

Supplementary Information

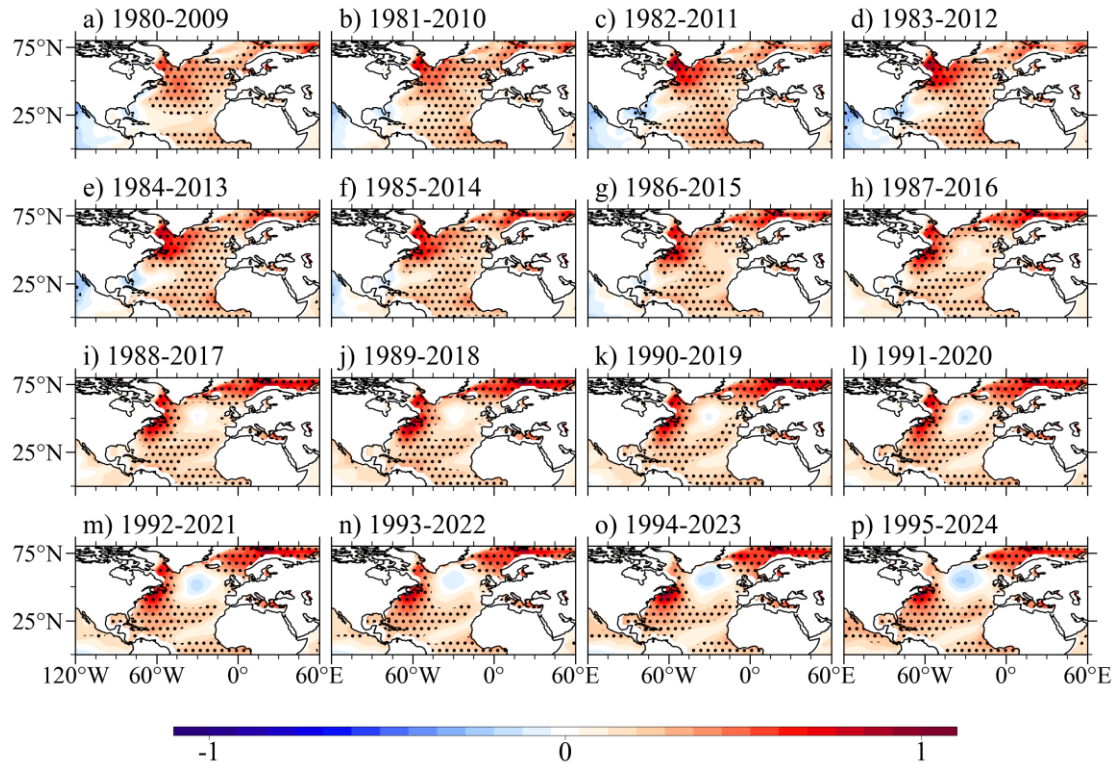
Mid-2000s Reversal of North Atlantic warming pattern reshapes hemispheric circulation and Eurasian cold extremes

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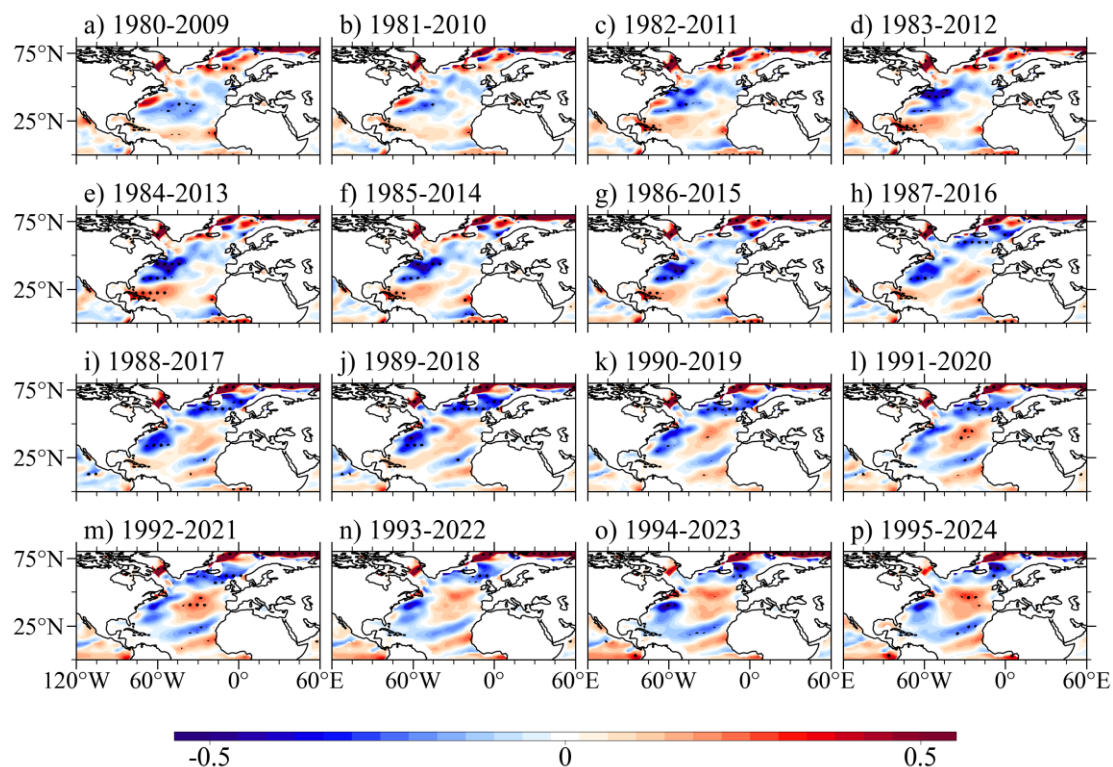
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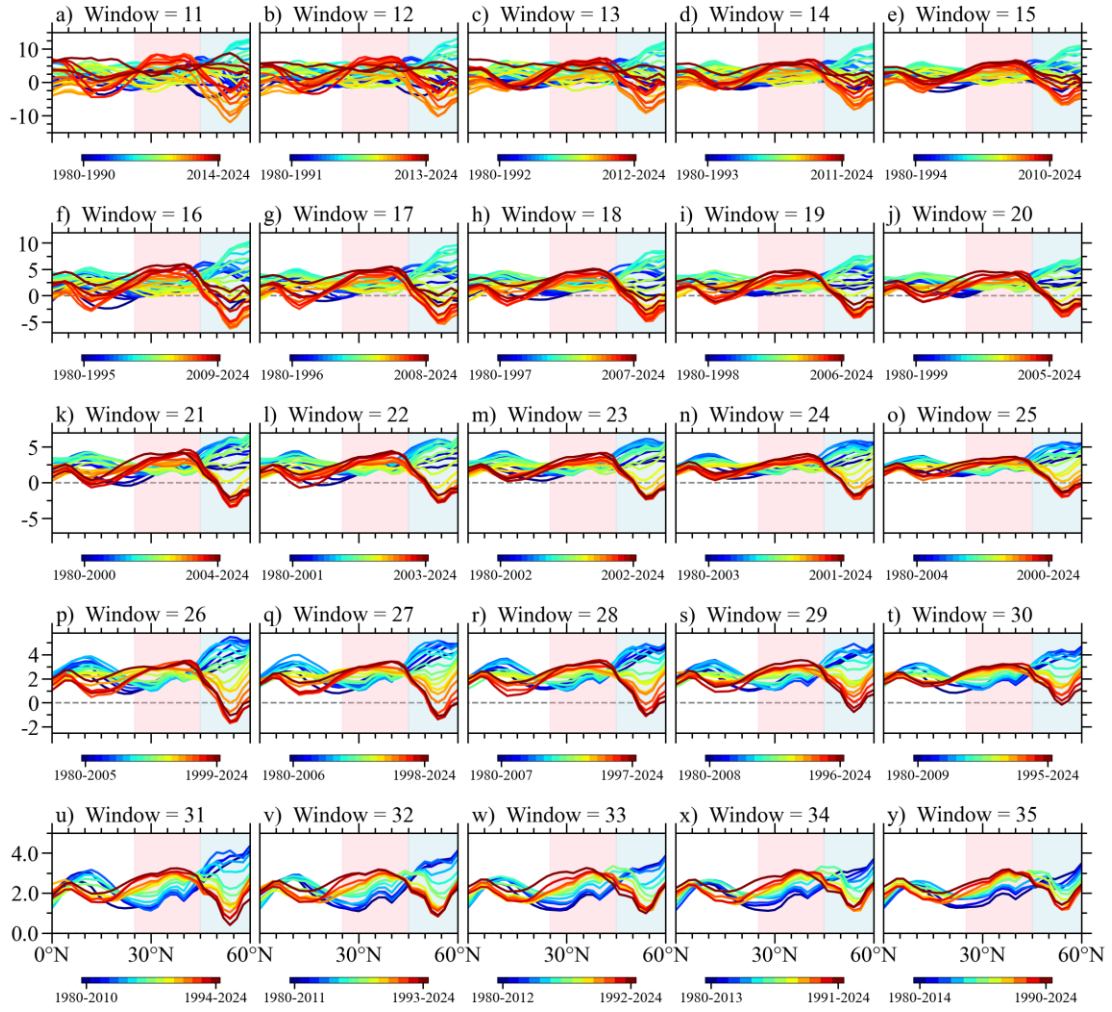
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15 **Fig. S1 | Winter North Atlantic 30-year linear raw sea surface temperature (SST) trends over**
 16 **successive 30-year sliding windows. a–p,** Linear trends (units: 10^{-1} K yr $^{-1}$) for successive
 17 overlapping 30-year periods from 1980–2009 to 1995–2024, respectively. Panel (a) corresponds to
 18 1980–2009, with each subsequent panel advancing by one year, ending with panel (p) for 1995–
 19 2024. Dots indicate grid points where trends are significant at the 95% confidence level.



