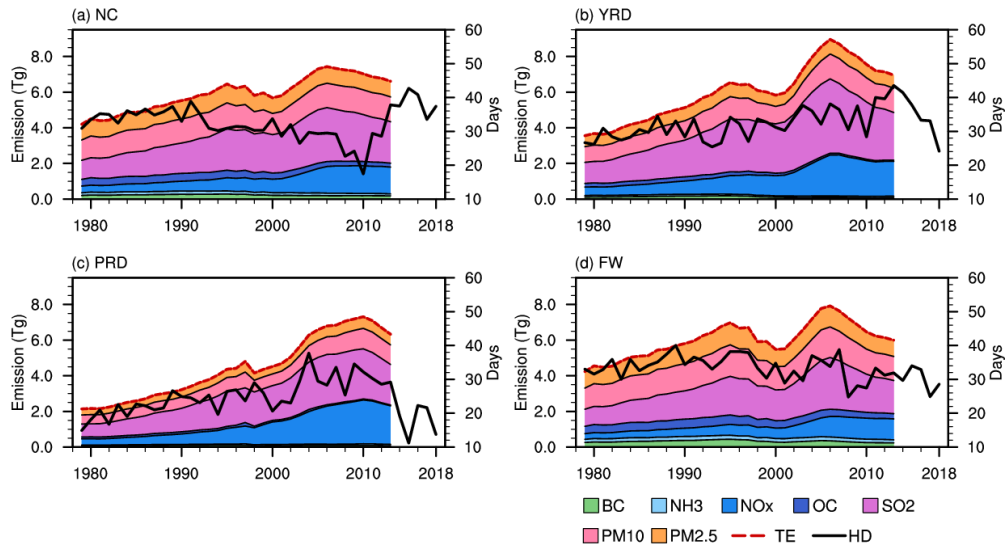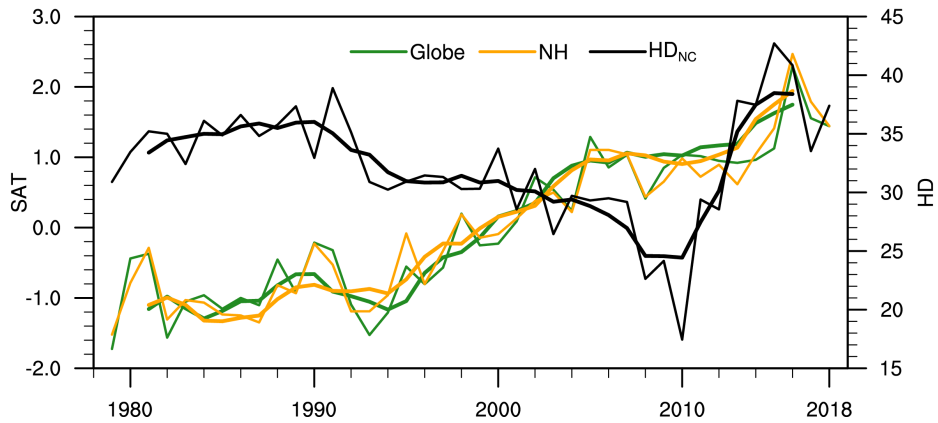1

Figure S1. Variations in December-January emissions (unit: Tg) of black carbon (BC), ammonia (NH$_3$), nitrogen oxide (NO$_x$), organic carbon (OC), sulfur dioxide (SO$_2$), PM$_{10}$ and PM$_{2.5}$ over North China (a), YRD (b), PRD (c) and Fenwei Plain (d) from 1979 to 2013, and the variation of haze days from 1979 to 2018 (black soild line). The red dashed line represents the total emissions of the seven pollutions.
