

Temporal Overlap Between Global Seismicity and Planetary Configuration Dates

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Research Article

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Temporal Overlap Between Global Seismicity and Planetary Configuration Dates

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Abstract

Identifying statistical relationships in non-stationary seismic catalogs requires methods that account for strong temporal dependence. We investigate temporal overlap between global seismicity and deterministic planetary configuration dates derived from NASA JPL Horizons ephemerides. The analysis uses 2010–2012 USGS global earthquake catalogs ($M_w > 6.5$), represented as binary daily occupancy series to reduce sensitivity to aftershock clustering and repeated events within the same day. Planetary reference dates are generated using a predefined geometric filtering procedure applied independently to planetary ephemerides, without reference to geophysical observations. The statistical significance of the observed overlaps is then evaluated using a non-parametric circular-shift surrogate framework, in which only the deterministic reference dates are shifted relative to the fixed seismic catalogs while their internal temporal structure is preserved. Observed same-day overlaps exceeded surrogate expectations in all three years, and the combined three-year analysis also showed a significant excess ($p = 0.0009$). The surrogate analysis indicates that these overlaps occur more frequently than expected from chance alignment under the tested null model, motivating further investigation of their geophysical basis without assuming a physical coupling mechanism.

Keywords

Earthquakes; planetary configurations; planetary ephemerides; distance geometry; surrogate data analysis; temporal overlap

1. Introduction

Earthquake catalogs are highly non-stationary due to clustering from aftershock sequences, stress redistribution, and fault interactions, resulting in strong temporal dependence [1, 2, 3]. Because this inherent clustering violates the assumptions of independent Poisson processes, conventional correlation metrics are prone to detecting false periodicities or spurious alignments. Such behavior complicates statistical inference in earthquake catalogs and motivates the use of comparison frameworks that preserve key empirical temporal structure [4].

External stress perturbations have been widely investigated as potential modulators of seismicity. Tidal stresses associated with lunar and solar forcing have been examined across a range of tectonic settings, with some studies reporting statistically detectable modulation of earthquake timing in specific regimes [5, 6]. However, detecting weak external temporal effects remains challenging because earthquake occurrence exhibits strong temporal dependence and long-range variability, making apparent correlations difficult to interpret [7]. These challenges motivate the use of rigorous surrogate-based evaluation frameworks when comparing seismicity with deterministic external timing sequences. Recent large-scale analyses have also examined statistical relationships between global seismic catalogs and astronomical ephemeris datasets using time-series decomposition and comparisons of long-term temporal variability [8].

In this study, we investigate the temporal overlap between global seismicity and an externally constructed set of planetary configuration dates based on NASA JPL Horizons ephemerides [9]. The analysis is based on the 2010–2012 USGS global earthquake catalogs [10] for events with a reported moment magnitude of $M_w > 6.5$. The inclusion of three consecutive annual catalogs allows assessment of whether the observed correspondence is restricted to a single year or persists across multiple years. Earthquake activity is represented as a daily occupancy series, where all events within a given day are collapsed into a single occupied day so that major aftershock sequences do not disproportionately influence the overlap statistic. The planetary configuration dates are generated using a predefined geometric filtering criterion applied a priori to the planetary ephemerides.

Statistical comparison uses a circular-shift surrogate approach applied to each annual catalog and to the combined three-year dataset. The procedure preserves the spacing between the externally defined dates while randomizing their temporal alignment relative to the corresponding fixed earthquake occupancy series. Because only the deterministic reference dates are shifted, the empirical clustering structure of each seismic catalog is preserved throughout the analysis. The observed overlaps are then evaluated against the corresponding surrogate distributions under the null hypothesis of temporal independence. This study therefore investigates whether the observed temporal overlap between planetary configuration dates and global seismicity exceeds expectations under the adopted surrogate framework across multiple annual catalogs. The objective is to establish whether such a statistical relationship exists while leaving the investigation of possible physical mechanisms beyond the scope of the present study.

2. Data and Methods

2.1 Earthquake Catalog and Occupancy Representation

The year 2011 was initially selected as the primary study year because it provides a global earthquake catalog containing substantial natural seismic clustering. To evaluate whether the observed temporal correspondence is restricted to 2011 or persists more generally, the analysis was expanded to include the adjacent years 2010 and 2012. Earthquake data were obtained from the United States Geological Survey (USGS) Earthquake Hazards Program Comprehensive Catalog [10]. Search criteria were defined a priori to include all global earthquakes recorded during 2010–2012 with reported moment magnitude $M_w > 6.5$. The resulting catalogs provide global coverage of major earthquakes across diverse tectonic environments.

To reduce sensitivity to short-timescale aftershock clustering, the catalog was transformed into a binary daily occupancy representation. Earthquake origin times (UTC) were projected onto discrete calendar days represented by integer day indices spanning the full annual calendar for each year analyzed, such that multiple earthquakes occurring on the same day were treated as a single occupied day. This formulation reduces sensitivity to clustered seismic occurrence while preserving a simple empirical representation of earthquake occurrence.

