values in most models. Therefore, these results are consistent with observations and support the presence of a cross-seasonal linkage between tropical central Pacific SST anomalies and Antarctic stratospheric polar temperatures. We have added Section 6 (Lines 626-644) to discuss CMIP6 results .**

**In terms of sensitivity experiments, recent modeling studies suggest that sea ice loss in the Amundsen Sea and the broader Antarctic region can have pronounced impacts on stratospheric temperatures (Song et al., 2025). We have added this discussion at the end of Section 4.2 (Lines 517-520).**

2. Although the climatological geopotential height at 100 hPa is characterized by a wave-1 pattern, geopotential height anomalies appear to show a wave-2 pattern. Does the wave-2 component of geopotential height anomalies exhibit an in-phase or out-of-phase relationship with the climatological pattern? How do the vertical propagations of different planetary wave components change?

**Reply: As shown in Figure R3, although the wave-2 pattern exhibits a strong amplitude, its phase during July–September is nearly orthogonal to the climatological wave-2 phase. Consequently, the wave-2 component is not reinforced, and the process is instead primarily dominated by the wave-1 pattern. This discussion has been added to the last second paragraph of Section 4.1 (Lines 443-446).**

3. The author used ±5 standard deviation as a threshold to select warm and cold nino4 years. Whether the results are sensitive to the value of thresholds?

**Reply: As shown in Figures R1 and R2, we tested two additional standard deviation thresholds (±0.75σ and ±1σ), and the results remain consistent with those obtained using the ±0.5σ threshold. Therefore, our conclusions are not sensitive to the choice of threshold, indicating that the findings are robust and reliable. In the seventh paragraph of Section 3 (Lines 298-300), we have added "The ±0.5 standard deviation is chosen to include relative strong warm and cold events, but the results are not sensitive to the choice of the threshold value."**

4. Why was the SST region of 160°W–130°W and 30°S–60°S selected as the SST index related to the loss of sea ice in Amundsen and Ross Seas? It seems that SST in this area has a weak relationship with sea ice reduction in Amundsen and Ross Seas. It might be more suitable to use SST averaged over 50°S–65°S instead.

**Reply: Following the reviewer's comments, we have replaced the SST region with 50°S–65°S in the revised manuscript.**

5. The authors conclude that surface heat flux is largely associated with sea-ice loss, where the ocean releases heat through sea-ice changes to heat the lower atmosphere, thereby maintaining high-pressure anomalies that strengthen planetary waves and ultimately weaken the. However, the results from multi-regression analysis show that the contribution of sea ice is relatively weak. How can this phenomenon be explained? Why is the contribution of sea ice relatively weak if it is considered a key factor?

**Reply: Following the first reviewer's suggestion, we have removed the regression analyses involving the sea ice concentration index and the South Pacific SST index. This adjustment was made because both indices are highly correlated with the boreal winter Niño4 index, violating the assumption of conditional independence. As a result, Antarctic sea ice and South Pacific SST likely act as**

**intermediate processes through which tropical central Pacific SST anomalies influence the Antarctic stratosphere. When the Niño4 index is included in the regression model, its strong correlation with these two indices indicates that they are not independent predictors, leading to weak contributions from Antarctic sea ice and South Pacific SST. In contrast, when the Niño4 index is excluded, the contribution of the sea ice index increases substantially (approximately 18%). This result is consistent with the sensitivity experiment findings (Song et al., 2025).**

6. Why does the net surface heat flux remain persistently negative in certain regions (approximately 40°–60°S, 90°–140°W), indicating that the ocean continuously absorbs heat from the atmosphere, while the SST anomalies in these regions are weakening? Does this imply that the weakening of SST is controlled by oceanic heat transport?

