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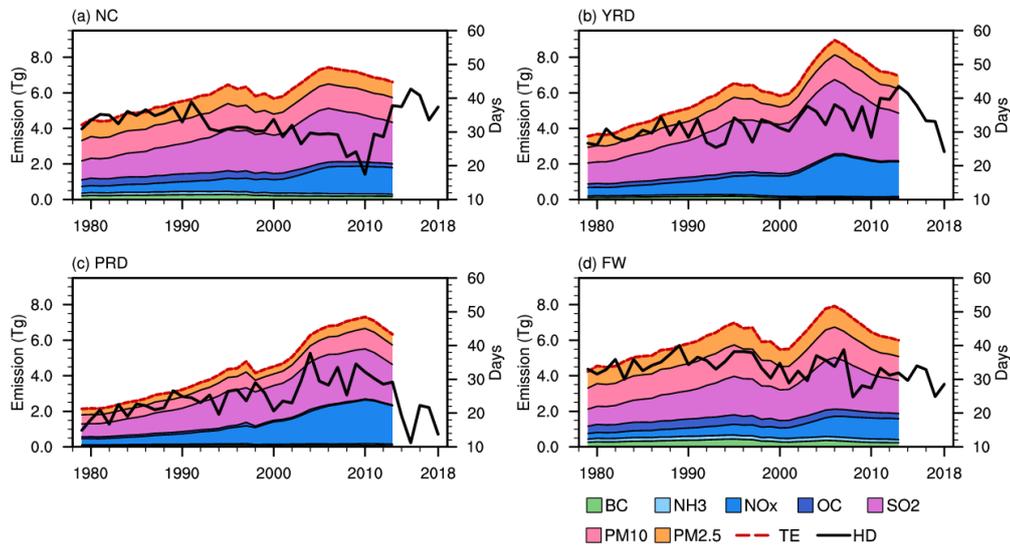
Supplement of

Roles of climate variability on the rapid increases of early winter haze pollution in North China after 2010