Under this representation, multiple earthquakes occurring on the same calendar day correspond to a single occupied day in the final occupancy series. For example, the 11 March 2011 Tohoku-Oki mainshock and associated same-day aftershocks contribute only a single occupied day to the occupancy record. The resulting binary occupancy series serves as the fixed empirical baseline for surrogate evaluation.

2.2 Planetary Configuration Date Generation

The deterministic reference set in this study consists of timestamps generated independently of the earthquake catalog. Positional ephemerides were obtained from the NASA/JPL Horizons On-Line Ephemeris System [9] in heliocentric ecliptic coordinates (ICRF), with position coordinates expressed in astronomical units (AU), at 1-minute temporal resolution. The selection of the planetary configuration is described separately in Section 2.3. The resulting ephemerides were then evaluated independently for each study year using the corresponding geometric filtering procedure, yielding the reference dates used in the statistical analysis.

At each 1-minute time step, the coordinates of the Sun, fixed at the heliocentric origin (0,0,0), and the selected planetary bodies were assembled into a configuration matrix $X(t) \in \mathbb{R}^{N \times 3}$. The pairwise squared Euclidean distance matrix $D(t)$ was then computed:

$$D_{ij}(t) = \|x_i(t) - x_j(t)\|^2, \quad i, j = 1, \dots, N$$

where $x_i(t)$ denotes the Cartesian position vector of body i at time step t .

To eliminate dependence on absolute coordinate translation and orientation, the pairwise squared Euclidean distance matrix $D(t)$ was transformed into a congruence-invariant Gram matrix [11, 12]. The construction is summarized below.

Define the row mean of the squared distance matrix:

$$\bar{D}_{i.}(t) = \frac{1}{N} \sum_{j=1}^N D_{ij}(t)$$

and the lower-triangular global mean:

$$\hat{D}_{..}(t) = \frac{1}{N^2} \sum_{j=2}^N \sum_{k=1}^{j-1} D_{jk}(t)$$

Then define:

$$Do_i(t) = \bar{D}_{i.}(t) - \hat{D}_{..}(t)$$

The congruence-invariant Gram matrix $G(t)$ was then constructed elementwise as:

$$G_{ij}(t) = \frac{1}{2} \left(Do_i(t) + Do_j(t) - D_{ij}(t) \right)$$

The congruence-equivalent Cartesian embedding was then recovered by singular value decomposition of the Gram matrix:

$$G(t) = U(t) \Sigma(t) U^T(t)$$

Because the original planetary configuration is embedded in three-dimensional Euclidean space, the corresponding Gram matrix has rank at most three in exact arithmetic. The embedded coordinate representation was therefore reconstructed using the three dominant singular values as:

$$X^*(t) = U_3(t) \Sigma_3^{1/2}(t)$$

yielding a geometrically equivalent three-dimensional configuration for evaluation against a predefined geometric criterion.

The numerical tolerance was set to $\varepsilon = 10^{-4}$ AU for the adopted 1-minute ephemeris sampling interval. At this temporal resolution, consecutive embedded configurations are expected to vary smoothly. A different sampling interval would require reassessment of the tolerance. Additionally, a scaling factor $\alpha = 0.35$ was applied to the base tolerance to impose a more restrictive bound on the numerical threshold, yielding the effective threshold $\alpha\varepsilon$. The planetary configuration condition was therefore evaluated as:

$$\max_{i,j} (|X_{ij}^*(t) - X_{ij}^*(t-1)|) < \alpha\varepsilon,$$

If the inequality was satisfied, the embedding was considered numerically continuous, and the evaluation proceeded to the following time step. Otherwise, the timestamp was recorded as a candidate associated with a geometric degeneracy. Although the congruence invariance of $X^*(t)$ was preserved, the detected degeneracy was associated with a sign reversal in the column vectors of the orthogonal matrix $U(t)$. This behavior can be explained by the properties of singular value decomposition [13].

2.3 Planetary Configuration Selection

The planetary configuration used in this study was selected through an iterative configuration-construction procedure. The process was initialized using the four inner solar planets (Mercury, Venus, Earth, and Mars), representing the planetary bodies nearest to Earth. The procedure described in Section 2.2 was then applied to the complete ephemeris sequence for each study year to identify configuration dates.

The resulting timestamp count was used as an indicator of geometric constraint, with larger counts reflecting a less restrictive geometric definition. Configurations producing many timestamps were interpreted as insufficiently constrained, indicating that the geometric criterion was satisfied by a broad range of positional arrangements and therefore did not provide a sufficiently constrained geometric reference set. In such cases, an additional celestial body was incorporated into the existing configuration while retaining all previously included bodies, and the date-generation procedure was repeated. The Moon was first added to the inner-planet configuration, followed by Jupiter when further constraint was required according to the predefined nested expansion sequence used throughout the study. This iterative process continued until the count was reduced to a bounded level, defined here as no more than 100 candidate timestamps per year, consistent with a bounded geometric reference set suitable for subsequent statistical analysis. The same selection procedure was applied uniformly across all years.

The resulting planetary reference dates are therefore determined entirely by the ephemeris data and the predefined geometric construction. Earthquake observations enter the analysis only after the planetary configuration dates have been generated and selected, at the subsequent overlap and surrogate-analysis stage.

