

Contrasting Changes in Tropical Cyclone Activity over the East Sea of Vietnam during 1983–2024

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Short Report

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Abstract

Tropical cyclone (TC) activity over the East Sea of Vietnam (ESV) exhibits substantial interannual and interdecadal variability, but changes in its different components need not be coherent. We examine TC activity during 1983–2024 using IBTrACS best-track data, with JTWC 1-min winds as the principal intensity record. Poisson generalized linear models quantify annual and seasonal frequency changes, while Mann–Kendall tests and Sen’s slopes assess accumulated cyclone energy (ACE) and lifetime maximum intensity (LMI). Tropical-storm (≥ 34 kt) and ≥ 64 -kt frequencies decrease by about 4.0% and 5.8% decade⁻¹, respectively, although neither trend is significant. Main-season frequency decreases significantly by 6.8% decade⁻¹, whereas off-season activity shows no significant change. ACE decreases by about 6.6% decade⁻¹ with marginal significance ($p = 0.052$), while annual maximum LMI is nearly unchanged ($+ 0.52$ kt decade⁻¹; $p = 0.565$). Extreme LMI values persist despite limited change in the central intensity distribution. Frequency and ACE also indicate a possible mid-1990s transition not evident in LMI metrics. These results show asynchronous changes in TC occurrence, seasonality, accumulated activity, and peak intensity rather than uniform intensification or weakening.

1. Introduction

The western North Pacific (WNP) is the world’s most active tropical-cyclone (TC) basin, and the East Sea of Vietnam (ESV) is strongly affected by both locally generated storms and TCs migrating westward from the WNP. These storms repeatedly affect Vietnam through damaging winds, heavy rainfall, storm surge, and coastal flooding. Detecting long-term regional changes is therefore important, but TC activity is multidimensional: changes in frequency need not parallel changes in seasonality, accumulated activity, or extreme intensity.

Previous studies show that WNP intensity trends depend on the metric, period, and best-track dataset. Changes have been reported in the location and variability of lifetime maximum intensity (LMI), landfall intensity, and major-TC exceedance probability (Kossin et al. 2014; Mei and Xie 2016; Song et al. 2018; Kossin et al. 2020). Dataset differences can also alter inferred trends, especially for intense storms (Song et al. 2010; Shimada et al. 2020; Kawabata et al. 2023; Sezaki et al. 2025).

Previous studies have documented pronounced interannual and interdecadal variability in TC activity over the East Sea of Vietnam and the surrounding region. Cao et al. (2019) identified a mid-1990s change in SCS tropical cyclogenesis, Tran-Quang et al. (2020) reported an epochal shift in TC activity affecting Vietnam, and Huang et al. (2022) showed contrasting decadal behavior between locally generated SCS TCs and storms entering from the WNP. Huang et al. (2025) further found increasing variability in SCS LMI during 1980–2024. These studies imply that an aggregate trend can conceal differences among seasons, intensity classes, and TC populations.

Here we ask whether TC frequency, seasonality, accumulated cyclone energy (ACE), and intensity changed coherently during 1983–2024. We quantify annual and seasonal frequency trends across intensity classes, compare ACE with LMI, examine the intensity distribution and its upper tail, and test for

interdecadal change points. The analysis is designed to distinguish a uniform change in TC activity from contrasting evolution among complementary metrics.

2. Data and Methods

2.1. Data and study domain

Best-track data for 1983–2024 were obtained from IBTrACS v4r01. The analysis domain was defined as 5°–25°N and 100°–130°E (Fig. 1), representing the East Sea of Vietnam from its eastern boundary at 130°E westward toward the Vietnamese mainland. All TC activity metrics reported in this study were calculated only from storm positions located within this analysis domain. TCs originating within the domain were included from genesis, whereas TCs migrating westward from the western North Pacific were included from the first 6-hourly position after entering west of 130°E. Records were standardized to UTC and 6-hourly intervals; invalid positions and duplicate timestamps were removed.

Because agency wind estimates use different averaging periods, they were not merged indiscriminately. JTWC 1-min maximum sustained winds were used as the principal intensity series for ACE and LMI. JMA and NCHMF records were used for cross-reference during data screening, while the trend results reported below are based on the JTWC-consistent intensity series.

2.2. TC metrics

A tropical storm (TS) was defined by maximum sustained wind ≥ 34 kt. Annual counts were also evaluated for ≥ 64 -kt storms and ≥ 130 -kt super typhoons. Seasonal counts were divided into the main TC season (May–November; MJJASON) and the off-season (December–April; DJFMA).