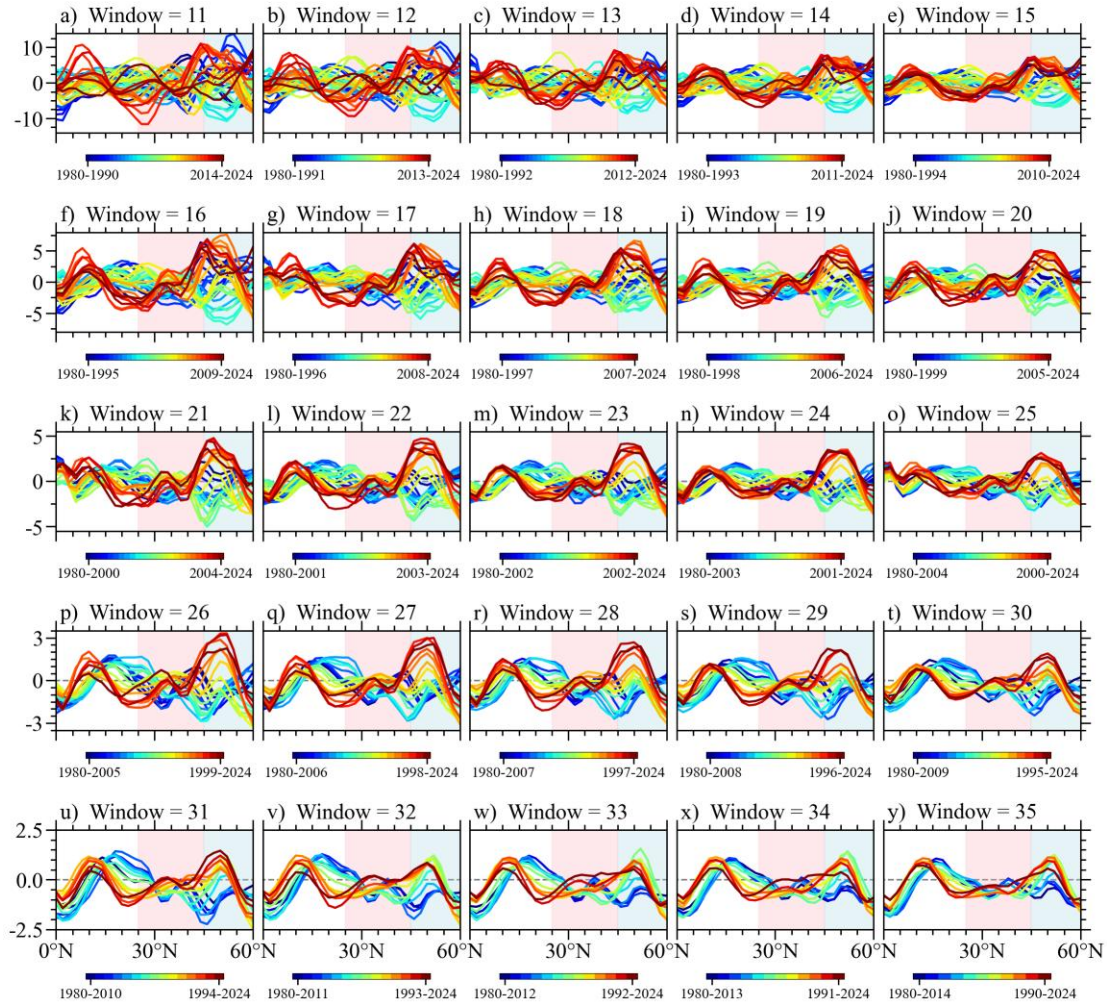
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22 **Fig. S2 | Winter North Atlantic 30-year linear raw negative meridional SST gradient (SSTg)**
 23 **trends over successive 30-year sliding windows. a–p,** Linear trends (units: $10^{-7} \text{ K m}^{-1} \text{ yr}^{-1}$) for
 24 successive overlapping 30-year periods from 1980–2009 to 1995–2024, respectively. Panel (a)
 25 corresponds to 1980–2009, with each subsequent panel advancing by one year, ending with panel
 26 (p) for 1995–2024. Dots indicate grid points where trends are significant at the 95% confidence
 27 level.



