Atsusa samusa mo higan made: Statistical validation of a Japanese weather proverb across eight stations over 76 years

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Running title: Statistical validation of a Japanese equinox proverb

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Abstract

Background: Weather proverbs encode centuries of observational knowledge, yet few have been subjected to rigorous statistical testing. The Japanese proverb *atsusa samusa mo higan made* ("heat and cold last only until the equinox") asserts that seasonal temperature transitions coincide with the vernal and autumnal equinoxes. Despite growing international interest in weather folklore verification, no formal study has examined this widely known Japanese proverb.

Methods: We analyzed daily mean temperature data from eight Japan Meteorological Agency stations spanning latitudes 26.3–43.1°N over 76 years (1950–2025). Temperature transition points were identified using the Pruned Exact Linear Time (PELT) change point detection algorithm and segmented regression with bootstrap confidence intervals. Temporal trends were assessed via Mann-Kendall tests, and spring–autumn asymmetry was evaluated using Wilcoxon signed-rank tests. All tests used a two-sided significance threshold of $\alpha = 0.05$.

Results: The proverb showed approximate consistency with autumn temperature patterns but not spring. Autumn PELT-detected transition points occurred close to the autumnal equinox (median offset: +4.0 days; interquartile range [IQR]: -2.0 to +14.0; Cohen's $d = 0.25$–0.51), whereas spring transitions lagged substantially behind the vernal equinox (median offset: +10.0 days; IQR: 0.0 to +16.0; $d = 0.26$–0.76). This spring–autumn asymmetry was statistically significant at four of eight stations after Benjamini-Hochberg correction ($q < 0.05$). Mann-Kendall tests revealed significant increasing trends in autumn offsets at four stations (+0.12 to +0.18 days/year, $q < 0.05$), suggesting that autumn cooling is progressively delayed. Sensitivity analyses (unrestricted PELT, block bootstrap, modified Mann-Kendall) confirmed the robustness of all primary findings. Naha (26.3°N) exhibited distinctly large offsets in both seasons, consistent with subtropical thermal inertia.

Conclusions: The proverb *atsusa samusa mo higan made* is approximately consistent with autumn temperature patterns but not spring, and the correspondence for autumn appears to be declining over time—a trend consistent with climate warming. These findings parallel

international studies showing that traditional weather knowledge, while rooted in genuine climatic patterns, requires reinterpretation as temperatures rise.

Keywords: weather proverb, equinox, change point detection, PELT, climate change, Japan, seasonal transition, folklore verification

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1. Introduction

Weather proverbs represent a form of traditional ecological knowledge, distilling centuries of empirical observation into memorable aphorisms. While often dismissed as unscientific, these sayings may encode genuine climatic signals that merit formal evaluation. Recent studies have shown that statistical verification of weather folklore can yield insights into both the reliability of traditional knowledge and the impacts of contemporary climate change.

Matczak et al. (2020) systematically tested 28 Polish weather proverbs using contingency tables and Heidke Skill Scores (HSS), finding that most proverbs performed only marginally above chance (overall HSS = 0.01), with accuracy declining over time—a pattern attributed to climate change and the geographic displacement of proverb origins following post-World War II border shifts. Skvareninova et al. (2022) examined the European "Ice Saints" folklore (predicting late frost around May 11–14) in Slovakia and discovered a climate-change paradox: earlier hawthorn flowering now overlaps *more* with the frost window at lower altitudes, reshaping the mechanism by which the proverb remains relevant. Chen et al. (2025) assessed a Chinese lunisolar agricultural proverb across 699 stations, showing strong regional heterogeneity—the proverb's rapid warming criterion was met across 60.6% of China's area, with strongest agreement in its region of origin (Jiangsu–Zhejiang–Shanghai), but the associated summer heat prediction applied to only 15.9% of China's total area.

Despite this growing body of international research, Japanese weather proverbs remain entirely unexamined in the peer-reviewed literature. Searches of PubMed, Web of Science, CiNii, and J-STAGE using both English and Japanese keywords yielded no formal studies. This gap is notable given Japan's rich meteorological folklore and the country's extensive, high-quality observational records maintained by the Japan Meteorological Agency (JMA).

The proverb *atsusa samusa mo higan made* (暑さ寒さも彼岸まで, literally "heat and cold last only until the equinox") is among the most widely known weather sayings in Japan. *Higan* refers to the Buddhist observance periods centered on the vernal and autumnal equinoxes, and the proverb asserts that summer heat subsides by the autumn equinox and winter cold abates by the spring equinox. The equinoxes mark the dates when the Sun crosses the celestial equator, producing roughly equal day and night lengths. In temperate climates, these astronomical events approximately coincide with seasonal temperature transitions, providing a physical basis for the proverb.

However, the relationship between astronomical equinoxes and temperature transition points is not straightforward. Thermal lag—the delay between peak solar radiation and peak temperature caused by the thermal inertia of land and ocean surfaces—introduces a systematic offset. This lag is expected to differ between spring and autumn due to asymmetric heating and cooling dynamics, and may also vary with latitude and proximity to the ocean. Furthermore, anthropogenic climate change could shift temperature transition points relative to the fixed astronomical calendar, potentially undermining the proverb's validity.

The present study addresses this research gap by applying change point detection and segmented regression methods to 76 years of daily temperature data from eight JMA stations spanning Japan's latitudinal range (26.3–43.1°N). Our objectives were: (1) to quantify the offset between astronomical equinoxes and statistical temperature transition points; (2) to test for spring–autumn asymmetry in these offsets; (3) to examine latitudinal variation; and (4) to assess temporal trends that may reflect climate change impacts on the proverb's validity.

2. Methods

All statistical tests used a two-sided significance threshold of $\alpha = 0.05$ unless otherwise stated.

2.1 Data

Daily mean temperature (T_{avg}) data were obtained from the JMA's historical weather database (https://www.data.jma.go.jp/risk/obsdl/) for eight stations selected from the JMA network of 159 stations (Table 1). Selection criteria were: (1) location at or near a prefectural capital to ensure long-term, well-maintained records; (2) continuous observation from at least 1950; and (3) geographic distribution spanning Japan's latitudinal range from Hokkaido (43°N) to Okinawa (26°N), representing major climate zones. The study period was 1950–2025 (76 years), chosen because 1950 marks the beginning of consistently digitized daily records across all selected stations. Seven stations had complete records for this period; Naha had 2.7% missing daily values due to post-war data gaps. In the initial quality control step, gaps of three or fewer consecutive days were filled by linear interpolation, while longer gaps were retained as missing values. Any remaining missing values were subsequently filled by linear interpolation immediately prior to PELT analysis, as the algorithm requires complete data (see §2.3).

Table 1. Study stations and their characteristics.

Station	Latitude (°N)	Region	Climate type	Observation start	Missing data
Sapporo	43.06	Hokkaido	Humid continental	1876	0%
Sendai	38.26	Tohoku	Humid subtropical	1927	0%
Tokyo	35.69	Kanto	Humid subtropical	1875	0%
Nagoya	35.17	Chubu	Humid subtropical	1891	0%
Osaka	34.68	Kinki	Humid subtropical	1883	0%
Hiroshima	34.40	Chugoku	Humid subtropical	1879	0%
Fukuoka	33.58	Kyushu	Humid subtropical	1890	0%
Naha	26.34	Okinawa	Humid subtropical / Tropical	1890	2.7%

2.2 Equinox date calculation

Astronomical equinox dates were computed for each year using the PyEphem library (Rhodes, 2011), which provides precise ephemeris calculations. UTC times were converted to Japan

Standard Time (JST = UTC + 9 hours) before extracting calendar dates. The vernal equinox day of year (DOY) ranged from 78 to 81, and the autumnal equinox DOY ranged from 266 to 267 across the study period.

