Implementation of a New Histogram Technique Based on Solar Time for Local Seismicity Analysis

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***Abstract* – Seismological studies require the analysis and comparison of data collected over long periods and across vast territories encompassing various geodynamic provinces. The stochastic nature of earthquakes complicates the detection of latent periodic cycles in background seismicity. The use of daily histograms helps to overcome these difficulties; however, their effectiveness becomes limited when analyzing large, fragmented regions. This is due to both the differing dynamics of seismic activity across regions and the challenge of distinguishing anthropogenic explosions from natural low-magnitude earthquakes.**

This study proposes a new histogram methodology based on local solar time. Applying this approach to data spanning from the Apennines to the Armenian Highlands makes it possible to identify artificial disturbances and separate them from natural seismicity across the full range of magnitudes, as well as to more accurately describe the character of local seismic activity. The article describes the algorithm of the method and discusses the possible outcomes of its application.

***Keywords* – Earthquake daily distribution, daily histograms, solar local time**

I. INTRODUCTION

Earthquake research requires long-term monitoring across wide territories. The stochastic and impulsive nature of seismic events makes it difficult to identify hidden periodicities in background seismicity. According to the empirical Gutenberg–Richter law, the number of low-magnitude events exceeds that of strong earthquakes by approximately an order of magnitude for each magnitude step, making weak events the main content of local catalogs. However, analyzing background seismicity is difficult because the number of recorded weak events strongly depends on the density of the seismic monitoring network. Moreover, anthropogenic explosions of low magnitude are often misclassified as seismic events and included in local catalogs.

As a result, statistical analysis of background seismicity is hindered, and such events are often removed from catalogs by discarding low-magnitude events, believing this improves catalog uniformity and representativeness. Indeed, this approach can overcome the catalog inconsistencies related to network density and quality. As seen in the example of Armenia's seismicity during the instrumental observation period (Fig. 1), the number of events varies greatly depending both on network density, which was updated in the 1960s and 1980s, and on fluctuations related to foreshock and aftershock activity of large earthquakes (e.g., the 2011 Van earthquake, M = 7.2). The obtained results show that the absolute maximum corresponds to 5125 events in 2011 and the absolute minimum to -242 events in 1966. Data on the given diagram was analyzed using a Q test showing that with 99% confidence, the given anomaly of seismic activity in 2011 is significant.

$$Q = gap/range = 4369/4883 = 0.89$$

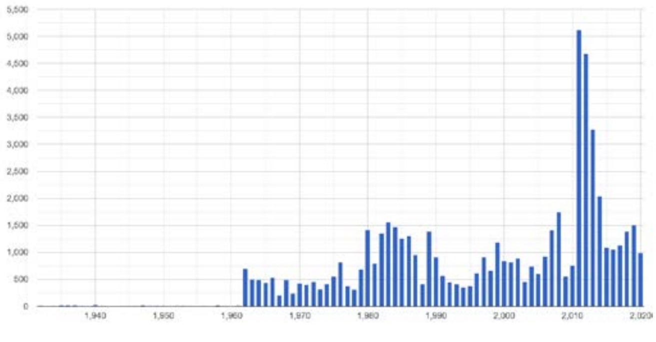

Fig. 1. Number of earthquakes per year. Armenia, 1932–2020

The software for all calculations was made by PHP + JS with the use of Google Charts.

This example shows that both temporal and spatial homogeneity of local catalogs are affected by anthropogenic fluctuations, especially regarding the number of weak events. Such variability makes it difficult to identify periodicities due to the non-uniform nature of observed time series. Discarding weak events can help to create more representative regional catalogs, but it also introduces downsides.

The histogram of annual earthquake occurrences shows an absolute minimum in July and an absolute maximum in November (Fig. 2). The distribution revealed that the number of seismic events fluctuates by more than 30% throughout the year. The figure also shows that seismic activity varies according to the season. For various reasons, seismic activity is more active between November and January. The applied Q test shows, with 90% confidence that the obtained rate of maximum seismic activity in November is not random and is significant.

