Supplementary information for:

What controls the interannual variation of Hadley cell extent in the Northern Hemisphere: Physical mechanism and empirical model for edge variation

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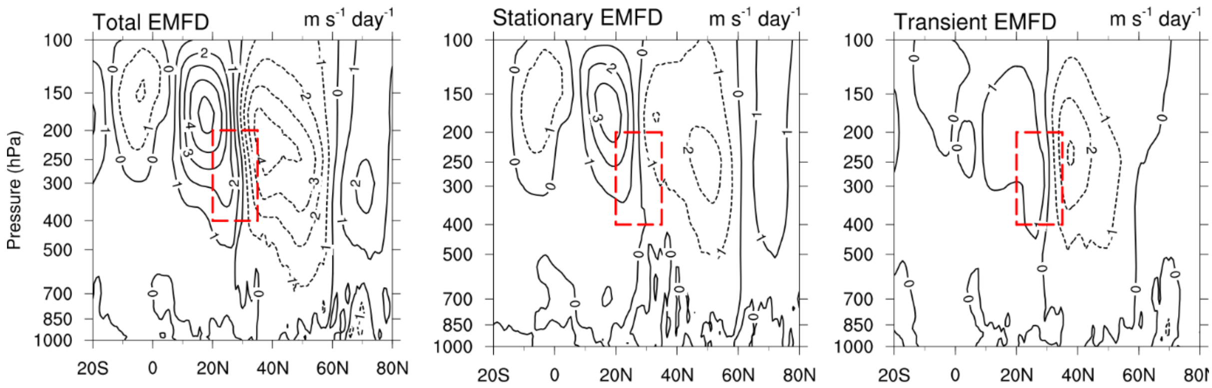
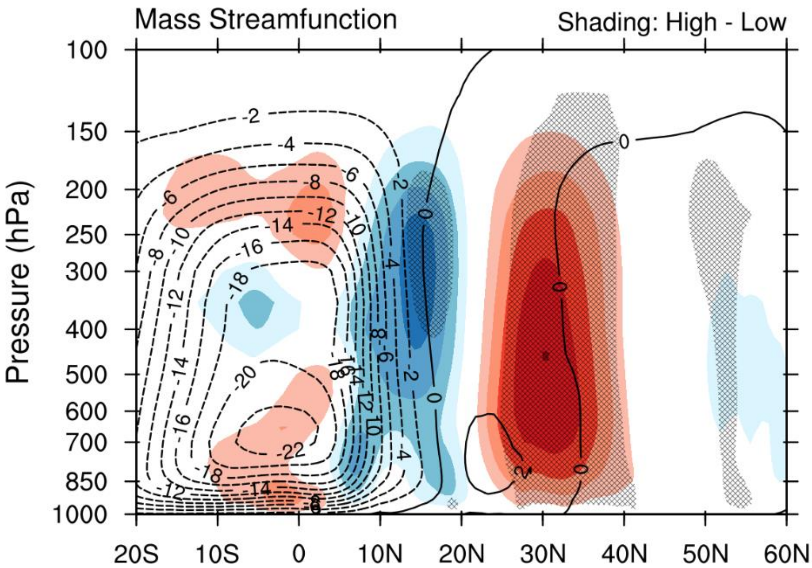
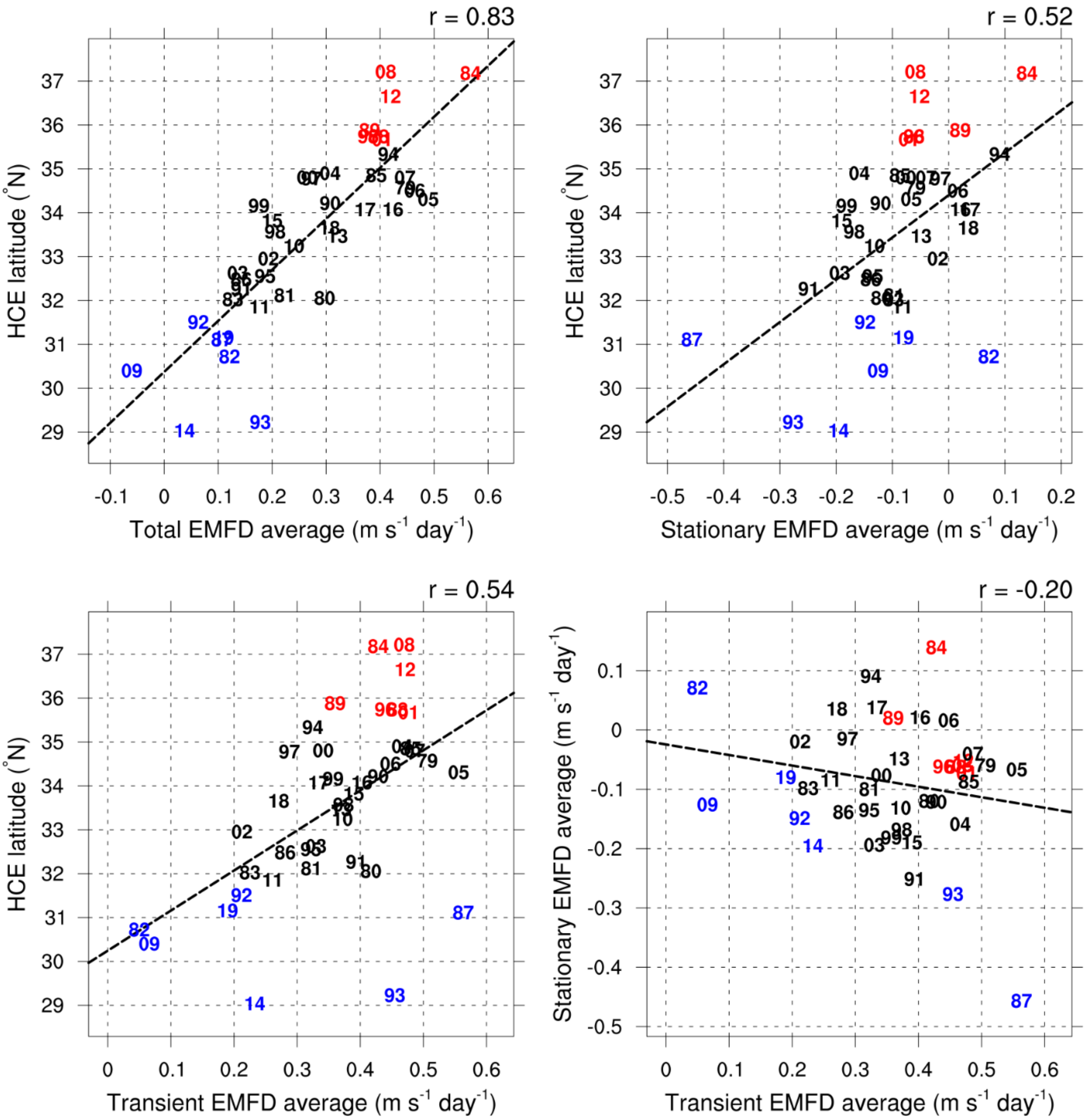