2.3 Change point detection

PELT-detected temperature change points (hereafter "transition points") were identified using the Pruned Exact Linear Time (PELT) algorithm (Killick et al., 2012) implemented in the Python *ruptures* library (Truong et al., 2020). These transition points represent statistically detected regime shifts in the daily temperature series and do not necessarily correspond to physiologically perceived or climatologically defined seasonal boundaries. For each station-year combination, PELT was applied to the 365/366-day mean temperature series with the following parameters: radial basis function (RBF) kernel, minimum segment size of 14 days, and Bayesian Information Criterion (BIC) penalty ($2 \times \log n$). As noted in §2.1, any remaining missing values after initial quality control were filled by linear interpolation at this stage, as the PELT algorithm requires complete data.

For each year, the change point nearest to the vernal equinox (within ±60 days) was identified as the spring transition point, and similarly for the autumnal equinox. As a sensitivity analysis, we also performed unrestricted change point selection (no ±60-day window), selecting the nearest change point to each equinox from all PELT-detected points across the full year (see §4.5). The offset was defined as:

$$offset = \mathrm{DOY}_{\mathrm{transition}} - \mathrm{DOY}_{\mathrm{equinox}}$$

where positive values indicate transitions occurring after the equinox and negative values indicate transitions preceding it.

2.4 Segmented regression

To estimate temperature breakpoints with confidence intervals, we fitted piecewise linear regression models of the form:

$$T(d) = \beta_0 + \beta_1 \cdot d + \beta_2 \cdot \max(d - bp, 0)$$

where d is the day of year, bp is the breakpoint, β_1 is the pre-breakpoint slope, and $\beta_1 + \beta_2$ is the post-breakpoint slope. The optimal breakpoint was determined by grid search (1-day resolution) over a ±60-day window centered on the equinox date, minimizing the residual sum of squares (RSS). Bootstrap 95% confidence intervals for the breakpoint were derived from 1,000 resamples with replacement (2-day grid resolution for computational efficiency), taking the 2.5th and 97.5th percentiles of the bootstrap distribution.

2.5 Temporal trend analysis

Secular trends in the spring and autumn offsets were assessed using the Mann-Kendall nonparametric trend test (Mann, 1945; Kendall, 1948), with Sen's slope estimator providing the magnitude of change in days per year. Stations with fewer than 10 valid offset values were excluded from trend analysis. As robustness checks, we performed: (1) ordinary least squares (OLS) regression of offset on year with Newey-West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors (lag = $\lfloor n^{1/3} \rfloor$) to account for potential serial correlation in the annual offset series; and (2) the Hamed and Rao (1998) modified Mann-Kendall test, which corrects the variance of the S statistic for autocorrelation.

As an exploratory analysis, the study period was divided into three intervals: 1950–1979 (pre-warming baseline, n = 30 years), 1980–1999 (transition period, n = 20 years), and 2000–2025 (recent warming, n = 26 years). These boundaries were chosen to approximate the onset of accelerated global warming identified in the climate literature.

2.6 Spring–autumn asymmetry test

The asymmetry between spring and autumn offsets was tested using the Wilcoxon signed-rank test (paired, two-sided), comparing the absolute offset values for the same year at each station. This nonparametric approach was chosen because the offset distributions showed substantial deviation from normality. To account for potential temporal dependence in the paired offset series, we supplemented standard Wilcoxon tests with block bootstrap p-values (block length =

5 years, 10,000 resamples). Across all analyses, 24 hypothesis tests were performed (8 Wilcoxon signed-rank tests + 16 Mann-Kendall tests [8 stations × 2 seasons]). Benjamini-Hochberg (BH) correction (Benjamini & Hochberg, 1995) was applied jointly to control the false discovery rate at $q < 0.05$.

2.7 Software

All analyses were performed in Python 3.14 using *ruptures* 1.1.9 for PELT, *pymannkendall* 1.4.3 for Mann-Kendall tests (including Hamed-Rao modification), *scipy* 1.15.2 for Wilcoxon tests, *statsmodels* 0.14.4 for regression and Benjamini-Hochberg correction, and *ephem* 4.2 for equinox calculations. Code and data are available at https://github.com/rehabilitation-collaboration/higan-temperature.

3. Results

3.1 Overall offset distributions

Across 608 station-year combinations (8 stations × 76 years), 606 yielded transition points within the ±60-day search window (two Naha years had no change point within the window). Among these 606 valid cases, the PELT-detected autumn temperature transition occurred a median of 4.0 days after the autumnal equinox (IQR: −2.0 to +14.0 days; mean ± SD: 5.5 ± 11.7 days). In contrast, the spring transition lagged 10.0 days behind the vernal equinox (IQR: 0.0 to +16.0 days; mean ± SD: 7.6 ± 14.1 days) (Table 2, Figure 1, Figure 6).

The annual temperature profile for Tokyo (Figure 2) illustrates the typical relationship between equinox dates and temperature transitions.

Table 2. PELT-detected temperature transition offsets from the equinox, by station and season (1950–2025).

Station	Spring median (days)	Spring IQR	Spring mean ± SD	Autumn median (days)	Autumn IQR	Autumn mean ± SD
Sapporo	+10.0	−1.0 to +15.0	+5.3 ± 12.7	+4.0	−1.2 to +13.2	+5.7 ± 11.2
Sendai	+15.0	+5.0 to +16.0	+10.2 ± 13.3	+6.0	−1.0 to +14.0	+6.0 ± 12.2
Tokyo	+10.0	+0.8 to +15.0	+8.0 ± 13.4	+1.0	−2.0 to +9.0	+2.6 ± 10.2
Nagoya	+5.0	−5.0 to +15.0	+3.9 ± 15.3	+3.5	−1.0 to +13.0	+4.7 ± 10.8
Osaka	+10.0	+5.0 to +15.2	+8.8 ± 13.2	+3.0	−2.0 to +9.0	+3.4 ± 10.5
Hiroshima	+10.0	−1.0 to +15.0	+6.9 ± 14.3	+3.5	−6.0 to +13.0	+3.4 ± 11.6
Fukuoka	+10.0	−1.0 to +15.2	+7.5 ± 14.6	+3.0	−6.2 to +14.0	+3.6 ± 12.8
Naha	+15.0	+5.0 to +25.0	+12.1 ± 18.3	+13.5	+3.0 to +22.0	+13.2 ± 14.3
All	**+10.0**	**0.0 to +16.0**	**+7.6 ± 14.1**	**+4.0**	**−2.0 to +14.0**	**+5.5 ± 11.7**

Effect sizes (Cohen's d = mean offset / SD) ranged from small to medium: spring d = 0.26–0.76 (median across stations: 0.52), autumn d = 0.25–0.51 for temperate stations (median: 0.38). Naha was an exception with a large autumn effect size (d = 0.93). These values indicate that equinox offsets, while statistically significant, represent modest departures relative to year-to-year variability.