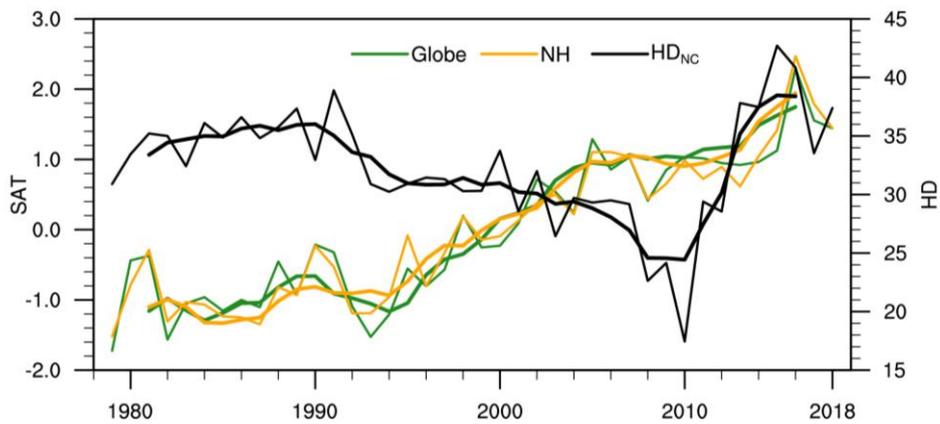
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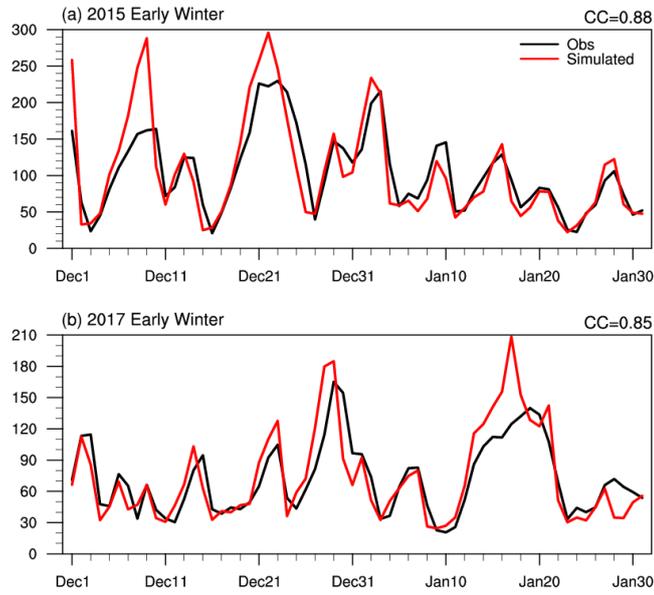
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 2 **Figure S1.** Variations in December-January emissions (unit: Tg) of black carbon (BC), ammonia (NH₃), nitrogen oxide (NO_x),
 3 organic carbon (OC), sulfur dioxide (SO₂), PM₁₀ and PM_{2.5} over North China (a), YRD (b), PRD (c) and Fenwei Plain (d) from
 4 1979 to 2013, and the variation of haze days from 1979 to 2018 (black solid line). The red dashed line represents the total
 5 emissions of the seven pollutions.
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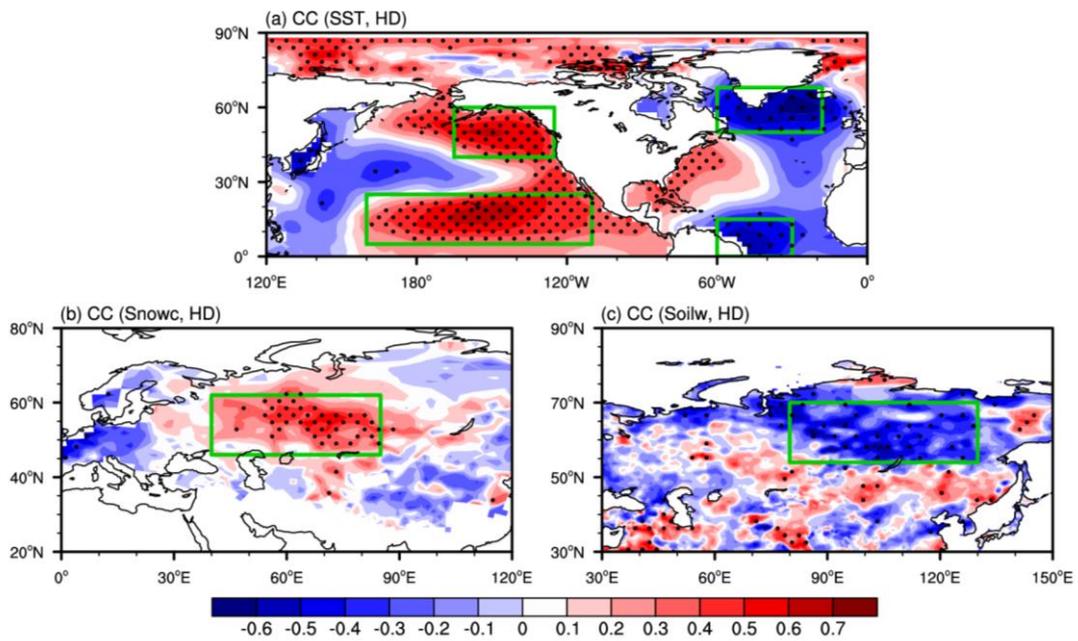


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 8 **Figure S2.** Time series of SAT (unit: °C) averaged over globe (green) and Northern Hemisphere (yellow) and HD_{NC} (black)
 9 from 1979 to 2018. Thick lines indicate 5-year running averaged time series. The two time series of SAT are standardized for
 10 comparison.



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 12 **Figure S3.** Temporal evolutions of observed (black) and simulated (red) PM_{2.5} concentrations (unit: $\mu\text{g m}^{-3}$; blue) in 2015 (a)
 13 and 2017 (b) early winter in North China.