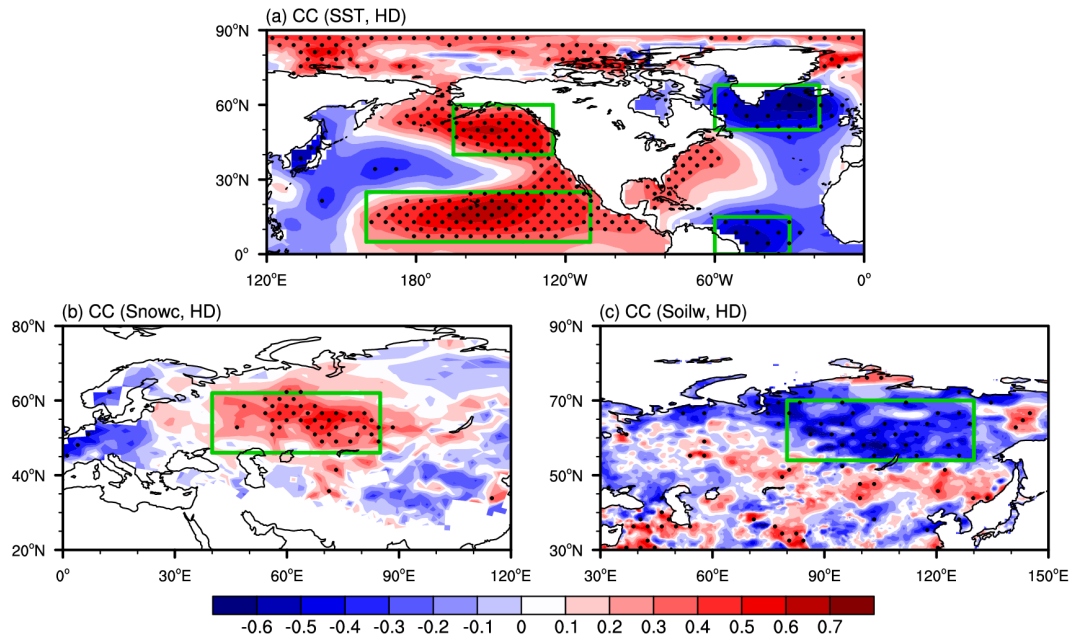

Figure S2. Time series of SAT (unit: °C) averaged over globe (green) and Northern Hemisphere (yellow) and HD$_{NC}$ (black) from 1979 to 2018. Thick lines indicate 5-year running averaged time series. The two time series of SAT are standardized for comparison.
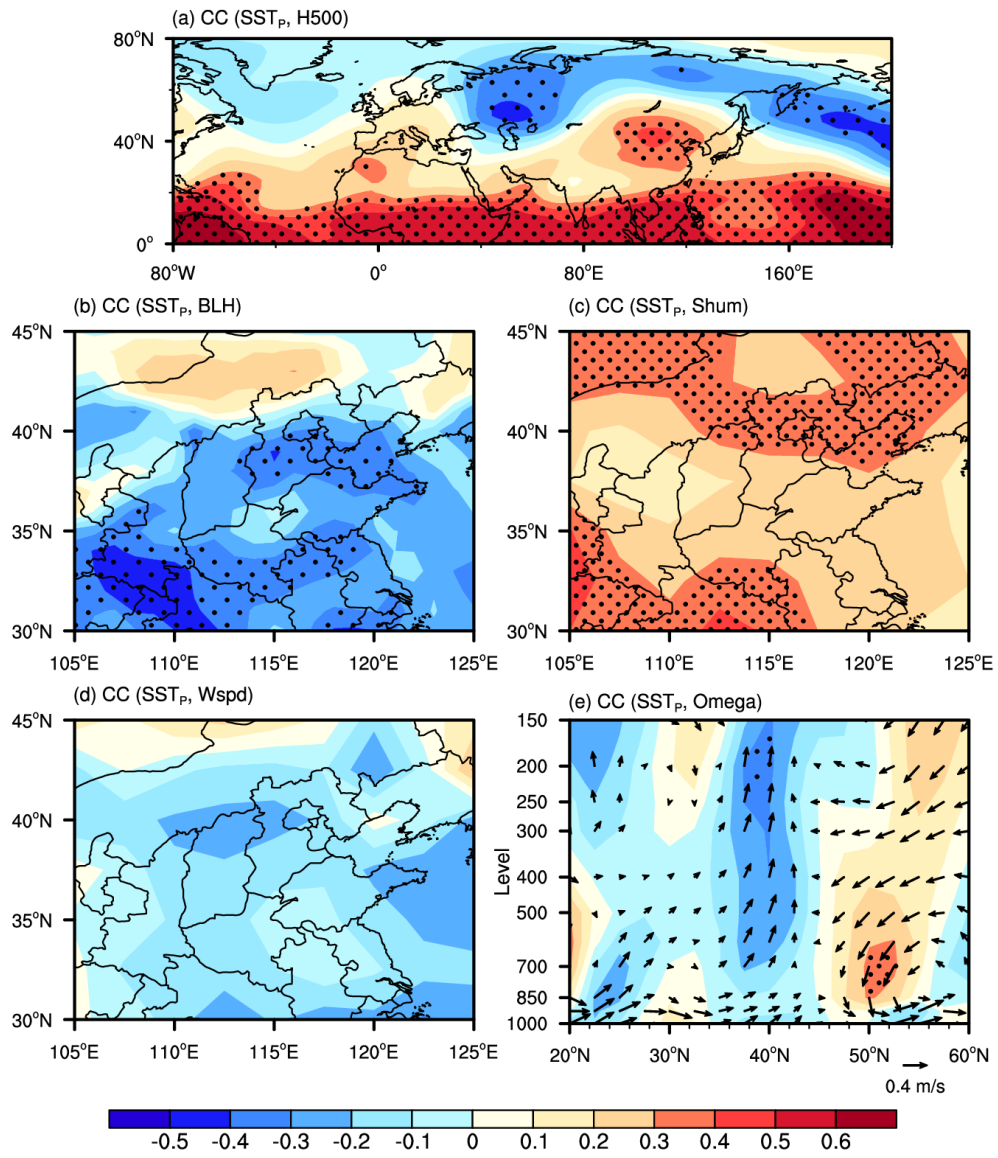
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Figure S3. Correlation coefficients between HD_{NC} and autumn SST (a), October-November