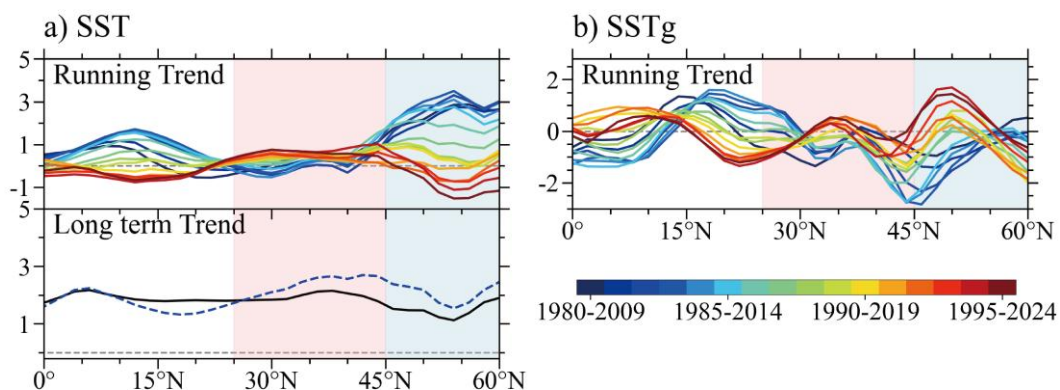
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30 **Fig. S3 | Zonal-mean North Atlantic raw sea surface temperature (SST) trends (75°W–30°E)**
 31 **computed over varying sliding windows from 1980 to 2024. a–y, Linear trends (units: 10^{-2} K yr $^{-1}$)**
 32 **calculated using sliding window lengths from 11 years (a) to 35 years (y), respectively, in increments**
 33 **of one year. Each panel corresponds to a different sliding window length, and the associated color**
 34 **bar is therefore adjusted accordingly to reflect the varying number of time intervals in each case.**
 35 **The light pink and light blue shading denote the mid-latitude North Atlantic (25°N–45°N) and**
 36 **subpolar North Atlantic regions (45°N–60°N), respectively.**



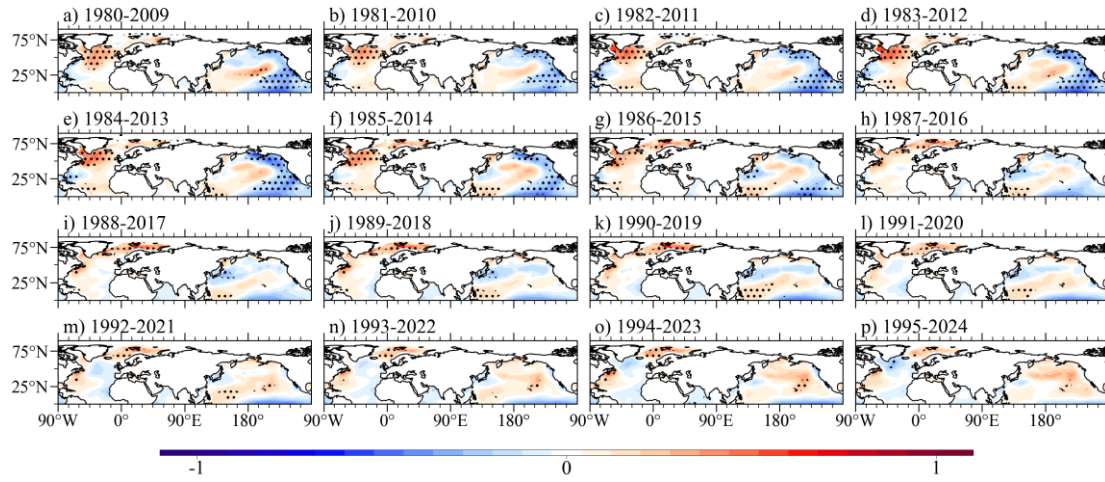
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39 **Fig. S4 | Zonal-mean North Atlantic raw negative meridional SST gradient (SSTg) trends. a–**
 40 **y, Linear trends (units: $10^{-8} \text{ K m}^{-1} \text{ yr}^{-1}$) calculated using sliding window lengths from 11 years (a)**
 41 **to 35 years (y), respectively, in increments of one year. Each panel corresponds to a different sliding**
 42 **window length, and the associated color bar is therefore adjusted accordingly to reflect the varying**
 43 **number of time intervals in each case. The light pink and light blue shading denote the mid-latitude**
 44 **North Atlantic (25°N–45°N) and subpolar North Atlantic regions (45°N–60°N), respectively.**