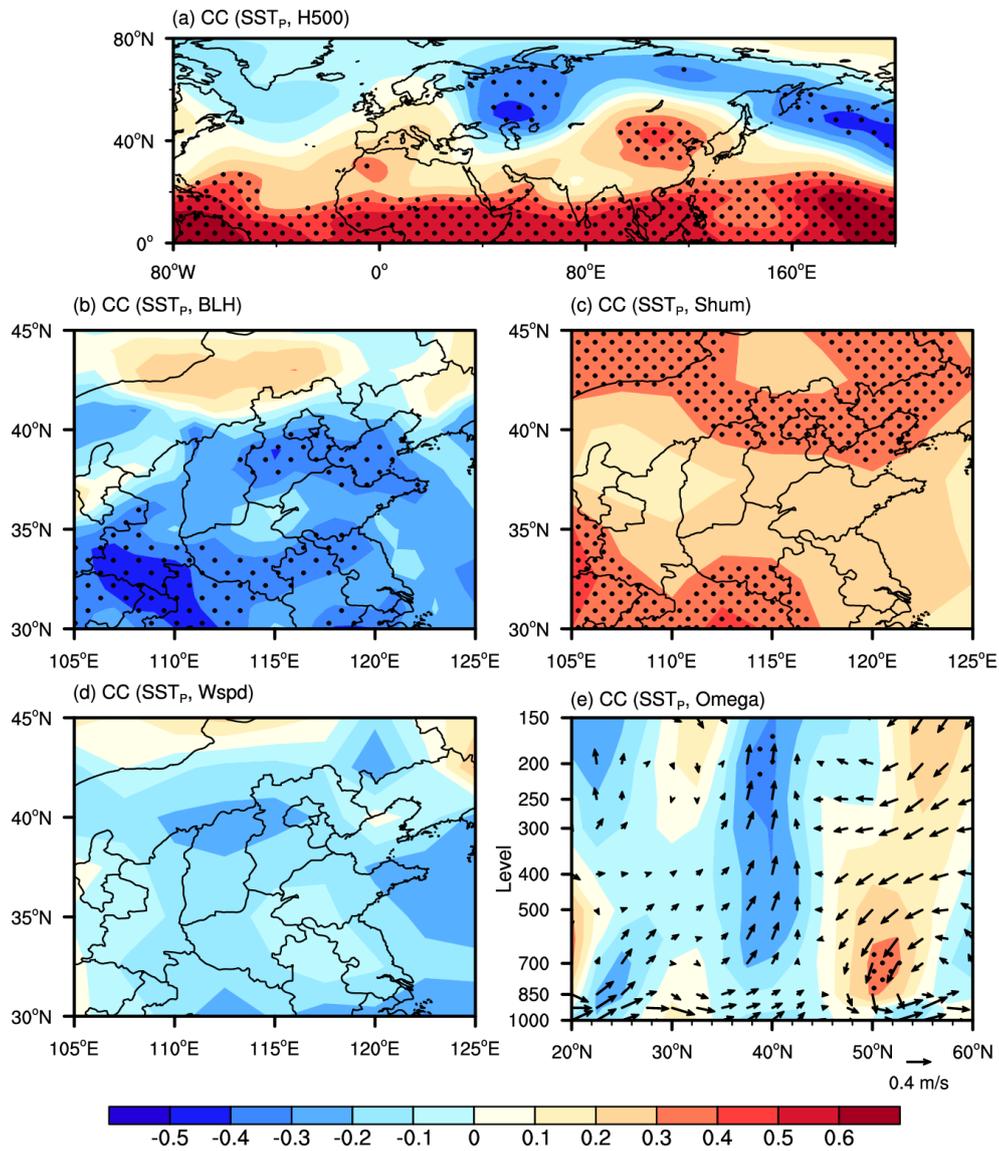
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 16 **Figure S4.** Correlation coefficients between HD_{NC} and autumn SST (a), October-November snow cover (b) and autumn soil
 17 moisture (c) from 1979 to 2018. The green boxes represent the regions where the four indices are defined. The linear trend
 18 was removed. Black dots indicate that the CCs were above the 95% confidence level.

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22 **Figure S5.** Correlation coefficients between SST_P and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and
 23 omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the
 24 95% confidence level.

