



QBO–TC relationship in the western North Pacific is nonstationary

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1 Introduction

- Tropical cyclones (TCs) in the western North Pacific cause severe casualties and infrastructure destruction through wind gusts, storm surges, and extreme rainfall.
- TC tracks can be modulated by large-scale climate variability.
- Among various climate modes, the stratospheric Quasi-Biennial Oscillation (QBO) has been suggested to affect TC tracks, although its influence in recent decades remains controversial.

Research goals

- Does the influence of QBO on TC tracks over the western North Pacific remain significant?
- How does the QBO modulate TC tracks over the western North Pacific?

2 Data & Methods

TC Track Data

: Regional Specialized Meteorological Center-Tokyo Typhoon Center Best Track Data (JJASO)

Dataset	Variables	Resolution	Period
ERA5	U, V, Z, T	1.5°×1.5°	1976–2024
NOAA OLR	OLR	Monthly	1979–2024
ERSST v5	SST	2.0°×2.0°	1976–2024

Table. 1| Datasets used in this study.

QBO Index

: Vertical wind shear anomaly between 50 and 70-hPa using zonal-mean U (5°S – 5°N)

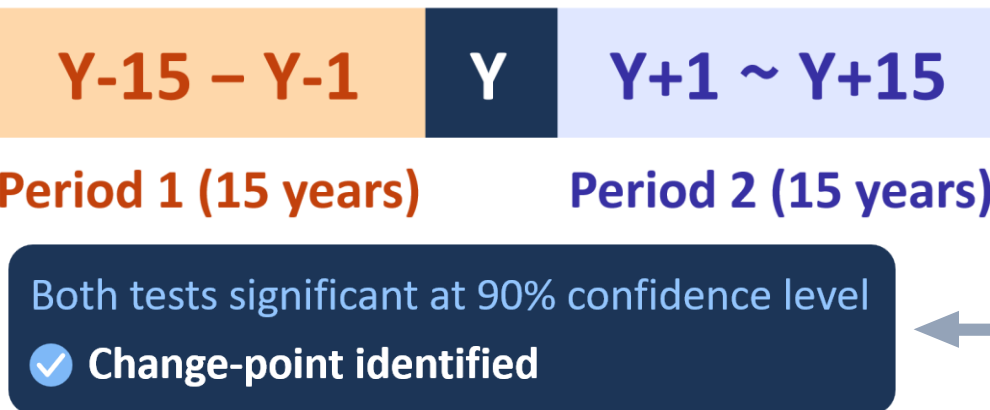
Removing ENSO signal

: $A_{res} = A - rc(A, Ni\tilde{n}o3.4 \text{ index}) \times Ni\tilde{n}o3.4 \text{ index}$

✖ Long-term trends are also removed from each variable.

Change-point detection

① Sliding window



② Two independent tests



Linear Baroclinic Model (LBM)

Resolution	T42 with 20 sigma (σ) level
Damping timescale	Topmost two levels: 0.5 day Mid-levels: 20 days Lowest three levels: 0.5 day
Basic state	JJASO-mean basic states during P1 (1979–2004) and P2 (2005–2024), excluding strong ENSO years
External forcing	Steady diabatic heating and cooling near 165°E, 20°N, 135°E, 20°N, and 170°E, 10°N
Integration time length	15 days

Table. 2| Configuration of the linear baroclinic model (Watanabe & Kimoto, 2000).

