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Examining the Quasi-Biennial Oscillation Modulation of Rossby Waves and the Northern Hemisphere Stratospheric Polar Vortex Using Ertel's Potential Vorticity

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It is recognised that the strength of the northern hemisphere winter stratospheric polar vortex is related to the phase of the equatorial quasi-biennial oscillation (QBO). When the QBO at 50hPa is in its westerly phase (QBOw), the vortex is stronger and colder. When the QBO is in its easterly phase (QBOe), the vortex becomes weaker and warmer. Previous studies have suggested that Rossby waves, especially those of planetary scale, play a critical role in linking the QBO to the polar vortex strength, although the mechanism which explains this modulation is unclear.

In this study, we investigate the QBO modulation of planetary and synoptic waves using Ertel's potential vorticity (PV). It is known that the ability of a Rossby wave to propagate in the stratosphere depends on a positive background meridional PV gradient existing. We examine three PV diagnostics, each of which is based, in part, on this gradient. These diagnostics include a Rossby wave breaking criterion, a wave activity density quantity and the frequency of reversals in PV gradient. Together, they enable us to identify the key regions where wave breaking, wave propagation and wave-mean flow interaction occur in response to the two phases of the QBO. These three diagnostics are calculated using the high resolution, ECMWF ERA-Interim reanalysis PV data on nine isentropic surfaces in the stratosphere over the period 1979-2012.

We find that the QBO affects planetary and synoptic waves in different ways, with preferential latitudes and different zonal structures in the stratosphere. For the first time, we find that an enhanced poleward advection of the negative PV gradient anomalies from low latitudes to high latitudes is associated with QBOw in the middle stratosphere and lower stratosphere, where the QBO excites barotropic instability and generates synoptic waves in the subtropics. In the middle stratosphere, the residual meridional circulation transports these tropical anomalies to middle latitudes to affect the polar vortex directly. In the lower stratosphere, this poleward advection indirectly affects the strength of the vortex by modulating the ability of planetary waves to propagate vertically into the stratosphere. At high latitudes, the QBOw conditions modulate planetary waves by enhancing the wave density and also wave breaking at $\sim$35N, whilst reducing wave activity at $\sim$65N. Under QBOe conditions, the opposite effect occurs. These results suggest that the QBO modulation of the polar vortex occurs via a combined effect of synoptic wave-mean flow interaction in the subtropical to middle latitudes and a modulation of planetary waves at middle to high latitudes.