

Text S1. Calculation of snowpack metrics

In this study, three metrics were used to characterize snowpack: maximum snow water equivalent (SWE_{max}), snow cover end date (SCED), and snowmelt. These indicators represent the accumulation, melting, and timing aspects of snowpack. SWE_{max} was defined as the maximum grid value within each hydrological year. We defined SCED as the last day within a hydrological year (from 1 October to 30 May of the following year) on which snow cover persisted for five consecutive days (Wang et al., 2018), to minimize the influence of short-lived snowfall events on the estimation of the SCED. The formulation is as follows:

$$SCED = \max \{t\} + 4 \quad \{t \in [0, m - 4] \text{ and } \min\{S_t\} > 0\} \quad (1)$$

where t denotes the Julian day; m represents the Julian day within the hydrological year; and S_t refers to the snow water equivalent value, with $S_t = 0$ indicating non-snowpack.

Spring snowmelt was calculated by summing the monthly snowmelt for each month of the spring season (March, April, and May). The snowmelt for each month was determined as the difference between the SWE of the previous and current months.

$$\text{Month melt} = \begin{cases} \text{SWE}_{m-1} - \text{SWE}_m, & \text{if } \text{SWE}_{m-1} - \text{SWE}_m > 0 \\ 0, & \text{otherwise} \end{cases} \quad m \in \{3,4,5\} \quad (2)$$

$$\text{Spring melt} = \text{March melt} + \text{April melt} + \text{May melt} \quad (3)$$

Text S2. Calculation of crop yield anomaly

Crop yield anomaly is calculated for each grid cell to represent crop yield variation. We use Locally weighted regression model (LOWESS) to exclude the overall yield increase resulting from technological advances in each grid point (Hendrawan et al., 2022). The anomaly we calculated was assumed to that mainly influenced by climate disruptions, the formulation is as follows:

$$\theta_t = \frac{Y_t - \hat{Y}_t}{\hat{Y}_t} \times 100\% \quad (4)$$

where Y_t is crop yield and \hat{Y}_t is the long-term trend obtained by LOWESS.

Figure S1. Spatial distribution of the annual means of crop yield anomaly during 2000–2022. (a) maize, (b) spring wheat, and (c) soybean.

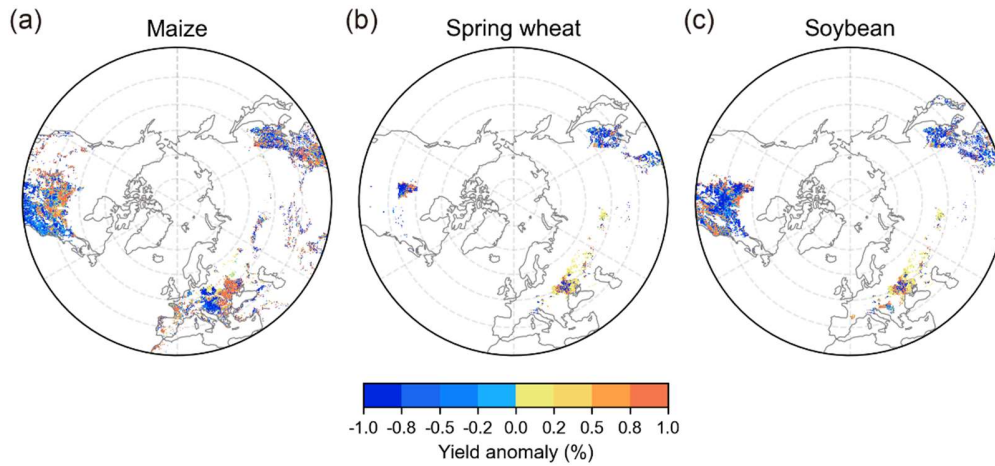


Figure S2. Spatial distribution of the annual means of crop yield sensitivity to soil moisture during 2000–2022. (a) maize, (b) spring wheat, and (c) soybean.

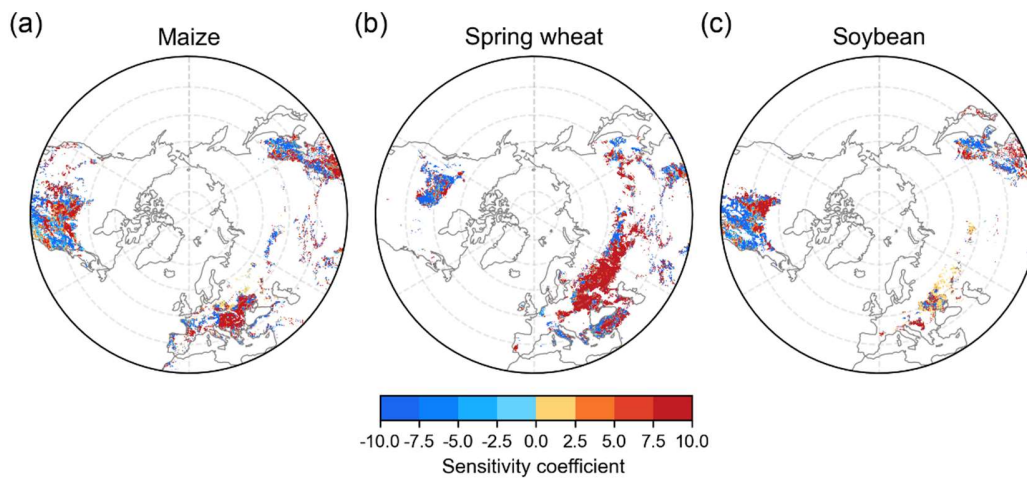


Figure S3. Performance of the DLM models. (a–c) indicate the R between crop yield anomalies and predicted by DLM.