3.2 Segmented regression breakpoints

Segmented regression models showed strong goodness of fit (mean R^2 = 0.85, range: 0.60–0.91). Spring breakpoints (DOY 56–72) consistently preceded the vernal equinox (DOY ~80) by 8–24 days, with wide bootstrap 95% confidence intervals (Table 3). Autumn breakpoints (DOY 240–261) clustered closer to the autumnal equinox (DOY ~266), with narrower confidence intervals at most stations. The slope change at breakpoints was consistent: across all eight stations, spring warming accelerated by a mean of +0.18 °C/day and autumn cooling accelerated by a mean of −0.22 °C/day (Supplementary Table S1). The four representative stations in Table 3 showed somewhat larger slope changes.

Table 3. Segmented regression breakpoint estimates with 95% bootstrap confidence intervals.

Station	Season	Optimal BP (DOY)	95% CI (DOY)	Slope change (°C/day)	Mean R^2
Sapporo	Spring	56	40–92	+0.320	0.842
Sapporo	Autumn	244	226–287	−0.255	0.885
Tokyo	Spring	65	42–102	+0.301	0.779
Tokyo	Autumn	242	226–265	−0.331	0.866
Osaka	Spring	60	42–86	+0.327	0.807
Osaka	Autumn	240	230–262	−0.500	0.905
Naha	Spring	72	32–120	+0.272	0.598
Naha	Autumn	261	248–294	−0.307	0.824

Note: Four representative stations shown. Full results for all eight stations are provided in Supplementary Table S1.

3.3 Spring–autumn asymmetry

The Wilcoxon signed-rank test indicated significant spring–autumn asymmetry (spring absolute offsets > autumn absolute offsets) at six of eight stations ($p < 0.05$; Table 4). After Benjamini-Hochberg (BH) correction across all 24 hypothesis tests (see §2.5–2.6), four stations retained significance (Tokyo, Osaka, Nagoya, Sendai; $q < 0.05$), while Sapporo ($q = 0.088$) and Hiroshima ($q = 0.078$) became non-significant. Block bootstrap p-values, which account for temporal dependence, were uniformly smaller than standard Wilcoxon p-values, confirming that the asymmetry results are robust to autocorrelation (Table 4). The two stations that were non-significant even before correction—Fukuoka ($p = 0.076$) and Naha ($p = 0.059$)—both showed marginal asymmetry. Naha exhibited a distinctive pattern: both spring and autumn offsets were large (medians +15.0 and +13.5 days, respectively), suggesting that neither equinox serves as a reliable transition point marker in the subtropics.

Table 4. Wilcoxon signed-rank test for spring–autumn asymmetry of absolute offsets.

Station	n	Spring abs. median	Autumn abs. median	Wilcoxon W	p	q (BH)	p (bootstrap)	Sig. (BH)
Sapporo	76	10.0	9.0	1030.0	0.037	0.088	<0.001	No
Sendai	76	15.0	9.0	985.0	0.013	0.040	<0.001	Yes
Tokyo	76	12.0	8.5	753.0	<0.001	0.006	<0.001	Yes
Nagoya	76	10.0	7.5	875.0	0.002	0.017	<0.001	Yes
Osaka	76	10.0	6.5	822.0	<0.001	0.011	<0.001	Yes
Hiroshima	76	10.0	9.0	1042.5	0.029	0.078	<0.001	No
Fukuoka	76	12.5	9.0	1120.0	0.076	0.130	<0.001	No
Naha	74	20.0	13.5	1007.5	0.059	0.113	<0.001	No

Note: q values are Benjamini-Hochberg adjusted across all 24 hypothesis tests. Bootstrap p-values are from block bootstrap (block length = 5 years, 10,000 resamples).

3.4 Temporal trends

Mann-Kendall tests revealed no significant temporal trends in spring offsets at any station (all $p > 0.05$, slope ≈ 0 days/year). In contrast, autumn offsets showed significant increasing trends at four of eight stations (Table 5a, Figure 3): Sapporo (+0.16 days/year, $p = 0.003$), Nagoya (+0.12 days/year, $p = 0.012$), Osaka (+0.12 days/year, $p = 0.012$), and Fukuoka (+0.18 days/year, $p = 0.005$). After BH correction, all four retained significance ($q < 0.05$). Three additional stations showed near-significant increases (Sendai $p = 0.061$, Tokyo $p = 0.092$, Hiroshima $p = 0.052$).

The Hamed-Rao modified Mann-Kendall test, which corrects for autocorrelation in the variance of the S statistic, yielded consistent results: the same four stations remained significant, and Hiroshima autumn additionally became significant ($p = 0.047$ modified vs. 0.052 original). Newey-West HAC standard errors further corroborated these findings (Table

5b): all four significant autumn trends remained significant under HAC correction, with SE ratios of 0.81–0.93× relative to conventional OLS, indicating minimal serial correlation in the annual offset series. For Sendai, the autumn trend that was non-significant under Mann-Kendall (p = 0.061) became significant under HAC OLS (p = 0.027), suggesting the nonparametric test may be conservative at this station.

Table 5a. Mann-Kendall trend test results for equinox offsets (1950–2025).

Station	Spring slope (d/yr)	Spring *p*	Autumn slope (d/yr)	Autumn *p*	Autumn trend
Sapporo	0.000	0.233	**+0.160**	**0.003**	Increasing
Sendai	0.000	0.578	+0.104	0.061	(marginal)
Tokyo	0.000	0.986	+0.031	0.092	(marginal)
Nagoya	0.000	0.665	**+0.122**	**0.012**	Increasing
Osaka	0.000	0.853	**+0.118**	**0.012**	Increasing
Hiroshima	0.000	0.396	+0.114	0.052	(marginal)
Fukuoka	−0.087	0.203	**+0.181**	**0.005**	Increasing
Naha	0.000	0.800	+0.093	0.134	No trend

Table 5b. OLS vs. Newey-West HAC comparison for autumn offsets at stations with significant or near-significant trends.

Station	OLS slope (d/yr)	OLS SE	OLS *p*	HAC SE	HAC *p*	SE ratio
Sapporo	+0.164	0.056	0.004	0.047	<0.001	0.85
Sendai	+0.113	0.063	0.077	0.051	0.027	0.81
Tokyo	+0.088	0.053	0.097	0.047	0.058	0.89
Nagoya	+0.133	0.055	0.018	0.051	0.009	0.92
Osaka	+0.137	0.053	0.012	0.047	0.004	0.89
Hiroshima	+0.120	0.060	0.048	0.059	0.043	1.00
Fukuoka	+0.179	0.064	0.006	0.052	<0.001	0.81

3.5 Era comparison

Dividing the study period into three eras revealed a clear temporal pattern in autumn offsets (Table 6, Figure 5). During the 1950–1979 baseline period, autumn transitions occurred close to or even before the equinox (median offsets: −6.0 to +3.0 days). By the 2000–2025 period, autumn offsets had shifted markedly later (+3.5 to +9.0 days for temperate stations). The most dramatic shift was observed in Fukuoka: from a median of −6.0 days (pre-equinox) in 1950–1979 to +9.0 days (post-equinox) in 2000–2025, a shift of 15 days.

Spring offsets showed a contrasting pattern, with slight decreases in recent decades at several temperate stations (e.g., Sapporo: +10.0 to +2.5 days; Tokyo: +10.0 to +5.0 days), consistent with earlier spring warming onset under climate change.

Table 6. Median equinox offsets by era (days).

