

Seasonal variation of global-mean and zonal-mean gravity wave momentum fluxes in the stratosphere and mesosphere revealed by a GW-permitting GCM

Soichiro Yamamoto¹, Kaoru Sato¹, and Shingo Watanabe^{2, 3}

¹ Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Tokyo, Japan

² Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, Japan

³ Advanced Institute for Marine Ecosystem Change, Organization of Advanced Studies, Tohoku University, Miyagi, Japan

Contact: yamamoto-soichiro@eps.s.u-tokyo.ac.jp

✓ Manuscript submitted to Journal of Geophysical Research: Atmospheres

Purpose of this study

The seasonal variation and global distribution of GWs in the whole stratosphere and mesosphere are examined by performing one-year hindcast simulations of 2022 with a high-top GW-permitting GCM.

Model

Forecast model	GW-permitting GCM, JAGUAR [Watanabe & Miyahara, 2009]
Model description	- Model top : ~150 km - T639L340 : $\lambda_h \geq 60$ km $\Delta z \approx 330$ m for $z = 11\text{--}107$ km - Validated with observations from a global atmospheric radar network [Sato et al., 2023]
Cycle of simulations [Okui et al., 2025]	3-day spectral nudging of large-scale components of total horizontal wavenumber $n = 0\text{--}15$ to JAWARA [Koshin et al., 2025] 4-day free-run simulation
Experiment period	January 2022 – December 2022
	- GWs: Small-scale components with $n = 21\text{--}639$ (i.e., horizontal wavelengths ~ 60 km $< \lambda_h < \sim 2,000$ km) - Absolute horizontal momentum flux (AMF) associated with GWs $\rho_0 \left(1 - f^2 / \hat{\omega}^2\right) \sqrt{(u'w')^2 + (v'w')^2}$is calculated following Geller et al. (2013) $\rho_0 \sqrt{w'^2(u'^2 + v'^2)} \left[1 - f^2 / \hat{\omega}^2\right]^2 \left[1 + f^2 / \hat{\omega}^2\right]^{-1}, \text{ where } f^2 / \hat{\omega}^2 = \frac{f^2 g^2}{w'^2 N^4} \overline{(T'/T_0)^2}$

1 Seasonal variation of GW momentum flux

Global-mean AMF (GM-AMF) (Figures 1a and 1b)

- Maximized in the solstitial seasons; minimized in the equinoctial seasons
- Solstitial seasons : **JJA** > **DJF**
- Equinoctial seasons : **SON** > **MAM** below $z = \sim 65$ km
MAM > **SON** above $z = \sim 65$ km

NH- and SH-mean AMF (Figures 1c–1f)

- Seasonal contrast
 - Upper mesosphere : summer > winter
 - Stratosphere to mid-mesosphere : winter > summer
- Hemispheric contrast
 - Summer : NH (in **JJA**) > SH (in **DJF**)
 - Winter : SH (in **JJA**) > NH (in **DJF**)