3 Weakening of QBO–TC Relationship

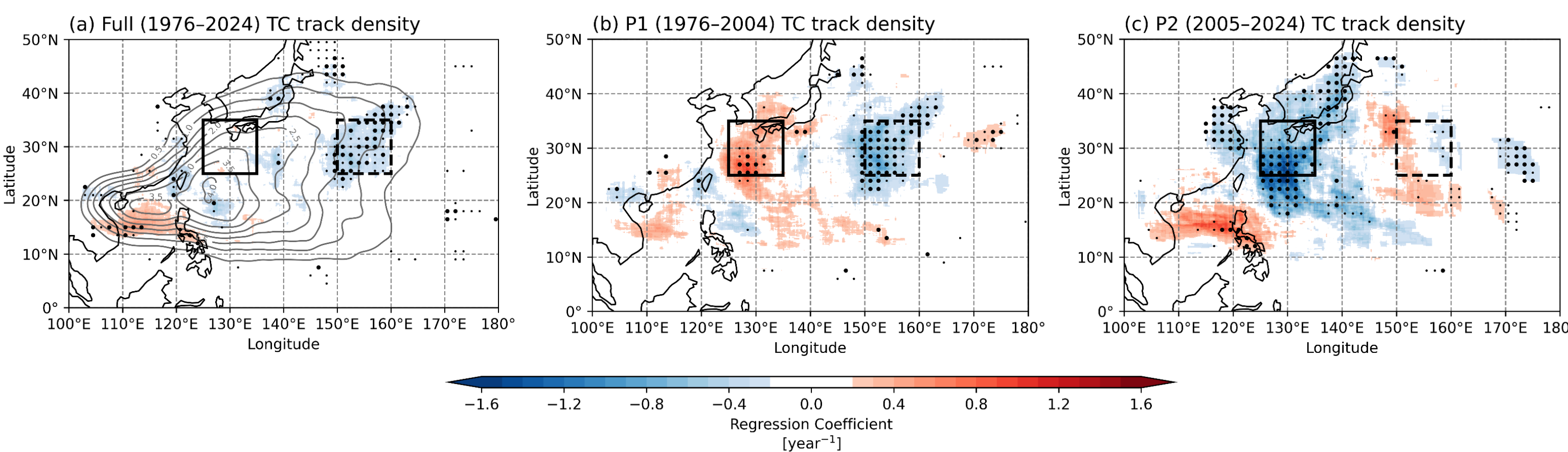


Fig. 1| TC track density regressed onto the QBO index for (a) the full period (1976–2024), (b) P1 (1976–2004), and (c) P2 (2005–2024). Gray contours in (a): climatological TC track density (max 4.33 year⁻¹). Dots: significance at 95% (large) and 90% (small). Boxes: East China Sea (125°–135°E, 25°–35°N; solid) and offshore east of Japan (150°–160°E, 25°–35°N; dashed).

- The relationship between the QBO and TC tracks in the western North Pacific is nonstationary and varies over time.
- The enhanced TC activity over the East China Sea under the westerly QBO phase, evident during P1 (1976–2004), has reversed after 2004.

4 Change-point detection

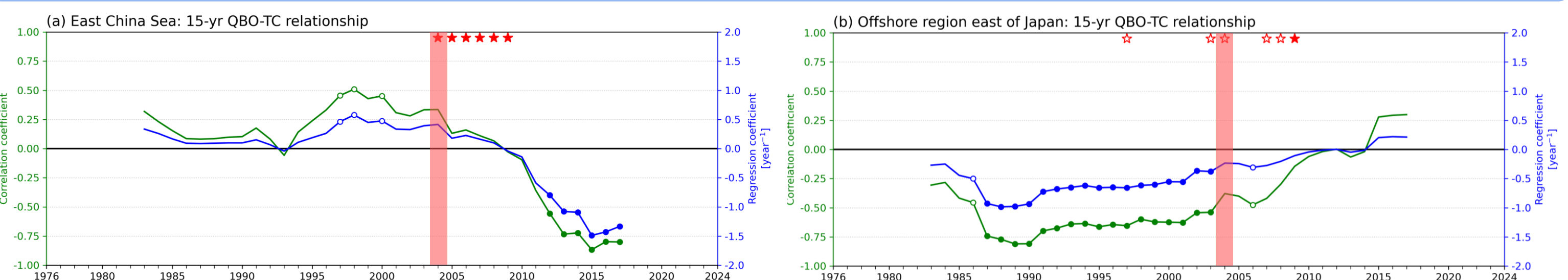


Fig. 2| Temporal evolution of the QBO–TC relationship over the (a) East China Sea and (b) offshore region east of Japan (solid and dashed boxes in Fig. 1) during 1976–2024, from 15-yr moving-window Pearson correlations (green; left axis) and regression coefficients (blue; right axis). Filled/open red stars (top): change-point years, where both the moving-correlation and Chow tests indicate a significant shift between the pre- and post-15-year periods at 95%/90%.

- The relationship shifts around the mid-2000s, dividing the period into P1 (1976–2004) and P2 (2005–2024).
- When the lengths of the pre- and post-periods are varied various years, the year 2004 persistently emerges as a change-point at the 95% confidence level (not shown).