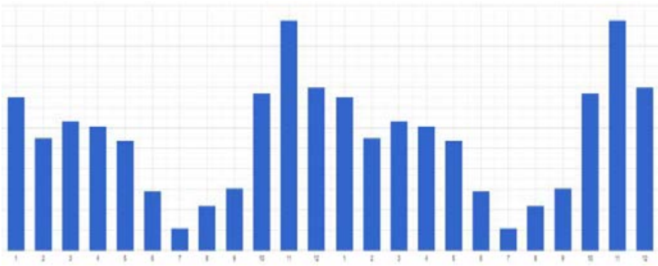

Fig. 2. Annual seismicity histogram for Armenia (1932–2020), with one-month intervals
(Double-plotted for better periodicity visualization.) Data from the seismic catalog of NSSP PA from 1961 to 2023

According to Chebyshev's theorem, regardless of the distribution shape, the most complete information about a process lies within data that do not exceed 3 standard deviations from the mean (Fig. 3). Anomalies contain less than 12% of the information about the process under study. Given the Gutenberg–Richter law, earthquakes with magnitude M < 3.5 constitute over 99% of regional seismic events.

This theorem supports the assertion that truncating seismic catalogs by a minimum magnitude removes the most information-rich part of the data concerning the nature of the process itself.

Anthropogenic variations in background seismicity are a significant obstacle to detecting hidden seismic activity cycles. In previous works, we proposed the use of histograms to help overcome these difficulties. The most intriguing results came from constructing daily histograms (Kazarian, Mkrtchyan). For instance, a daily histogram for Italy over the entire instrumental period reveals an uneven distribution of events throughout the day (Fig. 4).

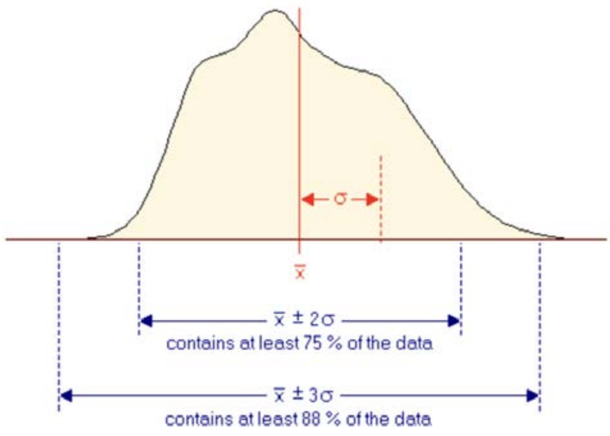

Fig. 3. Chebyshev's theorem: regardless of distribution shape, the most informative data about a process lie within 3 standard deviations from the mean.

The histogram was constructed by counting the number of events occurring at the same time of day, irrespective of magnitude. The study revealed both 24-hour and 12-hour seismicity cycles for the region.

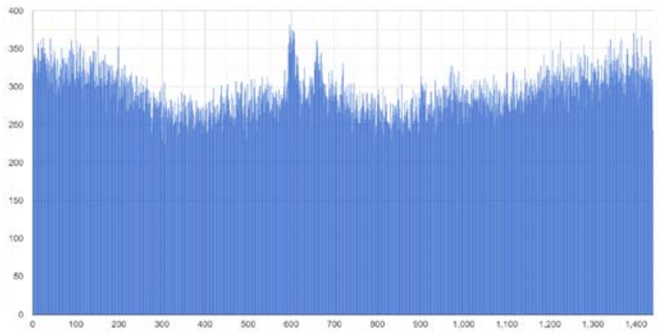

Fig. 4. Daily histogram, Italy (1981–2018), 1-minute binning. Lolli B., Randaz zo D., Vannucci G., Gasperini P. (2020) The Homogenized Instrumental Seismic Catalog (HORUS) of Italy from 1960 to Present, Seismol. Res. Lett, doi: 10.1785/0220200148

The presence of these daily and semi-daily cycles clearly indicates a relationship with the solar tidal cycle. The lunar-solar component of oceanic tides has periods of 12:25 and 24:50, and due to the constant daily shifting of its peak, cannot manifest clearly on daily histograms. This result suggests that daily modulation of seismicity is more likely related to the Sun's position relative to the earthquake epicenter, rather than the absolute tidal height.

