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Role of natural external forcing factors in modulating the Indian summer monsoon rainfall, the winter North Atlantic Oscillation and their relationship on inter-decadal timescale

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We use reconstructed data and multi-centennial integrations performed with the Bergen Climate Model Version 2 to investigate the impact of natural external forcing factors on the Indian summer monsoon (ISM) rainfall, the winter North Atlantic Oscillation (NAO), and the potential relationship between the ISM rainfall and the winter NAO on decadal to inter-decadal timescales. The model simulations include a 600-yr control integration (CTL600) and a 600-yr integration with time-varied natural external forcing factors from 1400 to 1999 (EXT600). Both reconstructed data and the simulation showed increased ISM rainfall 2-3 years after strong volcanic eruptions. Strong volcanic eruptions decrease the Indian Ocean sea surface temperature (SST), which increases the strength of the southwesterly winds over the Arabian Sea. With negative externally-forced radiative anomaly, the lower stratospheric pole-to-equator winter temperature gradient is enhanced, leading to a positive winter NAO anomaly with a time lag of one year. There is no significant correlation between the winter NAO and ISM rainfall in CTL600. However, the ISM rainfall is significantly positively correlated with the winter NAO in EXT600, with the NAO leading by 2-4 years, which is consistent with the NAO-ISM rainfall relationship in the reconstructed data. We suggest that natural external forcing factors regulate the inter-decadal variability of both the winter NAO and the ISM rainfall and thus likely lead to an increased statistical but not causal relationship between them on the inter-decadal timescale over the past centuries.