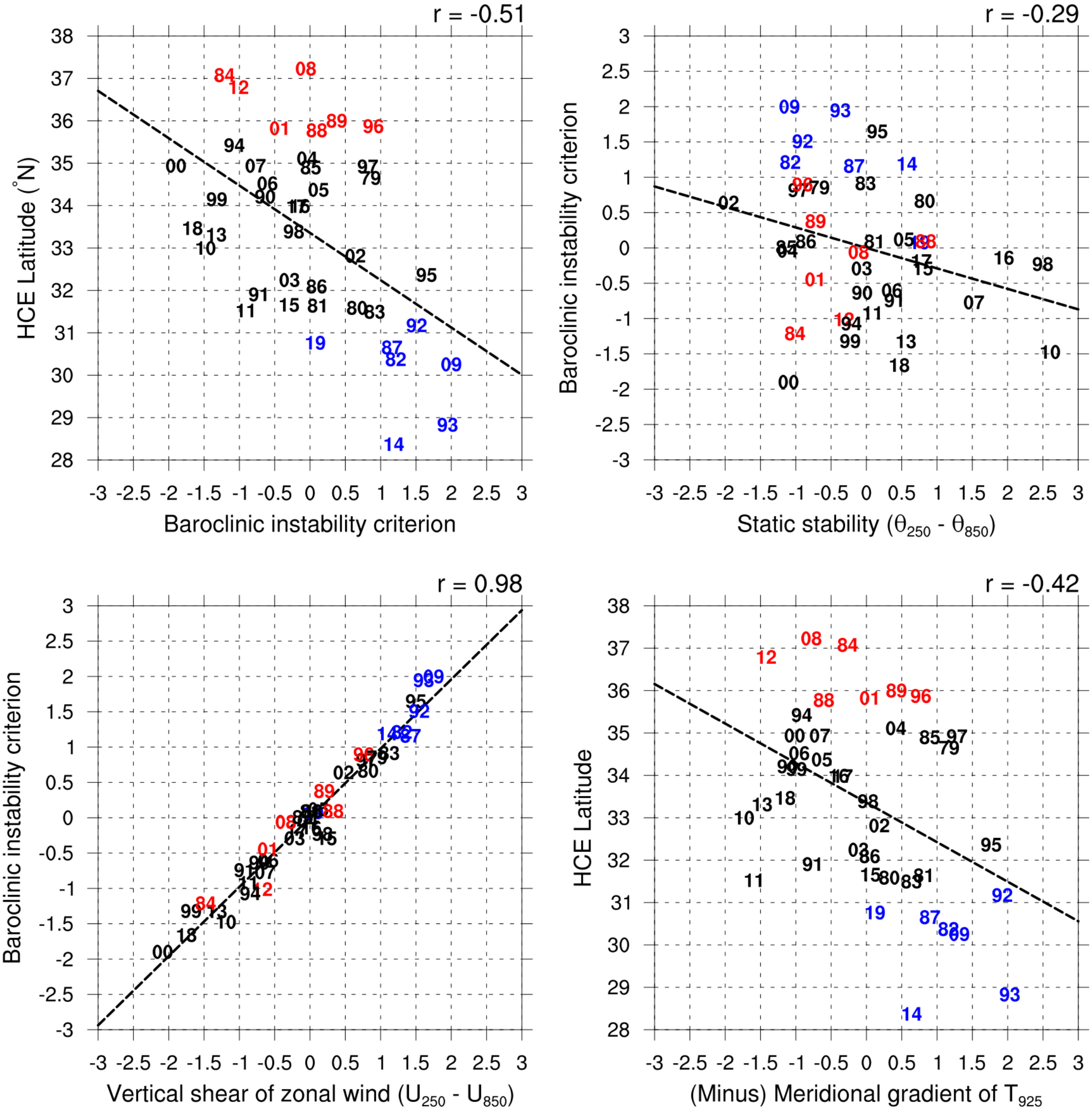
Supplementary Figure 1. EMDF structure for DJFM. Latitude–height plot of EMFD (in units of m s^{-1} day^{-1}) averaged over 41 years for (**a**) total wave, (**b**) stationary wave, and (**c**) transient wave. Red box denotes a region enclosed by [400–200 hPa, 20°–35°N].



