Supporting Information for

Recent tangible interannual variability of monsoonal orographic rainfall in the Eastern Himalayas

Pratik Kad[1], and Kyung-Ja Ha[1,2,3]

[1]Department of Climate System, Pusan National University, Busan, South Korea

[2]Center for Climate Physics, Institute for Basic Science, Busan, South Korea

[3]BK21 School of Earth and Environmental Systems, Pusan National University, Busan, South Korea

Contents of this file

Moist static energy

The moist static energy is used as a thermodynamic variable, which represents the addition of dry static energy and latent energy as:

$$h = C_p T + gz + L_v q$$

where C_p is the specific heat at constant pressure, g is the gravitational constant, z is the height above the surface, and L_v is the latent heat of vaporization.

Buoyancy diagnostics

The moist air parcel buoyancy approach has been taken from previous work(Pascale et al., 2017). To evaluate changes in the atmospheric convective instability, we calculate the buoyancy index(Fu et al., 2021; Pascale et al., 2017; Randall, 2015) at each horizontal grid point with a vertical level.

$$b = \frac{(h_{10m} - h_{env})}{2}$$

Where $h_{10m} = C_p T_{10m} + g z_{10m} + L_v q_{10m}$ is moist static energy at a surface 10m and h_{env} is the environmental saturation moist static energy.

The anomalous buoyancy index Δb is taken with respect to mean state climatology. Positive values indicate upward, and negative values indicate downward acceleration.

ITCZ location

ITCZ location(Byrne & Schneider, 2016) is defined as the latitude closest to the equator where zonal mean streamfunction vertically averaged between 700 and 300 hPa is zero.

$$\phi_{ITCZ} = \phi_{\int \Psi} = 0$$

ITCZ width

The ITCZ width(Byrne & Schneider, 2016) is defined as the latitude distance between the maxima and minima points using the zonal mean streamfunction vertically averaged between 700 and 300.