**Reply: As shown in Figures 8m–o of the manuscript, the net surface heat flux over the southeastern Pacific region (approximately 40°–60°S, 90°–140°W) exhibits negative anomalies. However, these negative anomalies gradually weaken from January–March to July–September, indicating a reduction in the oceanic heat uptake from the atmosphere. Consequently, the strength of the positive SST anomalies in this region also decreases over time. In addition, we also believe that oceanic heat transport may play an key role. However, this topic is beyond the scope of the present study, and we will continue to explore it in future work.**

Minor comments:

1. Suggest adding the composited difference of the wave reflective index to Figure 6.

**Reply: The composited difference of the wave reflective index has been added in Figure 7. A brief discussion is given in the forth-to-last paragraph of Section 4.1 (Lines 450-452). In particular, we have added "In addition, the wave reflection index exhibits a significant negative anomaly south of 30 °S in the upper stratosphere (Fig. 7i). This further indicates that planetary waves are strongly refracted toward the mid- and high-latitude stratosphere (Fig. 7c)."**

2. It is necessary to provide the correlation coefficients between the monthly PSA index, SIC in the Amundsen Sea and Ross Sea, and the SSTSP and the July-September mean T10-30

**Reply: The correlation coefficients have been added in the Table 3 in the revised manuscript.**

3. Line 73: In addition to other factors, sea ice has been recognized as an important influence on the SPV (e.g., Rea et al., 2024; Song et al., 2025; Sun et al., 2015), with important implications for Southern Hemisphere climate variability.

**Reply: The references have been cited in the third paragraph of Introduction.**

Reference:

Rea, D., et al., Interannual Influence of Antarctic Sea Ice on Southern Hemisphere Stratosphere-Troposphere Coupling, Geophysical Research Letters, 51, e2023GL107478, https://doi.org/10.1029/2023GL107478, 2024.

Song, J., et al., Impact of Early Winter Antarctic Sea Ice Reduction on Antarctic Stratospheric Polar Vortex, JGR Atmospheres, 130, e2024JD041831, https://doi.org/10.1029/2024JD041831, 2025.

Sun, L., et al. Mechanisms of Stratospheric and Tropospheric Circulation Response to Projected Arctic Sea Ice Loss, Journal of Climate, 28, 7824–7845, https://doi.org/10.1175/JCLI-D-15-0169.1, 2015.

