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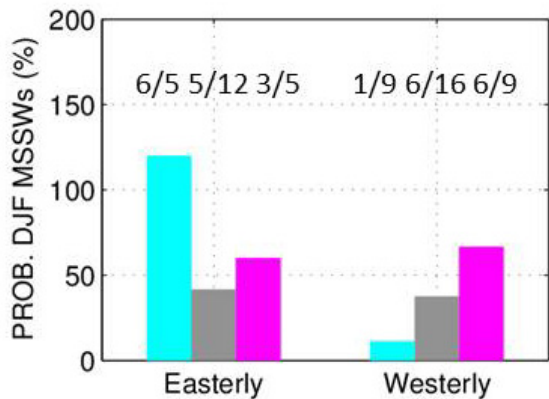


Figure 1. Probability (%) of MSSWs from December to February for the QBO easterly and westerly phases: cyan for LA, gray for NT, and magenta for EL. The EL and LA winters are defined as when the NINO3.4 index falls in the bottom or top 25 % of the 56 years, respectively. The panel includes the numbers of the MSSWs (numerator) and winters (denominator).

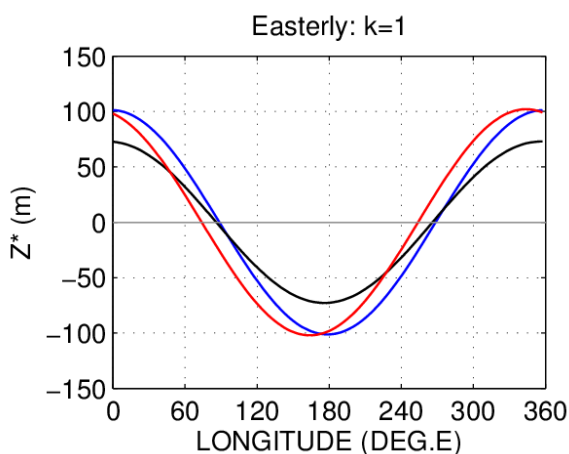


Figure 2. Composite longitudinal structures of the stationary wave of zonal wavenumber 1 at 60°N, 300 hPa from December to February for the QBO easterly phase: blue for LA, black for NT, and red for EL.

- Changes in occurrence of major stratospheric sudden warmings (MSSWs) for Northern winter with El Niño/Southern Oscillation (ENSO) and Quasi-Biennial Oscillation (QBO) are investigated using the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis data for 56 years.
- La Niña (LA) and El Niño (EL) phases of the ENSO are defined using the NINO3.4 index. Easterly and westerly phases of the QBO are classified with a 0 m/s threshold of the equatorial zonal wind at 50 hPa.
- Our results reveal complex changes in the MSSW probability with both ENSO and QBO (Fig. 1). When the QBO is in a westerly phase, the MSSW probability increases with the ENSO sea-surface temperature condition in the eastern equatorial Pacific, i.e., from LA, through neutral (NT), to EL years. When the QBO is easterly, the probability significantly increases for LA years than for NT years, whereas the probability is not significantly different between NT and EL years.
- A characteristic feature is the high MSSW probability for the LA and QBO easterly winters, which is consistent with strengthened stationary wave with zonal wavenumber 1 compared to the climatology (Fig. 2).