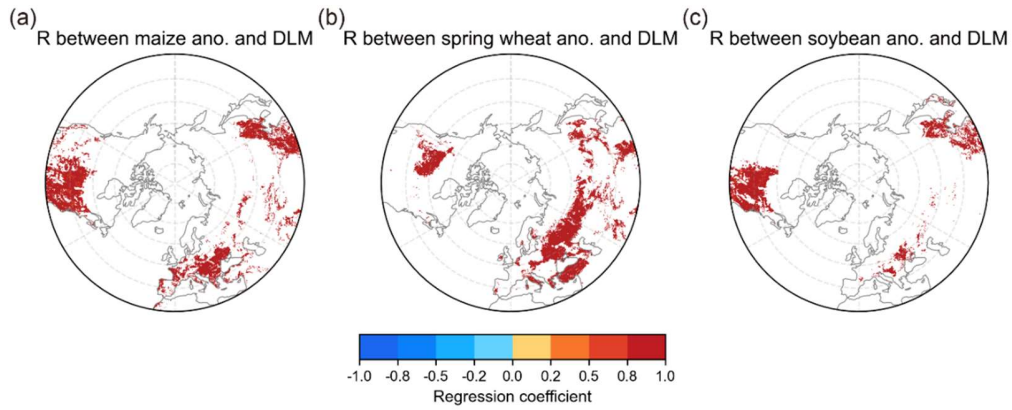
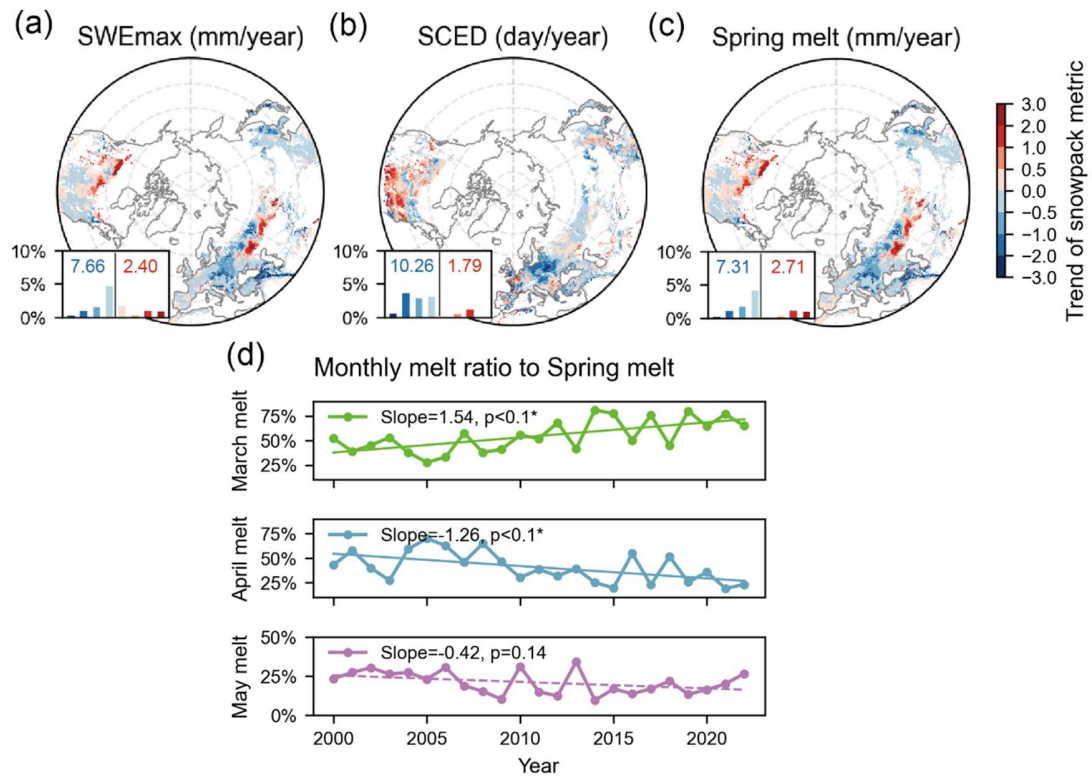


Figure S4. Interannual variations in snowpack metric from 2000 to 2022. (a–c) Spatial distribution of the trends of three snowpack metrics (SWE_{max}, SCED, and Spring melt) across the Northern Hemisphere. The inset bar plot indicates the proportion of significant negative and positive coefficients. (d) Trend of monthly snowmelt ratio to spring melt.



References

- Hendrawan, V. S. A., Kim, W., Touge, Y., Ke, S., & Komori, D. (2022). A global-scale relationship between crop yield anomaly and multiscalar drought index based on multiple precipitation data. *Environmental Research Letters*, *17*(1), 014037. <https://doi.org/10.1088/1748-9326/ac45b4>
- Wang, X., Wang, T., Guo, H., Liu, D., Zhao, Y., Zhang, T., Liu, Q., & Piao, S. (2018). Disentangling the mechanisms behind winter snow impact on vegetation activity in northern ecosystems. *Global Change Biology*, *24*(4), 1651–1662. <https://doi.org/10.1111/gcb.13930>