2.4 Statistical Assessment

Statistical significance was evaluated using a non-parametric circular-shift surrogate framework designed to test the null hypothesis of temporal independence between the planetary configuration dates and the earthquake occupancy series. Because the tested null concerns temporal alignment rather than the construction of the reference sequence, the surrogate procedure randomizes only the temporal phase relationship between the two datasets. The internal spacing structure of the planetary dates is therefore preserved. The

surrogate analysis was applied separately to each study year, producing separate overlap statistics and surrogate distributions for 2010, 2011, and 2012. The same circular-shift framework was subsequently applied to the combined three-year dataset using the corresponding aggregated planetary date sequence and earthquake occupancy series.

Let L denote the total number of days in the analysis interval ($L = 365$ or $L = 366$) for a common or leap year, respectively, and $L = 1096$ for the combined 2010–2012 analysis. Let $A = \{a_1, a_2, \dots, a_m\}$ denote the set of planetary configuration dates expressed as integer day indices within $[1, L]$. Let $B = \{b_1, b_2, \dots, b_n\}$ denote the set of occupied earthquake calendar days derived from the $M_w > 6.5$ seismic catalog. The observed overlap statistic, K_{obs} , is defined as the number of shared calendar days between A and B :

$$K_{\text{obs}} = \sum_{i=1}^m I(a_i \in B)$$

where I denotes the indicator function.

Surrogate realizations were generated by applying uniform circular temporal shifts to the planetary date set. For each surrogate iteration t , an integer phase shift δ_t was sampled uniformly from the interval $[0, L - 1]$, and the shifted date set was computed as:

$$A'_t = \{((a_i + \delta_t - 1) \bmod L) + 1 : a_i \in A\}$$

This transformation preserves the relative spacing of the planetary dates while randomizing their temporal alignment relative to the fixed earthquake occupancy series. The empirical seismic catalog remained fixed throughout the analysis to preserve the observed temporal clustering structure of the earthquake record.

For each realization, K_t counted occupied days shared by the shifted planetary dates A'_t and the fixed earthquake occupancy series B . The 200,000 surrogate realizations were used to estimate the null distribution, with their mean defining the expected overlap. The one-tailed test used a significance level of 0.05, with the 95th percentile as the rejection threshold.

The empirical Monte Carlo p -value was then calculated as:

$$p = \frac{1}{M} \sum_{t=1}^M I(K_t \geq K_{\text{obs}})$$

where $M = 200,000$ denotes the total number of surrogate realizations. Under this framework, low p -values indicate overlap levels exceeding expectations generated under the tested null model of temporal independence.

3. Results

3.1 Geometric Stability and Configuration Selection

The configuration-selection procedure described in Section 2.3 was applied independently to each study year using ephemeris datasets sampled at 1-minute intervals. This sampling yields 525,600 planetary configurations for a standard 365-day year and 527,040 for a leap year like 2012. This procedure reduced these large annual datasets to only 15–20 candidate timestamps for the final selected planetary body set in each year. The candidate timestamp counts obtained, together with the planetary body sets evaluated, are provided in Table 1.

Year	Planetary body set	Candidate timestamps
2010	Mercury, Venus, Earth, Mars	20
2011	Mercury, Venus, Earth, Mars	3,354
2011	Mercury, Venus, Earth, Moon, Mars	8,834
2011	Mercury, Venus, Earth, Moon, Mars, Jupiter	20
2012	Mercury, Venus, Earth, Mars	15

Table 1. Candidate planetary configuration timestamps identified during the configuration-selection procedure for each planetary body set evaluated. These counts were used to assess geometric constraint and determine the selected planetary body set for each year before statistical comparison with earthquake occurrence data.

For 2010 and 2012, the initial inner-planet configuration consisting of Mercury, Venus, Earth, and Mars produced 20 and 15 candidate timestamps, respectively. Both values were

below the predefined selection threshold and therefore satisfied the configuration-selection criterion without the inclusion of additional celestial bodies. In contrast, application of the same inner-planet configuration to the 2011 ephemeris produced 3,354 candidate timestamps, indicating a substantially larger number of detected geometric degeneracies during that year. Following the predefined nested expansion procedure described in Section 2.3, the Moon was incorporated into the existing configuration while retaining all previously included bodies. This expansion increased the candidate count to 8,834 timestamps, indicating that the inclusion of the Moon did not alleviate the abundance of detected geometric degeneracies. Jupiter was therefore added as the next body in the expansion sequence, reducing the candidate count to 20 timestamps and yielding a bounded configuration set comparable in size to those obtained for 2010 and 2012. This behavior illustrates that the configuration-selection procedure was not simply a monotonic reduction in candidate count with each added body; rather, the geometric degeneracy structure depended on the planetary configuration being evaluated.

These results indicate substantial year-to-year differences in the geometric behavior of the planetary configuration model. In particular, the 2011 ephemeris exhibited a markedly larger number of geometric degeneracies than 2010 and 2012 when only the inner planets were considered. The configuration-selection procedure therefore served as a geometric stabilization mechanism, producing a bounded and well-defined set of planetary configuration timestamps prior to any comparison with earthquake occurrence data.

