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*Supplement of*

# Interannual variability of the boreal summer tropical UTLS in observations and CCMVal-2 simulations

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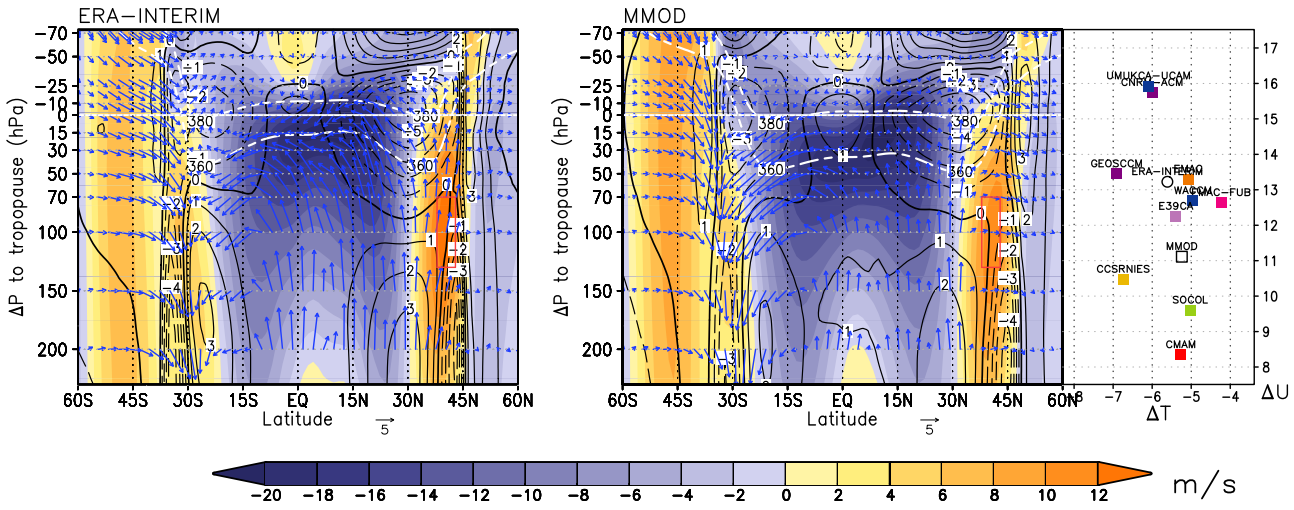


**Figure S1:** Latitude–height sections of JA long-term mean anomaly of the zonal velocity averaged over 30° in longitudes, centred where the 150 hPa eastward directed divergence free zonal wind maximizes, from the zonal average (shaded). All data interpolated to pressure levels relative to the tropopause height. Left: ERA-Interim (35 years); right: the multi-model average (45 years). Black contours show the temperature anomalies of the respective latitude sections from the zonal average. White dashed contours indicate the 360 and 380 K isentropic levels. Blue arrows denote the meridional (in m/s) and vertical velocity (in mm/s). The maximum of the zonal wind anomaly and the minimum of the temperature anomaly near the tropopause are displayed as scatter plot for individual models (squares), the multi-model average, and ERA-Interim (circle).

