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On the importance of Mongolian cyclones to East Asian dust storm activities

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Desert-dust aerosols affect the climate, human health, and socio-ecomomic activities. In East Asia, the passage of Mongolian cyclones induce dust-emitting winds in the Gobi Desert. While cyclones are known as driver of dust outbreaks, the relative contribution of Mongolian cyclones to the total East Asian dust emission amount and the dust aerosol optical depth has not been quantified from a climatological perspective. To address this gap in knowledge, the present study systematically assesses the co-occurrence of Mongolian cyclones and dust aerosols in East Asia for 2001 to 2022. This study pairs output of the automated detection algorithm for extra-tropical cyclones in ERA5 re-analysis from the ETH Zürich with data for dust aerosols from multiple sources. Through the use of multiple dust data sets, we account for the substantial data uncertainty for dust aerosols in term of the spatial pattern and the absolute emission magnitudes, which can differ by an order of magnitude. The climatological analysis shows a high frequency and intensity for the occurrence of Mongolian cyclones in the lee of the Altai-Sayan Mountains (100E^{o}–125E^{o} and 37N^{o}–53N^{o}), favouring the seasonal dust activity in the Gobi Desert. The results highlight a tight constraint on the mean Mongolian cyclone contribution to the total dust emission amount of 39-47% in the spatial mean for spring based on data from MERRA-2 and Wu et. al. (2022), despite substantial differences in the absolute emission magnitudes. The dust-laden air from the Gobi Desert during such events typically moves southeastwards over China in the wake of the cyclones affecting the aerosol optical depth. For southern Mongolia and Northeastern China (105E^{o}–130E^{o} and 37N^{o}–52N^{o}), we estimate 34% (MERRA-2) to 43% (CAMS) of the dust aerosol optical depth (DOD) being associated with Mongolian cyclones. A decrease in dust emission fluxes and dust storm frequencies have been reported for Northern China in the past two decades and is thought to be connected to decreasing near-surface winds. Our results point to a negative trend in the dust emission flux and DOD associated with the occurrence of Mongolian cyclones. However, our results also point to the co-occurrence of particularly intense Mongolian cyclones, measured by the 99th percentile of the wind speed, with exceptionally strong dust storms in recent years, e.g., in March 2021, despite a mean negative trend in dust activity. Given the connection of Mongolian cyclone to high-impact dust storms in East Asia, the potential future development of such events should be addressed in future research.