

European Heatwaves Aggravated by Recent Summer Arctic and North Atlantic Circulation Changes

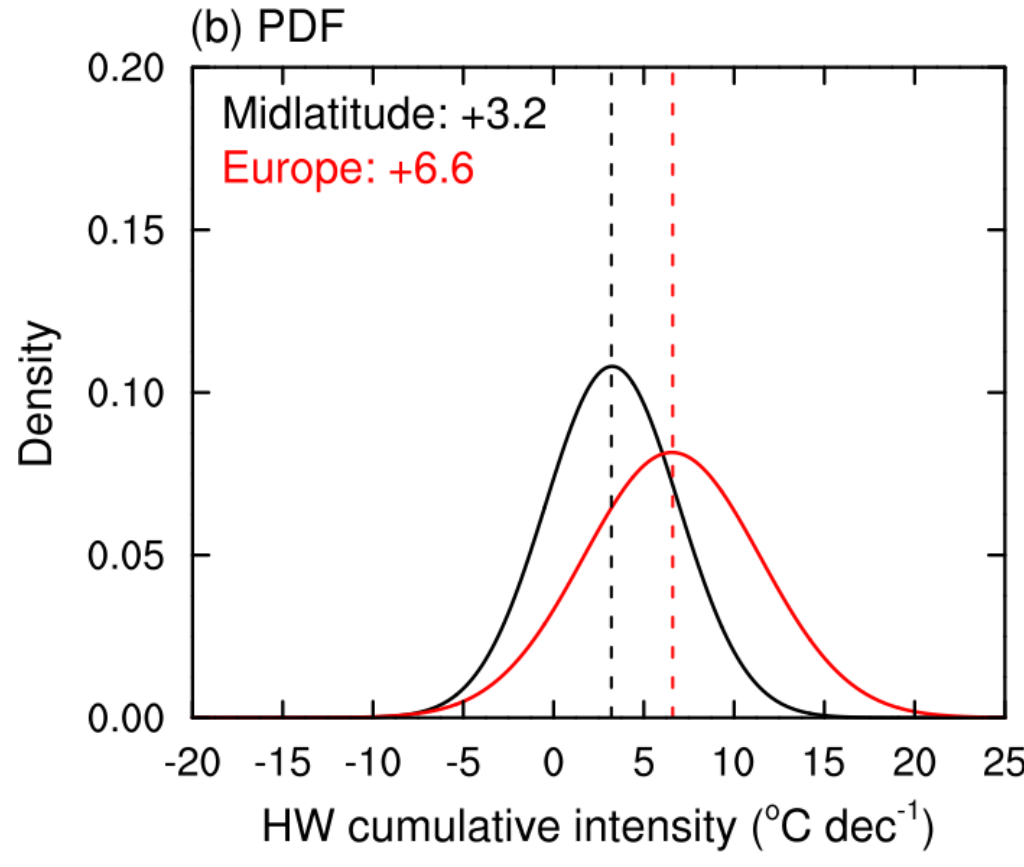
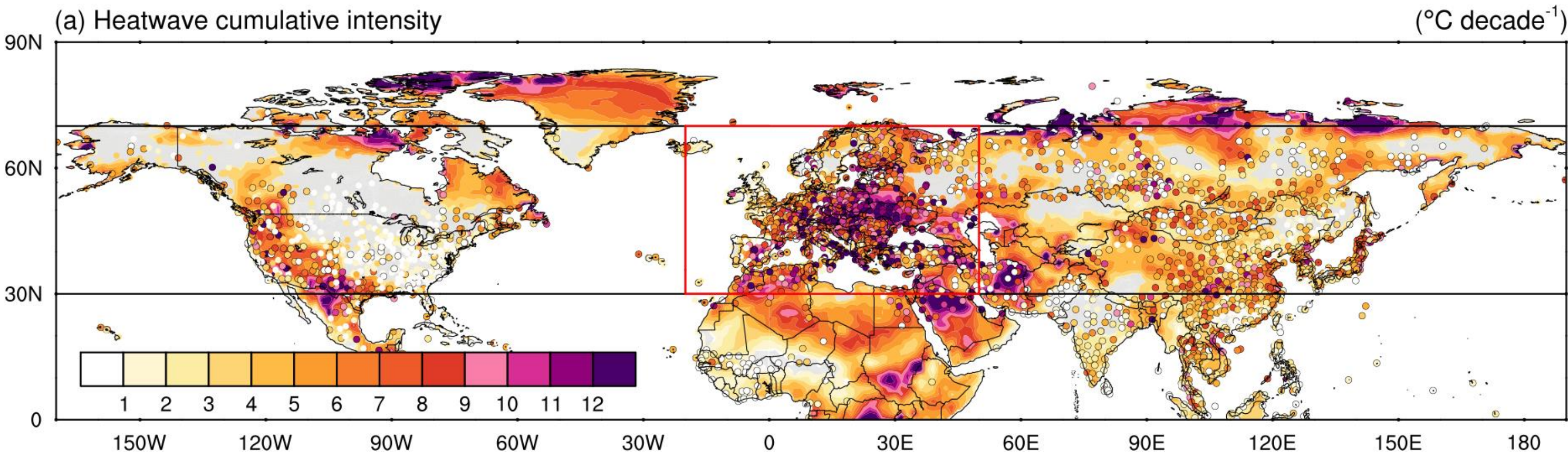