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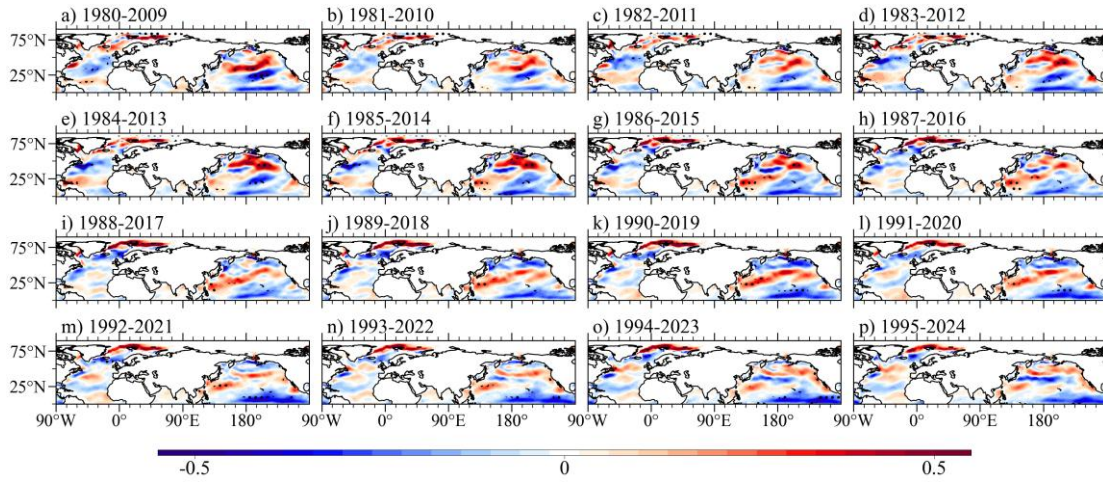
47 **Fig. S5 | Meridional structures of zonal-mean North Atlantic sea surface temperature (SST)**
 48 **trends. a**, Top: Latitudinal profiles of 30-year sliding trends for global-mean-temperature-removed
 49 (GMT-removed) SST (units: $10^{-2} \text{ K yr}^{-1}$). Bottom: Zonal-mean comparisons of raw long-term linear
 50 trends (blue dashed line) and GMT-forced long-term trends (black solid line). **b**, Latitudinal profiles
 51 of 30-year sliding trends for the GMT-removed negative meridional SST gradient (SSTg; units: 10^{-2}
 52 $\text{K m}^{-1} \text{ yr}^{-1}$). Colors in the top panel of (a) and in (b) denote different 30-year sliding window
 53 periods from 1980–2009 to 1995–2024. Shading highlights the mid-latitude (light pink; 25°N – 45°N)
 54 and subpolar (light blue; 45°N – 60°N) North Atlantic regions.



56

57 **Fig. S6 | Winter Northern Hemisphere 30-year linear global-mean-temperature-removed**
 58 **(GMT-removed) sea surface temperature (SST) sliding trends over successive 30-year sliding**
 59 **windows. a–p, Linear trends (units: 10^{-1} K yr $^{-1}$) for successive overlapping 30-year periods from**
 60 **1980–2009 to 1995–2024, respectively. Panel (a) corresponds to 1980–2009, with each subsequent**
 61 **panel advancing by one year, ending with panel (p) for 1995–2024. Dots indicate grid points where**
 62 **trends are significant at the 95% confidence level.**

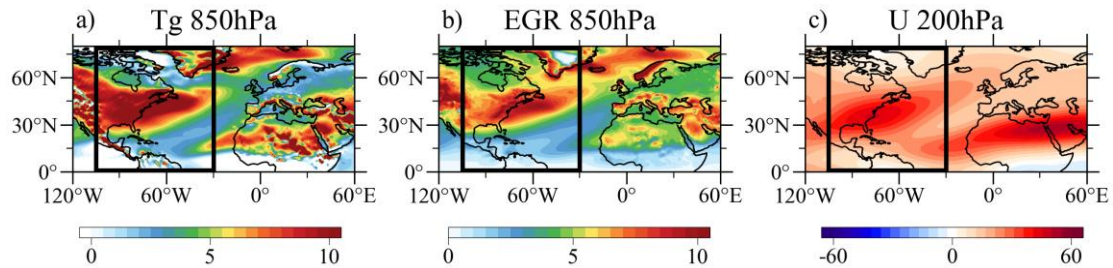
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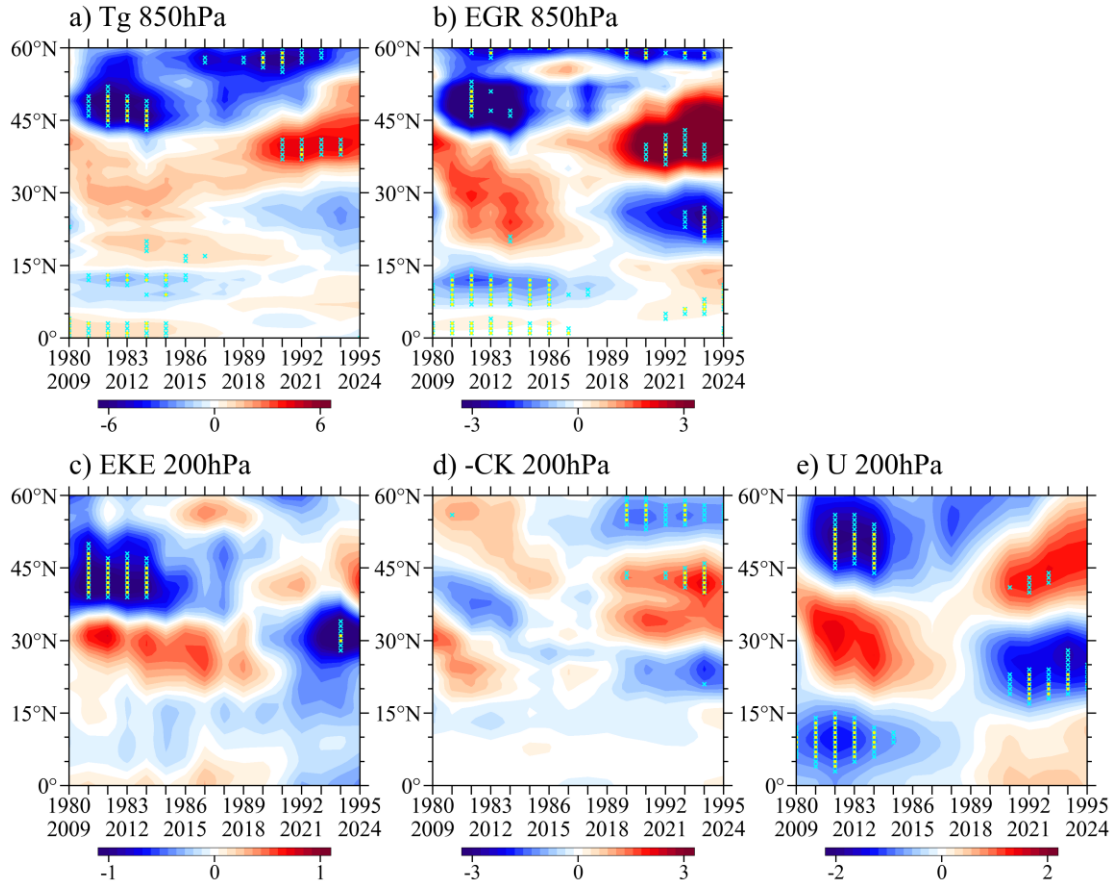
65 **Fig. S7 | Winter Northern Hemisphere 30-year linear global-mean-temperature-removed**
 66 **(GMT-removed) negative meridional SST gradient (SSTg) sliding trends over successive 30-**
 67 **year sliding windows. a–p,** Linear trends (units: $10^{-1} \text{ K yr}^{-1}$) for successive overlapping 30-year
 68 periods from 1980–2009 to 1995–2024, respectively. Panel (a) corresponds to 1980–2009, with
 69 each subsequent panel advancing by one year, ending with panel (p) for 1995–2024. Dots indicate
 70 grid points where trends are significant at the 95% confidence level.