Supplementary Figure 2. Streamfunction composite for JJAS. Mass streamfunction for climatology (contour) and high-minus-low HCE latitude year composite (shading) for JJAS. Units are 10^{10} kg s^{-1}. Hatching denotes a significant area at the 95% confidence level.

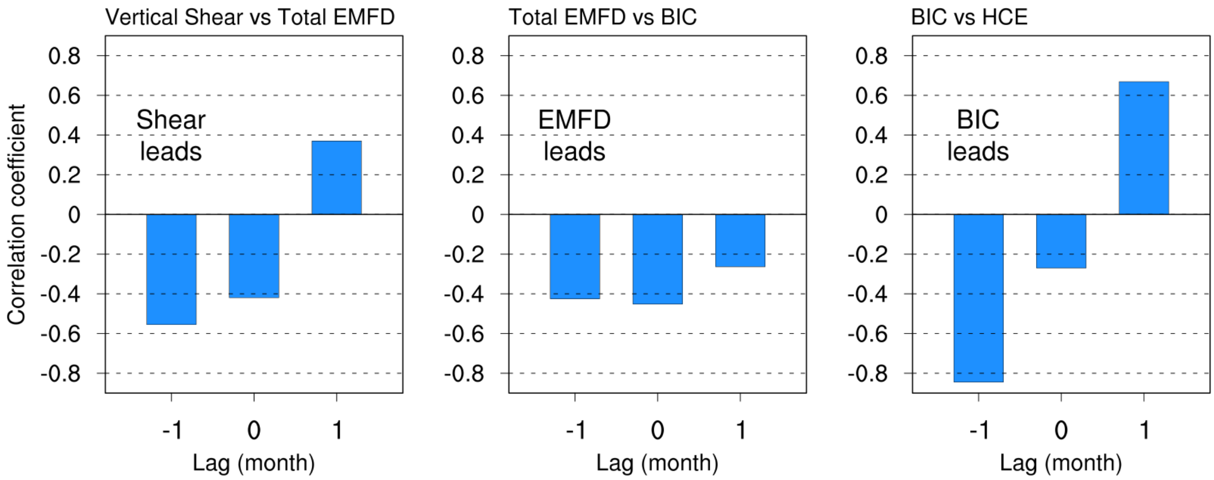


Supplementary Figure 3. Relationship between HCE latitude and EMFD for JJAS. (**a**) Scatter plot of (a) HCE latitude vs. EMFD averaged over a box enclosed by [400–200 hPa, 25°–40°N] for individual years during JJAS. The same as (a) except for (**b**) stationary wave and (**c**) transient wave. (**d**) EMFD from stationary wave vs. that from transient wave. The linear correlation is shown at the caption and linear regression lines are superimposed.

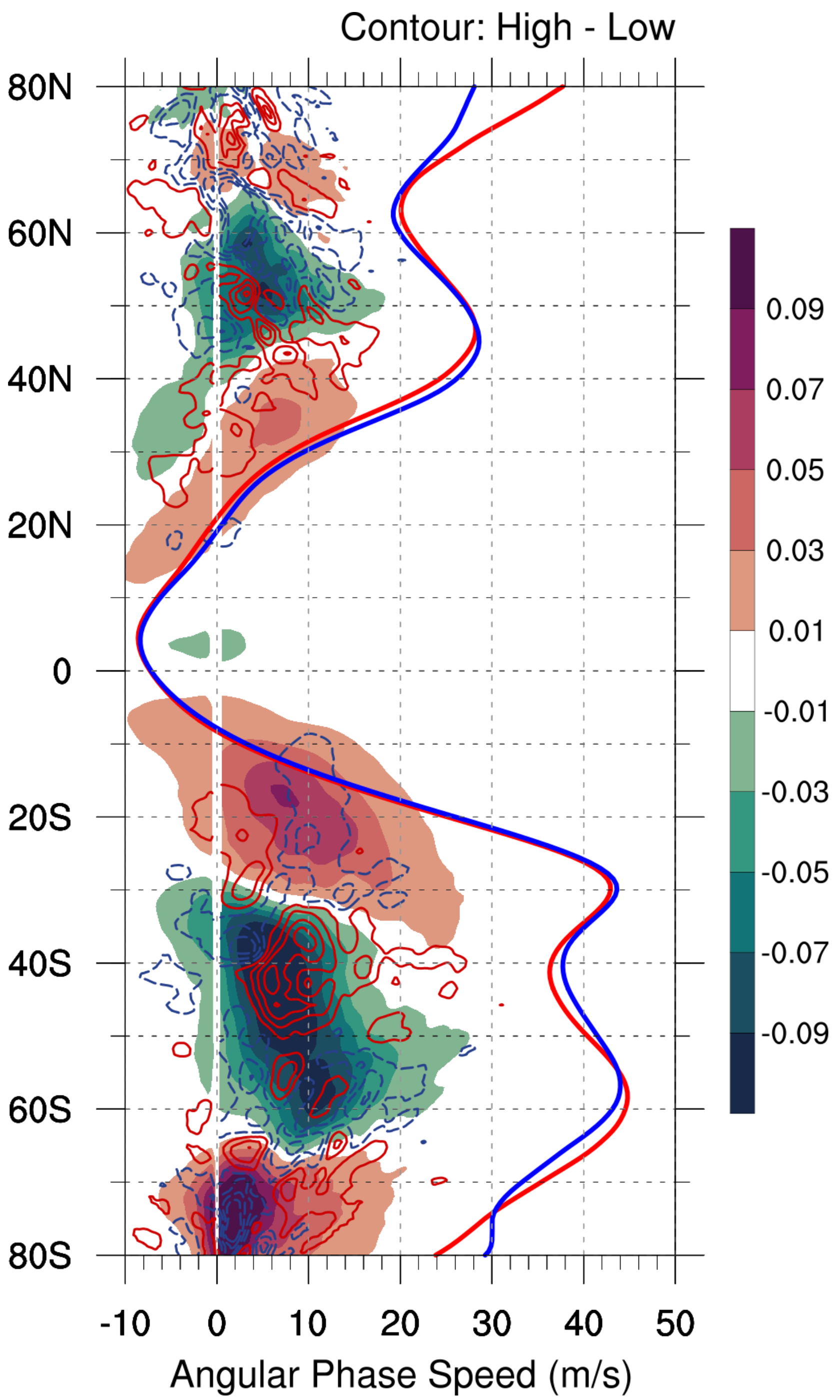


Supplementary Figure 4. Relationship between HCE latitude and baroclinicity for JJAS.