El Noh¹, Joowan Kim^{1*}, Yu Kosaka², Sang-Wook Yeh³, Seok-Woo Son⁴, Baik-Min Kim⁵, Dim Coumou⁶, Kai Kornhuber⁷, Sang-Yoon Jun⁸, Woosok Moon⁶, Masato Mori², and Jeong-Hun Kim²

¹Kongju National University, ²University of Tokyo, ³Ewha Womans University, ⁴Seoul National University, ⁵Pukyong National University, ⁶Vrije Universiteit Amsterdam, ⁷International Institute for Applied Systems Analysis (IIASA), ⁸Korea Polar Research Institute



1. Motivation



European HW duration intensified (>100%) since 2010

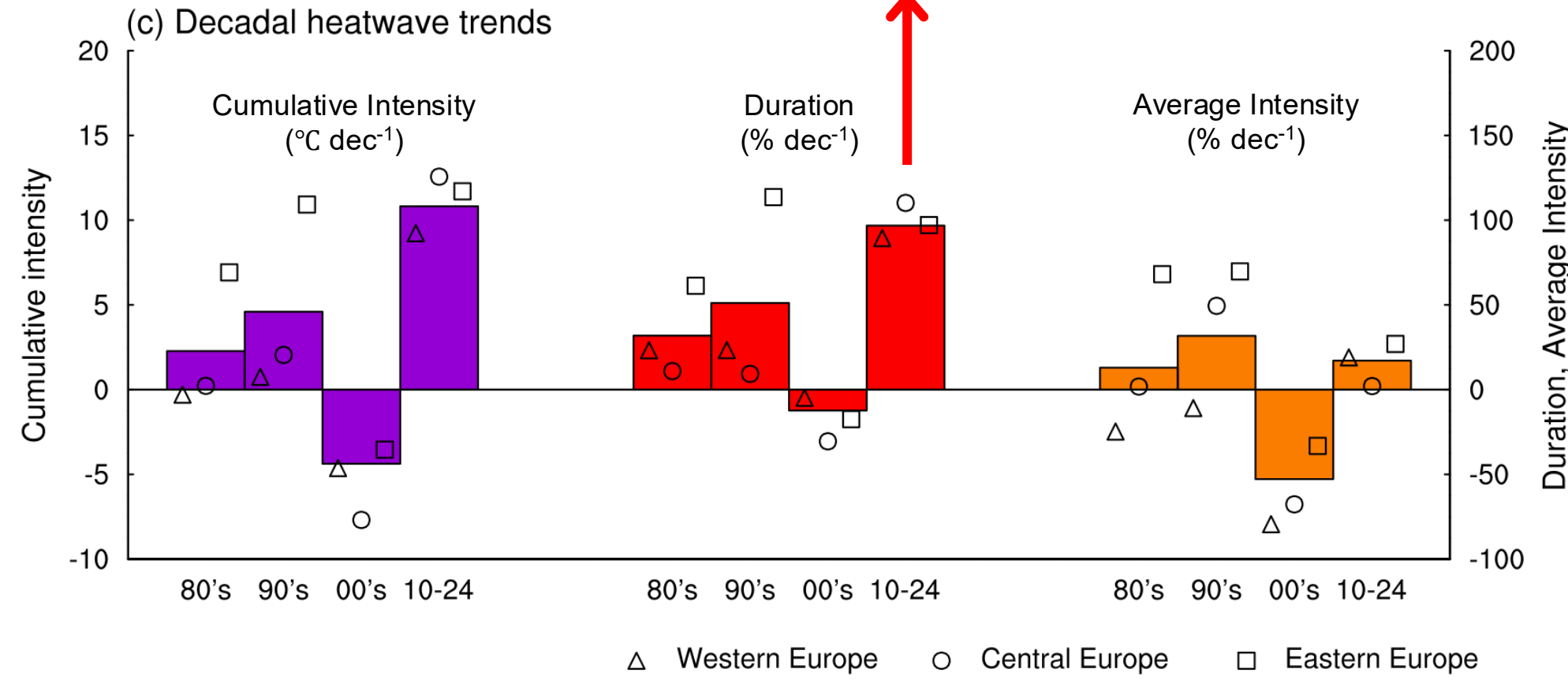


Figure 1. (a) Spatial distribution of decadal trends of heatwave cumulative intensity (°C decade⁻¹) from 1979 to 2024 during boreal summer (June–August). (b) Probability distribution function of decadal trend of heatwave cumulative intensity of all observation stations for Europe (in red, as the region included in red box of (a)) and the midlatitudes excluding Europe (in black). (c) Regional comparison of decadal heatwave trends across European subregions for different decades (1980s, 1990s, 2000s, 2010-24).