5 Change in the background circulation

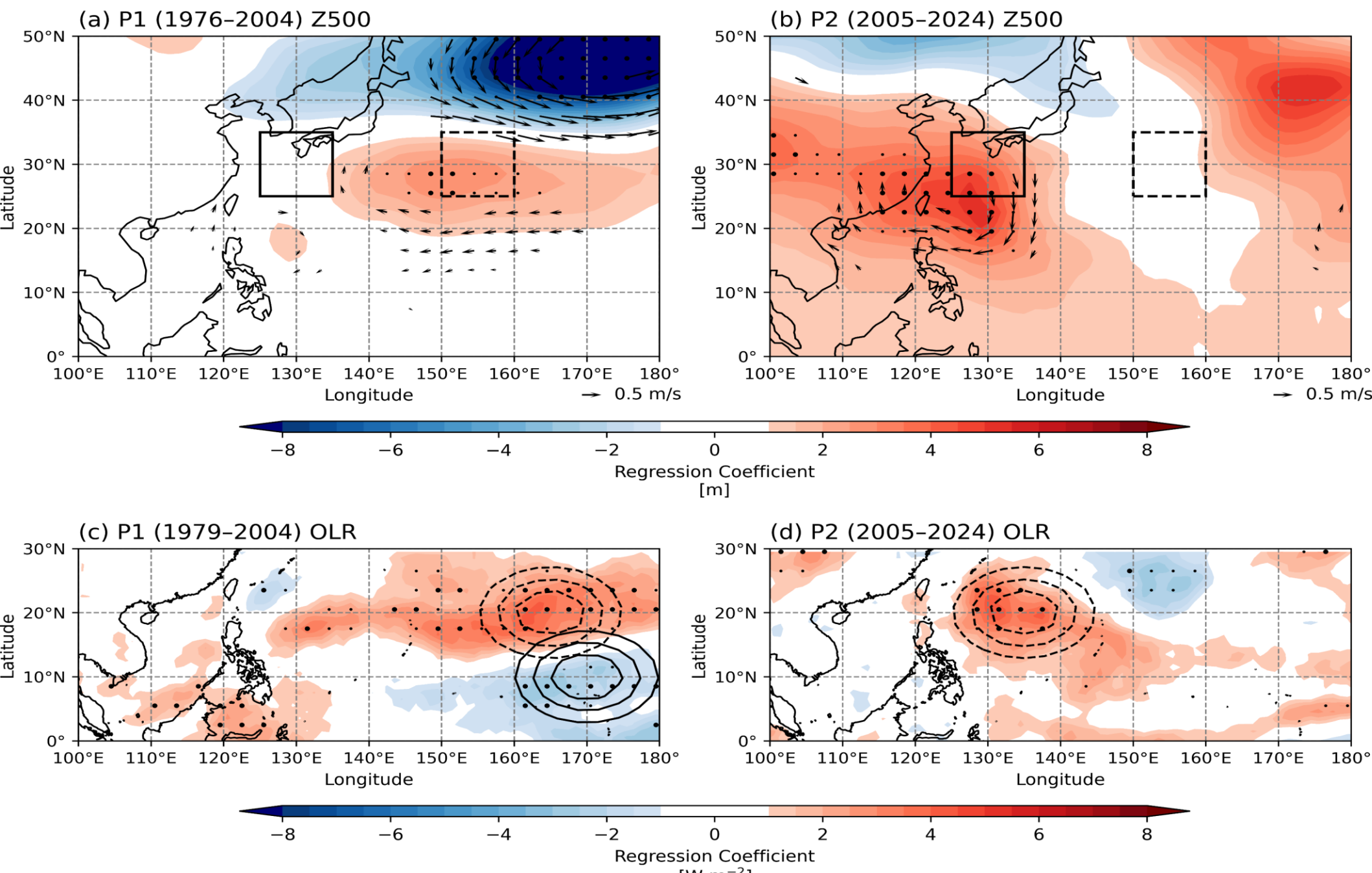


Fig. 3| Regression onto the QBO index of (a, b) Z500 (shading) and 200–850-hPa vertically averaged wind anomalies (vectors; only 95%-significant values shown), and (c, d) OLR, for (a, c) P1 and (b, d) P2. Dots: significance at 95% (large) and 90% (small). Contours in (c, d): key convective regions, with solid (dashed) lines for enhanced (suppressed) convection under the westerly QBO phase.

- The decadal change in QBO–TC relationship is closely related to QBO-related anticyclonic circulation anomaly around 30°N.
- Decadal changes also emerge in the tropical and subtropical convection that can induce the anticyclonic circulation anomaly.