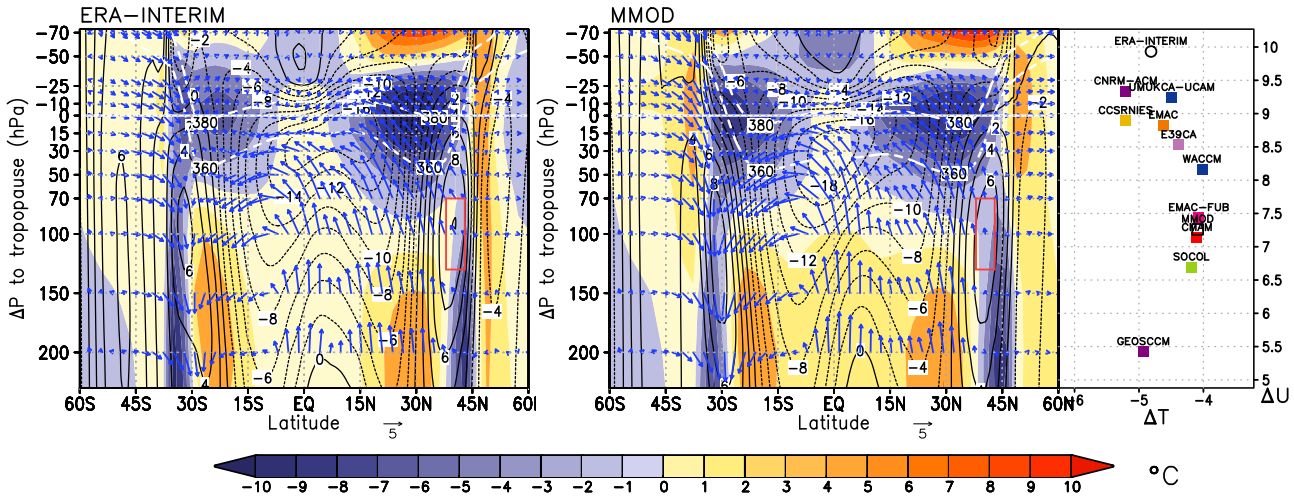


**Figure S2:** As Fig. 1 but for fixed sectional average from 60–120°E, and temperature anomalies displayed shaded.

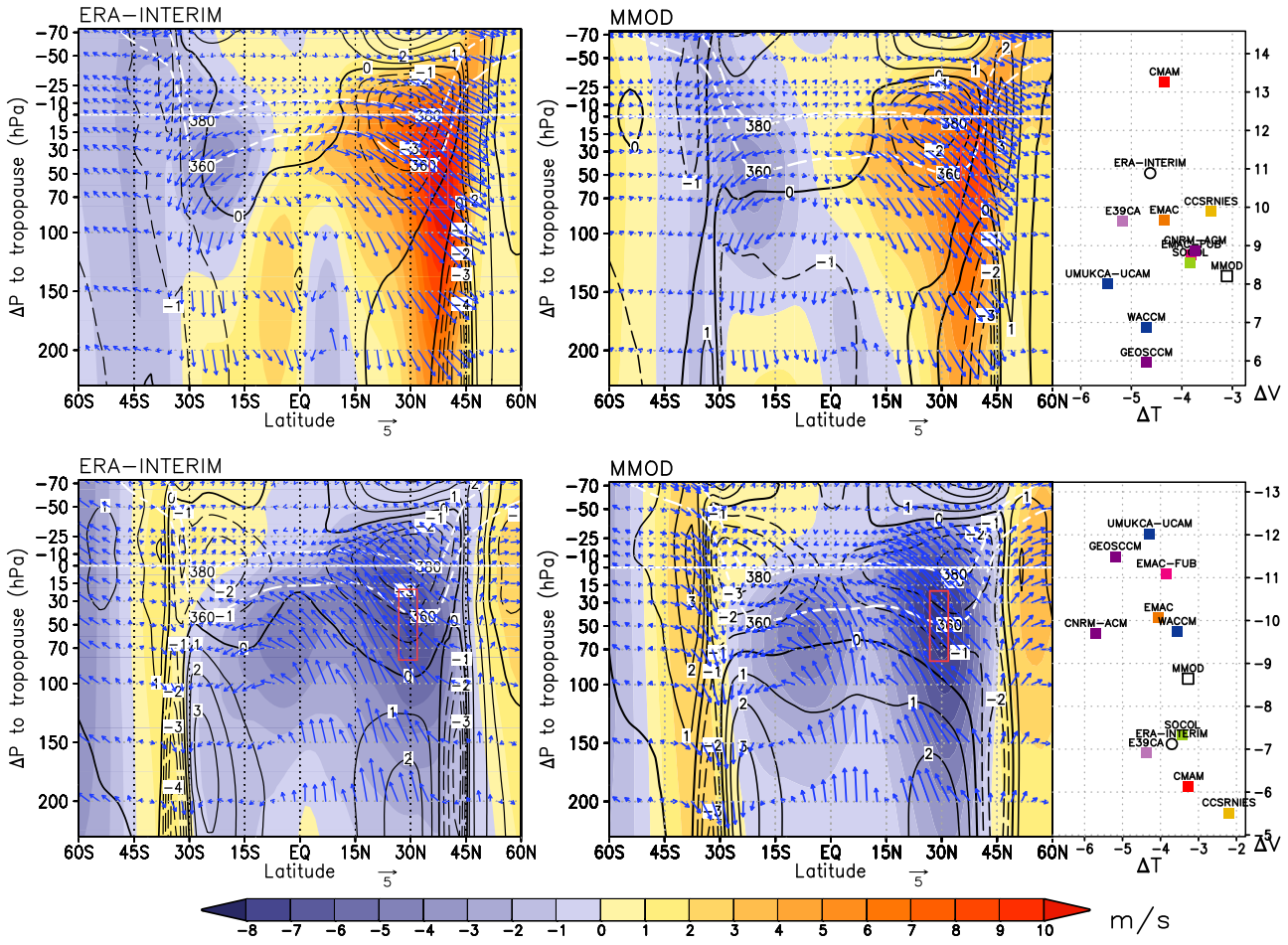


**Figure S3:** As Fig. 1 but for the meridional velocity averaged over 30° in longitudes; top: centred at the western flank of the AMA where the 150 hPa northward directed divergence free meridional wind maximizes, relative to the zonal average; bottom: centred at the eastern flank of the AMA where the 150 hPa southward directed divergence free meridional wind maximizes, relative to the zonal average.

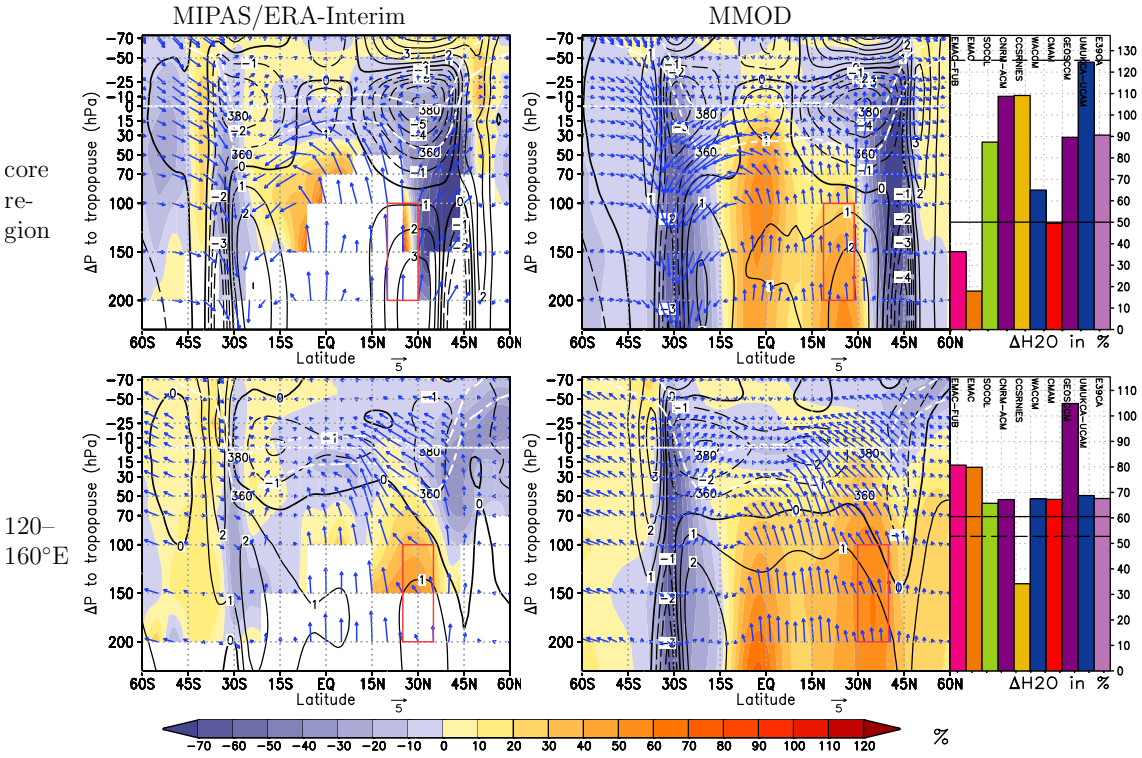


**Figure S4:** Latitude–height sections for pressure levels relative to the tropopause pressure for JA climatologies of the multi-model mean (right) and MIPAS($H_2O$)/ERA-Interim(temperature) (left): Anomalies of $H_2O$ mixing ratios in % averaged over 30° in longitudes, centred where the 150 hPa eastward directed divergence-free zonal wind maximizes (shaded) (top), and averaged between 120° –160°E (bottom), shading interval is 10%; temperature anomalies (black contours) of the latitude sections from the zonal average. White dashed contours indicate the 360 and 380 K isentropic levels. Blue arrows denote the meridional (in m/s) and vertical velocity (in mm/s). The maximum of the $H_2O$ anomaly within the region enclosed by the red rectangle for individual models is displayed as bar chart, where the solid horizontal line represents the multi-model average, and the dashed horizontal line represents the maximum of the MIPAS data.