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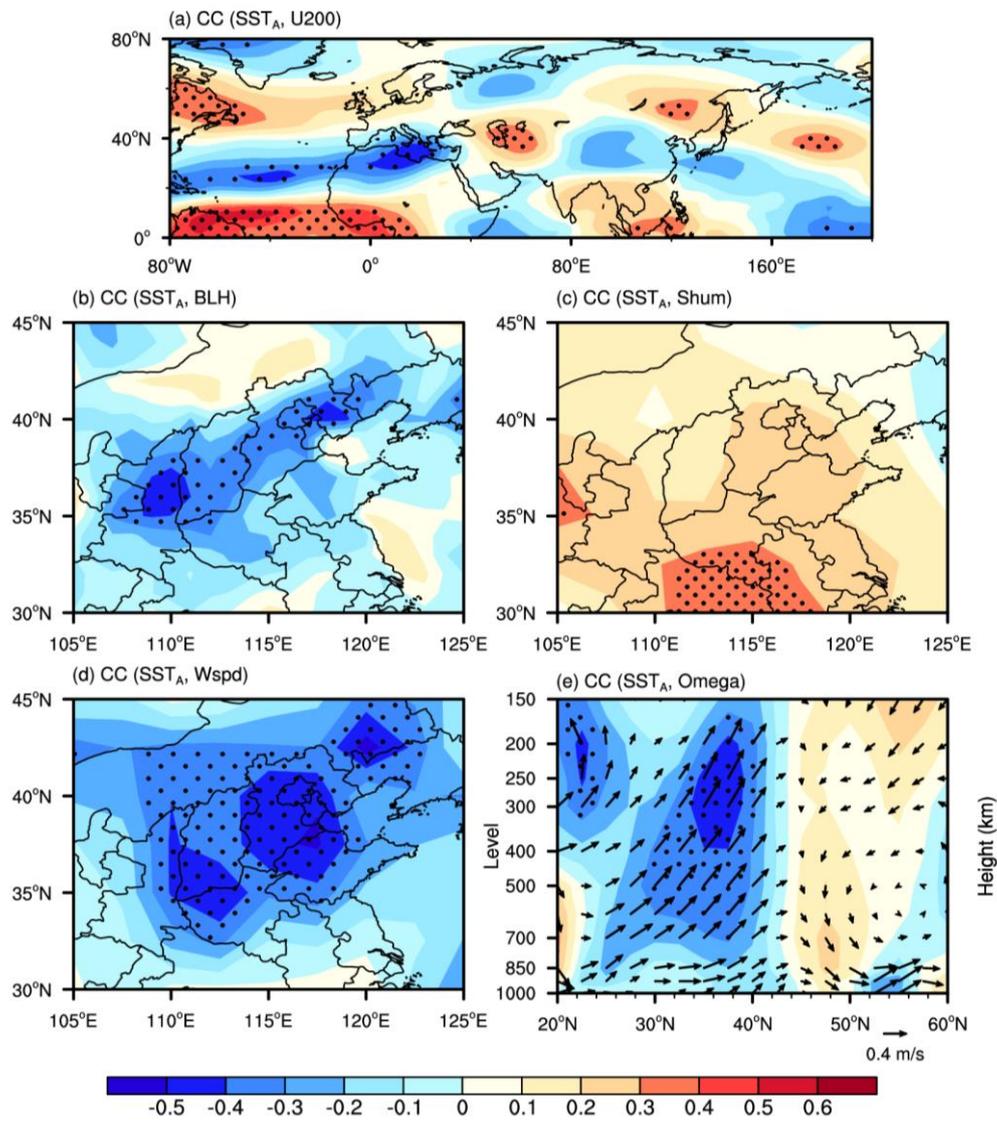
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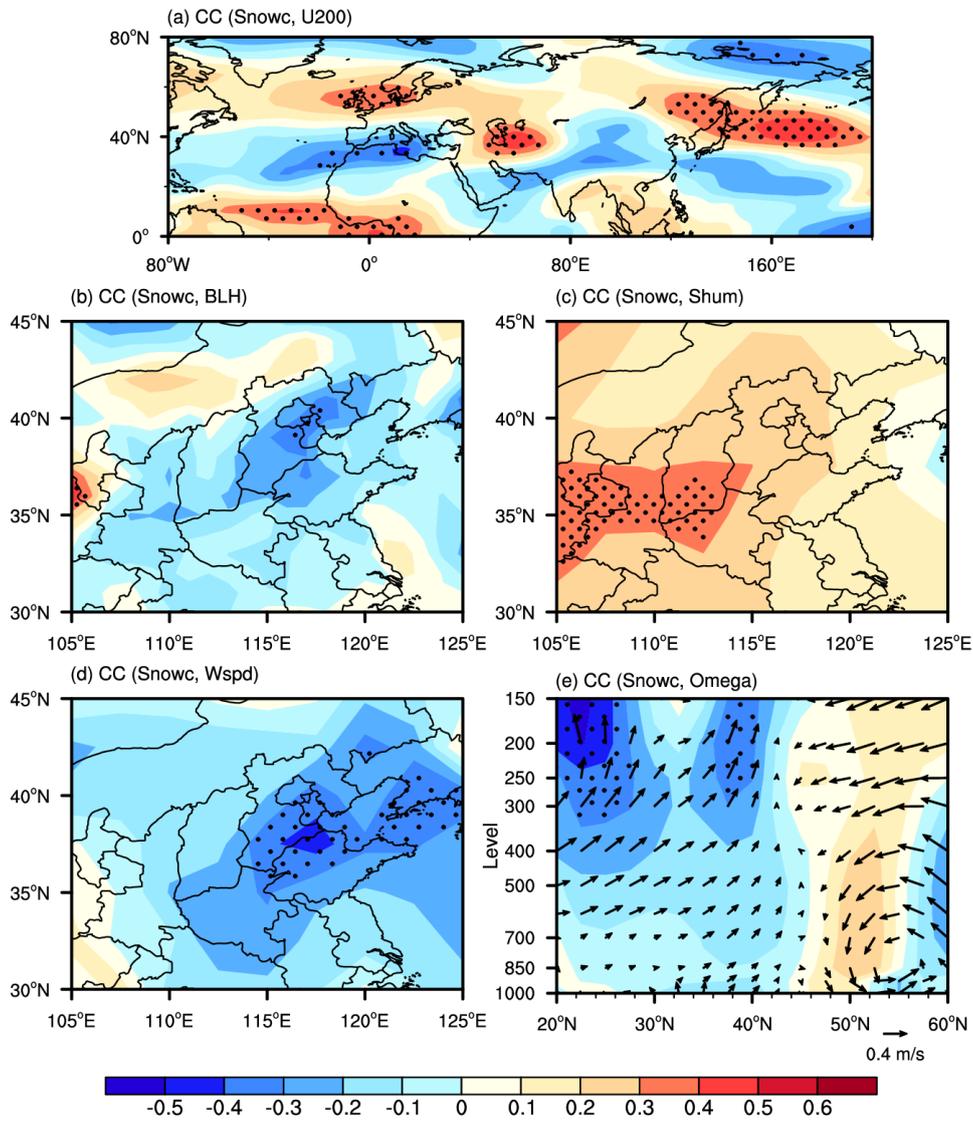
32 **Figure S6.** Correlation coefficients between $-1 \times \text{SST}_A$ and H500 (a), BLH (b), specific humidity (c), surface wind speed (d)
 33 and omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above
 34 the 95% confidence level.