1. Line 116: “muiti-regression”-> “multi-regression”

**Reply: Done.**

2. Line 202: “bule”-> “green”

**Reply: Done.**

3. Line 442: “clod Niño4 years”-> “cold Niño4 years”

**Reply: Done.**

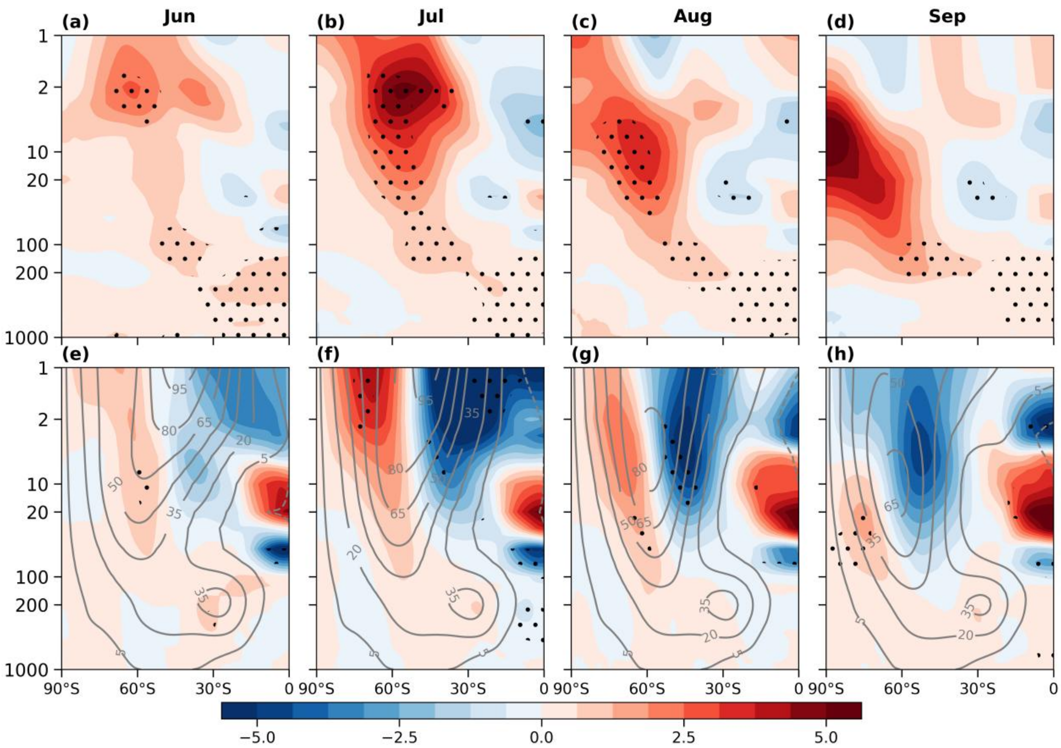


**Figure R1.** Composite differences between warm and cold stratospheric years (±0.75σ) from June to September. (a-d) zonal–mean temperatures profile (shaded, unit: K). (e-h) zonal–mean zonal winds profile (shaded, unit: m/s); The climatological mean of zonal-mean zonal winds is computed from 1991-2020 (contour, unit: m/s). Black dots indicate regions statistically significant at the 95 % confidence level.

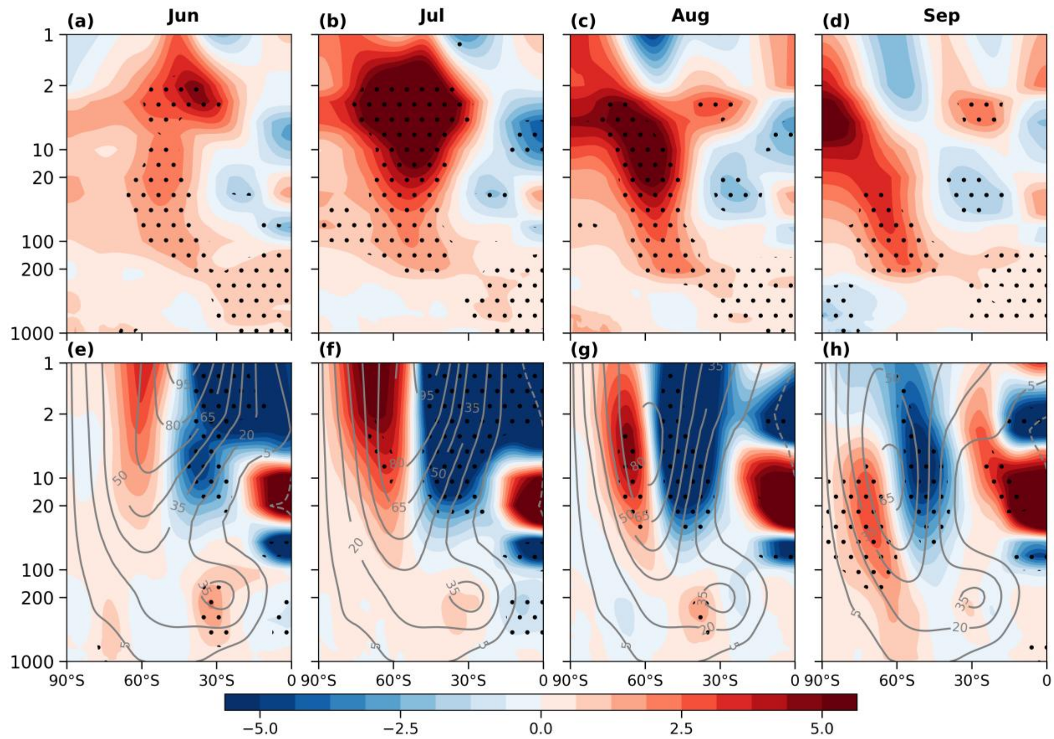


**Figure R2.** Composite differences between warm and cold stratospheric years (±1σ) from June to September. (a-d) zonal–mean temperatures profile (shaded, unit: K). (e-h) zonal–mean zonal winds profile (shaded, unit: m/s); The climatological mean of zonal-mean zonal winds is computed from 1991-2020 (contour, unit: m/s). Black dots indicate regions statistically significant at the 95 % confidence level.

