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The Efficiency of Upward Wave Propagation Near the Tropopause and Reflection from the TIL: importance of the form of the refractive index

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The connection between the polar stratospheric vortex and the vertical component of the Eliassen–Palm flux in the lower stratosphere and upper troposphere is examined in model level data from ERA5. The particular focus of this work is on the conditions that lead to upward wave propagation between the tropopause and the bottom of the vortex near 100 hPa. The ability of four different versions of the index of refraction to capture this wave propagation is evaluated. The original Charney and Drazin index of refraction includes terms ignored by Matsuno that are shown to be critical for understanding upward wave propagation just above the tropopause both in the climatology and during extreme heat flux events. By adding these terms to the Matsuno index of refraction, it is possible to construct a useful tool that describes wave flux immediately above the tropopause and at the same time also describes the role of meridional variations within the stratosphere. It is shown that a stronger tropopause inversion layer tends to restrict upward wave propagation. It is also shown that while only 38% of extreme wave-1 Eliassen–Palm flux vertical component (F_z) at 100 hPa events are preceded by extreme F_z at 300 hPa, there are almost no extreme events at 100 hPa in which the anomaly at 300 hPa is of opposite sign or very weak. Overall, wave propagation near the tropopause is sensitive to vertical gradients in buoyancy frequency, and these vertical gradients may not be accurately captured in models or reanalysis products with lower vertical resolutions.

To better understand the role of the TIL for transmission and reflection of waves, an analytical quasi-geostrophic planetary scale model is used to examine the role of the tropopause inversion layer (TIL) in wave propagation and reflection. The model consists of three different layers: troposphere, TIL and stratosphere. It is shown that a larger buoyancy frequency in the TIL leads to weaker upward transmission to the stratosphere and enhanced reflection back to the troposphere, and thus reflection of wave packets is sensitive not just to the zonal wind but also to the TIL's buoyancy frequency. The vertical-zonal cross section of a wavepacket for a more prominent TIL in the analytical model is similar to the corresponding wavepacket for observational events in which the wave amplitude decays rapidly just above the tropopause. Similarly, a less prominent TIL both in the model and in reanalysis data is associated with enhanced wave

transmission and a non-detectable change in wave phase above the tropopause. Models with a poor representation of the TIL will necessarily miss all of these effects.

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