$$\phi_{\mathrm{width}} = (\phi_{max} - \phi_{\mathrm{min}})$$

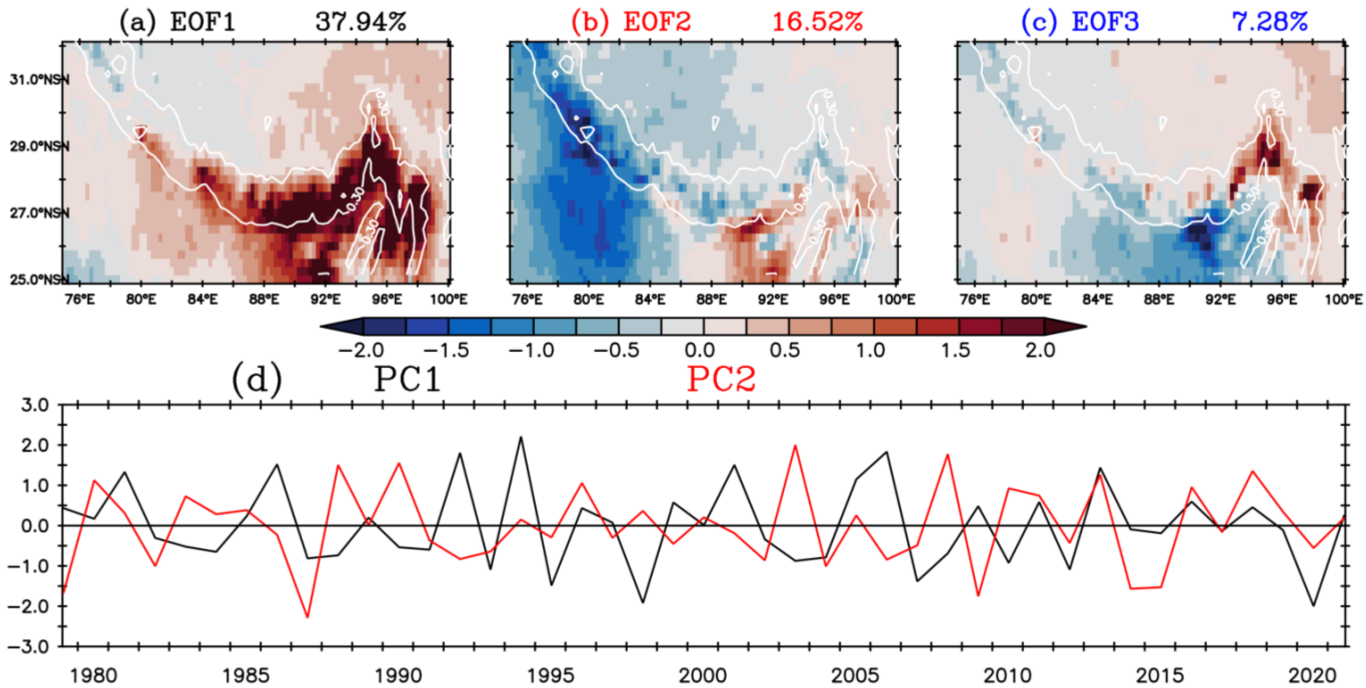

Figure S1. Empirical orthogonal function (EOF) analysis for rainfall. The upper panel shows three dominant EOF modes of Himalayan monsoonal rainfall. The lower panel shows the principal component (PC) time series corresponding to the first and second EOF modes. The leading mode variability (a) suggests high variability, which is compatible with the Eastern Himalayan variability (Main Fig.3).