snow cover (b) and autumn soil moisture (c) from 1979 to 2018. The green boxes represent the regions where the four indices are defined. The linear trend was removed. Black dots indicate that the CCs were above the 95% confidence level.

Figure S4. Correlation coefficients between SST_P and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and

omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the
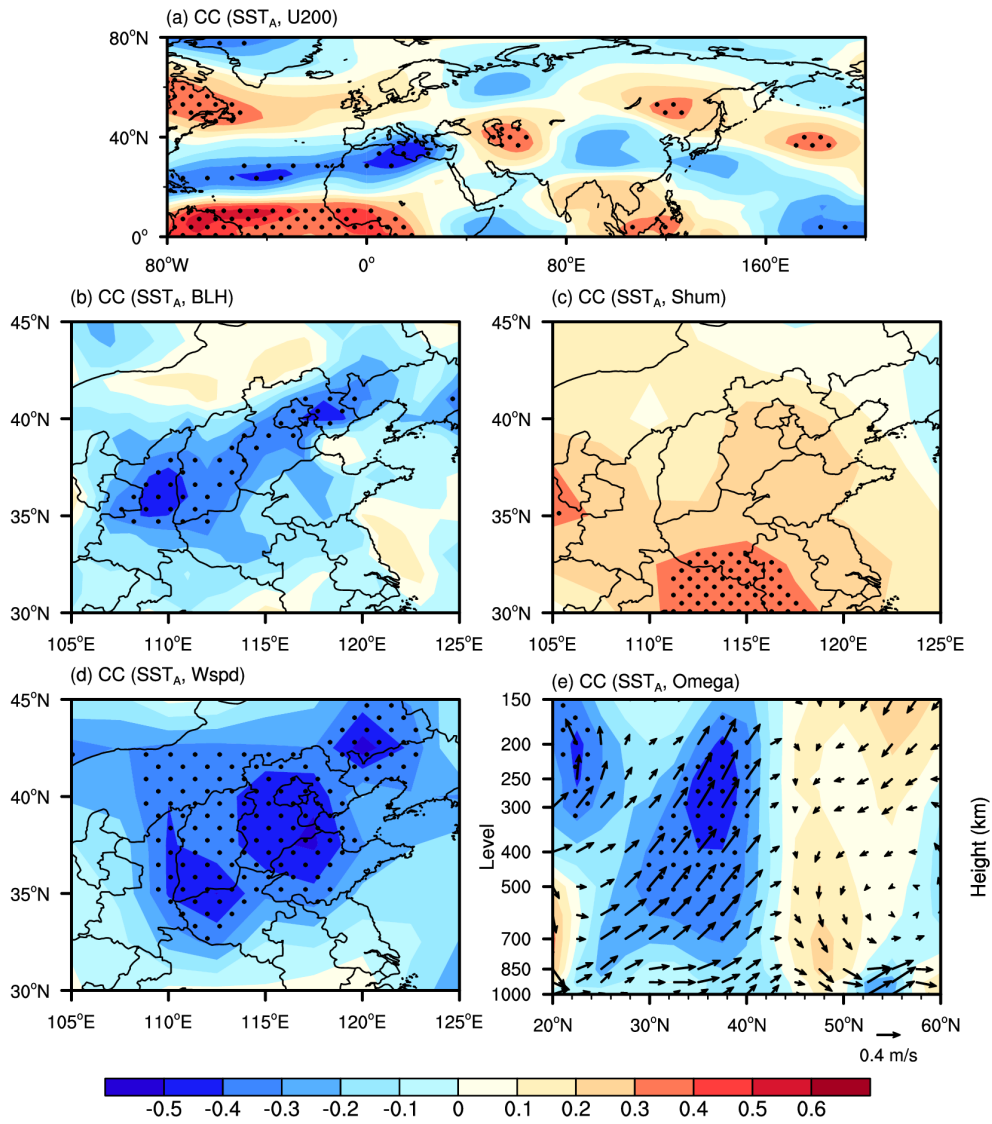
95% confidence level.