ACE was calculated from 6-hourly JTWC 1-min winds as $ACE = 10^{-4} \sum V^2$ for observations with $V \geq 34$ kt, where V is maximum sustained wind in knots. Annual ACE was calculated by summing all qualifying 6-hourly storm observations within the analysis domain west of 130°E, including observations from genesis for TCs forming within the domain and from the first position west of 130°E for TCs entering from the WNP. For each storm, regional lifetime maximum intensity (LMI) was defined as the highest JTWC 1-min maximum sustained wind attained while the storm was located within the analysis domain west of 130°E. For TCs entering from the western North Pacific, the calculation began at the first 6-hourly position west of 130°E; for TCs forming within the domain, it began at genesis. Annual maximum LMI and storm-level LMI distributions were evaluated separately; annual P95(LMI) was additionally used in the change-point analysis.

2.3. Statistical analysis

Annual and seasonal TC counts were modeled with a Poisson generalized linear model using a log link, $\log(\lambda t) = \beta_0 + \beta_1(t - t_0)$. Trends were expressed as $100[\exp(10\beta_1) - 1]\%$ decade⁻¹ with 95% confidence intervals. Dispersion was checked from residual deviance relative to degrees of freedom; the principal count series was not overdispersed ($\varphi \approx 0.48$).

Trends in annual ACE and annual maximum LMI were assessed with the Mann–Kendall test and Sen’s slope. Trend-free pre-whitening was applied when first-order serial correlation was present. Fifteen-year running Sen slopes were used to describe temporal modulation of the trends. Potential abrupt changes in TS count, ACE, annual maximum LMI, and P95(LMI) were evaluated with the Pettitt test. Results with $p < 0.05$ were considered statistically significant, while $0.05 \leq p < 0.10$ was interpreted as marginal evidence.

3. Results and Discussion

3.1. Spatial context of TC activity

TC tracks form a broad westward corridor across the East Sea of Vietnam (Fig. 1b), reflecting contributions from both locally generated TCs and storms entering the region from the western North Pacific. Genesis is more concentrated toward the eastern portion of the analysis domain (Fig. 1c), while the highest regional LMI values occur mainly near the eastern boundary and generally decrease farther west toward Vietnam (Fig. 1d). These spatial characteristics highlight the influence of both locally generated TCs and westward-moving WNP storms on TC activity within the East Sea of Vietnam, while all temporal metrics analyzed below are calculated exclusively from storm observations within the analysis domain west of 130°E.

3.2. Frequency changes depend on intensity and season

Annual TS frequency (≥ 34 kt) decreases by about 4.0% decade⁻¹ (95% CI: -9.9 to + 2.3%), and ≥ 64 -kt frequency decreases by 5.8% decade⁻¹ (- 13.3 to + 2.3%); neither trend is significant (Fig. 2a,b). In contrast, ≥ 130 -kt super-typhoon frequency shows a weak positive tendency of 3.7% decade⁻¹ with a wide confidence interval (- 13.8 to + 24.9%; Fig. 2c). The record therefore does not support a common trend across intensity classes.

A clearer signal emerges seasonally (Fig. 3). Off-season frequency increases weakly by 5.9% decade⁻¹ (- 9.1 to + 23.4%) and is not significant, whereas main-season frequency decreases significantly by 6.8% decade⁻¹ (- 12.2 to - 1.2%). The annual decline is consequently weaker (4.0% decade⁻¹) because opposing seasonal tendencies partly offset each other. Annual counts therefore mask the strongest frequency signal in the record. Comparable interdecadal and population-dependent variability has been reported for regional TC activity in previous studies (Cao et al. 2019; Tran-Quang et al. 2020; Huang et al. 2022).

3.3. ACE declines without a corresponding LMI trend

Annual ACE shows a downward tendency (Fig. 4a). The trend-free pre-whitening Mann–Kendall test gives $\tau = -0.21$ and $p = 0.052$, while the Sen slope of $\log(\text{ACE})$ is -0.0069 yr^{-1} , equivalent to about - 6.6% decade⁻¹. This is marginal rather than conventional statistical evidence. Fifteen-year running slopes alternate between negative and positive phases (Fig. 4b), indicating substantial interdecadal modulation.

Annual maximum LMI behaves differently, with a Sen slope of only $+0.052 \text{ kt yr}^{-1}$ ($+0.52 \text{ kt decade}^{-1}$), $\tau = 0.06$, and $p = 0.565$ (Fig. 4c). Running slopes likewise alternate in sign (Fig. 4d). Because ACE integrates frequency, intensity, and duration whereas LMI represents peak intensity, their divergence indicates that reduced accumulated activity has not been accompanied by systematic weakening or strengthening of peak storm intensity.

3.4. Stable central intensity distribution with persistent extremes

The intensity distribution supports this contrast (Fig. 5). Storms exceeding 34 and 64 kt occur regularly, whereas ≥ 114 - and ≥ 130 -kt events are rarer and episodic. Decadal LMI distributions have broadly overlapping medians and interquartile ranges, indicating limited displacement of the central distribution. Nevertheless, exceptionally intense storms remain present in recent decades, with values near 160–170 kt.