Station	Spring 1950–1979	Spring 1980–1999	Spring 2000–2025	Autumn 1950–1979	Autumn 1980–1999	Autumn 2000–2025
Sapporo	+10.0	+10.0	+2.5	+3.0	+6.5	+9.0
Sendai	+15.0	+12.5	+12.5	+3.0	+9.0	+9.0
Tokyo	+10.0	+10.0	+5.0	−1.0	+3.5	+3.5
Nagoya	+10.0	+5.0	+3.0	−1.0	+4.0	+6.0
Osaka	+10.0	+10.0	+8.0	+1.0	+4.0	+6.0
Hiroshima	+10.0	+10.0	+5.0	+1.0	+4.0	+9.0
Fukuoka	+12.0	+12.5	+5.0	−6.0	+3.5	+9.0
Naha	+15.0	+5.0	+20.0	+13.0	+10.5	+14.0

4. Discussion

4.1 Proverb validity: autumn approximately consistent, spring not

Our results indicate that the proverb *atsusa samusa mo higan made* is approximately consistent with observed temperature patterns for autumn but not for spring. The autumn equinox coincides approximately with the PELT-detected cooling transition point, with a median offset of only +4.0 days, though the effect size is small (Cohen's d = 0.25–0.51 for temperate stations), indicating substantial year-to-year variability. In contrast, the spring warming transition consistently lags the vernal equinox by approximately 10 days, and the asymmetry is statistically significant at four of eight stations after BH correction.

This spring–autumn asymmetry is consistent with the well-established phenomenon of thermal lag—the delay between peak solar forcing and peak temperature response due to the thermal inertia of land and ocean surfaces (Trenberth, 1983). In spring, solar radiation increases after the equinox, but oceanic and terrestrial thermal inertia delays the atmospheric temperature response. In autumn, the opposite occurs, but with a smaller lag because radiative cooling is more efficient than solar heating of thermally massive surfaces. Our finding parallels that of Skvareninova et al. (2022), who documented how thermal lag interacts with phenological timing to reshape the relevance of the European "Ice Saints" folklore.

4.2 Temporal trends suggest declining autumn correspondence

The most notable temporal finding is the progressive delay of autumn transition points. At four stations, autumn offsets increased significantly over 1950–2025, at rates of +0.12 to +0.18 days per year—a pattern that remained robust under BH correction, Hamed-Rao modified Mann-Kendall variance correction, and HAC standard errors. Over the 76-year study period, this is consistent with a cumulative shift of approximately 9–14 days. The era comparison supports this pattern: during 1950–1979, autumn transitions occurred near or even before the equinox at most stations, but by 2000–2025, they had shifted 4–15 days later.

This pattern is consistent with the broader observation reported by Matczak et al. (2020), who found declining accuracy of Polish weather proverbs over time. Our results suggest a plausible mechanism: warming temperatures extend the summer season, pushing the autumn cooling transition later relative to the astronomically fixed equinox date. However, we cannot attribute this trend specifically to anthropogenic climate change, as other factors—including the Pacific

Decadal Oscillation (PDO), urban heat island effects, and land use changes—may also contribute. Disentangling these factors would require a different study design.

Spring offsets showed no significant temporal trend. This asymmetry between spring and autumn trends is consistent with the earlier onset of spring warming documented in phenological studies globally, which could partially compensate for any thermal lag increase, maintaining a relatively stable offset from the equinox.

4.3 Latitudinal variation and the subtropical exception

The proverb's validity showed limited latitudinal variation among temperate stations (33.6–43.1°N), where autumn offsets ranged from +1.0 to +6.0 days (Figure 4). The clear exception was Naha (26.3°N), where both spring and autumn offsets were substantially larger (medians +15.0 and +13.5 days, respectively) and the spring–autumn asymmetry was non-significant.

This subtropical anomaly likely reflects the weaker seasonality and stronger oceanic influence at Naha. In subtropical climates, the annual temperature cycle has a lower amplitude and a greater phase lag relative to the solar cycle, making the equinoxes poor predictors of temperature transitions. The proverb, originating in the temperate Japanese mainland, was never intended to describe Okinawan climate.

This regional heterogeneity parallels the findings of Chen et al. (2025), who showed that a Chinese agricultural proverb's rapid warming criterion was met across 60.6% of China's area with strongest conformity in its region of origin, while the associated summer heat prediction applied to only 15.9% of China's total area. High-latitude and high-altitude regions were non-conforming in both respects.

4.4 Methodological comparison with prior studies

Our study employed change point detection (PELT) and segmented regression, which represent a methodological advance over prior weather proverb studies. Matczak et al. (2020) used contingency tables and binary classification, which required subjective thresholds for translating qualitative proverbs into testable hypotheses. Chen et al. (2025) used fifth-degree polynomial least-square fitting ($R^2 \approx 0.90$) but reported no formal hypothesis tests (no p-values anywhere in the paper). Our approach directly addresses the question "when does the seasonal temperature transition occur?" without imposing a binary framework, and provides bootstrap confidence intervals for the estimated transition dates.

The segmented regression models achieved high goodness of fit (R^2 = 0.60–0.91; Supplementary Table S1), indicating that the seasonal temperature curve is well-described by a piecewise linear model with a single breakpoint near the equinox. The consistent slope changes (mean +0.18 °C/day for spring and −0.22 °C/day for autumn across all stations; Supplementary Table S1) support the physical reality of a distinct transition event rather than a gradual shift. Formal residual diagnostics (normality and homoskedasticity tests) were not performed for individual station-year models, which is noted as a limitation.

4.5 Limitations

Several limitations should be noted.

Estimand definition. PELT-detected change points represent statistically optimal segmentation of the temperature series, not necessarily transitions that correspond to human thermal perception, agricultural phenology, or climatological definitions of seasonal boundaries. The proverb *atsusa samusa mo higan made* likely refers to a subjective experience of thermal comfort, which depends on humidity, wind, and adaptation—none of which are captured by daily mean temperature alone. Our analysis tests whether a statistical abstraction (PELT change point) approximately coincides with an astronomical event (equinox), which is a necessary but not sufficient condition for the proverb's validity.

Search window constraint. Our primary analysis selected the change point nearest to each equinox within a ±60-day window. This design could, in principle, bias results toward the equinox by restricting the candidate pool. To assess this, we performed a sensitivity analysis with unrestricted change point selection (no window restriction), choosing the nearest change point from all PELT-detected points across the full year. Results were identical in 100% of 606 station-year combinations for both seasons (Supplementary Table S2), demonstrating that the ±60-day restriction had no effect on our findings. This robustness arises because PELT consistently detects major change points near the equinoxes as part of the natural seasonal temperature cycle.

Station coverage and spatial dependence. Our analysis used only eight stations, which do not capture microclimatic variation, coastal versus inland contrasts, or altitudinal effects. Furthermore, these stations are not spatially independent: neighboring stations share synoptic weather systems and climate forcing. We did not apply a mixed-effects model with station random effects because eight stations provide insufficient clustering for reliable variance component estimation. Expanding to the full JMA network of 159 stations would provide more granular spatial coverage and enable hierarchical modeling.

Urban heat island (UHI). UHI effects may influence results at urban stations, particularly Tokyo and Osaka. UHI tends to elevate minimum temperatures more than maximum temperatures, potentially affecting the timing of apparent transition points. However, we used mean daily temperature, which partially averages out this effect.

Multiple comparisons. We performed 24 statistical tests (8 Wilcoxon + 16 Mann-Kendall). Benjamini-Hochberg (BH) correction was applied to control the false discovery rate at $q < 0.05$. After correction, 8 of 10 originally significant tests retained significance: the four Mann-Kendall autumn trends (Sapporo, Nagoya, Osaka, Fukuoka) all survived, while Sapporo and Hiroshima Wilcoxon asymmetry tests became non-significant (Table 4). Conclusions in the main text are based on BH-corrected results.