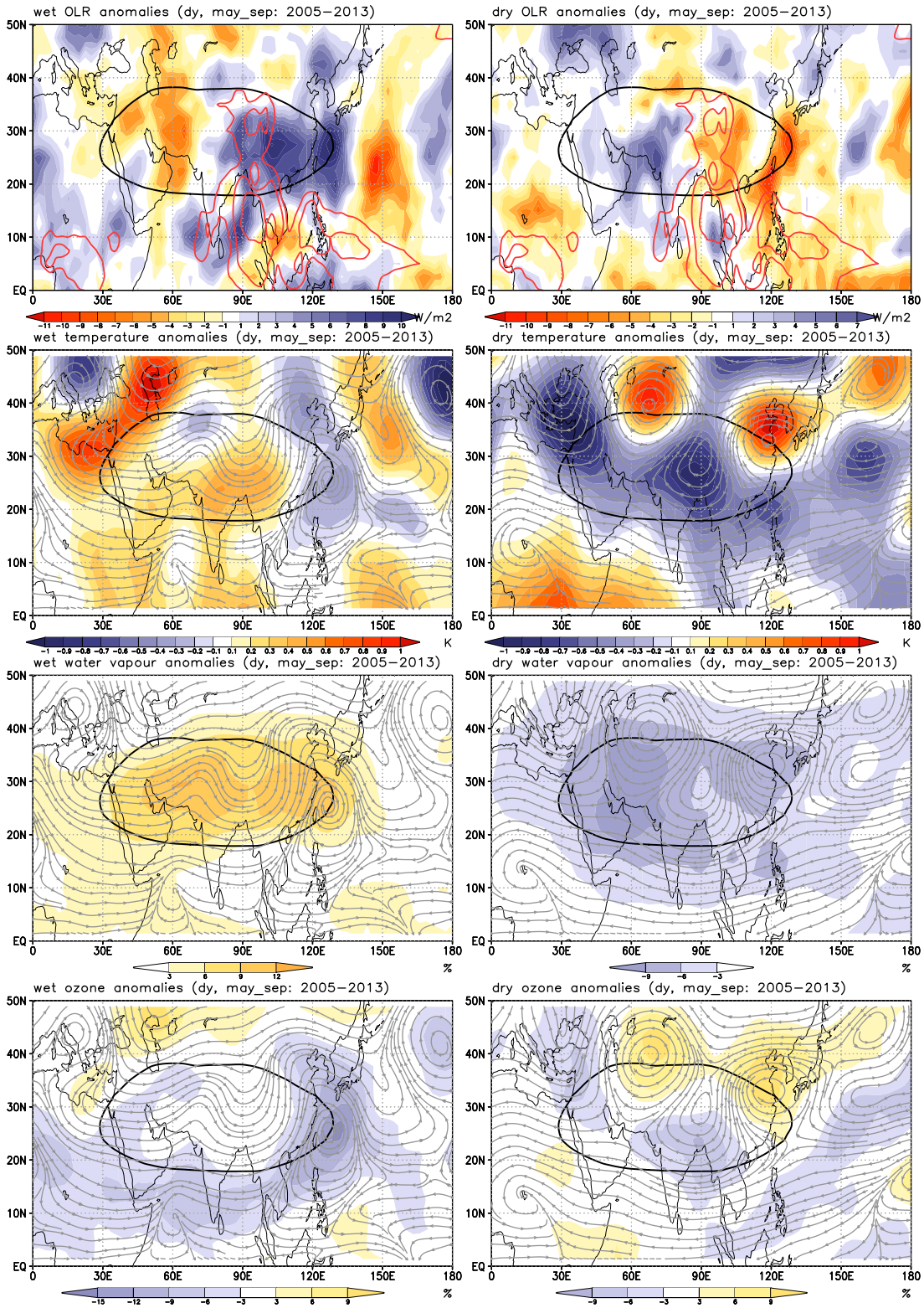


**Figure S5:** Composited anomalies for wet (left) and dry (right) 100 hPa ERA-Interim water vapor extrema from May to September over the Asian monsoon region (20–40°N, 40–140°E) analysed for years from 2005–2013, from top to bottom for NOAA OLR, ERA-Interim temperature, water vapour, and ozone without QBO and ENSO variability. Overlaid as streamlines in grey are the composited horizontal wind anomalies; the 16.750 m geopotential height contour is overlaid in black. Results for OLR are shown averaged 0–10 days prior to the stratospheric water vapour extrema; overlaid red contours indicate climatological OLR values $\leq$ 220 W m$^{-2}$. Adapted from Randel et al. [2015].