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40 **Figure S7.** Correlation coefficients between Snowc and H500 (a), BLH (b), specific humidity (c), surface wind speed (d) and
 41 omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above the
 42 95% confidence level.

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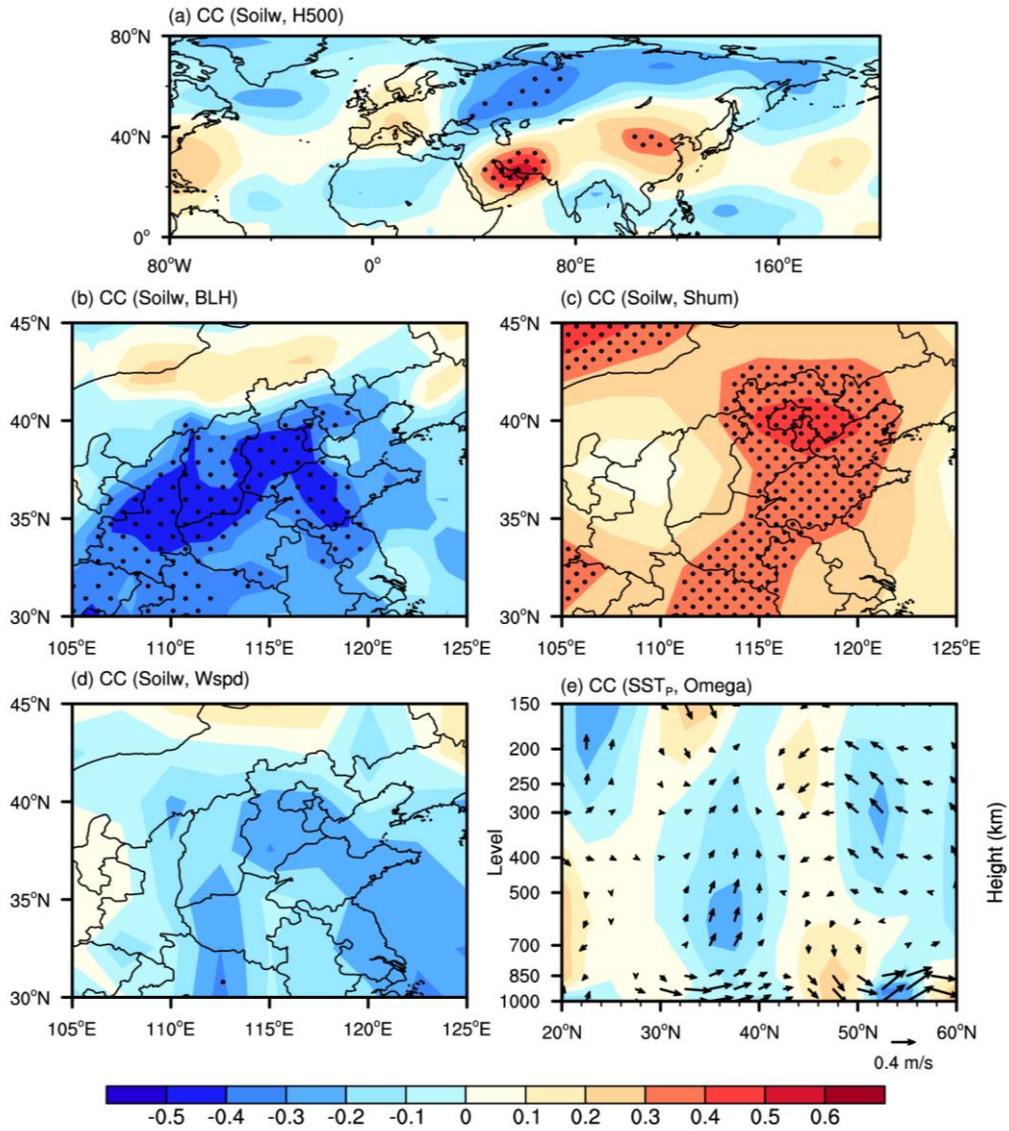