3.2 Statistical Significance of Same-Day Overlap

The candidate timestamps obtained from the selected planetary body sets were first reduced to unique planetary configuration dates, yielding 18 dates in 2010, 17 in 2011, and 13 in 2012. These planetary configuration dates were then matched against the corresponding earthquake occupancy series to determine the observed same day overlap for each annual catalog. The circular-shift surrogate framework described in Section 2.4 was subsequently applied to generate the corresponding surrogate overlap distributions, from which the expected overlap levels and empirical Monte Carlo p-values were obtained. The three annual analyses were treated as separate year-specific evaluations.

The corresponding overlap statistics are summarized in Table 2, and the resulting surrogate overlap distributions for each individual catalog are shown in Figures 1-3.

Year	Planetary Conf. Dates	Observed Overlap	Expected Overlap	p-value
2010	18	6	1.92	0.0081
2011	17	7	1.77	0.0085
2012	13	4	1.21	0.0190
2010–2012	48	17	4.87	0.0009

Table 2. Summary of planetary configuration dates, observed same-day overlap counts, expected overlap levels derived from the surrogate distributions, and empirical Monte Carlo p-values for each annual catalog and the combined three-year analysis.

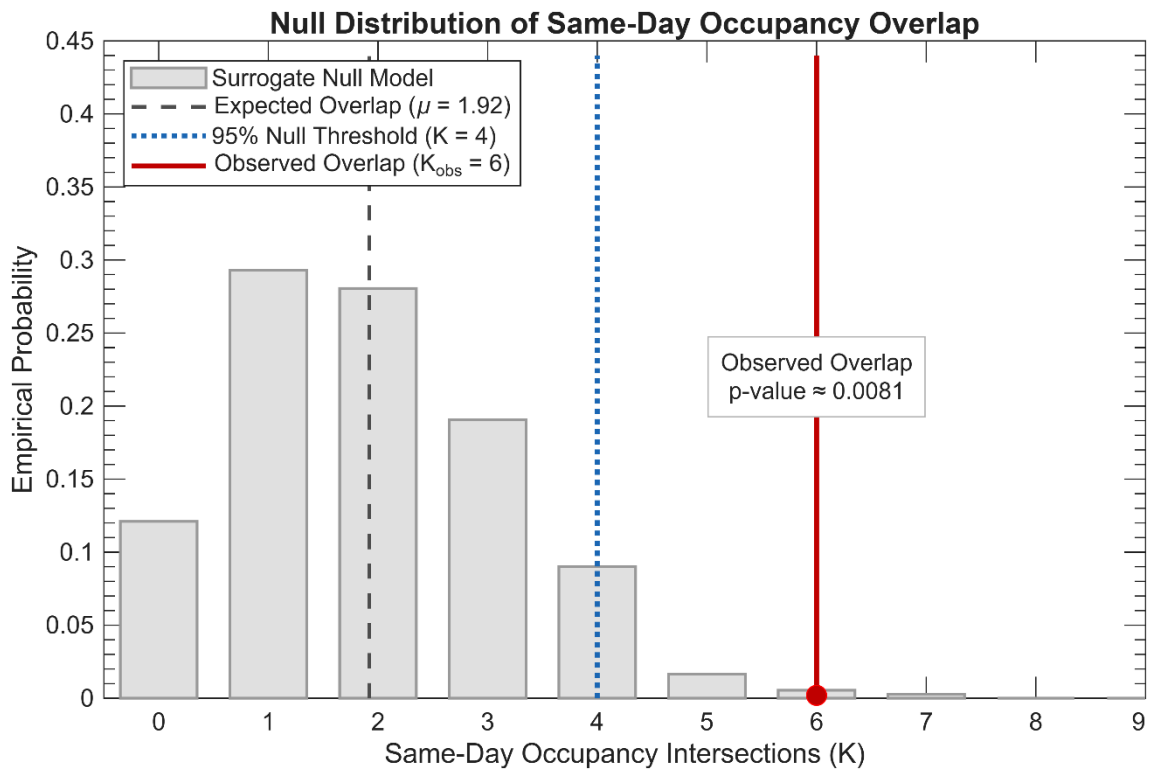


Figure 1. Empirical surrogate overlap distribution for the 2010 catalog. The red line indicates the observed overlap count, and the blue dotted line denotes the 95% significance threshold.