Figure S5. Correlation coefficients between – 1× SST_A and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the 95% confidence level.
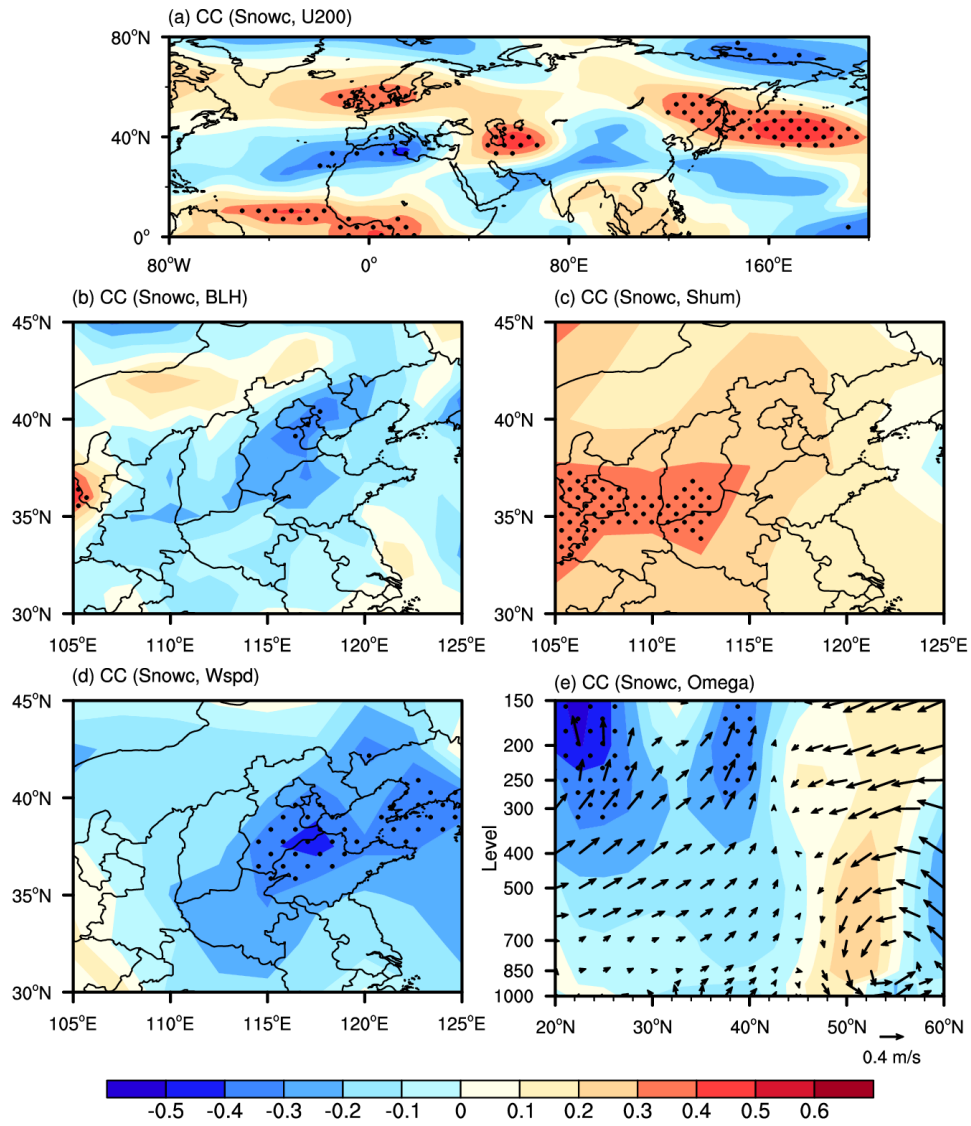
Figure S6. Correlation coefficients between Snowc and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the 95% confidence level.