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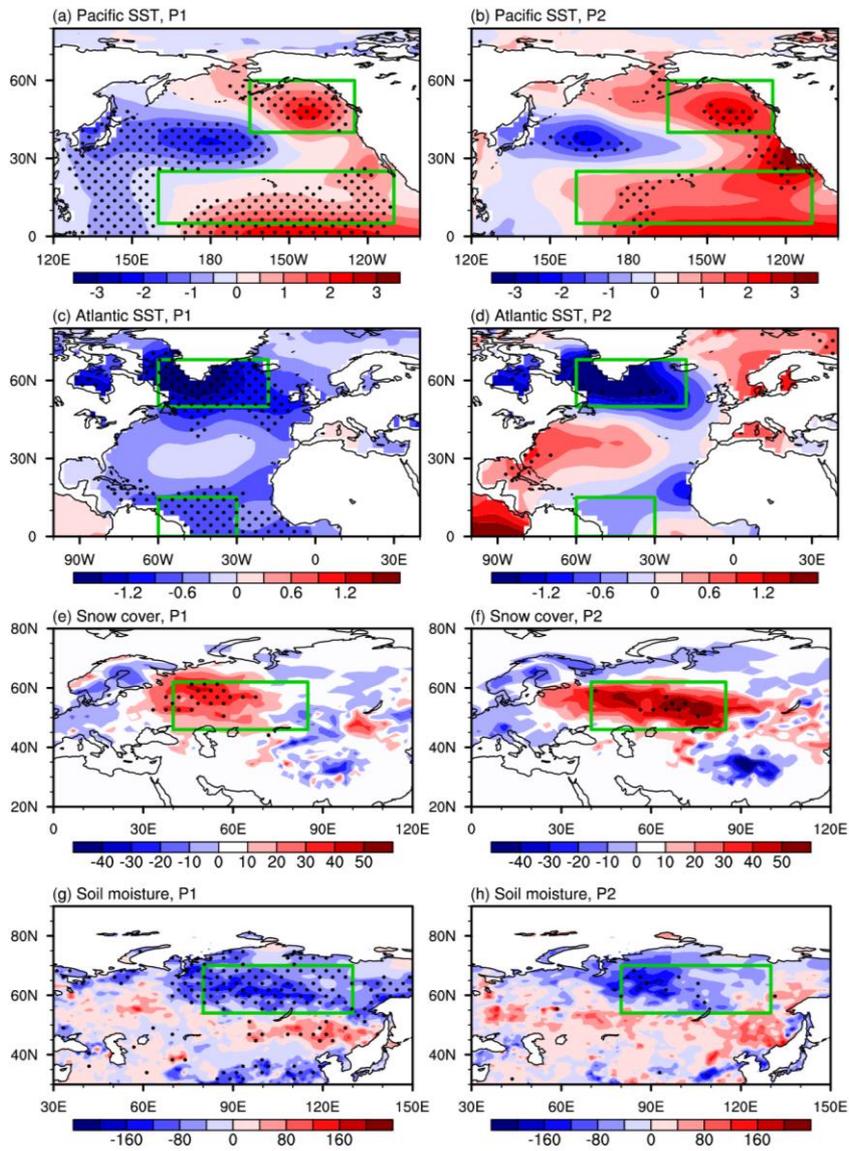
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50 **Figure S8.** Correlation coefficients between $-1 \times$ Soilw and H500 (a), BLH (b), specific humidity (c), surface wind speed (d)
 51 and omega (e) in early winter from 1979 to 2018. The linear trend was removed. Black dots indicate that the CCs were above
 52 the 95% confidence level.