These observations do not demonstrate a monotonic increase in the upper tail; rather, they show that a relatively stable central distribution can coexist with persistent, highly variable extremes. This interpretation is consistent with evidence that TC intensity variability and exceedance behavior can differ from central intensity trends (Song et al. 2018; Kossin et al. 2020; Huang et al. 2025).

3.5. Interdecadal transitions differ among metrics

The Pettitt test identifies 1996 as a potential change point in both TS frequency ($p = 0.074$) and ACE ($p = 0.079$; Fig. 6a,b). Although neither reaches $p < 0.05$, their agreement provides marginal evidence for a mid-1990s reorganization of storm occurrence and accumulated activity. Annual maximum LMI and P95(LMI) instead yield candidate changes in 2009 ($p = 0.329$) and 2010 ($p = 0.251$), respectively, with substantially weaker support (Fig. 6c,d).

The approximate mid-1990s timing is consistent with previously reported regional shifts in ESV cyclogenesis and TC activity affecting Vietnam (Cao et al. 2019; Tran-Quang et al. 2020). However, the present best-track analysis does not diagnose the responsible dynamics. Overall, the results indicate asynchronous changes: the clearest signals occur in seasonal frequency and accumulated activity, while peak-intensity metrics remain comparatively stable.

4. Summary

This study demonstrates that tropical cyclone activity over the East Sea of Vietnam during 1983–2024 has changed in a distinctly non-uniform and asynchronous manner. Rather than exhibiting a coherent increase or decrease across all metrics, the observed TC climate is characterized by contrasting changes in storm occurrence, seasonality, accumulated activity, and peak intensity.

The clearest signal is a seasonal redistribution of TC occurrence. Although annual frequencies of tropical storms ($\geq 34 \text{ kt}$) and stronger TCs ($\geq 64 \text{ kt}$) show nonsignificant downward tendencies, TC

frequency during the main season (May–November) decreases significantly by approximately 6.8% decade⁻¹, whereas off-season activity shows no significant long-term change. The annual trend therefore masks a more pronounced seasonal reorganization of regional TC activity. At the same time, the ≥ 130 -kt super-typhoon category does not exhibit the same decreasing tendency, although its weak positive trend is highly uncertain and statistically insignificant.

A second major contrast emerges between accumulated cyclone activity and peak intensity. Annual ACE decreases by approximately 6.6% decade⁻¹ with marginal statistical evidence ($p = 0.052$), whereas regional LMI remains nearly stationary ($+ 0.52$ kt decade⁻¹; $p = 0.565$). The decadal LMI distributions likewise show little systematic shift in their central tendency, while exceptionally intense storms continue to occur in the upper tail. Thus, reduced storm occurrence and accumulated activity have not been accompanied by a corresponding systematic weakening of the strongest TCs.

The change-point analysis provides further evidence that different components of TC activity have evolved differently. Both TC frequency and ACE indicate a possible transition around 1996, whereas regional LMI and P95(LMI) show no comparable mid-1990s shift. Although the statistical evidence for the 1996 transition is marginal, the common timing in frequency and ACE suggests that interdecadal variability has affected TC occurrence and accumulated activity more strongly than peak-intensity characteristics.

Taken together, these results indicate that no single trend adequately describes recent TC change over the East Sea of Vietnam. Declining main-season frequency and ACE can coexist with relatively stable peak intensity and persistent extreme storms. Consequently, fewer TCs do not necessarily imply weaker extreme-TC hazard, while the occurrence of individual super typhoons does not by itself demonstrate basin-wide intensification. Regional assessments should therefore distinguish among frequency, seasonality, accumulated activity, and extreme intensity, rather than using any one metric as a proxy for overall TC change.

The present study is limited by uncertainties in historical best-track intensity estimates and by the absence of explicit dynamical attribution. Future work should examine the robustness of these contrasts across alternative or homogenized best-track datasets and determine how changes in the monsoon circulation, western North Pacific subtropical high, vertical wind shear, ocean thermal conditions, and large-scale climate variability contribute to the observed seasonal and interdecadal signals.

Declarations

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Author Contribution

N.B.P., L.V.P., and N.D.N.H. were responsible for data collection, data processing, and statistical analyses. N.D.M. and N.B.P. developed the study concept, research framework, and methodological approach. N.D.M. led the manuscript preparation, including drafting the Introduction and conducting the overall revision and finalization of the manuscript. All authors reviewed and approved the final manuscript.

Data Availability

The tropical cyclone best-track data analyzed in this study are publicly available from the International Best Track Archive for Climate Stewardship (IBTrACS), version 4r01. Derived data and analysis scripts are available from the corresponding author upon reasonable request.