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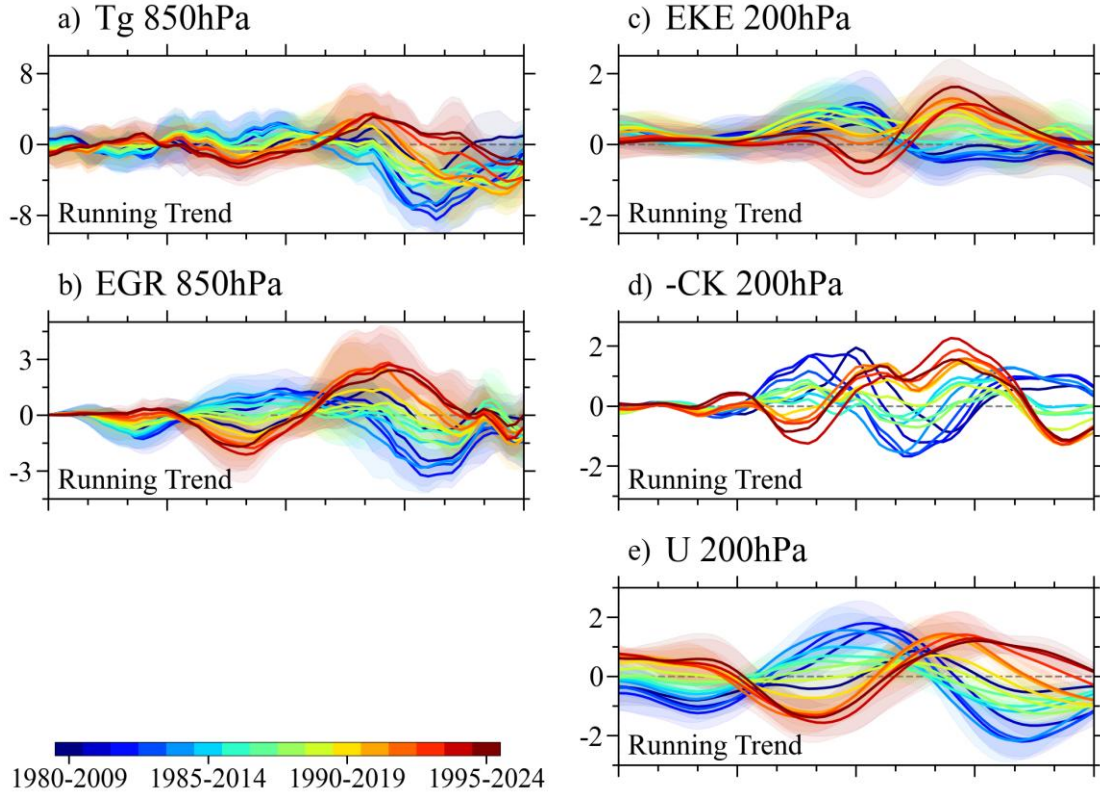
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73 **Fig. S8 | Climatological winter means of key baroclinic and jet-related fields. a,** Negative
 74 meridional temperature gradient at 850 hPa (Tg; unit: 10^{-6} K m^{-1}); **b,** Eady growth rate at 850 hPa
 75 (EGR; unit: 10^{-6} s^{-1}). **c,** Zonal wind at 200 hPa (U; unit: m s^{-1}). All fields are averaged over DJF
 76 1980–2024.



78

79 **Fig. S9 | Latitude–time distribution of zonal-mean 30-year sliding trends over the North**
 80 **American–North Atlantic sector (105°W–30°W).** a–e, 30-year sliding trends of (a) 850 hPa
 81 negative meridional temperature gradient (Tg; units: $10^{-8} \text{ K m}^{-1} \text{ yr}^{-1}$), (b) 850 hPa Eady growth rate
 82 (EGR; units: $10^{-8} \text{ s}^{-1} \text{ yr}^{-1}$), (c) 200 hPa eddy kinetic energy (EKE; units: $\text{m}^2 \text{ s}^{-2} \text{ yr}^{-1}$), (d) 200 hPa
 83 barotropic energy conversion (-CK; units: $\text{m}^2 \text{ s}^{-3} \text{ yr}^{-1}$), and (e) 200 hPa zonal wind (U; units: m s^{-1}
 84 yr^{-1}). The horizontal axis denotes each 30-year sliding window (labeled with start and end years),
 85 and the vertical axis denotes latitude. Shading indicates the sliding trends. Yellow dots and blue
 86 crosses indicate trends that are statistically significant at the 95% and 90% confidence levels,
 87 respectively.



89

90 **Fig. S10 | Zonal-mean (105°W–30°W) meridional structures of raw 30-year running trends**91 **for atmospheric variables. a–e, 30-year linear sliding trends computed directly from the raw data**92 **for (a) 850 hPa negative meridional temperature gradient (Tg; units: $10^{-8} \text{ K m}^{-1} \text{ yr}^{-1}$), (b) 850 hPa**93 **Eady growth rate (EGR; units: $10^{-8} \text{ s}^{-1} \text{ yr}^{-1}$), (c) 200 hPa eddy kinetic energy (EKE; units: $\text{m}^2 \text{ s}^{-2}$** 94 **$\text{yr}^{-1}$), (d) 200 hPa barotropic energy conversion (-CK; units: $\text{m}^2 \text{ s}^{-3} \text{ yr}^{-1}$), and (e) 200 hPa zonal wind**95 **(U; units: $\text{m s}^{-1} \text{ yr}^{-1}$). Colors denote different 30-year sliding window periods from 1980–2009 to**96 **1995–2024, as indicated by the color bar. Shading denotes ± 1 standard deviation across longitudes**97 **within 105°W–30°W.**