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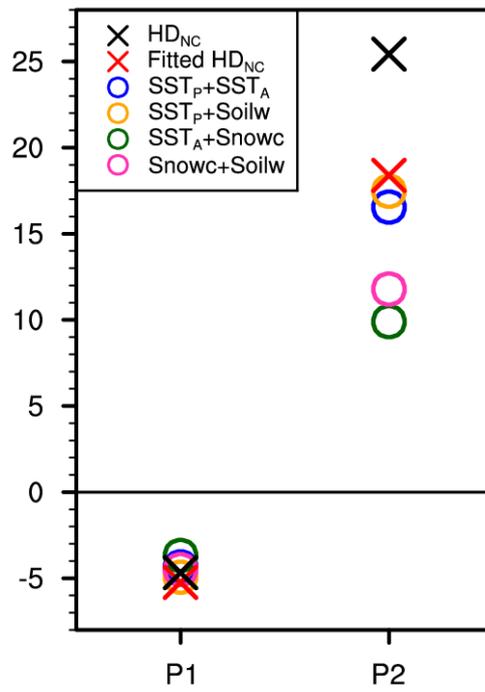


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55 **Figure S9.** The composite (Favor Years minus Unfavor Years) of the four external forcing factors in P1 and P2, respectively.

56 The green boxes represent the regions where the four indices are defined. Black dots indicate that the differences pass the 95%

57 confidence level of Student-t test.



58

59 **Figure S10.** The trends of fitted HD_{NC} in P1 and P2 fitted by two external forcing factors with insignificant correlation
 60 coefficient.