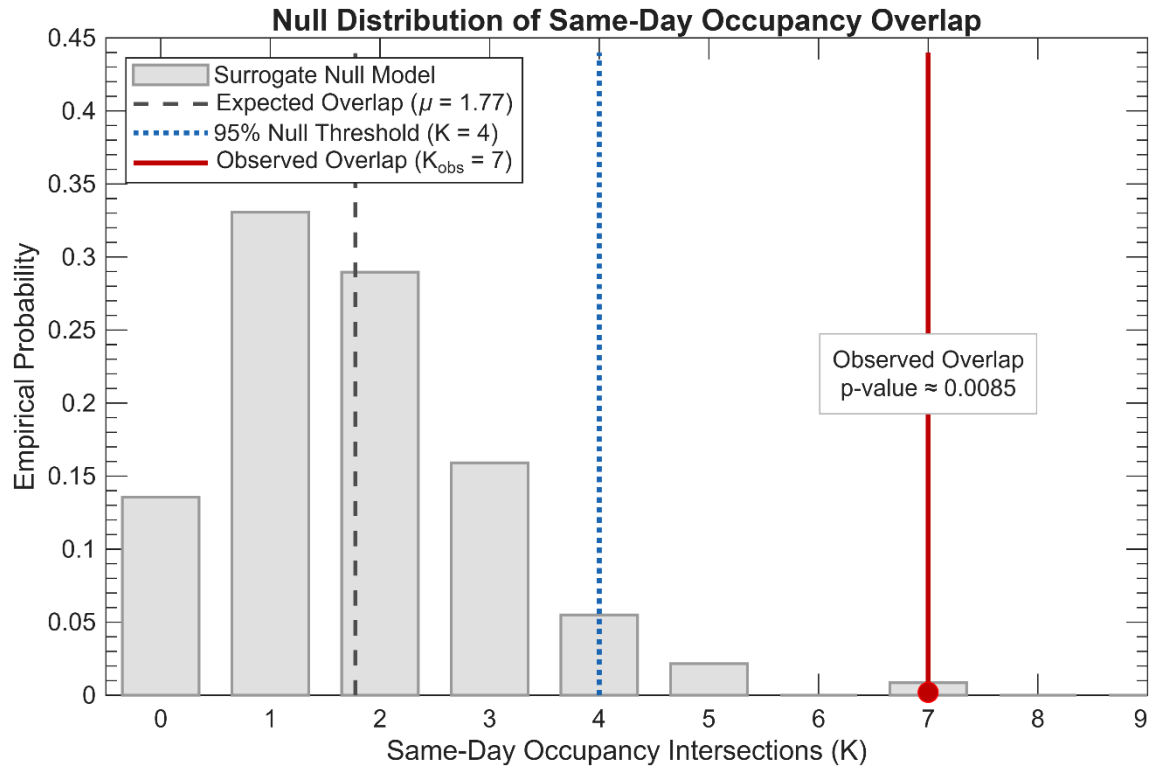


Figure 2. Empirical surrogate overlap distribution for the 2011 catalog. The red line indicates the observed overlap count, and the blue dotted line denotes the 95% significance threshold.

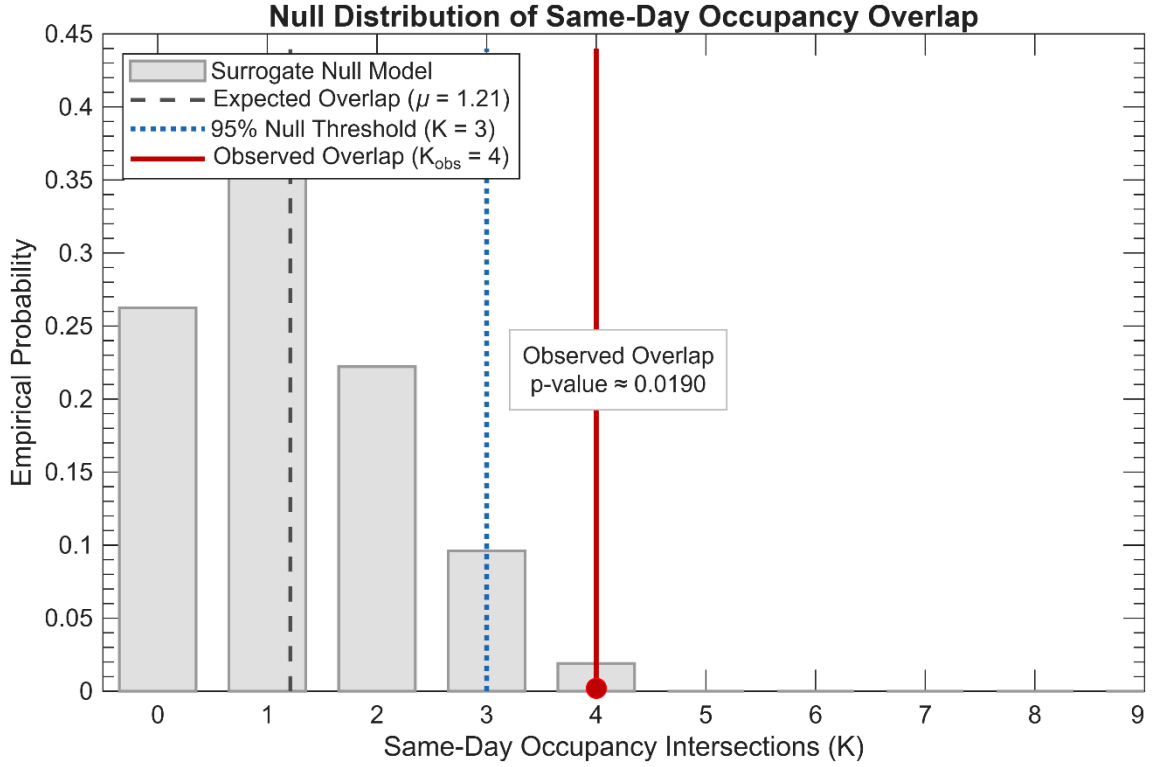


Figure 3. Empirical surrogate overlap distribution for the 2012 catalog. The red line indicates the observed overlap count, and the blue dotted line denotes the 95% significance threshold.