6 LBM experiments

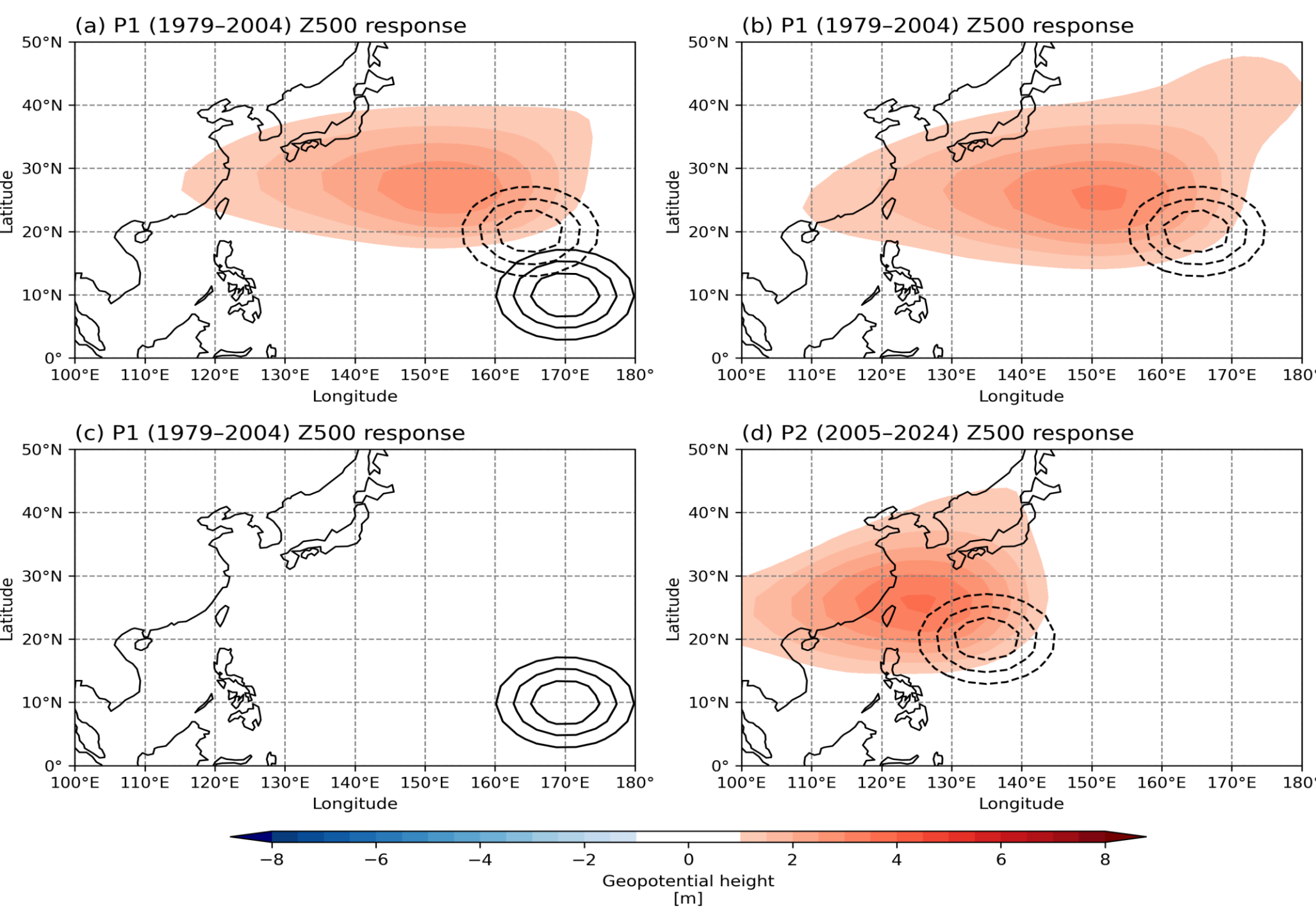


Fig. 4| Z500 response (shading) to thermal forcing (contours; solid: heating, dashed: cooling) in linear model experiments: (a) combined cooling (165°E, 20°N) and heating (170°E, 10°N) and (b) cooling only, (c) heating only, under the P1 background state; (d) cooling only (135°E, 20°N) under the P2 background state. Forcing locations and signs follow the observed WQBO-related OLR anomalies (Figs. 2c, d).

- When combined forcing is applied to the LBM, it simulates an anticyclonic circulation consistent with observations.
- Anticyclonic circulation is associated with changes in QBO-related convection anomalies over 20°N.