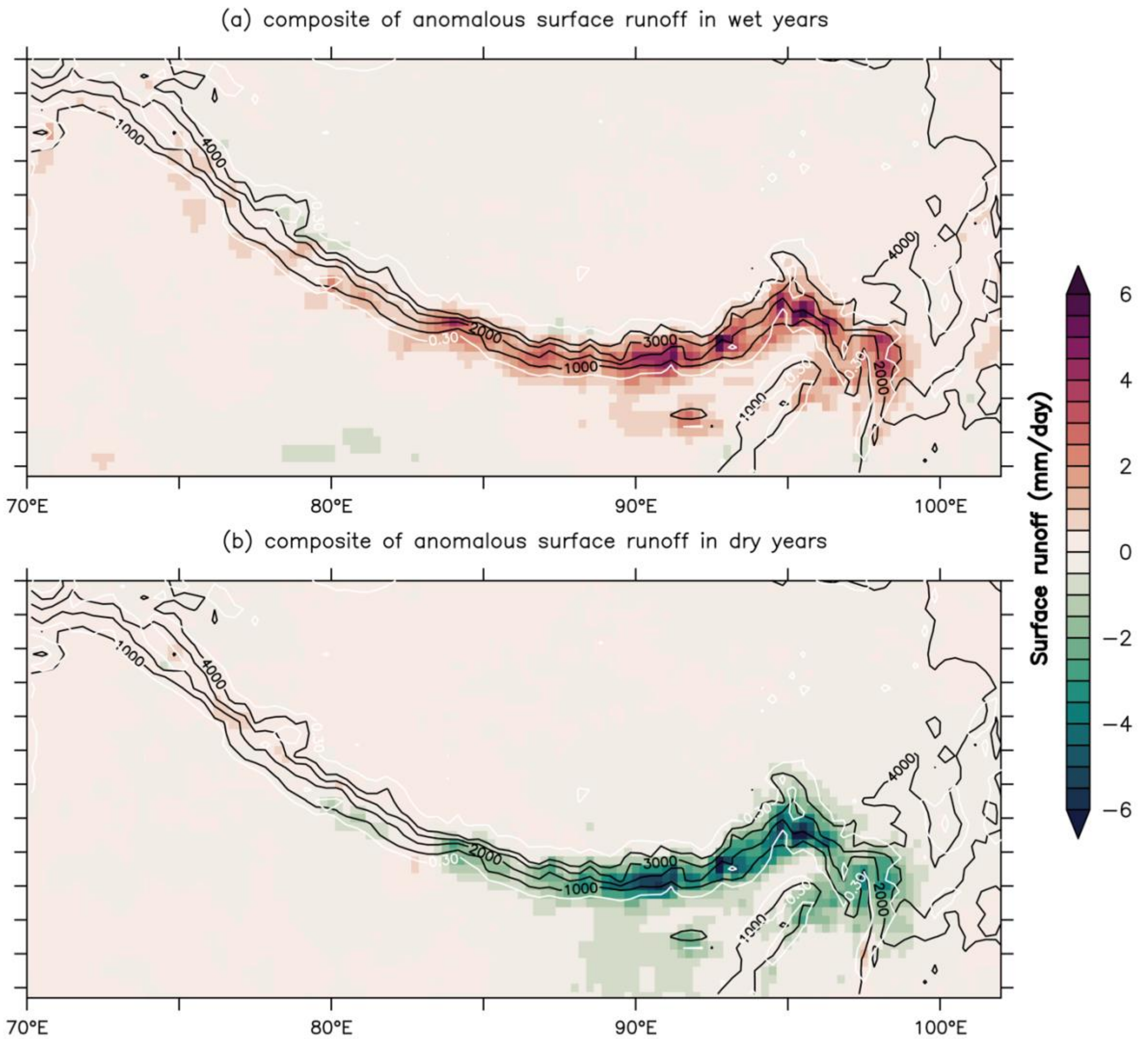

Figure S2. Composite map of surface runoff anomalies for wet and dry monsoon years. (a) Composite map of mean rainfall for wet years and (c) dry monsoon years. Shaded surface runoff with surface relief contour intervals of 1km and white contour intervals denotes steepness.