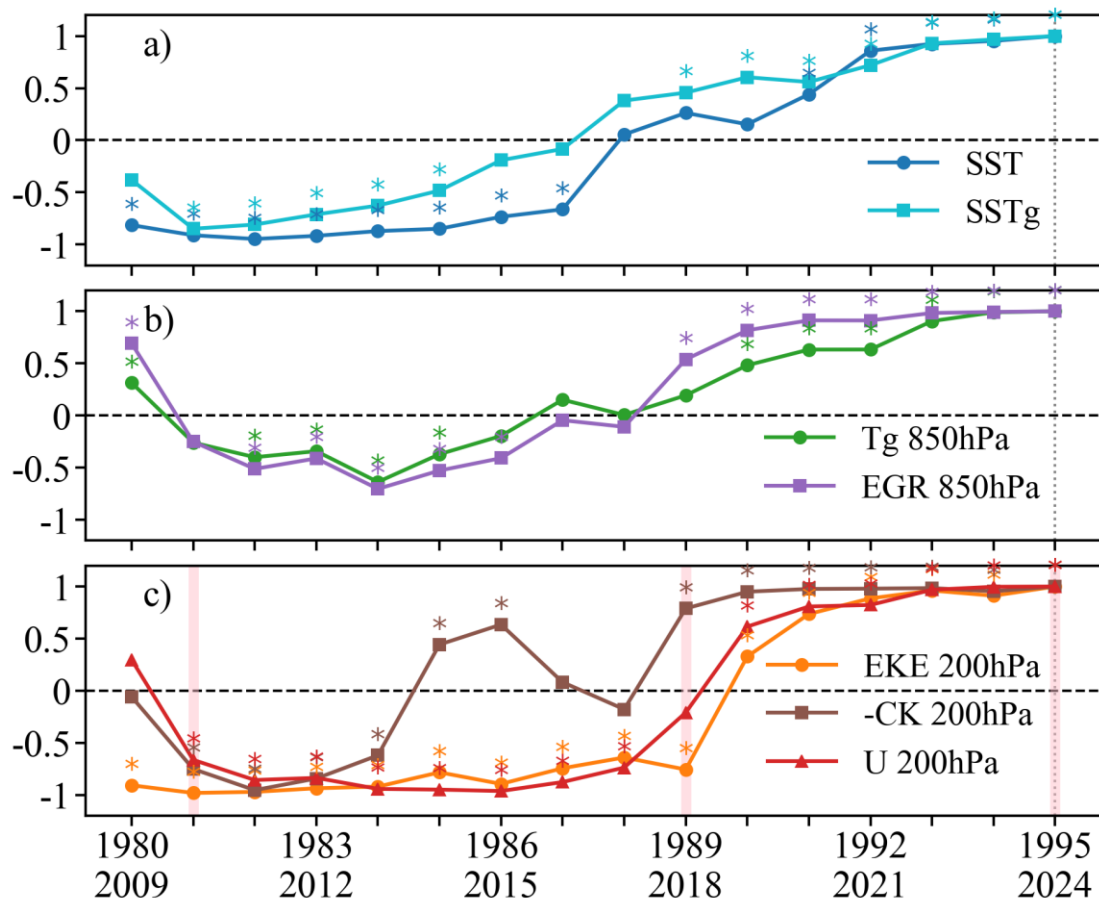
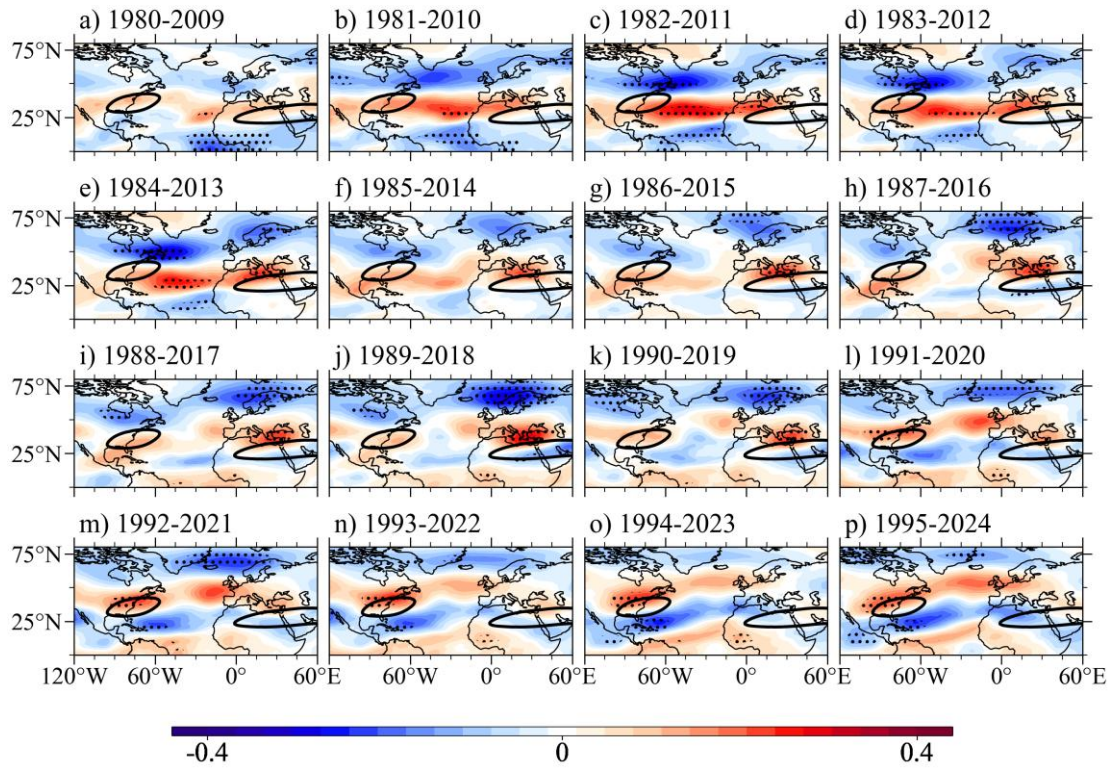
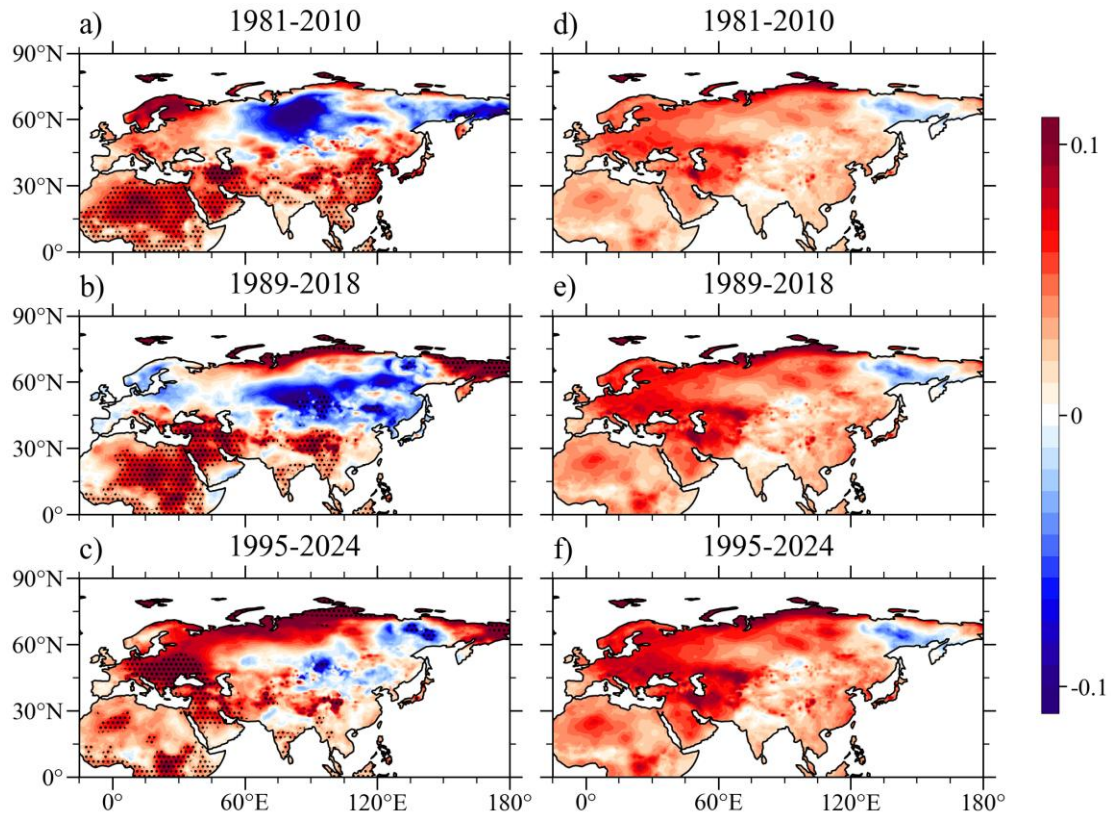