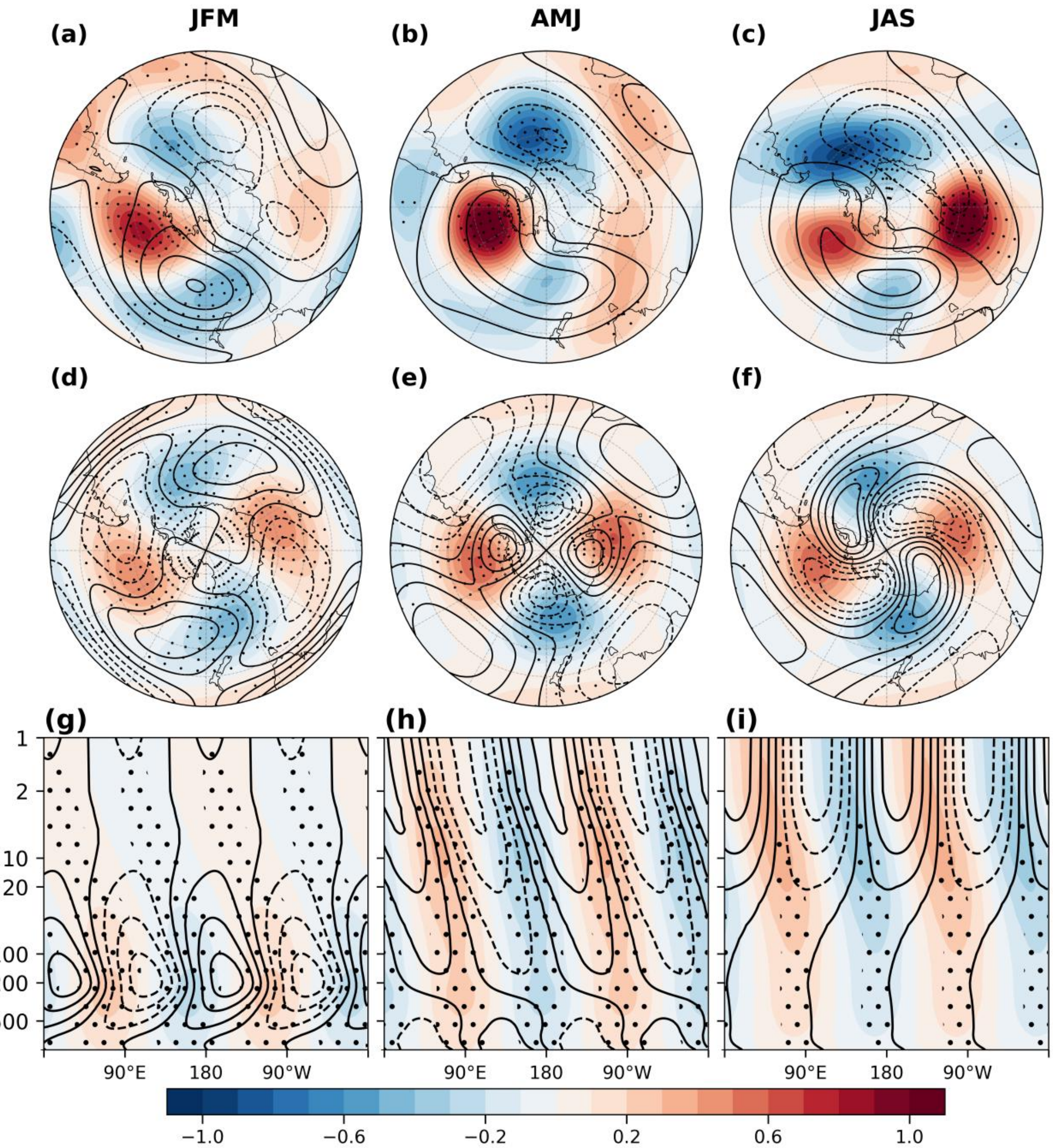


**Figure R3.** (a-c) Composite differences of geopotential heights at 100 hPa (shaded, unit: 5 dagpm) for three-month means of (a) January–March, (b) April–June and (c) July–September, where the climatological geopotential heights at 100 hPa is calculated from 1991–2020 (contours, unit: dagpm), (d-f) same as (a-c), but for wave-2 of geopotential heights at 100 hPa, and (g-i) same as (a-c), but for wave-2 of geopotential heights at 1000–1hPa averaged from 45 °S–75 °S (shaded, unit: 30 dagpm). Black dots indicate the regions statistically significant at the 95 % confidence level.