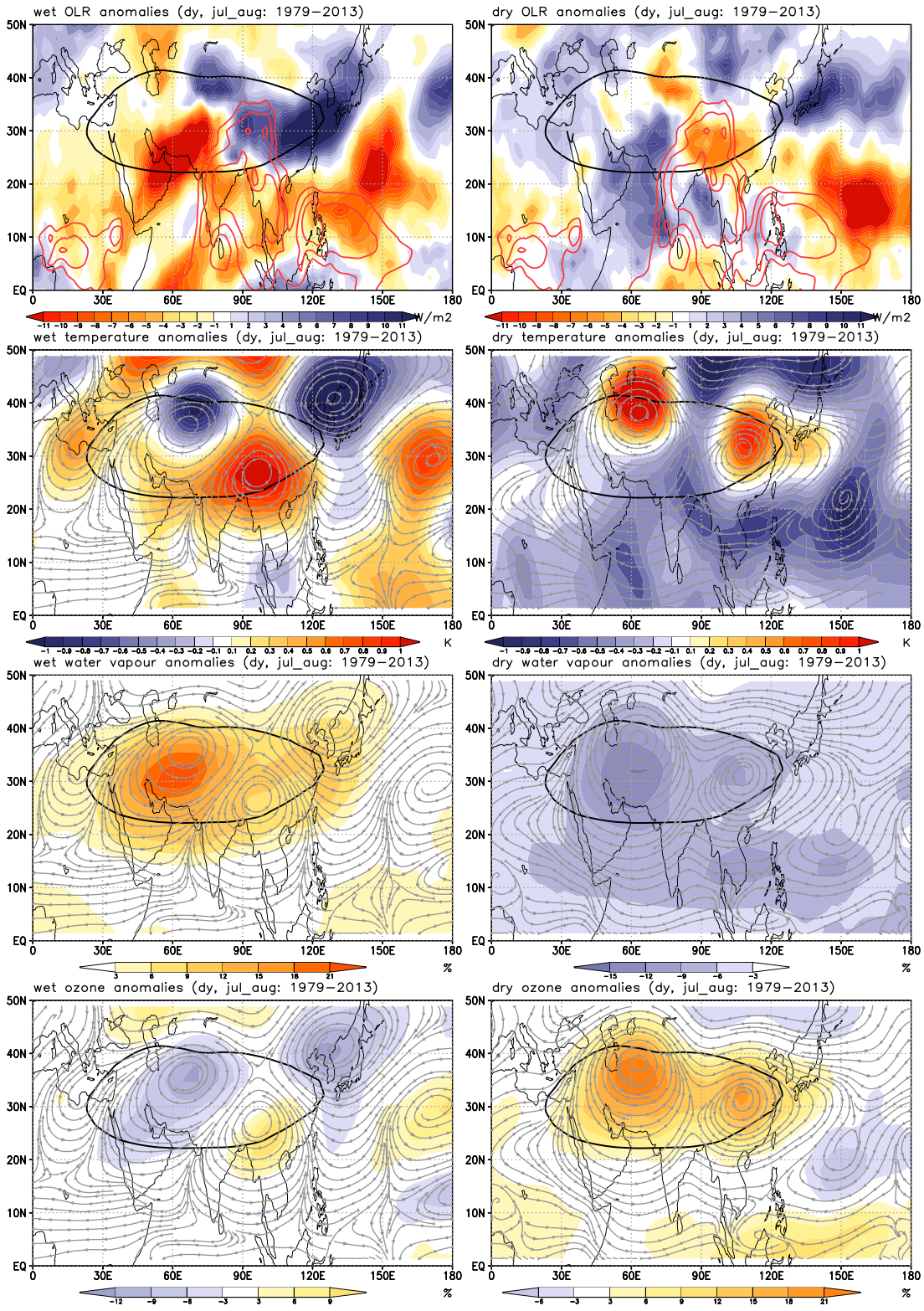


**Figure S6:** As Fig. 5 but using data from July to August for years from 1979–2013.

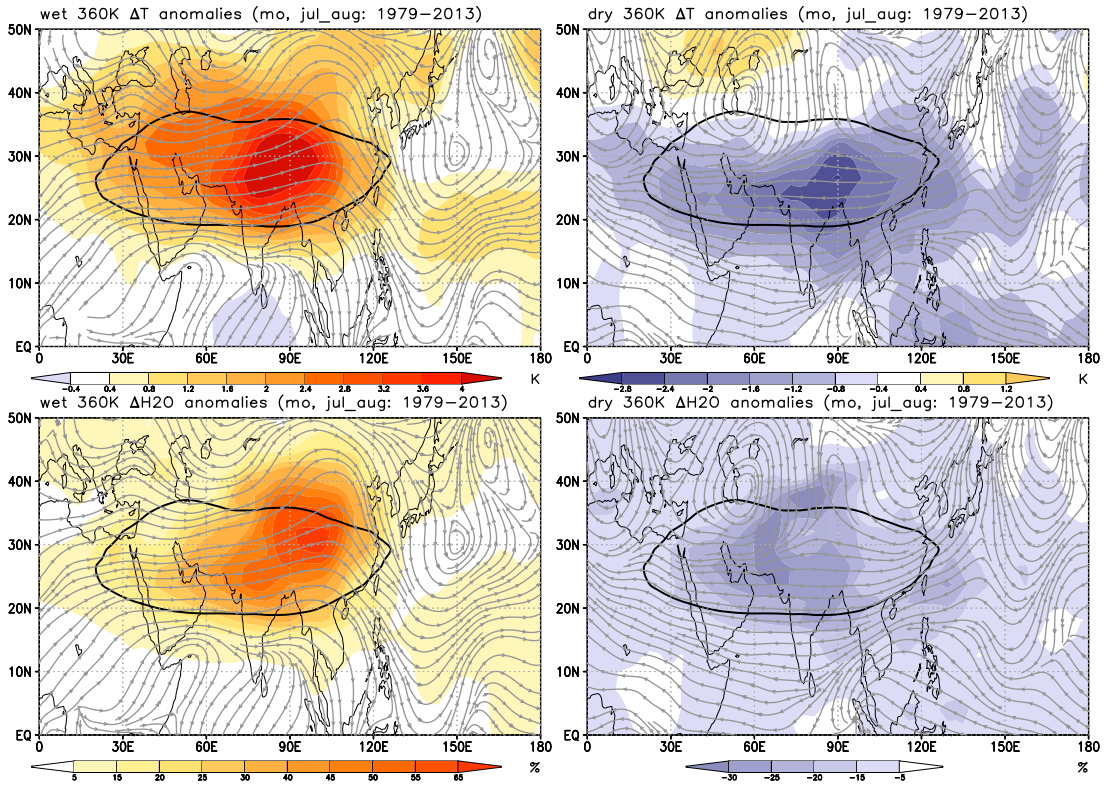


**Figure S7:** Composited anomalies for wet (left) and dry (right) 360 K monthly mean ERA-Interim water vapor extrema in July and August over the TP region (30–40°N, 70–100°E) analysed for years from 1979–2013; ERA-Interim temperature (top) and water vapour (bottom). The ERA-Interim data are preprocessed and do not include QBO and ENSO variability. Overlaid as streamlines in grey are the composited horizontal wind anomalies; the 3513 $\times$ $10^2$ $m^2$ $s^{-2}$ contour of the Montgomery streamfunction is overlaid in black.

# References

Randel, W. J., Zhang, K., and Fu, R.: What controls stratospheric water vapor in the NH summer monsoon regions?, J. Geophys. Res.: Atmos., doi:10.1002/2015JD023622, 2015.