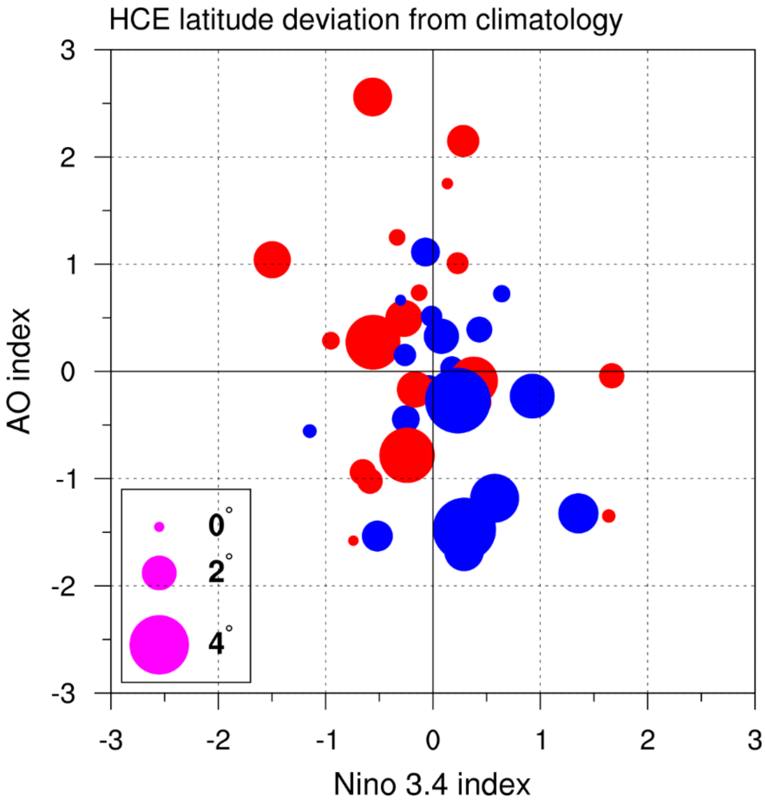
(a) BIC vs. HCE latitude (°N), (b) bulk static stability (K) vs. BIC, (c) vertical wind shear (m s^{-1}) vs. BIC, and (d) (–)meridional temperature gradient at 925 hPa (K m^{-1}) vs. HCE latitude (°N) for the latitudinal domain [25°–40°N]. All variables have been standardized except for HCE latitude.