2. Recent Summer Arctic/North Atlantic Changes

Since 2010: GRL cooling (-0.4 °C dec⁻¹), BKS warming (+2.2 °C dec⁻¹)
→ Temperature gradient: North Atlantic (enhanced), northern Eurasia (weakened)

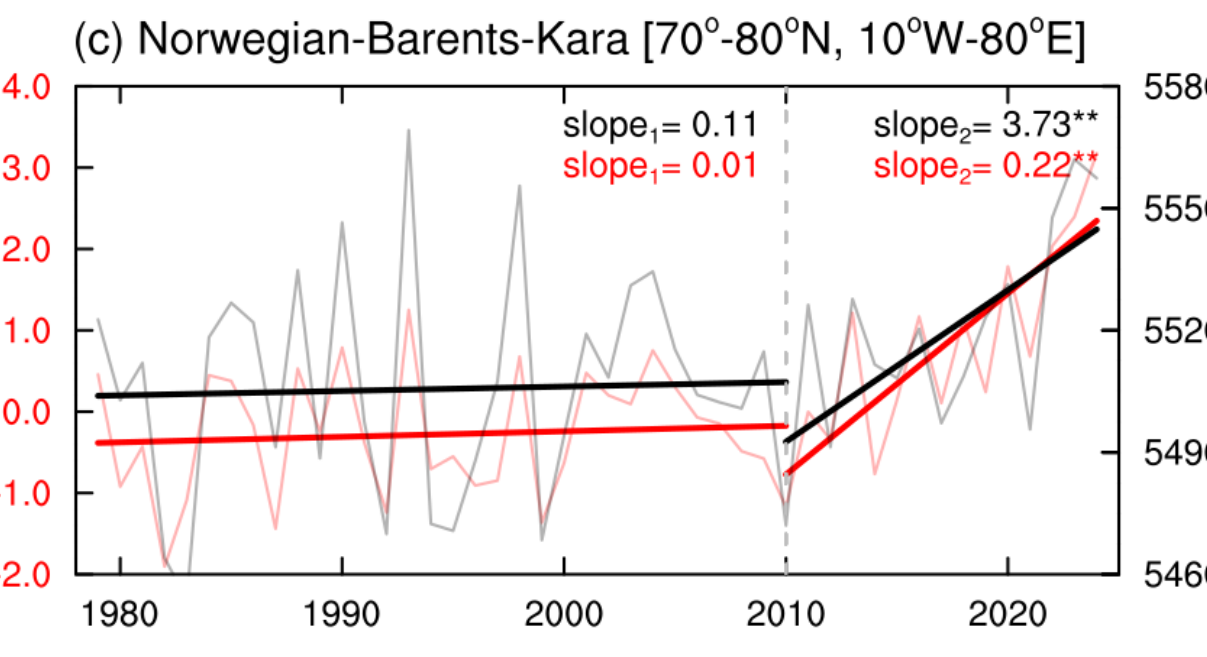
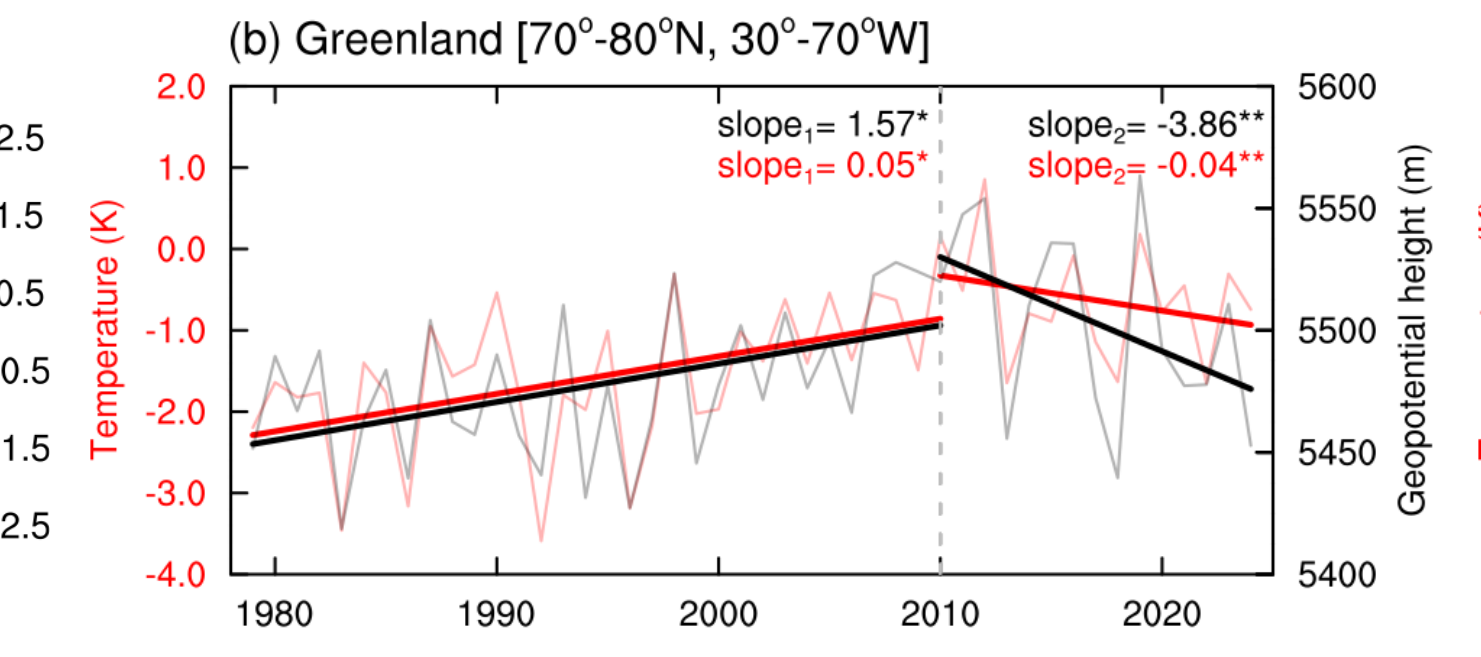
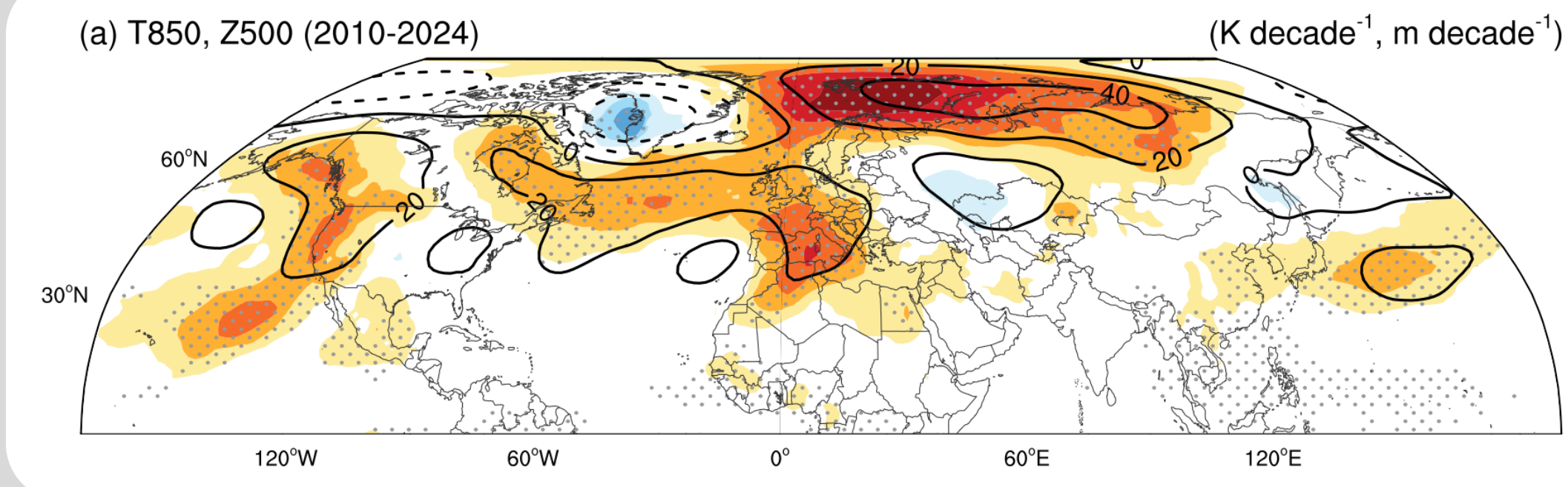
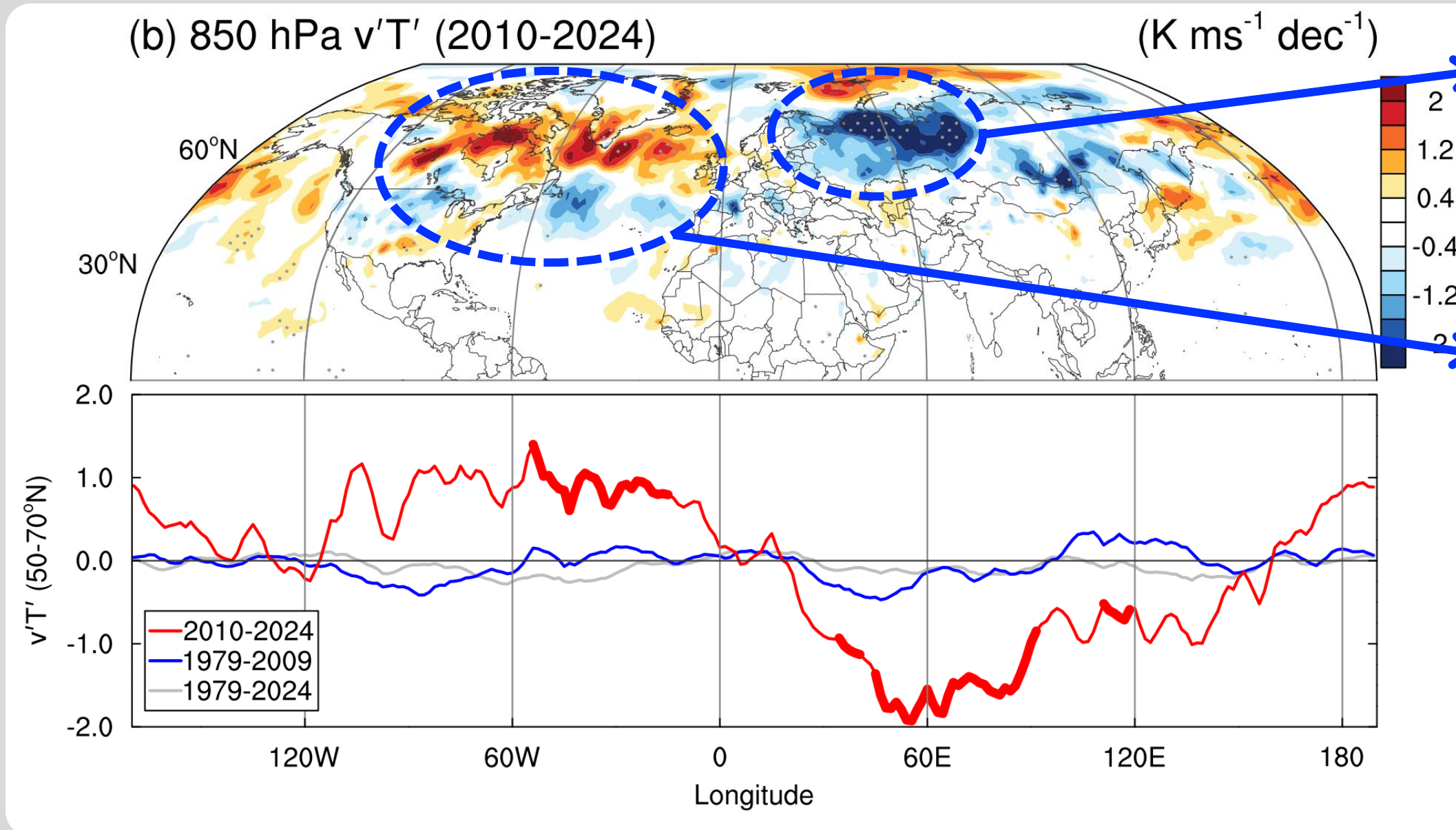