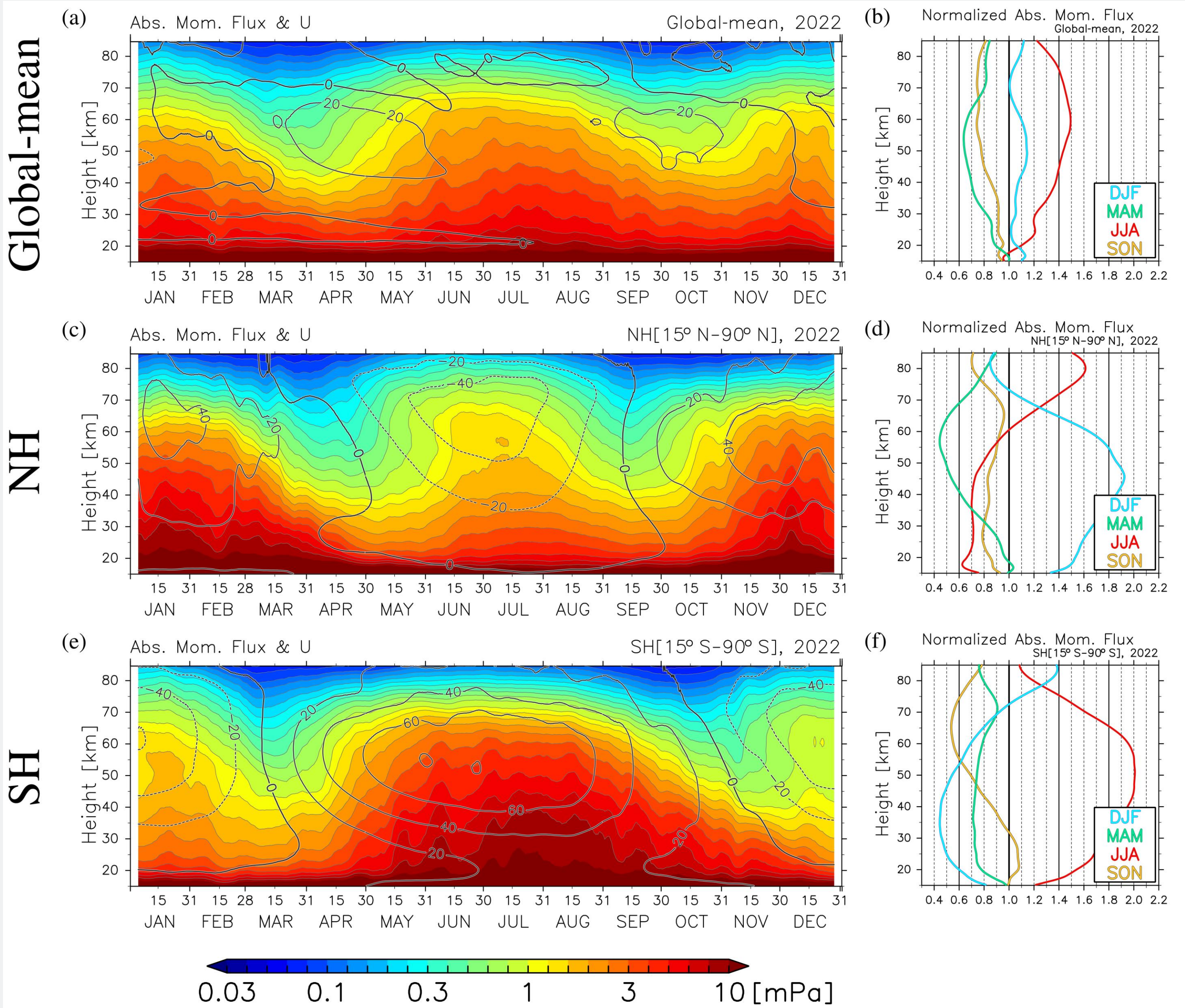


Figure 1. Panels (a, c, e) show time-height cross-sections of the AMF for (a) global-mean, (c) NH mean, i.e., average over 15°N–90°N, and (e) SH mean, average over 15°S–90°S in 2022. Solid and dashed contours show zonal-mean westerly and easterly winds at an interval of 20 m s⁻¹, respectively. Panels (b, d, f) show vertical profiles of the seasonal-mean AMF for the corresponding regions in panels (a, c, e), normalized by the annual-mean GM-AMF at each height.

Conclusion and Key Points

- GW absolute momentum flux in the upper mesosphere: summer > winter
- GWs in the summer hemisphere have sources at high latitudes
- Equatorward GWs are in-situ generated around the winter westerly jet

2 Global distribution of GW momentum flux

Summer hemisphere

- Strong over storm tracks between 50° and 70° latitude, in addition to the subtropical monsoon regions

Winter hemisphere

- Strong roughly along the polar night jets and over steep mountains and islands.