The circular-shift surrogate framework was also applied to the aggregated 2010–2012 dataset, and the resulting surrogate overlap distribution is shown in Figure 4. The observed overlap again exceeded surrogate expectations, yielding a statistically significant result for the combined three-year analysis ($p = 0.0009$). This combined analysis extends the annual results by demonstrating that the observed temporal correspondence is maintained when all three catalogs are evaluated jointly.

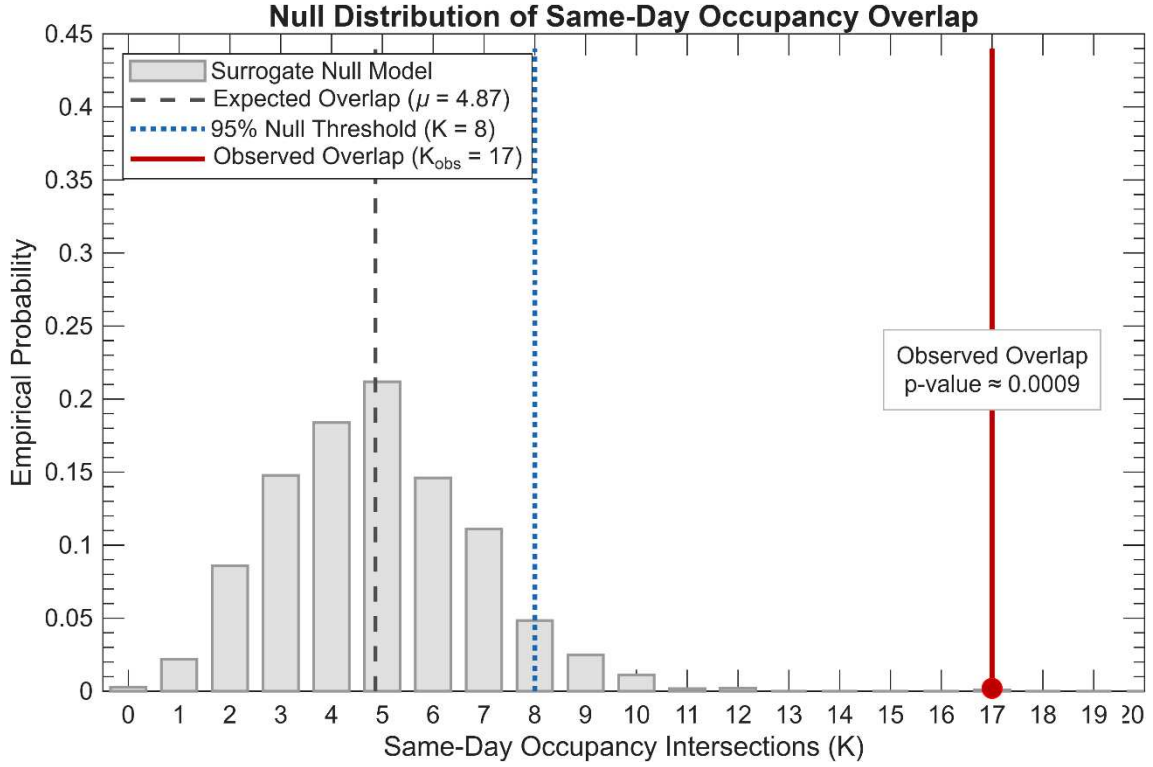


Figure 4. Empirical surrogate overlap distribution for the combined 2010–2012 analysis. The red line indicates the observed overlap count for the aggregated three-year dataset, and the blue dotted line denotes the 95% significance threshold.

3.3 Temporal Distribution of Overlap Events

To complement the statistical significance analysis, the planetary configuration dates and earthquake occupancy days were projected onto annual calendar timelines to visualize the temporal distribution of the observed overlap events. The corresponding timelines are shown in Figures 5-7. This representation restores the explicit chronology of events after the reduction of repeated seismic activity into unique daily occupancy intervals. The timelines indicate that the overlap events are distributed across multiple periods of each annual catalog rather than being concentrated within a single temporal cluster. This pattern suggests that the observed overlap is not driven exclusively by a localized sequence of seismic activity occurring within a limited interval of the study period.