Temporal dependence. The Wilcoxon signed-rank and Mann-Kendall tests assume independence of observations. To address temporal autocorrelation, we supplemented these with block bootstrap Wilcoxon p-values (which were uniformly smaller, strengthening conclusions) and Hamed-Rao modified Mann-Kendall tests (which confirmed all four significant autumn trends). These robustness checks indicate that temporal dependence does not inflate our significance findings.

Study period. The 76-year study period, while substantial, may be insufficient to distinguish anthropogenic warming trends from multi-decadal natural variability (e.g., Pacific Decadal Oscillation). Longer records from stations such as Tokyo (available from 1875) could address this limitation in future work.

Temperature only. The proverb *atsusa samusa* encompasses subjective thermal perception, which is also influenced by humidity, wind, and solar radiation. Future analyses incorporating apparent temperature indices (e.g., the Wet Bulb Globe Temperature) may provide a more complete assessment.

4.6 Implications and future directions

Our findings contribute to the growing literature on the scientific basis of traditional weather knowledge. The proverb *atsusa samusa mo higan made* appears to have been a reasonable empirical rule for autumn in the pre-warming era, but the correspondence between equinox dates and temperature transition points is declining over time. This has practical implications for public communication: the proverb's continued use may generate false expectations about the timing of autumn cooling, particularly in urban areas where UHI further delays the transition.

Future work should extend the station network, incorporate apparent temperature metrics, and compare the proverb's predictive skill against simple climatological forecasts. Cross-cultural comparison with equinox-related weather folklore from other countries (e.g., the European "Altweibersommer" or North American "Indian Summer") would further enrich understanding of how traditional knowledge encodes—and fails to track—climatic patterns.

Ethical considerations

This study used exclusively publicly available, fully aggregated population-level data from the Japan Meteorological Agency. No individual-level data were accessed. Under the Japanese Ethical Guidelines for Medical and Biological Research Involving Human Subjects (2021 revision), research using publicly available aggregate statistics does not require ethics committee review (Article 3, Paragraph 1, Item 1). As no human subjects were involved, no institutional review board approval or waiver was sought. This study was conducted in accordance with the principles of the Declaration of Helsinki where applicable to research using aggregate data.

Acknowledgments

AI assistance: Claude (Anthropic, claude-opus-4-6) was used for data analysis pipeline development, statistical computation, and manuscript drafting. The author verified all analyses, results, and references independently.

All references were verified against PubMed and CrossRef databases for accuracy of authors, titles, journal names, volumes, pages, and DOIs.

Author contributions (CRediT)

Mizuki Shirai: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization.

Conflict of interest

The author declares no conflicts of interest per ICMJE guidelines.

Funding

This research received no specific funding.

Data availability

Daily temperature data are publicly available from the Japan Meteorological Agency historical weather database (https://www.data.jma.go.jp/risk/obsdl/). Analysis code and processed data are available at https://github.com/rehabilitation-collaboration/higan-temperature.

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Figure legends

Figure 1. Distribution of PELT-detected temperature transition offsets from equinox dates across all eight stations (1950–2025). Positive values indicate transitions occurring after the equinox. Box plots show median, interquartile range, and 1.5× IQR whiskers. Spring offsets (left) are consistently larger than autumn offsets (right).

Figure 2. Annual temperature profiles with equinox dates and PELT-detected transition points for Tokyo (1950–2025 mean). Vertical dashed lines indicate the vernal equinox (DOY ~80) and autumnal equinox (DOY ~266). The grey shaded region shows ±1 SD of daily temperatures. (Referenced in §3.1.)

Figure 3. Temporal trends in autumn equinox offsets (1950–2025) for four stations with significant Mann-Kendall trends. Sen's slope and *p*-values are shown for each station. The increasing trend indicates progressive delay of autumn cooling relative to the equinox. (Referenced in §3.4.)

Figure 4. Latitudinal comparison of spring and autumn equinox offsets across eight stations. The subtropical station Naha (26.3°N) exhibits distinctly larger offsets in both seasons. Error bars show interquartile ranges. (Referenced in §4.3.)

Figure 5. Era-specific median equinox offsets for autumn. The baseline period (1950–1979) shows offsets near zero, while the recent period (2000–2025) shows substantially delayed transitions at all temperate stations. (Referenced in §3.5.)

Figure 6. Offset histograms for representative stations (Tokyo, Fukuoka, Naha) showing the distribution of spring (blue) and autumn (orange) transition offsets. Dashed vertical lines indicate the equinox (offset = 0). (Referenced in §3.1.)

Figures

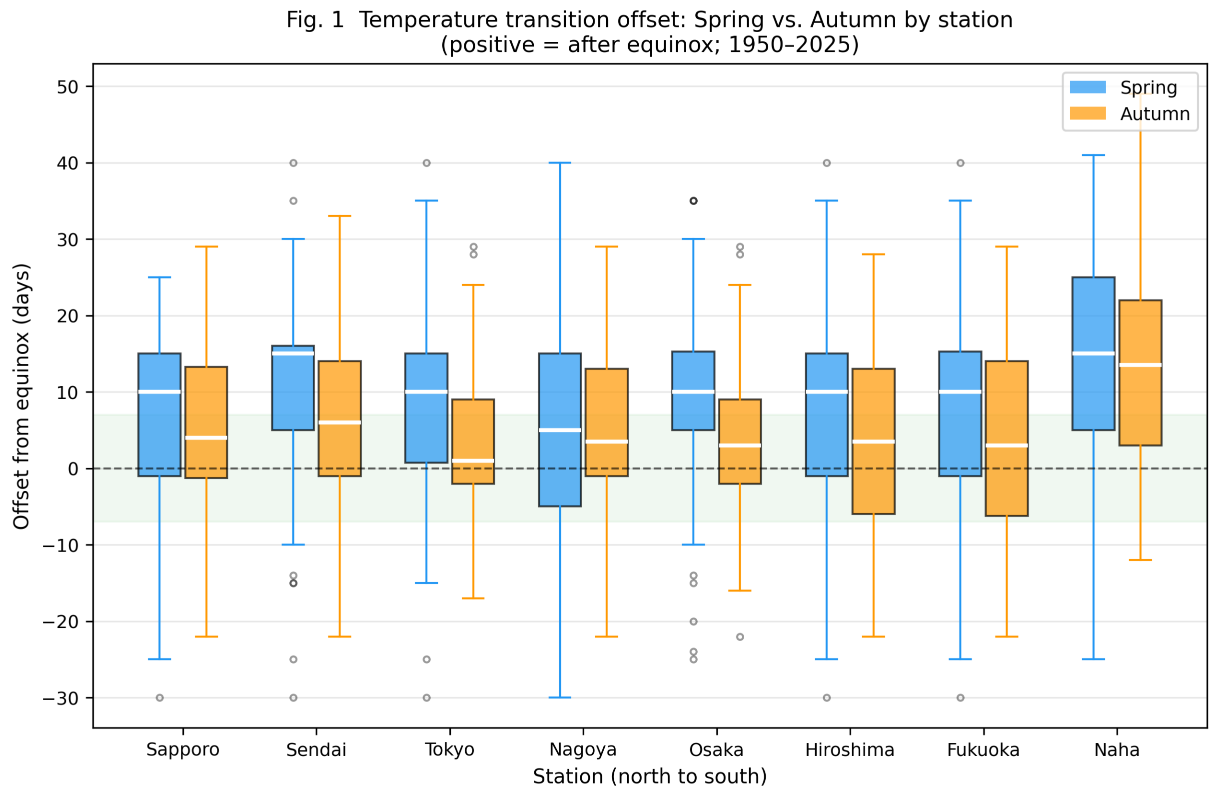

Figure 1.