Figure 2. Spatial distributions of decadal trends during boreal summer (June–August) in 850-hPa temperature (shading, K decade⁻¹) and 500-hPa geopotential height (contour, m decade⁻¹) for (a) 2010-2024. (b, c) Time series of 850-hPa temperature (red line, left axis) and 500-hPa geopotential height (black line, right axis) averaged over the (b) Greenland and (c) Barents-Kara Sea, respectively.

PART 1 Impact on Midlatitude Circulations

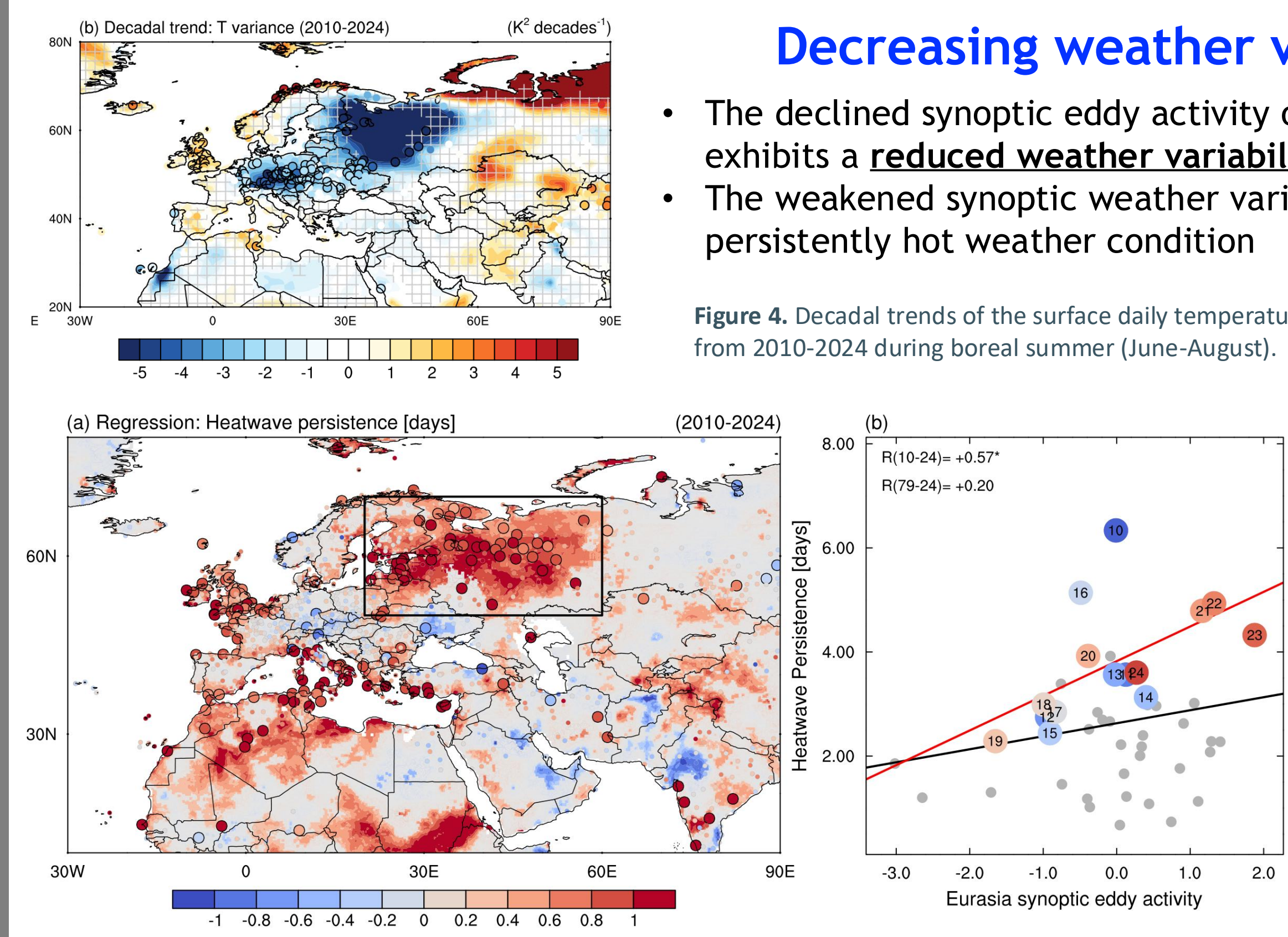
Temperature gradient change → **Synoptic eddy activity change** (1~10 days)