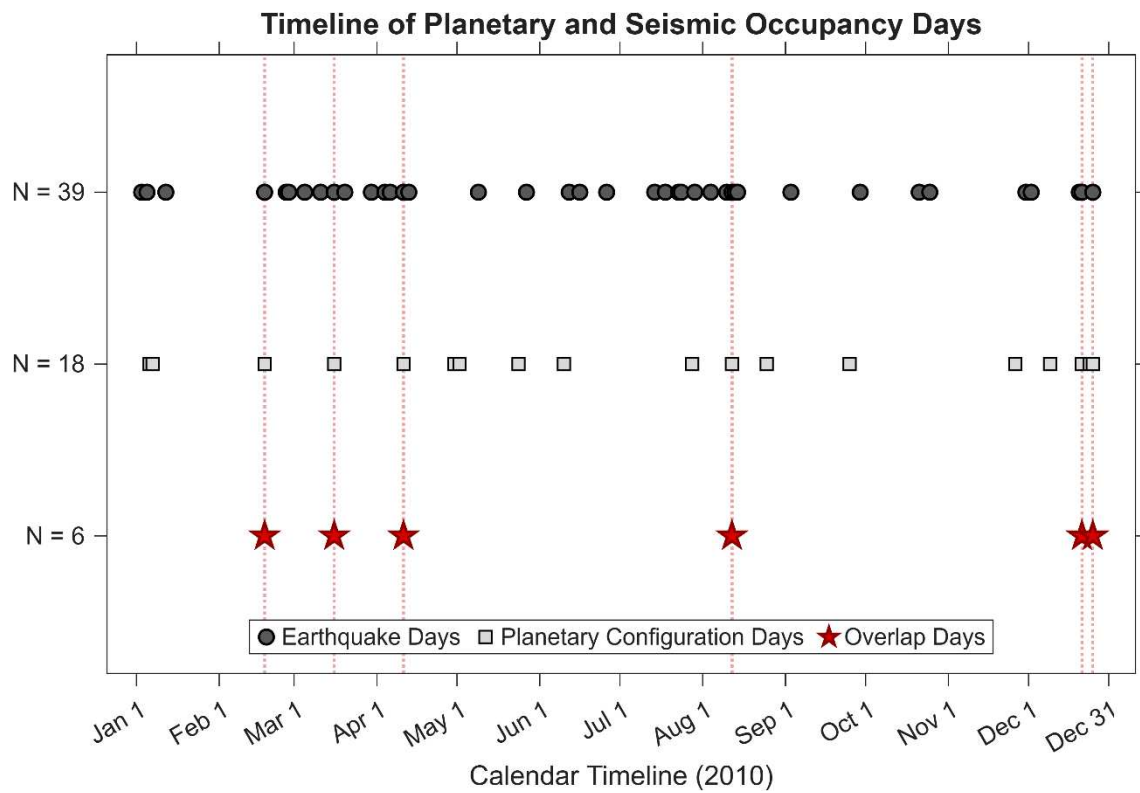


Figure 5. Timeline of planetary configuration dates and earthquake occupancy days for the 2010 calendar year.

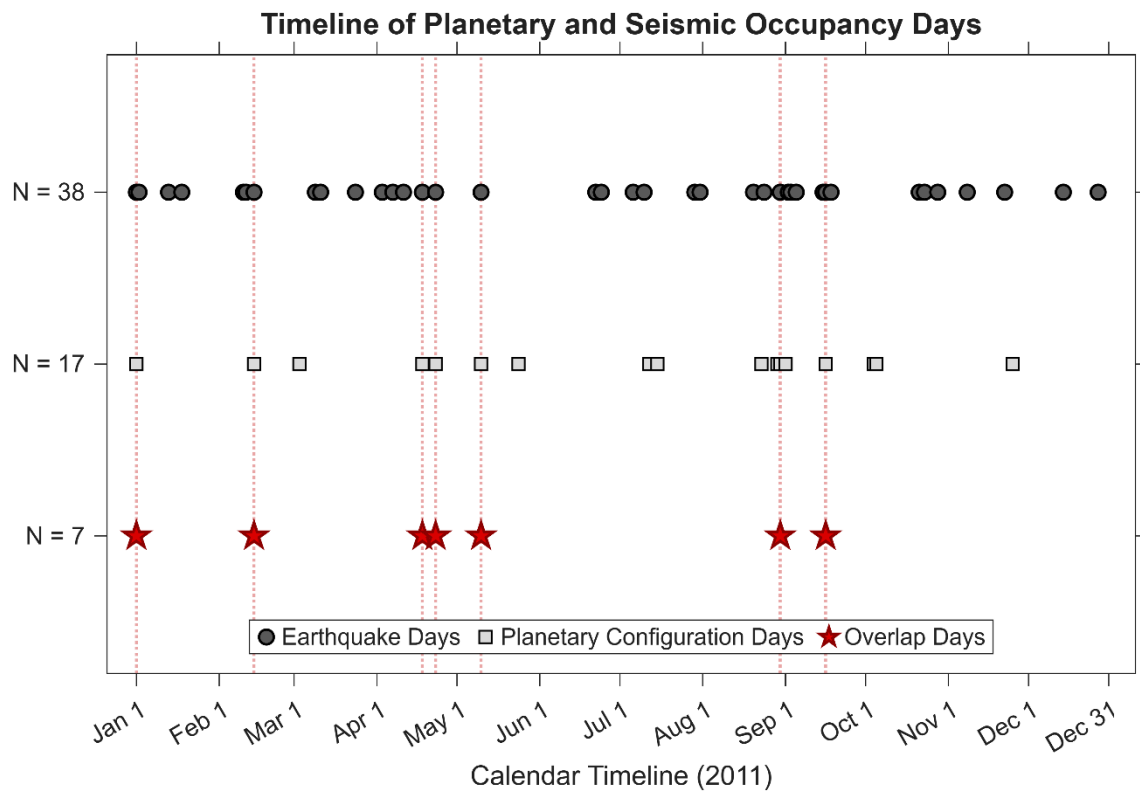


Figure 6. Timeline of planetary configuration dates and earthquake occupancy days for the 2011 calendar year.