This hypothesis requires a more accurate accounting of the Sun's true position relative to each epicenter. Using universal time (UTC) in histograms gives precise event timing but not the actual solar position at that moment. Local time is calculated by adding the time zone offset to UTC, but this is not always aligned with true solar time due to political boundaries.

Time zone widths vary by country and may exceed 15 degrees of longitude (Fig. 5). At 45° latitude, a true time zone is about 1200 km wide. This introduces a major error: for example, two earthquakes 1200 km apart (along latitude) occurring at the same UTC will actually experience different solar times, differing by up to one hour. Their relative solar positions will also differ.

Fig. 5. Territorial distribution of time zones

Thus, it is more reasonable to use true solar time based on the epicenter's longitude. This avoids inaccuracies arising from administrative time zones.

II. Methodology

The method proposed here is based on daily histograms, but with local solar time used as the time axis (calculated from each epicenter’s coordinates). This synchronizes daily phases independently of time zones and removes distortions caused by wide territorial coverage.

The most accurate way is to use the epicenter's longitude. Since UTC corresponds to the prime meridian (0°), locations in the eastern hemisphere “lead” UTC by a duration proportional to their longitude. That is, to compute solar time, add a time offset (in seconds) for eastern longitudes or subtract it for western ones.

For example, if an earthquake occurs at 8:00 UTC and the epicenter is at 15°E, the local solar time is 9:00. For 15°W, it would be 7:00.

Physically, longitude is the line over which the Sun is at zenith at local noon (12:00 p.m. solar time). The calculation accuracy was 1 second. The solar time formula is

Time (in seconds) = (h × 3600 + m × 60 + s) + (Longitude × 240)

Where h = hours, m = minutes, s = seconds

Example: The 1988 Spitak earthquake occurred on December 7 at 11:41 local time (07:41:00 UTC), epicenter at 44.23°E.

Calculation:
(7 × 3600 + 41 × 60 + 0) + (44.23 × 240) = 38,275 seconds
→ Real solar time: 10 hours, 37 minutes, 55 seconds.

Examples of recalculations to local solar time are shown in Fig. 6.

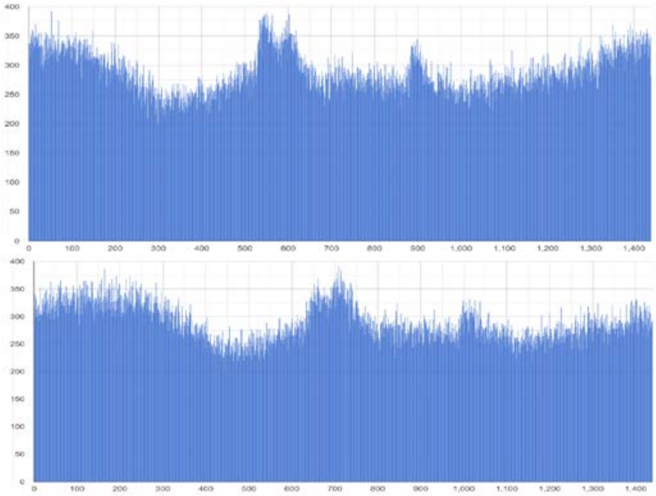

Fig. 6. Daily earthquake histograms for Turkey: 6.1 (UTC) and 6.2 (local solar time)
B.U. KOERI-RETMC (Boğaziçi University Kandilli Observatory and Earthquake Research Institute - Regional Earthquake-Tsunami Monitoring Center) 1965-2025, 1<M<8

Histograms recalculated to local solar time confirm earlier observed patterns, with small adjustments. As shown, seismic activity peaks shift slightly, including the absolute maximum.