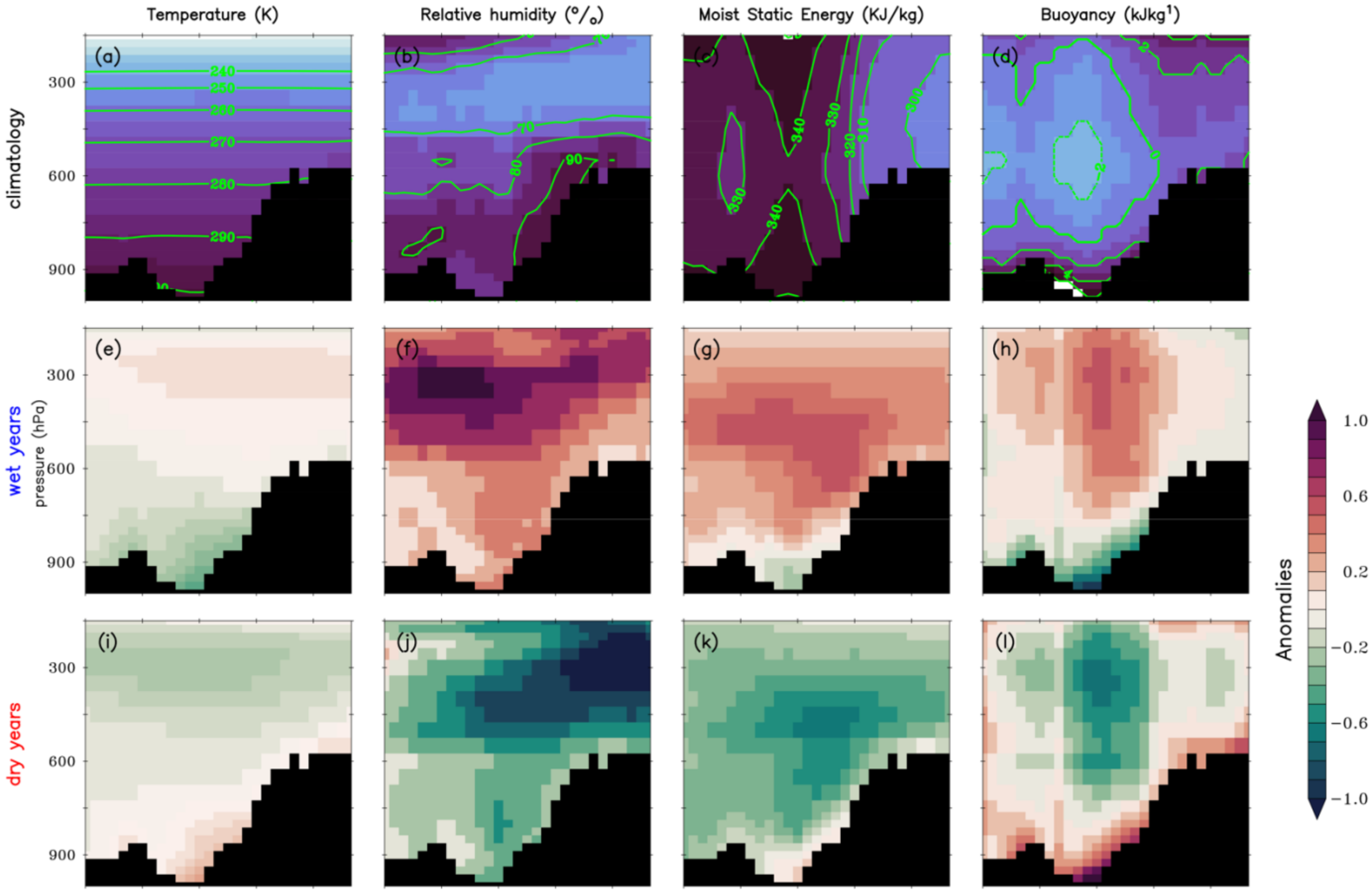

Figure S3. Thermal structure of mean monsoon state climatology, composite anomalies wet and dry monsoons. Cross section taken over green line represented in Fig 4 (a) where shaded quantities are temperature, relative humidity, moist static energy, and buoyancy. (a)-(c) for the mean state climatology of parameters with their green contour intervals units, (d)-(f) for composite wet monsoons, and (g)-(i) for dry monsoons respectively. Here, elevation topography region masked by black color.

Supplementary Table

	ITCZ location (°N) ϕ_{ITCZ}	ITCZ width (km) ϕ_{width}
Climatological mean	30.56	2585.29
Wet years (Δ)	31.03 (0.47)	2017.57 (-567.72)
Dry years (Δ)	30.60 (0.04)	2996.36 (411.07)

Table S1. Mean ITCZ feature indicated, Location and Width (For more information please see Figure 7)

Supplementary References

Byrne, M. P., & Schneider, T. (2016). Narrowing of the ITCZ in a warming climate: Physical mechanisms. *Geophysical Research Letters*, *43*(21), 11,350-11,357. https://doi.org/10.1002/2016GL070396

Fu, D., Chang, P., Patricola, C. M., Saravanan, R., Liu, X., & Beck, H. E. (2021). Central American mountains inhibit eastern North Pacific seasonal tropical cyclone activity. *Nature Communications 2021 12:1*, *12*(1), 1–11. https://doi.org/10.1038/s41467-021-24657-w

Pascale, S., Boos, W. R., Bordoni, S., Delworth, T. L., Kapnick, S. B., Murakami, H., et al. (2017). Weakening of the North American monsoon with global warming. *Nature Climate Change 2017 7:11*, *7*(11), 806–812. https://doi.org/10.1038/nclimate3412

Randall, D. A. (David A. (2015). *An introduction to the global circulation of the atmosphere*. Princeton University. Retrieved from https://press.princeton.edu/books/hardcover/9780691148960/an-introduction-to-the-global-circulation-of-the-atmosphere