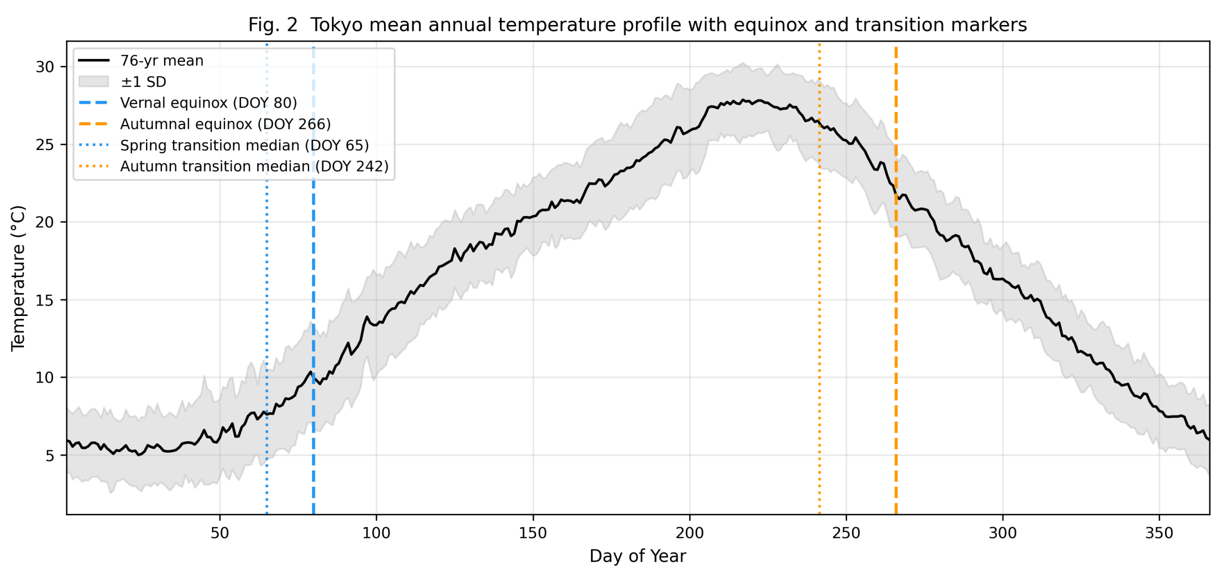

Figure 2.

Fig. 3 Temporal trend in autumn equinox offset (4 stations, 1950–2025)
Dashed line = Sen's slope; shading = ±7 days of equinox

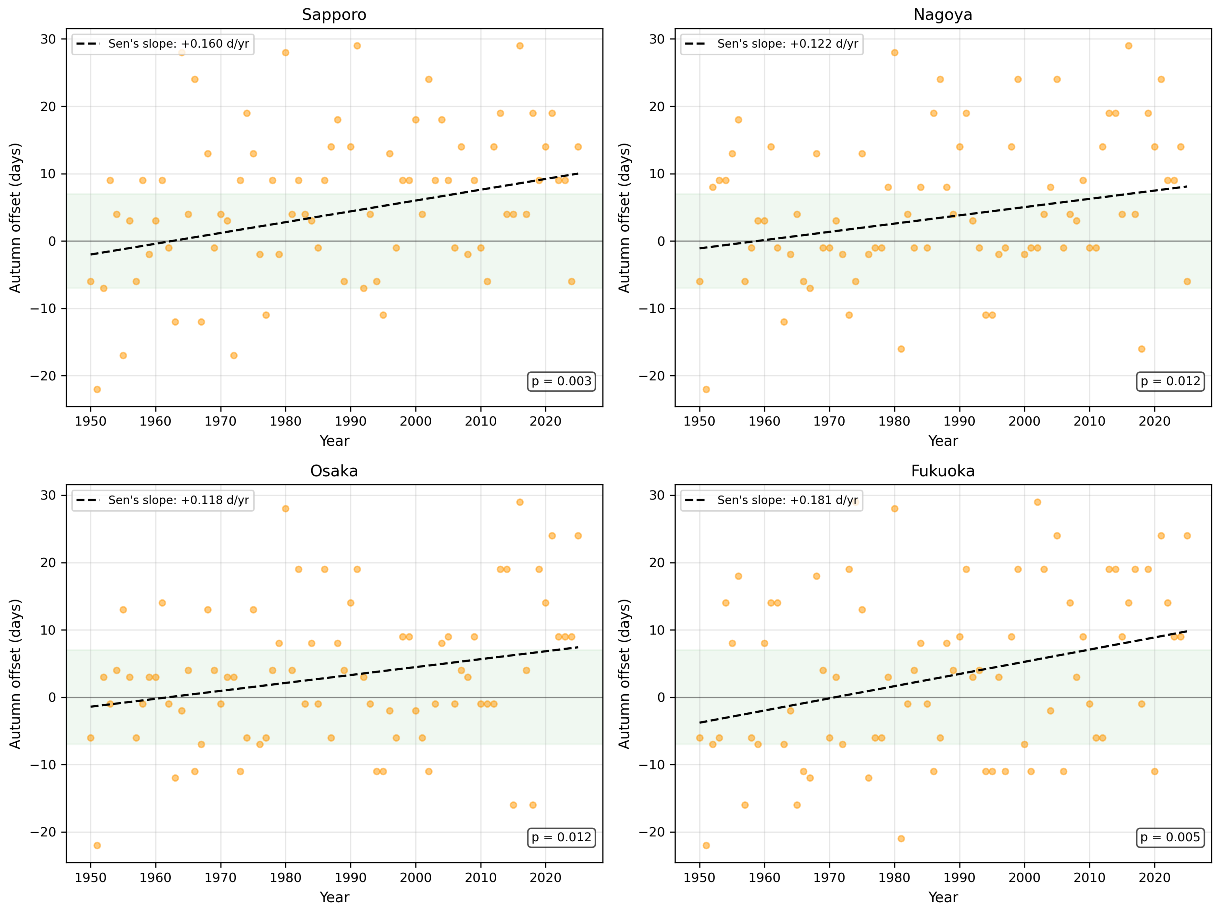

Figure 3.