Fig. S11 | Stage delineation of the internal oceanic and atmospheric trend evolution. a,
Temporal evolution of the spatial correlation between the zonally averaged North Atlantic SST (blue)
and SSTg (cyan) internal trend patterns in each 30-year sliding window against that of the final
reference period (1995–2024). b, As in (a), but for the 850 hPa Tg (green) and EGR (purple). c, As
in (a), but for the 200 hPa EKE (orange), -CK (brown), and U (red). Asterisks indicate statistical
significance at the 95% confidence level. Light pink vertical bars in panel (c) highlight the three
selected representative stages: 1981–2010 (Stage I), 1989–2018 (Stage II), and 1995–2024 (Stage
III).



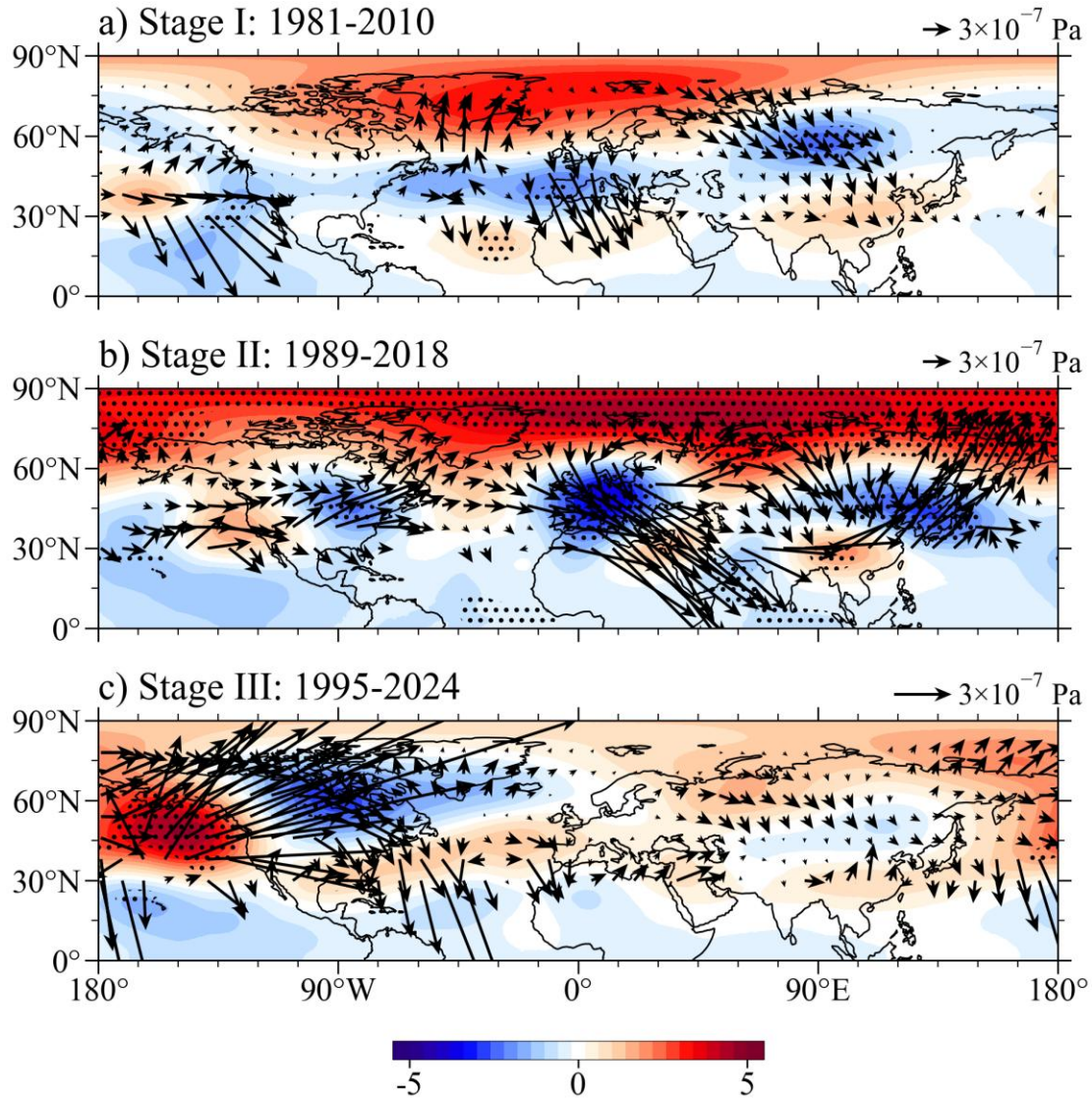
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110 **Fig. S12 | Winter 30-year linear global-mean-temperature-removed (GMT-removed) zonal**
 111 **wind (U) trends over successive 30-year sliding windows. a–p, Linear trends (units: m s⁻¹ yr⁻¹)**
 112 **for successive overlapping 30-year periods from 1980–2009 to 1995–2024, respectively. Panel (a)**
 113 **corresponds to 1980–2009, with each subsequent panel advancing by one year, ending with panel**
 114 **(p) for 1995–2024. The solid contour in each panel denotes the 30 m s⁻¹ climatological zonal wind.**
 115 **Dots indicate grid points where trends are significant at the 95% confidence level.**