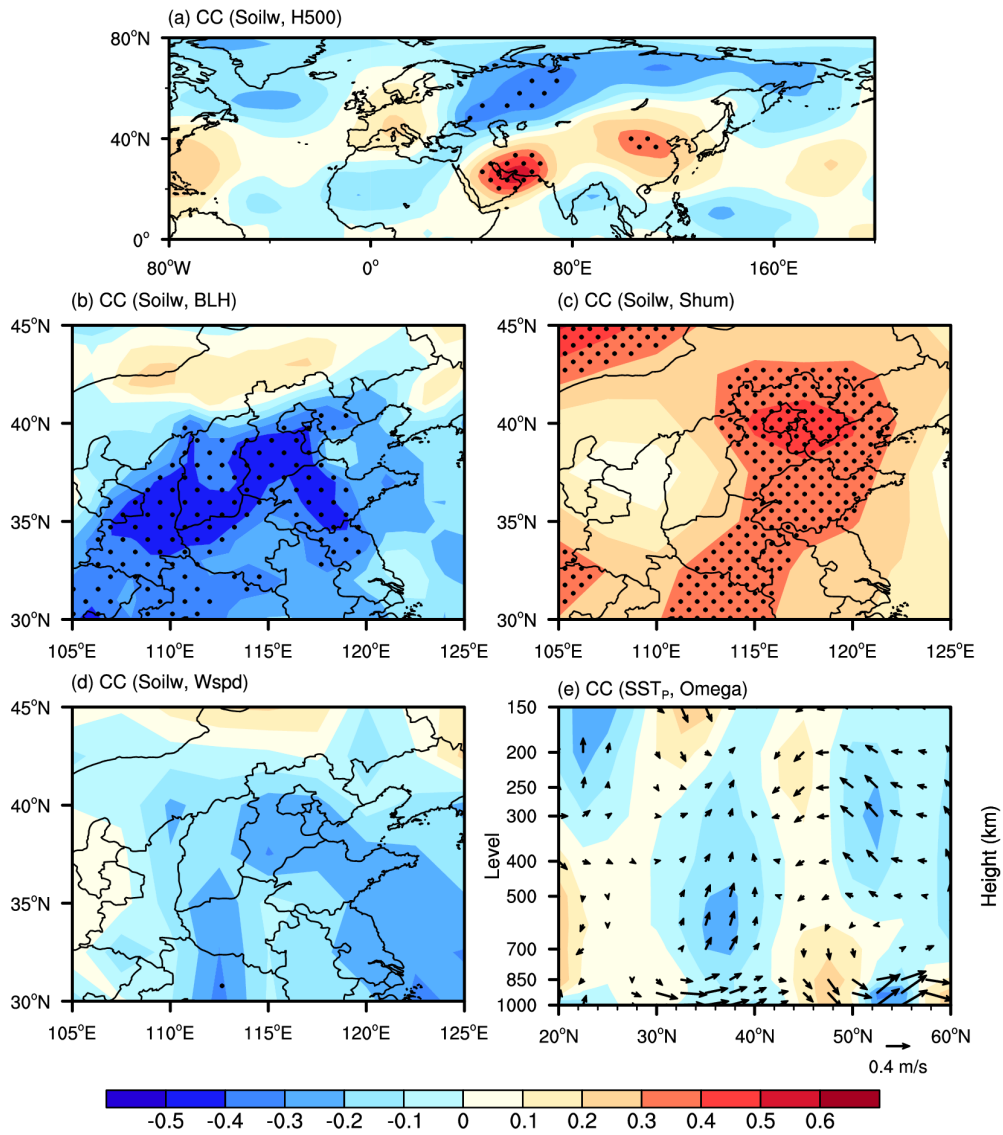
Figure S7. Correlation coefficients between –1× Soilw and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the 95% confidence level.