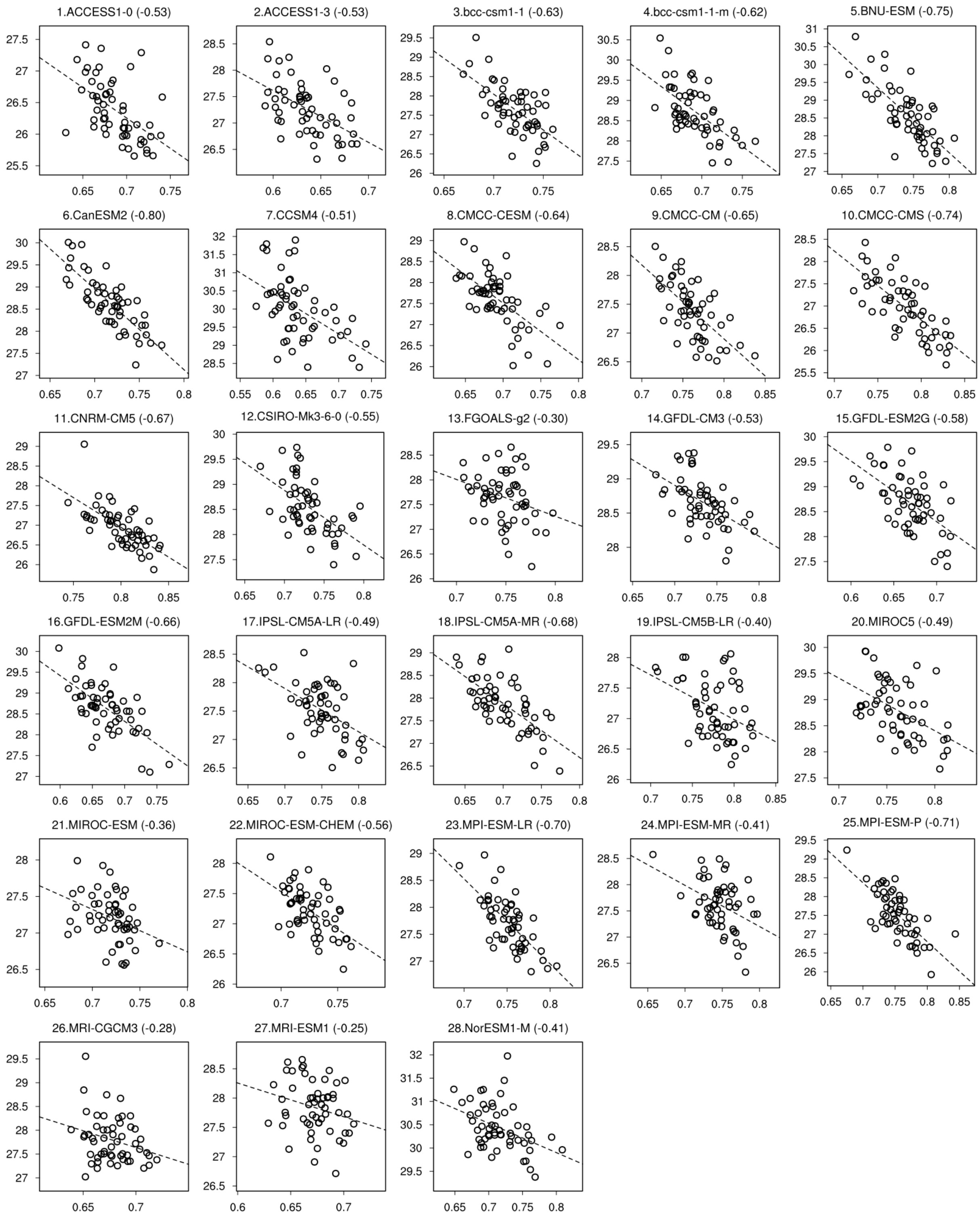
Supplementary Figure 5. Temporal correlaton of related variables with HCE variation for JJAS. Lead–lag correlation coefficients between (a) vertical shear vs EMFD, (b) EMFD vs BIC (baroclinicity), and (c) BIC vs HCE, using DJFM monthly data. Averaged latitudinal domain is [25°–40°N].



