On the role of Rossby wave breaking in quasi-biennial modulation of the stratospheric polar vortex

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The quasi-biennial oscillation (QBO) in the equatorial stratosphere is known to affect the variability of stratospheric polar vortex through the 'Holton-Tan effect' (HTE). This equatorial to extratropical teleconnection has been a subject of intensive research but the underlying mechanism remains ambiguous.

Rossby wave breaking (RWB) may play a role in the observed HTE owing to its ability to induce significant meridional transport from the edge of the polar vortex to the subtropics. Here we employ the reanalysis data set in isentropic coordinates from the National Centers for Environmental Prediction Climate Forecast System (NCEP/CFSR) to study such an effect. We examine climatological behaviors of RWBs and the corresponding changes in relation to the two QBO phases using the Rossby-Ertel potential vorticity (PV) on potential temperature surfaces. RWB events are identified as meridional gradient reversals or overturningof PV contours. Contributions from small and finite amplitude Rossby waves and wave-wave interactions are further examined in the context of momentum and eddy enstrophy budgets.

We find that nonlinear critical layers play an important role in the QBO modulation of RWBs during boreal winter (December to January). A northward shift of the zero wind line in association with the easterly phase of the QBO in the lower stratosphere alters the waveguide geometry of the winter stratosphere. As a result, nonlinear critical layers in the limit of small wave amplitudes are developed in subtropical lower stratosphere at 20-40°N, 450-550 K. Eastward propagating transient waves with phase speeds of 3-10 m s^{-1} are generated as the part of absorption, reflection and overreflection cycle via the formation of Kelvin cat's eye within the critical layers. These internally generated waves propagate polewards and upwards and become unstable in the middle to upper stratosphere. Their subsequent growth and breaking at 55-75°N, 550-1000 K result in a weaker more disturbed polar vortex and warm anomalies in the polar lower stratosphere at 60-90°N, 350-550 K. The associated RWBs involve finite amplitude waves and wave-wave interactions, which play a key role in the observed HTE. When the QBO in the lower stratosphere is in its westerly phase, RWBs are mainly associated with small amplitude quasi-stationary waves that propagate upward along the polar vortex edge. Breaking of those waves in the upper stratosphere results in warm anomalies in the polar upper stratosphere at 65-90°N, 1250-1500 K. In addition, we find that the QBO also modulates RWB in the subtropical southern hemisphere in association with inertial-barotropic instability of the easterly jet.

Key words: Quasi-Biennial Oscillation, Rossby wave breaking, stratospheric dynamics, Holton-Tan effect.