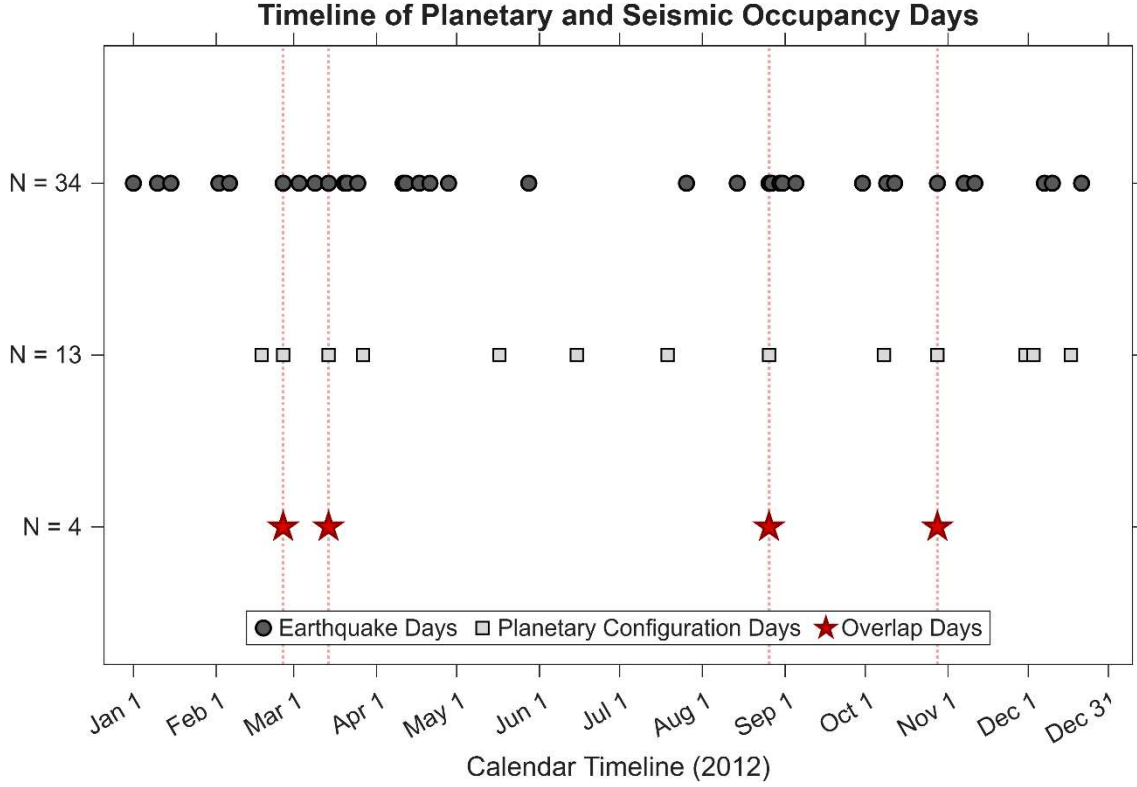


Figure 7. Timeline of planetary configuration dates and earthquake occupancy days for the 2012 calendar year.

4. Discussion and Conclusions

The analysis identified temporal overlap between planetary configuration dates and global seismicity that consistently exceeded expectations under the adopted circular-shift surrogate framework across the three study years (2010–2012). The corresponding combined three-year analysis likewise demonstrated a statistically significant excess over surrogate expectations, indicating that the observed correspondence is not restricted to a single catalog realization. The planetary configuration dates were generated independently of earthquake observations using a predefined geometric filtering procedure applied to planetary ephemerides. The configuration-selection analysis demonstrated that the geometric behavior of the planetary model differed substantially between years, requiring different levels of geometric constraint to obtain bounded planetary configuration sets suitable for subsequent comparison with earthquake occurrence data.

The present study therefore identifies an empirical temporal correspondence under the adopted null model but does not establish a physical coupling mechanism between planetary configurations and earthquake occurrence. The results should be interpreted as an observational finding rather than evidence of causation. Nevertheless, the consistency of the correspondence across three consecutive annual catalogs, together with the statistically significant combined three-year analysis, suggests that the observed relationship may warrant further examination in a geophysical context.

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Author contributions

T.N. conceived the study, performed the research, acquired and analyzed the data, developed the code and documentation, prepared the figures, and wrote the manuscript.

Data availability

MATLAB code and supporting data necessary to reproduce the planetary configuration dates, occupancy analysis, circular-shift surrogate frameworks, and figures presented in this study are publicly available through Zenodo at doi:10.5281/zenodo.21737429

Competing interests

The author declares no competing interests.

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