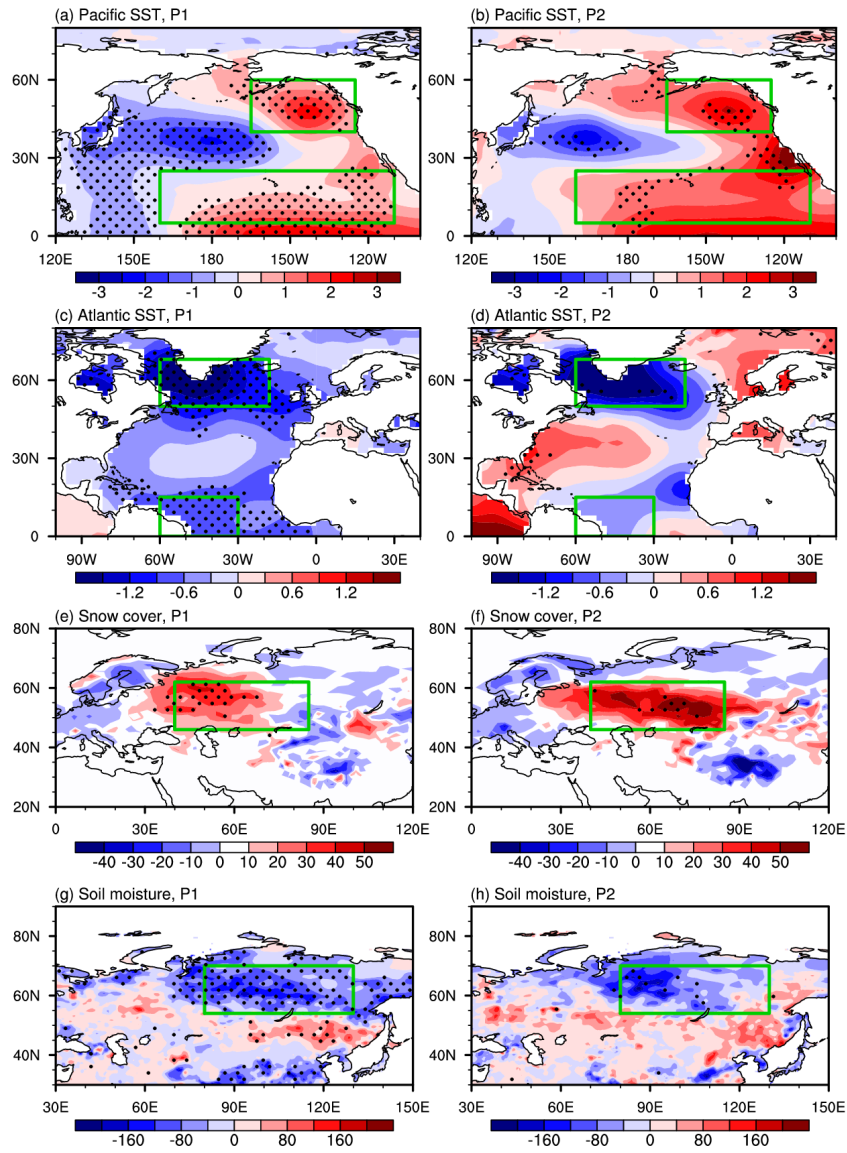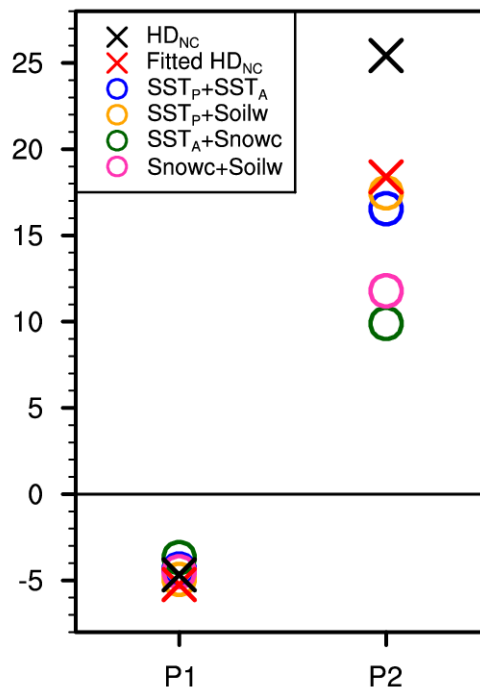**Figure S8.** The composite (Favor Years minus Unfavor Years) of the four external forcing factors in P1 and P2, respectively. The green boxes represent the regions where the four indices are defined. Balck dots indicate that the differences pass the 95% confidence level of Student-t test.

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Figure S9. The trends of fitted HD_{NC} in P1 and P2 fitted by two external forcing factors with insignificant correlation

58   coefficient.