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Figures

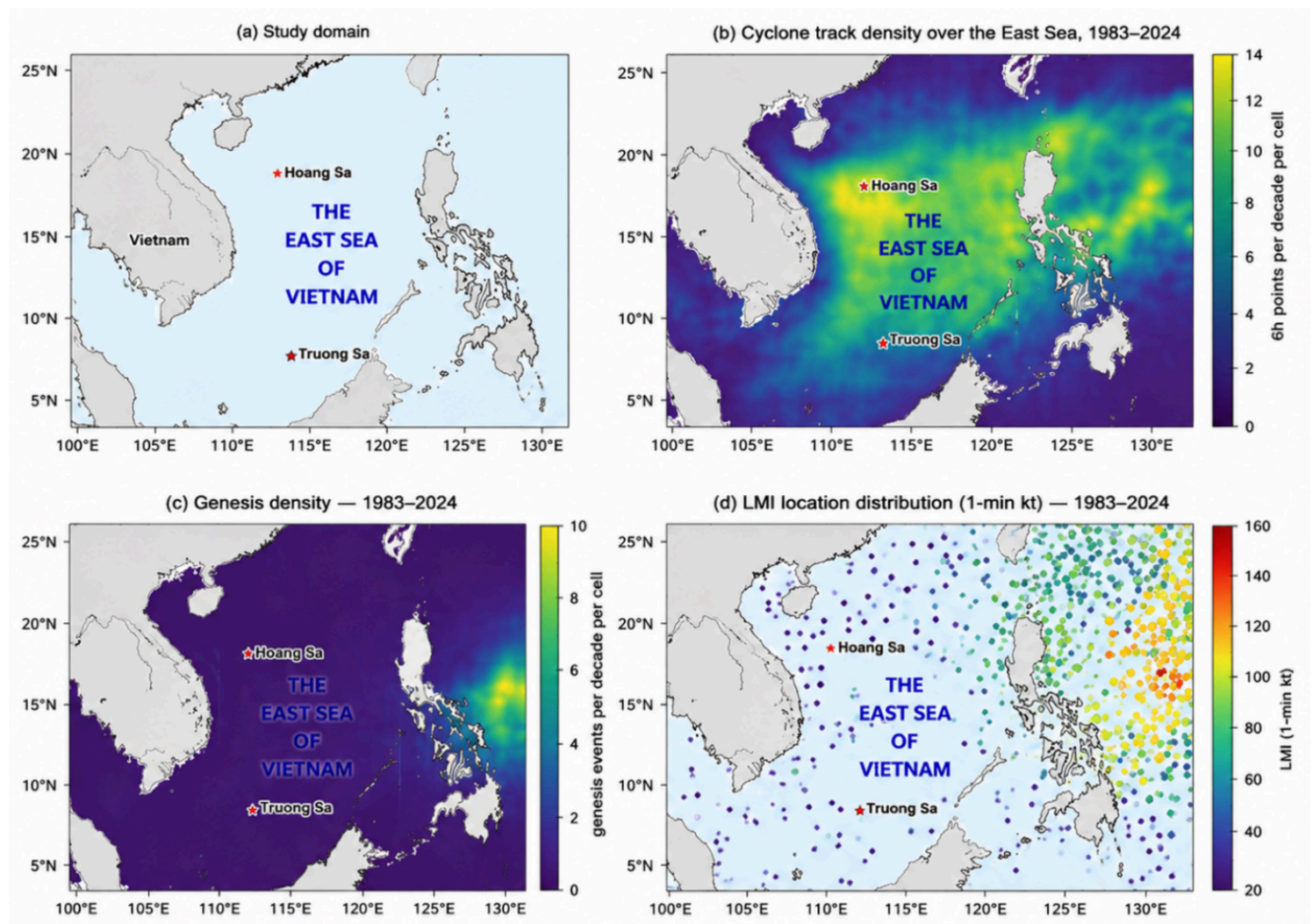


Figure 1

Spatial characteristics of tropical cyclone activity over the East Sea of Vietnam during 1983–2024. (a) Analysis domain bounded to the east by 130°E; (b) density of 6-hourly TC track points within the analysis domain; (c) TC genesis density; and (d) spatial distribution of regional lifetime maximum intensity (LMI).