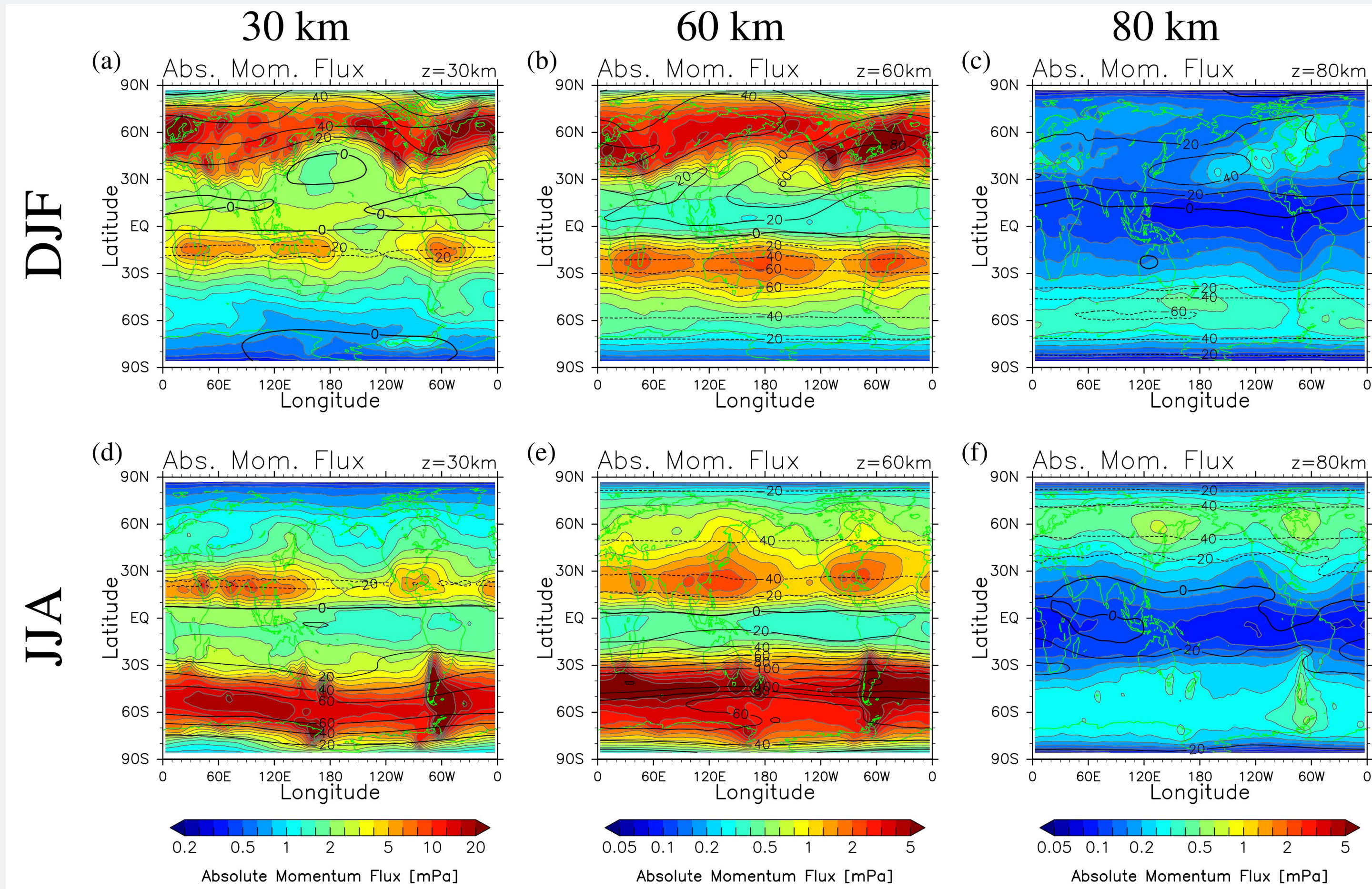


Figure 2. Horizontal maps of the seasonal mean of the AMF associated with GWs at (a, d) $z = 30$ km, (b, e) 60 km, and (c, f) 80 km. Panels (a, b, c) show results for DJF, while panels (d, e, f) show those for JJA. Solid and dotted contours indicate mean westerly and easterly winds at a 20 m s⁻¹ interval, respectively.