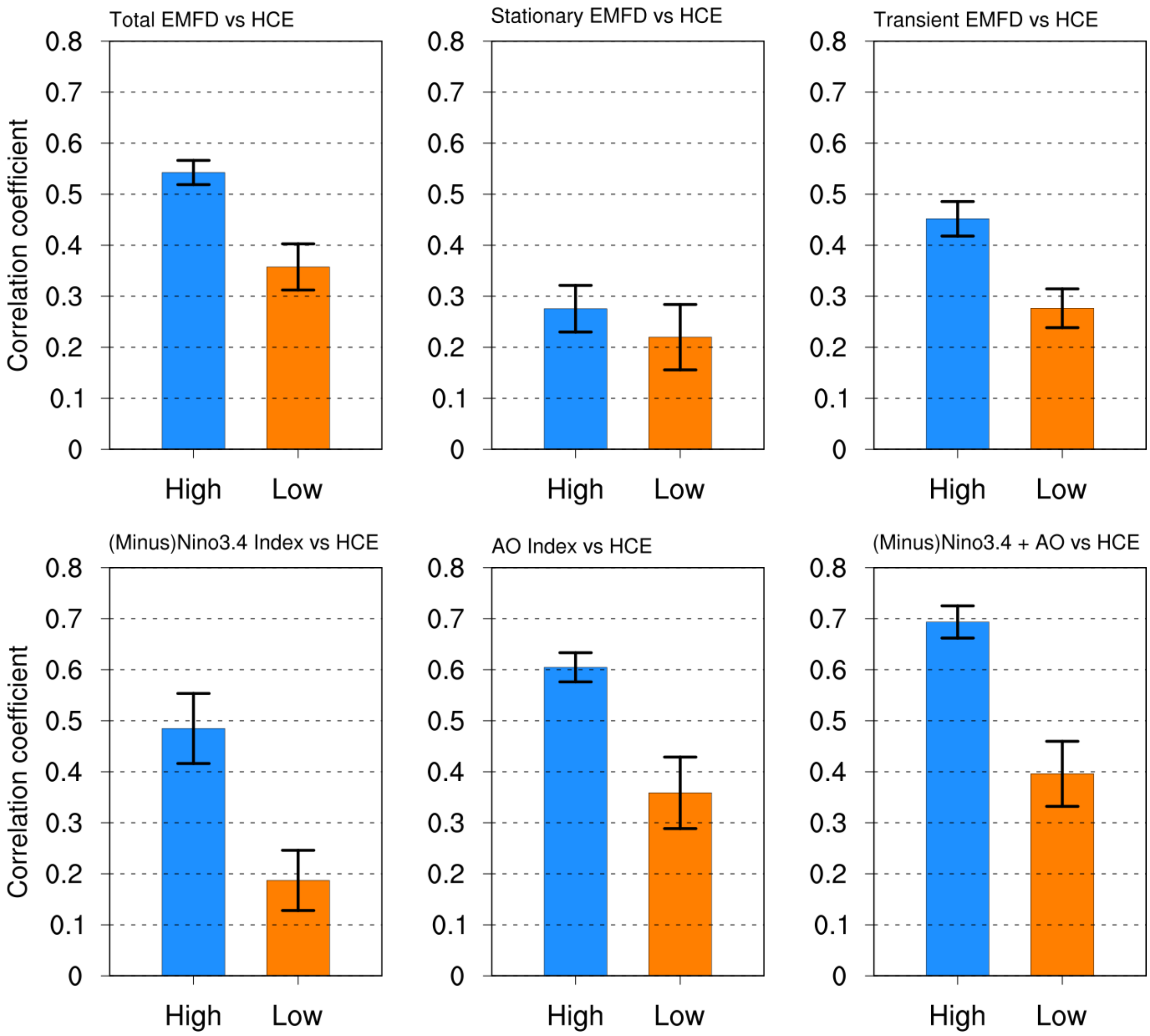
Supplementary Figure 6. Spectral analysis and application of critical latitude theory. Co-spectrum (m s^{-1} day^{-1}) of the EMFD at 250 hPa (red and blue contour, intervals of 0.01 m s^{-1} day^{-1} with zero omitted) during JJAS for high-minus-low HCE latitude years with climatology (shading, intervals of 0.02 m s^{-1} day^{-1}). On the right side are the 250-hPa zonal winds (m s^{-1}) divided by *cos*(latitude) for high (red line) and low (blue) HCE years.



Supplementary Figure 7. HCE latitude as a function of two natural variabilities during JJAS. Scatter plot of HCE latitude deviation from mean with respect to the axes of NIÑO3.4 and AO indices for 41-year data during JJAS. Positive (negative) deviations are in red (blue) dots with their size representing the magnitude of HCE latitude deviation.



Supplementary Figure 8. Validation using CMIP5 data for DJFM. Scatter plot of BIC (abscissa) averaged over [20°–35°N] vs. HCE latitude (°N, ordinate) for the period from 1950 to 2005 (55 DJFMs) for 28 CMIP5 models. Among these, 12 models (3, 4, 5, 6, 8, 9, 10, 11, 16, 18, 23, and 25) are selected as the high correlation model group, whereas 9 models (13, 17, 19, 20, 21, 24, 26, 27, and 28) are as the low correlation model group. The correlation coefficient is presented in the caption of each panel.



Supplementary Figure 9. Validation using CMIP5 two select groups for DJFM. Average correlation coefficient between HCE latitude and (**a**) total, (**b**) stationary, and (**c**) transient EMFD during DJFM for 10 high correlation and 8 low correlation model groups. EMFD is calculated for the domain [400–200 hPa, 20°–35°N], as shown in Supplementary Figure 1. Average correlation coefficients (**d**) between HCE latitude and (–)NIÑO3.4 index, (**e**) between HCE latitude and AO index, and (**f**) between HCE latitude and combined index using (–)NIÑO3.4+AO. Error bar represents standard error.