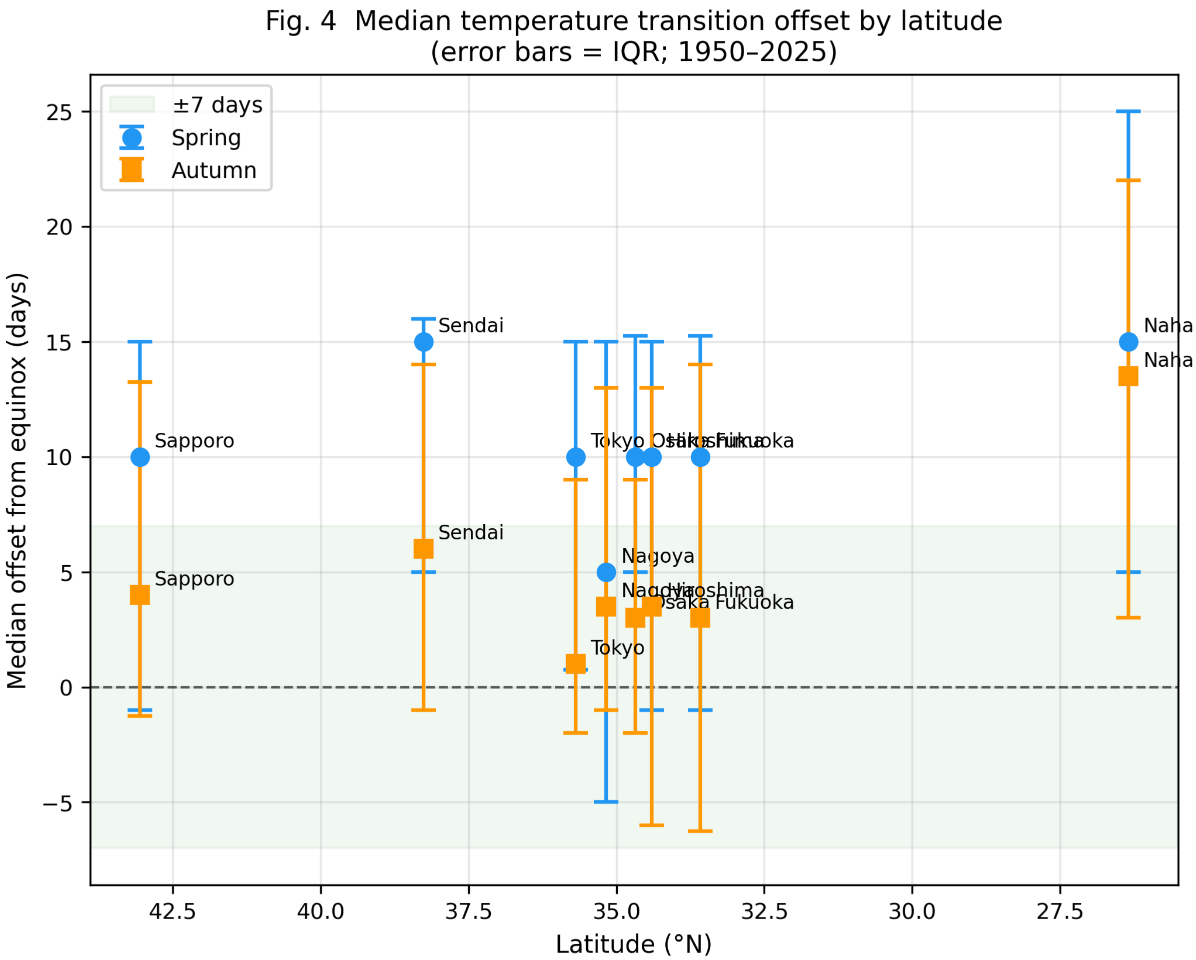
Fig. 4 Median temperature transition offset by latitude
(error bars = IQR; 1950–2025)
±7 days
Spring
Autumn
Median offset from equinox (days)
Latitude (°N)
25
20
15
10
5
0
−5
42.5
40.0
37.5
35.0
32.5
30.0
27.5
Sapporo
Sendai
Tokyo
Nagoya
Osaka
Hiroshima
Fukuoka
Naha

Figure 4.

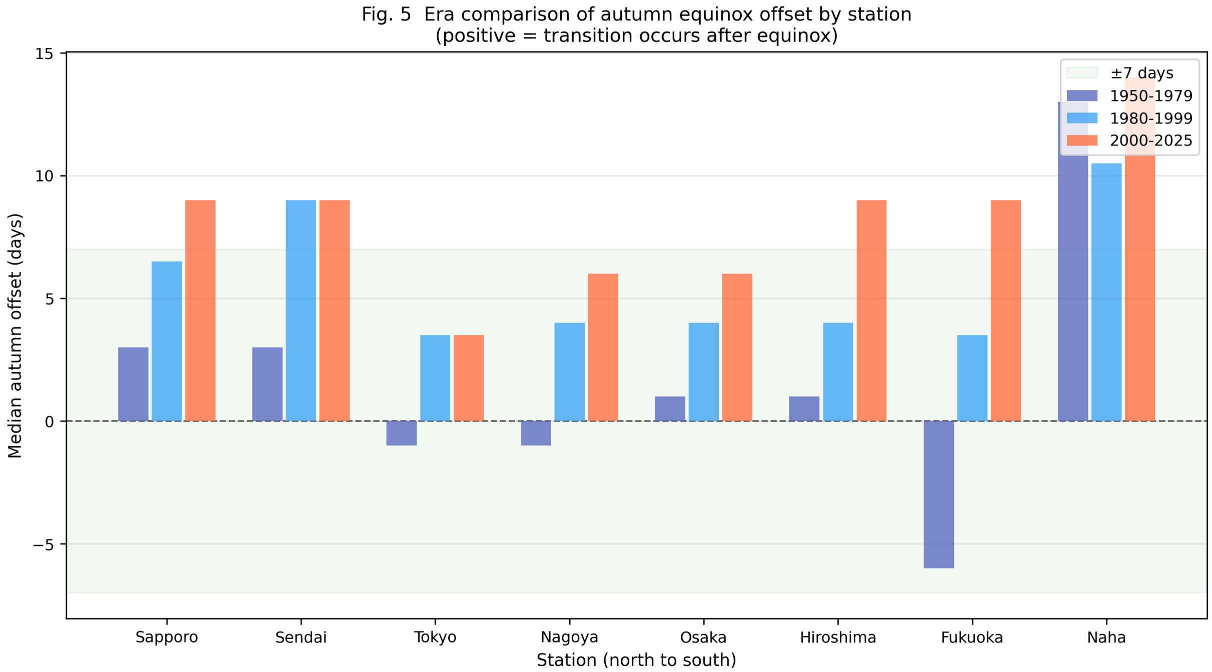
Fig. 5 Era comparison of autumn equinox offset by station
(positive = transition occurs after equinox)
±7 days
1950-1979
1980-1999
2000-2025
Median autumn offset (days)
15
10
5
0
−5
Sapporo
Sendai
Tokyo
Nagoya
Osaka
Hiroshima
Fukuoka
Naha
Station (north to south)

Figure 5.

Fig. 6 Distribution of spring and autumn offset — representative stations (1950–2025)
Dashed line = equinox; solid lines = season medians