3 GW propagation and in-situ generation

- GWs originating near 60°N in summer may contribute to the poleward extension of the weak-wind layer
- The sign of $\overline{v'w'}$ reverses at $z = \sim 75$ km in the winter upper mesosphere
- Equatorward GWs are in-situ generated around the winter westerly jet

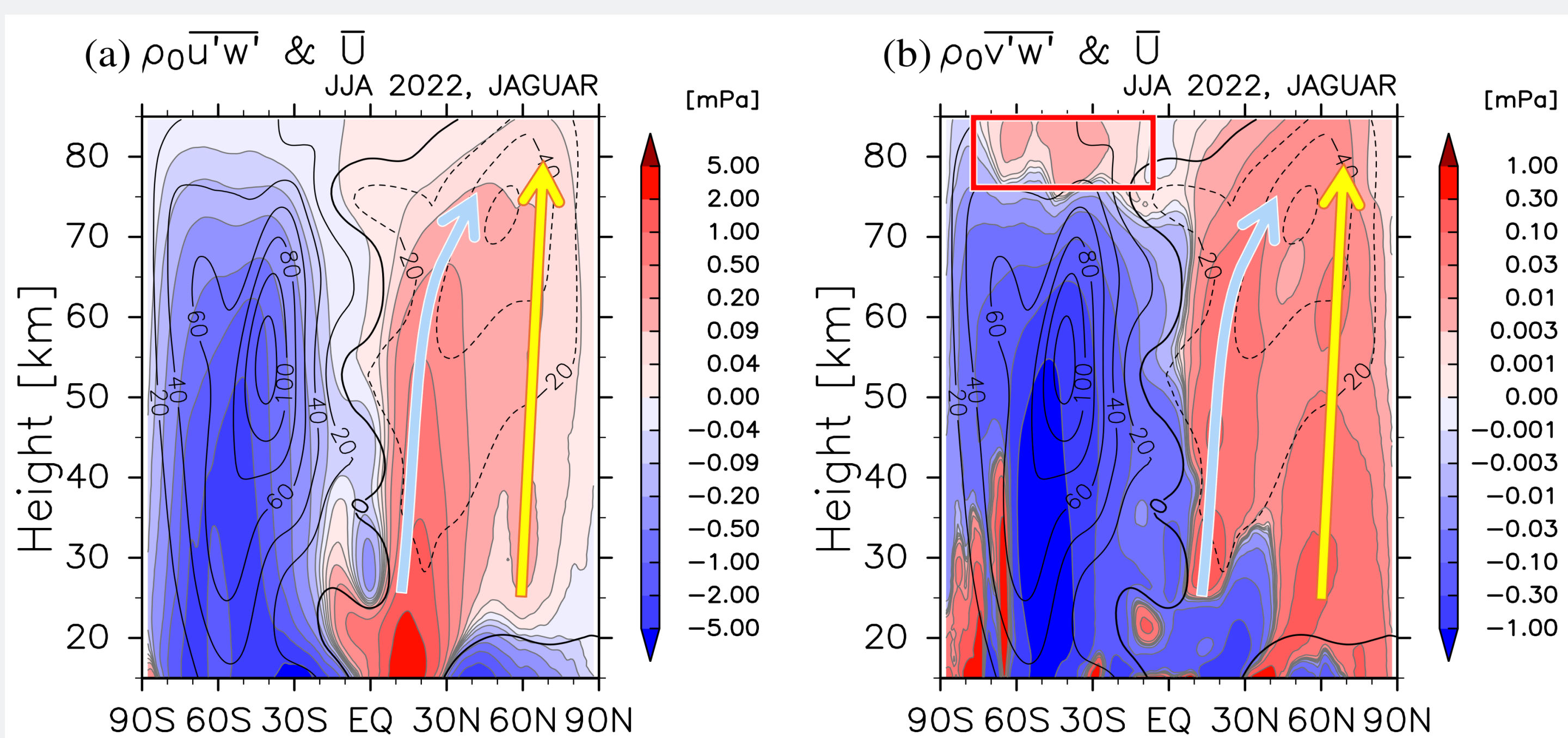


Figure 3. Meridional cross-sections of the seasonal-mean zonal-mean (a) zonal ($\rho_0 \overline{u'w'}$) and (b) meridional momentum flux ($\rho_0 \overline{v'w'}$) associated with GWs in JJA. Solid and dashed contours indicate westerly and easterly winds in 20 m s⁻¹ intervals, respectively.