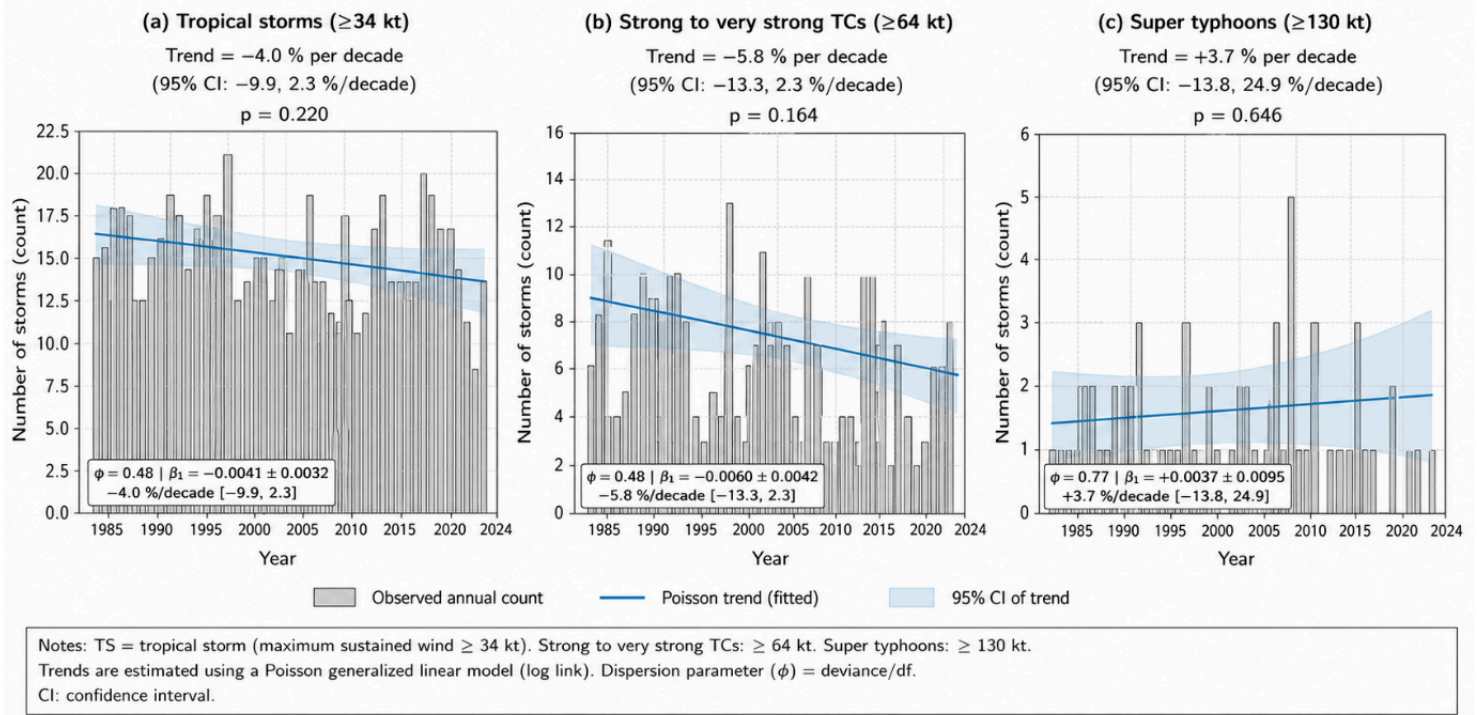


Figure 2

Long-term changes in tropical cyclone frequency by intensity category during 1983–2024. Annual frequencies of (a) tropical storms (≥ 34 kt), (b) TCs ≥ 64 kt, and (c) super typhoons (≥ 130 kt). Bars denote observed annual counts, solid lines fitted Poisson trends, and shading 95% confidence intervals.