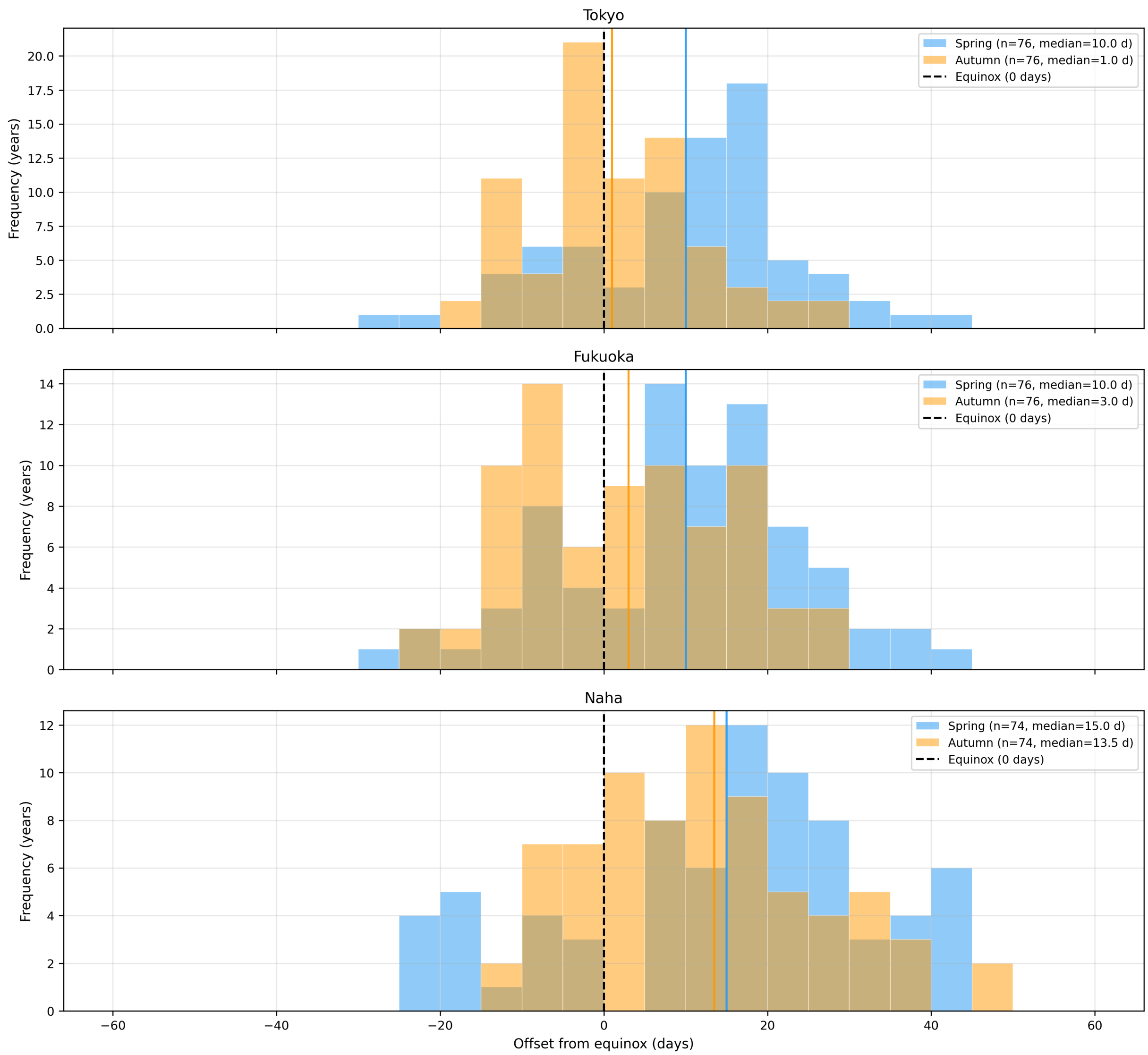

Figure 6.

Supplementary Materials

Atsusa samusa mo higan made: Statistical validation of a Japanese weather proverb across eight stations over 76 years

Mizuki Shirai

Table S1. Segmented regression summary for all eight stations (1950–2025). Breakpoints (BP) and confidence intervals (CI) are medians across 76 years. Slope change is the mean change in temperature trend at the breakpoint (°C/day). R^2 is the mean across years.

Station	Season	Median BP (DOY)	Median 95% CI (DOY)	Mean slope change (°C/day)	Mean R^2	*n* years
Sapporo	Spring	56.5	40–92	+0.215	0.841	76
Sapporo	Autumn	244.0	227–287	−0.260	0.885	76
Sendai	Spring	60.0	42–92	+0.186	0.800	76
Sendai	Autumn	242.5	225–262	−0.261	0.873	76
Tokyo	Spring	65.0	42–102	+0.156	0.779	76
Tokyo	Autumn	241.5	227–265	−0.230	0.866	76
Nagoya	Spring	57.5	39–98	+0.193	0.822	76
Nagoya	Autumn	240.0	231–262	−0.242	0.908	76
Osaka	Spring	60.5	43–86	+0.193	0.807	76
Osaka	Autumn	240.0	230–262	−0.219	0.905	76
Hiroshima	Spring	59.5	36–92	+0.211	0.814	76
Hiroshima	Autumn	241.0	232–272	−0.203	0.911	76
Fukuoka	Spring	58.5	34–108	+0.170	0.766	76
Fukuoka	Autumn	240.0	232–285	−0.211	0.900	76
Naha	Spring	72.5	32–120	+0.141	0.598	76
Naha	Autumn	261.0	248–295	−0.121	0.824	76

Table S2. Sensitivity analysis: restricted (±60-day window) vs. unrestricted PELT change point selection. The unrestricted method selects the change point nearest to each equinox from all PELT-detected points across the full year, without any search window restriction.

Station	Season	N years	Median offset (restricted)	Median offset (unrestricted)	Identical results
Sapporo	Spring	76	+10.0	+10.0	100%
Sapporo	Autumn	76	+4.0	+4.0	100%
Sendai	Spring	76	+15.0	+15.0	100%
Sendai	Autumn	76	+6.0	+6.0	100%
Tokyo	Spring	76	+10.0	+10.0	100%
Tokyo	Autumn	76	+1.0	+1.0	100%
Nagoya	Spring	76	+5.0	+5.0	100%
Nagoya	Autumn	76	+3.5	+3.5	100%
Osaka	Spring	76	+10.0	+10.0	100%
Osaka	Autumn	76	+3.0	+3.0	100%
Hiroshima	Spring	76	+10.0	+10.0	100%
Hiroshima	Autumn	76	+3.5	+3.5	100%
Fukuoka	Spring	76	+10.0	+10.0	100%
Fukuoka	Autumn	76	+3.0	+3.0	100%
Naha	Spring	74	+15.0	+15.0	100%
Naha	Autumn	74	+13.5	+13.5	100%

Note: Of 608 total station-year combinations, 606 yielded valid transition offsets under the restricted (±60-day) method (two Naha years had no change point within the window). Among these 606 comparable cases, restricted and unrestricted methods produced identical results, indicating that the search window restriction did not introduce bias.

Table S3. Hamed-Rao modified Mann-Kendall test results with variance correction for autocorrelation, compared with original Mann-Kendall.

Station	Season	Original *p*	Modified *p*	Sen's slope (d/yr)	Original sig.	Modified sig.
Sapporo	Spring	0.233	0.233	0.000	No	No
Sapporo	Autumn	0.003	0.008	+0.160	Yes	Yes
Sendai	Spring	0.578	0.578	0.000	No	No
Sendai	Autumn	0.061	0.061	+0.104	No	No
Tokyo	Spring	0.986	0.988	0.000	No	No
Tokyo	Autumn	0.092	0.111	+0.031	No	No
Nagoya	Spring	0.665	0.665	0.000	No	No
Nagoya	Autumn	0.012	0.006	+0.122	Yes	Yes
Osaka	Spring	0.853	0.804	0.000	No	No
Osaka	Autumn	0.012	0.012	+0.118	Yes	Yes
Hiroshima	Spring	0.396	0.396	0.000	No	No
Hiroshima	Autumn	0.052	0.047	+0.114	No	Yes
Fukuoka	Spring	0.203	0.240	−0.087	No	No
Fukuoka	Autumn	0.005	<0.001	+0.181	Yes	Yes
Naha	Spring	0.800	0.560	0.000	No	No
Naha	Autumn	0.134	0.134	+0.093	No	No

Note: The modified test applies the Hamed and Rao (1998) correction for autocorrelation in the variance of the S statistic. Hiroshima autumn gained significance under the modified test. All four originally significant trends remained significant.