7 Possible mechanisms

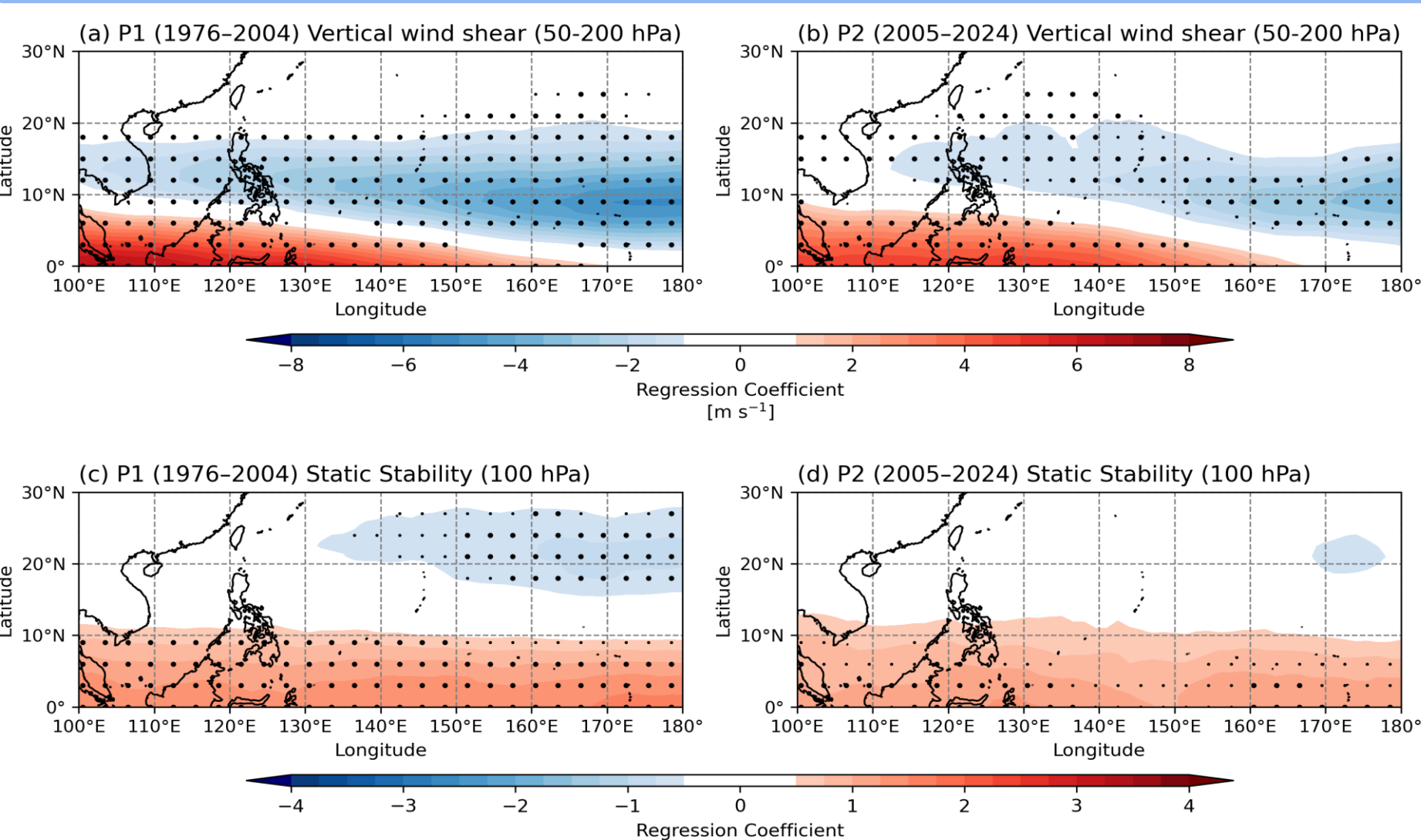


Fig. 5| Regression onto the QBO index of (a, b) 50–200-hPa vertical wind shear and (c, d) 100-hPa static stability, for (a, c) P1 (1976–2004) and (b, d) P2 (2005–2024). Dots: significance at 95% (large) and 90% (small).