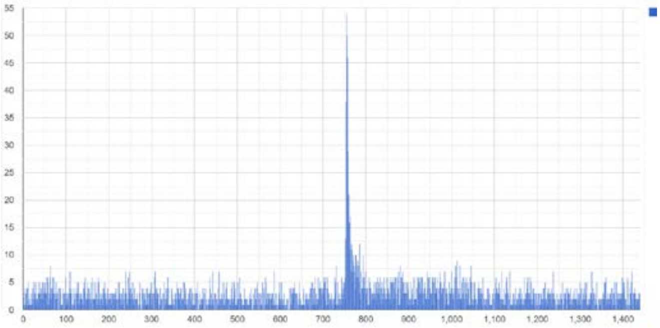

Fig. 7. Daily distribution of seismic events in Armenia, 2003–2007

The method was tested on a catalog of local earthquakes and anthropogenic events covering the region from the Apennine Peninsula to the Armenian Highlands. Constructing a daily histogram using local solar time helped identify events caused by quarry explosions in Armenia and adjacent areas (Fig. 7). The prominent activity peak, 11 times above average, is an artifact resulting from safety protocols that mandate blasting operations strictly between 12:00 and 13:00 local time. The applied Q test confirmed that with 99% confidence, the seismic activity between 12 and 13 hours local time is an outlier.

III. Discussion

The results presented in this study suggest a measurable relationship between background seismicity and solar tidal periodicity. Histograms constructed using local solar time, rather than administrative or UTC-based timing, reveal recurring diurnal and semi-diurnal cycles that would otherwise be obscured. These cycles manifest as statistically significant peaks near solar noon and midnight in several regions analyzed, particularly in the Armenian Highlands and Anatolia.

While earlier studies have identified periodicities in seismic activity, our method improves temporal alignment by accounting for the epicenter's actual solar position, thus enhancing signal clarity. This technique builds on the foundational work of Hao et al. (2019), who reported diurnal earthquake periodicity in Japan. However, by applying solar-time correction across broader, multi-time-zone regions, our method offers a generalized framework for spatially heterogeneous seismic networks. Notably, the observed 12-hour cycles do not align perfectly with the 12-hour 25-minute lunar tidal harmonics, further supporting a solar-dominated influence on these modulations.

From a physical standpoint, several plausible mechanisms may explain the observed timing. These include solid Earth tides induced by the Sun, diurnal thermal stress fluctuations in the upper crust, and atmospheric pressure loading. The persistence of bimodal daily peaks, even after anthropogenic events were filtered, points to natural stress variations potentially modulating fault sensitivity over the solar cycle.

Beyond theoretical insights, the histogram technique also offers practical benefits. In Armenia, for instance, the method successfully identified anthropogenic disturbances (e.g., quarry blasting) through distinct, narrow time windows of elevated seismicity. These signals, often overlooked in traditional catalog processing, can now be efficiently flagged and removed, improving catalog integrity and helping distinguish genuine seismic trends from human noise.

Despite promising results, the study has several limitations. No formal statistical significance testing (e.g., Schuster's test, Monte Carlo simulation) was performed to quantify the non-randomness of observed periodicities. Additionally, the seismic catalogs used vary in magnitude thresholds, event completeness, and network density, all of which may bias the shape of the histograms. Declustering algorithms were not systematically applied to exclude aftershocks, and future studies should evaluate whether the observed diurnal patterns persist in fully declustered datasets.

Taken together, these findings open the door for several avenues of future research. Comparative studies across additional geodynamic provinces may help clarify the role of regional tectonic settings and fault types in modulating these patterns. Furthermore, integration with tidal stress models and fault slip behavior could illuminate the coupling between periodic external forces and local stress regimes.

IV. Conclusion

Histograms based on solar time reveal distinct, recurring activity peaks characteristic of background seismicity. Anthropogenic events, such as blasting, form separate clusters, aiding in their identification and exclusion.

The method allows detection of zones with pronounced night or day activity, unaffected by time zone distortions. Using solar time in histograms improves the identification of natural seismic patterns. Unlike conventional approaches, this method is independent of administrative time and better suited for comparing spatially dispersed regions – especially those with complex geodynamics, such as the Caucasus, Apennines, and Anatolia.

Furthermore, the method has potential for improving prediction models by detecting stable daily cycles and anomalies that may serve as precursors to seismic events.

The proposed solar-time-based histogram technique is an effective tool for analyzing background seismicity, identifying anthropogenic impacts, and uncovering hidden patterns.

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