Northern Eurasia Weakened synoptic eddy heat flux
North Atlantic Poleward shifted synoptic eddy heat flux

Figure 3. Decadal trends during boreal summer (June–August) from 2010–2024 in 850-hPa eddy heat flux ($v'T'$, K m s⁻¹ decade⁻¹).

Mechanism 1

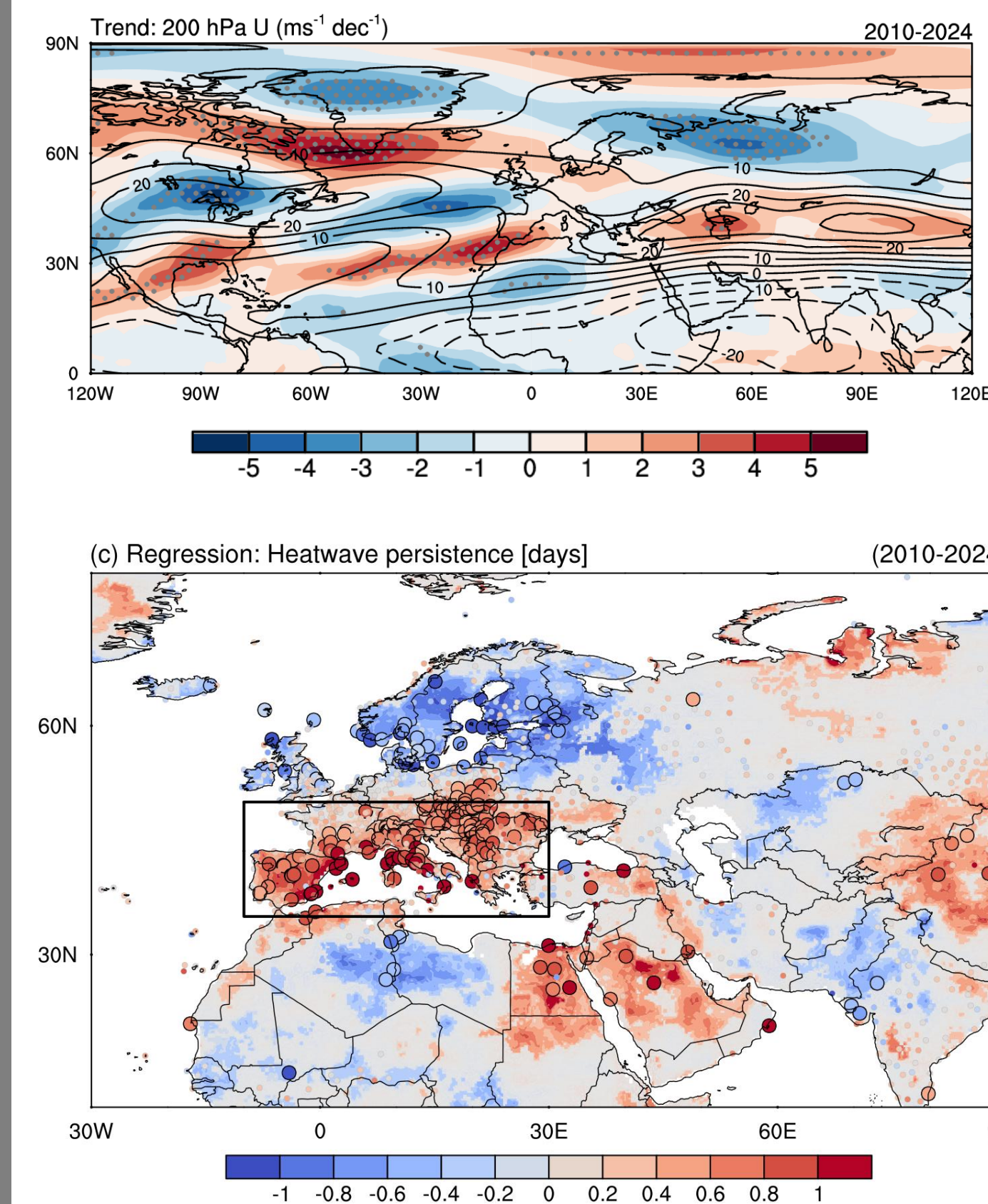


Decreasing weather variability

- The declined synoptic eddy activity over western Eurasia exhibits a **reduced weather variability**
- The weakened synoptic weather variability promotes persistently hot weather condition

Figure 4. Decadal trends of the surface daily temperature variance (K² decade⁻¹) from 2010-2024 during boreal summer (June–August).