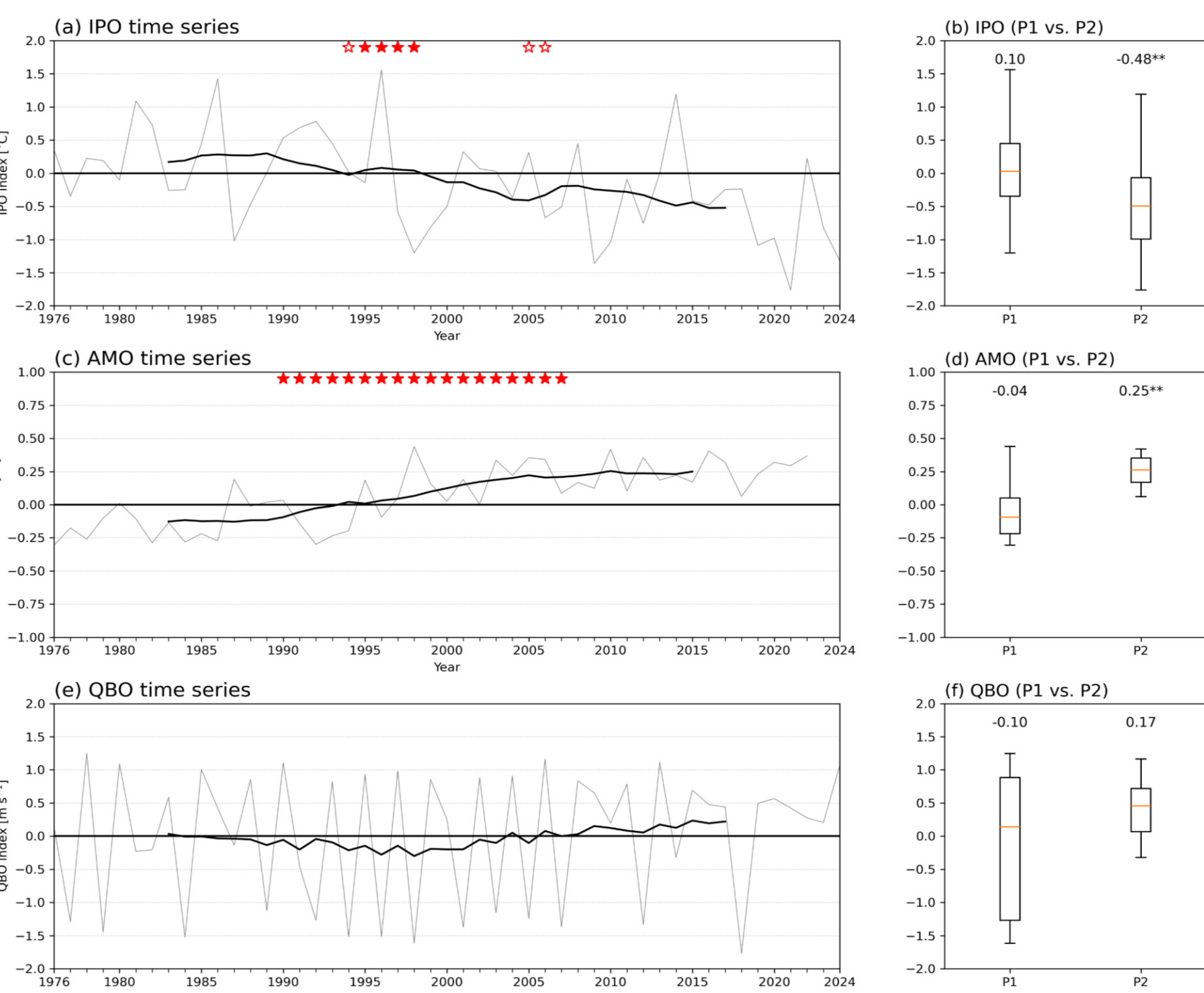


Fig. 6| (a, c, e) Time series of JJASO-mean (gray) and 15-yr running-mean (black) indices for 1976–2024, and (b, d, f) boxplots of the JJASO-mean index for P1 and P2, for the (a, b) IPO, (c, d) AMO, and (e, f) QBO. Filled/open red stars (left panels): change-point years, where the mean index differs significantly between the preceding and following 15-yr periods at 95%/90%. Numbers in right panels: period means; double asterisks: significant difference at 95%.

- Mechanisms linking the QBO to subtropical convection and its decadal change remain unclear.
- QBO index, static stability, and vertical wind shear show no systematic change between P1 and P2.
- Subtropical convection anomaly may instead arise from the QBO combined with tropospheric variability (e.g., IPO, AMO), which switched phase from P1 to P2.

8 Summary

- The relationship between the QBO and TC tracks in the western North Pacific has changed around the 2000s.
- The QBO-related anticyclonic circulation can be attributed to the decadal change in the QBO–TC relationship.
- QBO–subtropical convection mechanisms remain unclear.