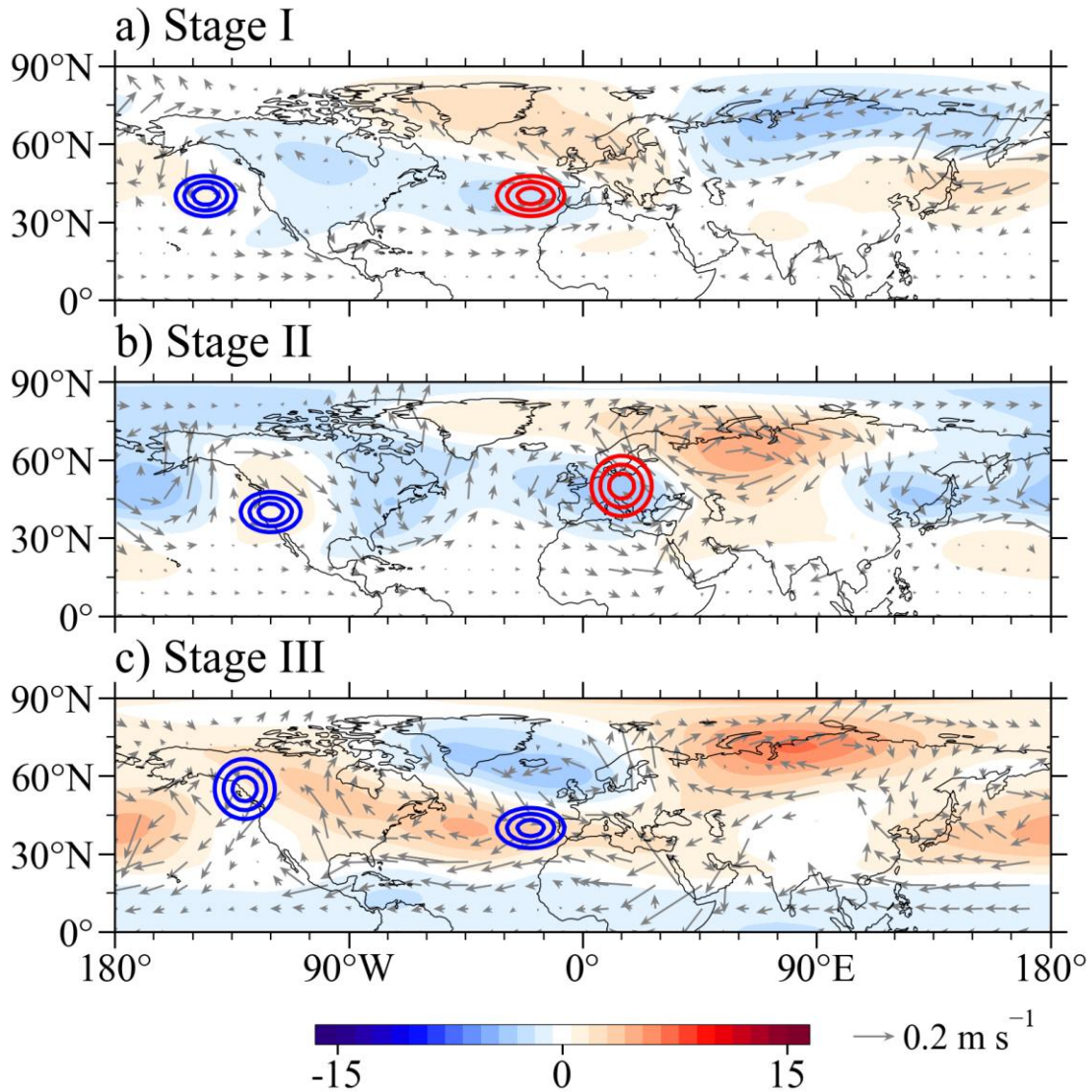
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118 **Fig. S13 | Three-stage evolution of the raw and global-mean-temperature-related (GMT-**
 119 **related) trends based on sliding window analysis in winter near-surface air temperature (T2m)**
 120 **over Eurasia. a–c, Raw linear trends of 2 m air temperature (T2m; units: K yr⁻¹) for the periods**
 121 **1981–2010 (a), 1989–2018 (b), and 1995–2024 (c). d–f, Corresponding global-mean-temperature-**
 122 **related (GMT-related) trend components of T2m for the periods 1981–2010 (d), 1989–2018 (e), and**
 123 **1995–2024 (f). Dots indicate grid points where trends are significant at the 95% confidence level.**



125

126 **Fig. S14 | Evolution of global-mean-temperature-removed (GMT-removed) 200 hPa**
 127 **geopotential height and wave activity flux trends across the Northern Hemisphere. a–c, Spatial**
 128 **circulation patterns for Stage I (1981–2010) (a), Stage II (1989–2018) (b), and Stage III (1995–**
 129 **2024) (c). Shaded contours represent the internal 200 hPa geopotential height trend fields (units:**
 130 **gpm yr⁻¹). Black vectors denote the corresponding horizontal wave activity flux (WAF; units: Pa).**
 131 **Dots indicate grid points where geopotential height trends are significant at the 95% confidence**
 132 **level.**



134

135 **Fig. S15 | Prescribed idealized vorticity forcings and the associated Linear Baroclinic Model**
 136 **(LBM) simulations. a–c,** Setup of the regional forcings applied in the LBM across three stages: (a)
 137 Stage I (1981–2010), (b) Stage II (1989–2018), and (c) Stage III (1995–2024). The colored contours
 138 highlight the prescribed idealized vorticity forcings, where red and blue contours indicate positive
 139 and negative vorticity sources, respectively. As a result of these applied drivers, shading and vectors
 140 depict the simulated steady-state geopotential height at 500 hPa (units: gpm) and horizontal wind
 141 anomalies at 850 hPa (units: m s^{-1}).