



## **Three-dimensional circulation structures leading to heavy summer rainfall over central North China**

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Using daily and hourly rain gauge records and Japanese 25 year reanalysis data over 30 years, this work reveals two major circulation structures leading to heavy summer rainfall events in central North China (CNC), and further analyzes the effects of the circulations on these rainfall events. One circulation structure has an extensive upper tropospheric warm anomaly (UTWA) covering North China (NC). By strengthening the upper anticyclonic anomaly and lower southerly flows around NC, the UTWA plays a positive role in forming upper level divergence and lower level moisture convergence. As a result, the warm anomalous circulation has a solid relationship with large-scale, long-duration rainfall events with a diurnal peak around midnight to early morning. The other circulation structure has an upper tropospheric cold anomaly (UTCA) located in the upper stream of NC. Contributed to by the UTCA, a cold trough appears in the upper stream of NC and an unstable configuration with upper (lower) cold (warm) anomalies forms around CNC. Consequently, CNC is covered by strong instability and high convective energy, and the cold anomalous circulation is closely connected with local, short-duration rainfall events concentrated from late afternoon to early nighttime. The close connections between circulation structures and typical rainfall events are confirmed by two independent converse analysis processes: from circulations to rainfall characteristics, and from typical rainfall events to circulations. The results presented in this work indicate that the upper tropospheric temperature has significant influences on heavy rainfall, and thus more attention should be paid to the upper tropospheric temperature in future analyses.