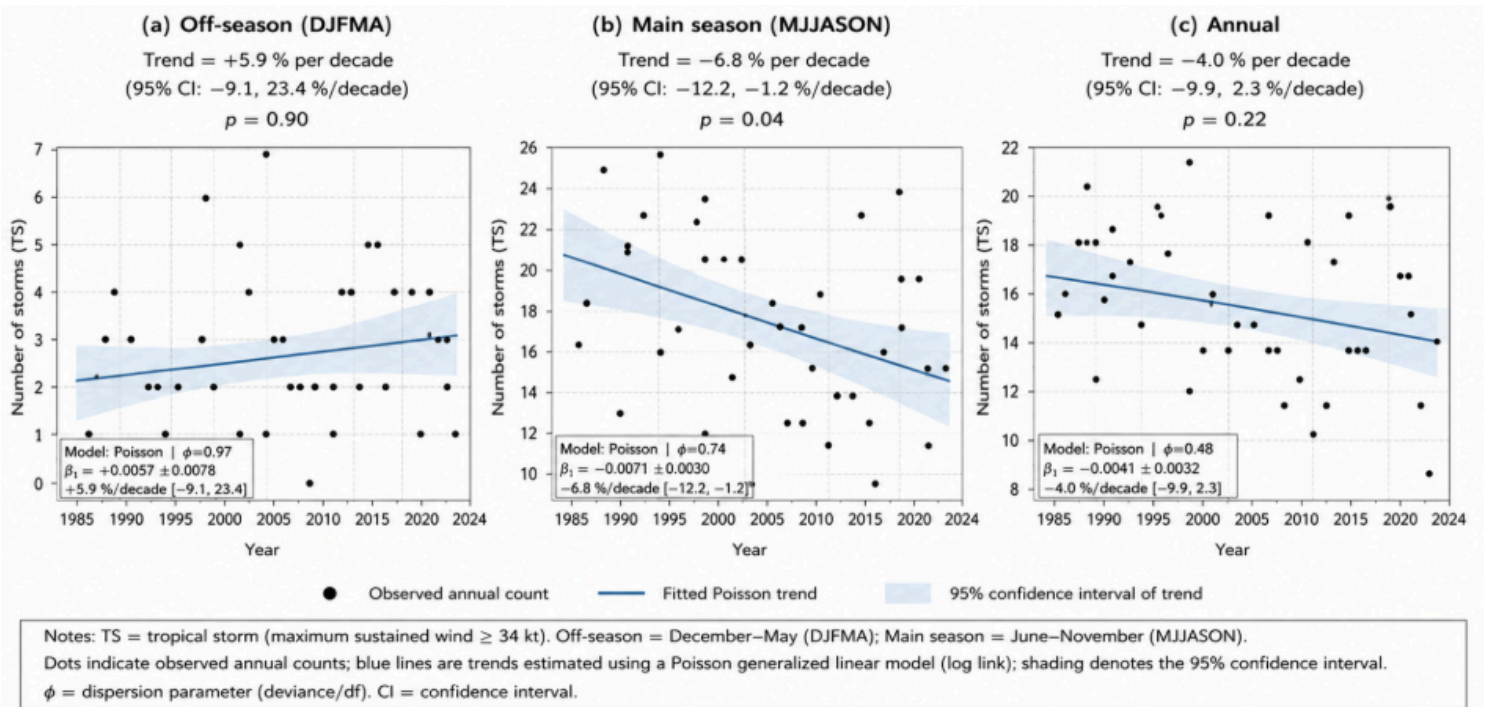


Figure 3

Seasonal trends in tropical-storm (≥ 34 kt) frequency during 1983–2024. Trends are shown for (a) the off-season (December–April; DJFMA), (b) the main TC season (May–November; MJJASON), and (c) the annual total. Dots denote observations, solid lines indicate fitted Poisson trends, and shading represents the 95% confidence intervals.