Mechanism 2



North Atlantic Jet shift

- The poleward shifted synoptic eddy heat flux exhibits a **shifted Atlantic polar-front jet**
- The northward shift jet promotes the invasion of warm flows from the subtropics and Sahara

Figure 6. Decadal trends of the 200-hPa zonal wind (m s⁻¹ decade⁻¹) for 2010-2024 during boreal summer (June–August). Black contour indicate climatology of the 200-hPa zonal wind.

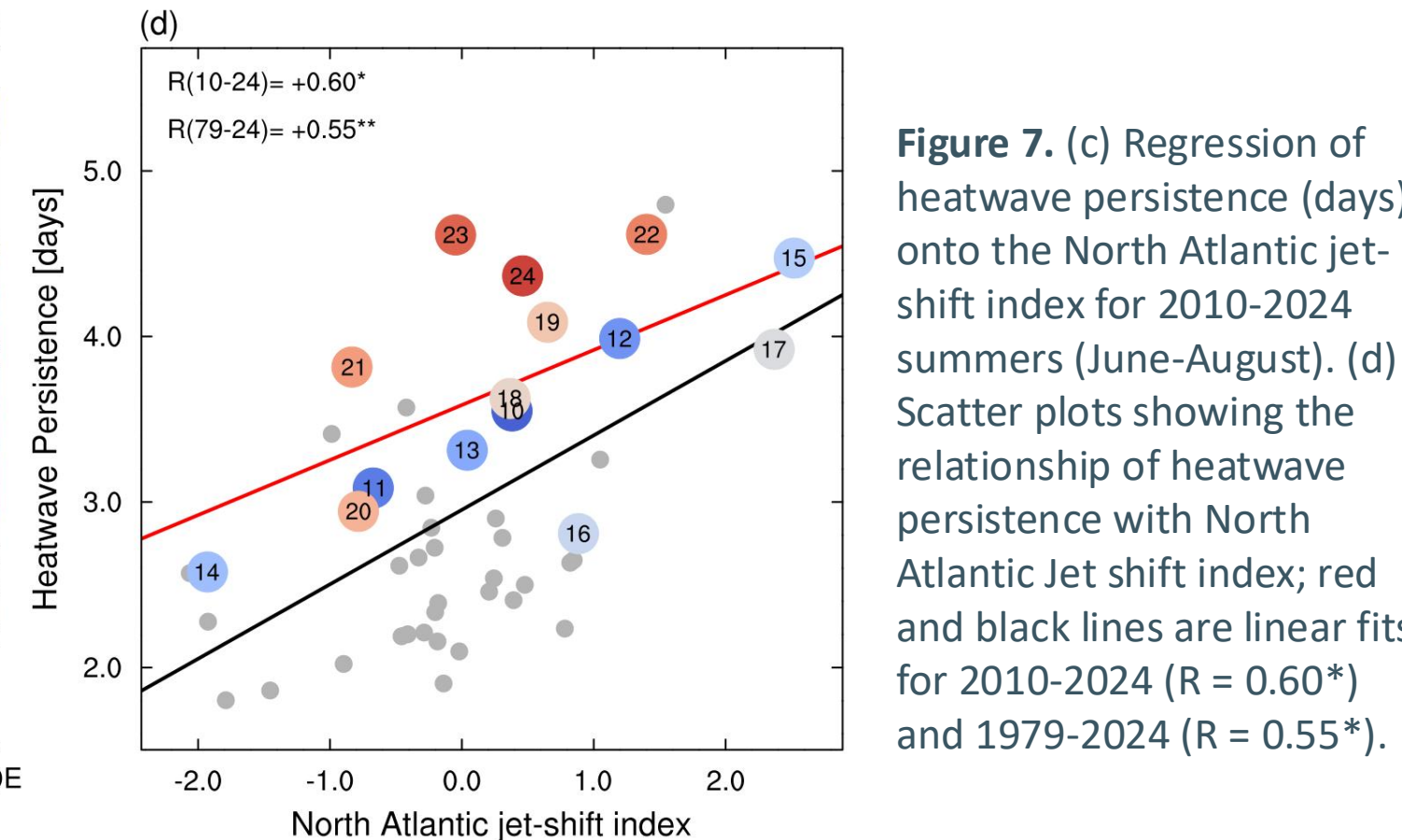


Figure 7. (c) Regression of heatwave persistence (days) onto the Eurasian synoptic eddy activity index for 2010-2024 summers (June–August). (d) Scatter plots showing the relationship of heatwave persistence with Eurasian synoptic eddy activity; red and black lines are linear fits for 2010-2024 (R = 0.57*) and 1979-2024 (R = 0.20).

