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# Water vapor variability in the Asian summer monsoon lower stratosphere from satellite observations and transport model simulations

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The Asian monsoon anticyclone is an important transport pathway for water vapor entering the global stratosphere. We use pentad-resolution gridded data from Aura Microwave Limb Sounder (MLS) satellite observations and CLaMS transport model simulations based on two atmospheric reanalyses to examine variations of water vapor in the lower stratosphere (100-68hPa) above the Asian summer monsoon during the warm seasons (May-September) of 2005 through 2017. Model outputs have been post-processed to facilitate direct comparison with MLS retrievals. A localized water vapor maximum is present in the upper troposphere and lower stratosphere above the Asian summer monsoon, with substantial interannual and intraseasonal variability superimposed on the mean seasonal cycle. The CLaMS simulations largely capture both the climatological distribution and variability of lower stratospheric water vapor but with a systematic moist bias, sharper spatial gradients, and larger variance in time relative to MLS. Applying principal component analysis to both vertical and horizontal variability of deseasonalized anomalies within this layer, we identify and describe the three leading modes of variability in lower stratospheric water vapor. The leading mode features regional-scale moistening or drying, with anomalies taking the same sign throughout the layer. Notably, cold point temperature anomalies are in phase with water vapor anomalies in the western part of the domain but out of phase in the eastern part of the domain, where the largest water vapor anomalies are located. The moist phase of this mode is also associated with systematically deeper convection through much of the monsoon domain. The second mode features a vertical dipole, with wet anomalies at 100 hPa (centered over the Persian Gulf but stretching across most of the domain) coupled with dry anomalies at 68 hPa and vice versa. This mode is linked to large anomalies in cold point temperature that span the southern part of the monsoon domain, with the moist phase at 100 hPa associated with warmer cold point temperatures. Warmer temperatures lead to negative anomalies in radiative heating in the lower stratosphere, which may in turn explain the dry anomalies at 68 hPa. The third mode features a horizontal dipole oriented east-to-west, with a deep layer of enhanced water vapor centered over the southeastern Tibetan Plateau coupled with dry anomalies in the west and vice versa. The moist phase of this mode is associated with more extensive cloud cover and deeper convection stretching across China from the eastern Tibetan Plateau. Cold point temperatures are colder and the upper-level monsoon anticyclone stronger in the eastern part of the domain, with opposing anomalies in the west. CLaMS is largely able to reproduce the first and third modes, but fails to capture the second mode and overemphasizes the importance of the third mode. Meanwhile, the monsoon season of 2017 emerges as a special case, with persistent large positive anomalies in lower stratospheric water vapor that are reproduced when CLaMS is driven using ERA-Interim but not when it is driven by MERRA-2. We discuss some possible explanations for these differences.