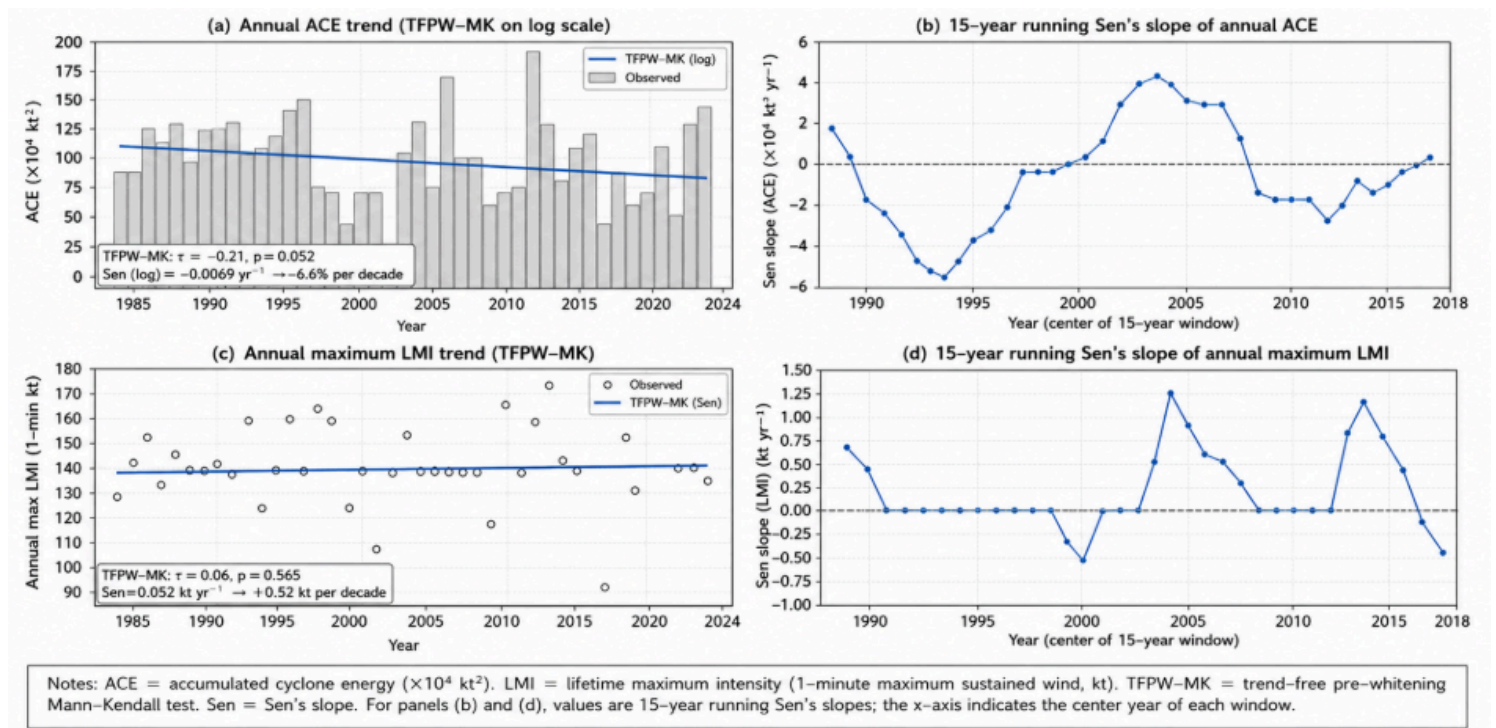


Figure 4

Contrasting changes in accumulated cyclone energy (ACE) and lifetime maximum intensity (LMI) during 1983–2024. (a) Long-term annual ACE trend; (b) 15-year running Sen slope of ACE; (c) long-term annual maximum LMI trend; and (d) 15-year running Sen slope of annual maximum LMI. Dashed horizontal lines in (b) and (d) indicate zero trend.

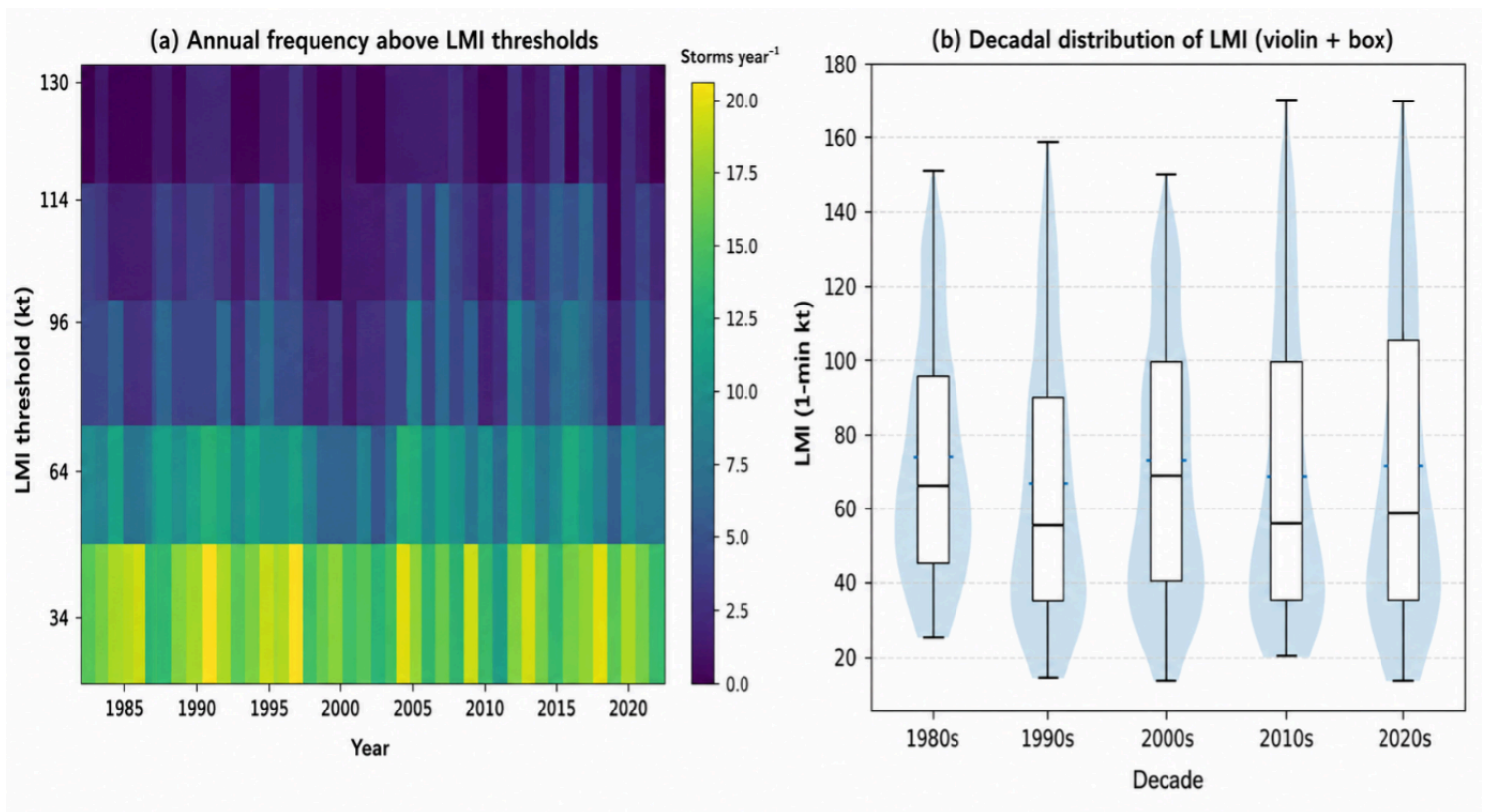


Figure 5

Temporal changes in the distribution of tropical cyclone lifetime maximum intensity (LMI) during 1983–2024. (a) Annual numbers of TCs exceeding LMI thresholds of 34, 64, 96, 114, and 130 kt; and (b) decadal storm-level LMI distributions represented by violin and box plots.