PART 2 Impact on Atmospheric Energy (Murakami 2011)

Recent Summer Arctic Change

Pm ($\bar{T}'^2$)
Mean Available Potential Energy

Baroclinic conversion
 $c_p \gamma \text{div}[(\bar{T}' - \langle \bar{T}' \rangle) u' T']$

Heat flux conv & T-gradient
North Atlantic (enhanced)
Northern Eurasia (weakened)

Pe (T'^2)
Eddy Available Potential Energy

Ke (u'^2)
Eddy Kinetic energy

Barotropic conversion
 $\text{div}(\bar{u} u' u' + \bar{v} v' v')$

Momentum flux conv & Mean flow gradient
Eddies reinforce the shifted jet

Km ($\bar{U}^2$)
Mean Kinetic energy

Decadal trend of the energy components

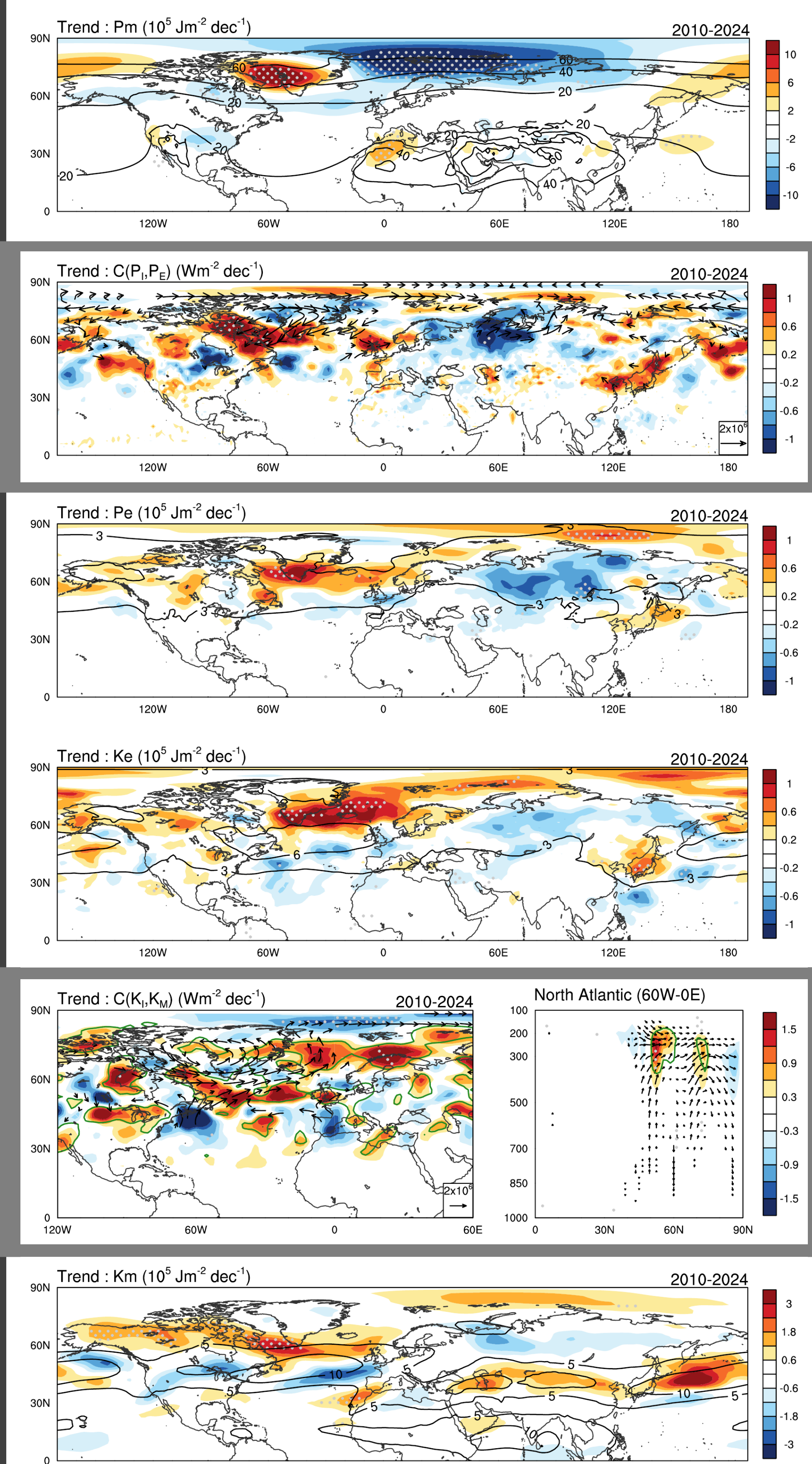


Figure 8. Decadal trend of the atmospheric energy components for 2010-2024 during boreal summer (June–August). Black contour indicate climatology.

Conclusion

- Summer Arctic warming has amplified since 2010 (in fact, BKS warming and GRL cooling/NA warming)
- BKS warming **weakened synoptic weather variabilities** over Northeastern Europe, causing persistent warm weather condition
- GRL cooling and North Atlantic warming shifted the North Atlantic jet northward, promoting warm subtropical air intrusion into Southwestern Europe
- Energetics support both pathways: **baroclinic conversion weakened over northern Eurasia**, and **eddy-to-mean kinetic energy conversion strengthened** along the shifted North Atlantic jet

Further Study

- Atmospheric energy:** how Arctic temperature changing alter mean-eddy interaction across the full Local energy cycle.
- Origin of recent changes:** determine whether BKS warming and Greenland cooling since 2010 stem from internal variability (e.g., NAO, AMOC), sea-ice loss, or external forcing.