REPLY TO LI ET AL:

Late 20th-century drought in northern China reflects influence of global warming, aerosols, and natural variability

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Day et al. (1) present a lens for understanding the rainfall climatology of eastern China. Frontal rainfall occurs year-round due to a unique juxtaposition of continental configuration and orography. By creating an algorithm to identify frontal rain events (FREs), we are able to identify changes in properties, such as their frequency, position, and daily intensity. In our conclusion, we suggest that climate forcings, such as global warming and aerosol loading, together with natural variability, may affect frontal rainfall or nonfrontal in particular, and alter specific properties of FREs. All three are likely to have played an impact in the South Flood–North Drought phenomenon.

The comment by Li et al. (2) advocates a particular mechanism that links increased aerosol concentration in northern China with decreased rainfall via a decrease in deep convection, cooling of the upper troposphere, and reduced land–sea contrast. This comment echoes Yu et al. (3), which, already refuted by Yang et al. (4), presents maps of changing summer precipitation and posits, without analysis, the link to aerosols. Our analysis (1) of the observations shows that the principal contributor to drought during the period of 1980–2007 is a decrease in FREs, and that daily rain accumulation during an FRE increased in the period of 1994–2007, when anthropogenic aerosols were more abundant compared with an earlier period. This latter finding would argue against the mechanism advocated by Li et al. (2). Cloud–aerosol interaction remains a major research area. Aerosols could lead to increase as well as decrease in total precipitation (e.g., ref. 5).

Furthermore, we challenge Li et al.'s (2) assertion that land–sea contrast is directly correlated with the quantity of rainfall in north China. The dynamics of the East Asian monsoon have been characterized as that of a "subtropical monsoon," where both continental configuration and the orography of the Tibetan Plateau upstream produce persistent frontal conditions (6). Even if we accept that the upper troposphere has cooled in northern China, its impact on rainfall would need to be understood in a broader context.

1 Day JA, Fung I, Liu W (2018) Changing character of rainfall in eastern China, 1951–2007. *Proc Natl Acad Sci USA* 115:2016–2021.
2 Li Z, et al. (2018) Suppression of the convective precipitation by the elevated man-made aerosols is responsible for large-scale droughts in north China. *Proc Natl Acad Sci USA* 115:E8327–E8328.
3 Yu S, et al. (2016) Anthropogenic aerosols are a potential cause for migration of the summer monsoon rain belt in China. *Proc Natl Acad Sci USA* 113:E2209–E2210.
4 Yang S, et al. (2016) Reply to Yu et al.: Global temperature change as the ultimate driver of the shift in the summer monsoon rain belt in East Asia. *Proc Natl Acad Sci USA* 113:E2211–E2212.
5 Fan J, Rosenfield D, Ding Y, Leung LR, Li Z (2012) Potential aerosol indirect effects on atmospheric circulation and radiative forcing through deep convection. *Geophys Res Lett* 39:1–7.
6 Chen J, Bordoni S (2014) Orographic effects of the Tibetan Plateau on the East Asian summer monsoon: An energetic perspective. *J Clim* 27:3052–3072.

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The authors declare no conflict of interest.

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