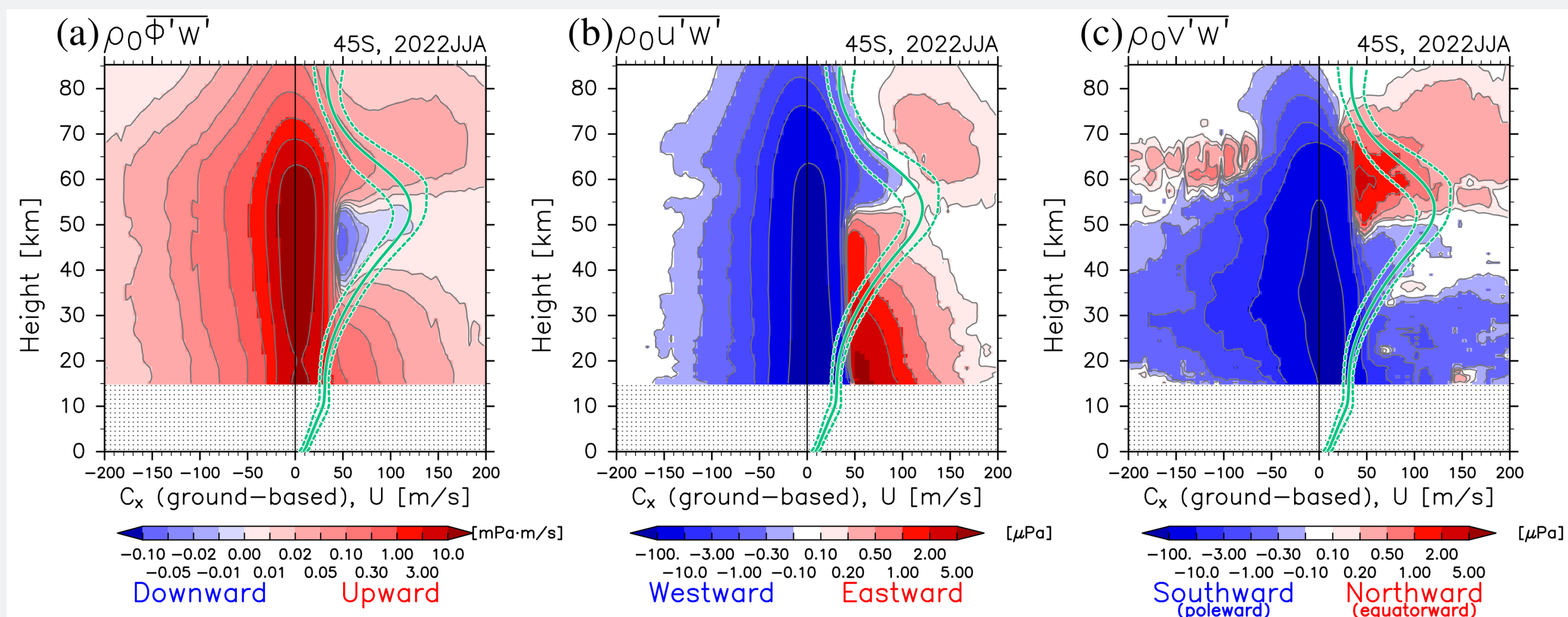


Figure 4. Zonal-mean (a) vertical fluxes of energy $\rho_0 \overline{\phi'w'}$, (b) $\rho_0 \overline{u'w'}$, and (c) $\rho_0 \overline{v'w'}$ associated with GWs at 45°S in JJA. The horizontal axis represents ground-based zonal phase velocity. Fluxes are integrated over 5 m s⁻¹ phase-speed bins. The green solid curve shows zonal-mean zonal wind $\bar{u}$ at 45°S in JJA and the dashed curves show its 5th and 95th percentiles in JJA.