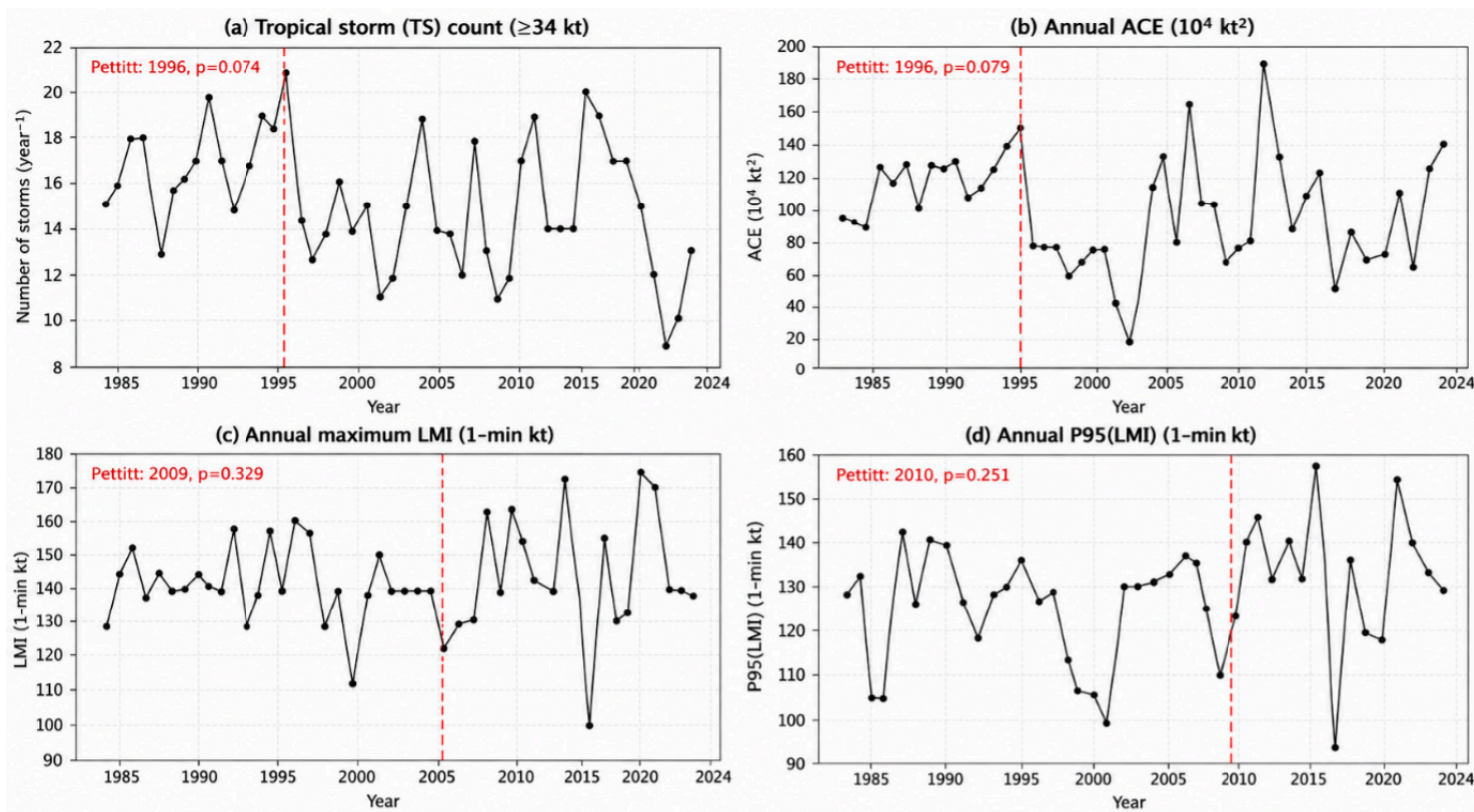


Figure 6

Pettitt change-point analysis of tropical cyclone activity during 1983–2024 for (a) tropical-storm frequency (≥ 34 kt), (b) annual ACE, (c) annual maximum LMI, and (d) annual P95(LMI). Red dashed lines indicate estimated change-point years; p-values are shown in each panel.